Final Report

BFRP Rebar Characterization and Performance

Testing Protocol and Material Specifications for Basalt Fiber Reinforced Polymer Bars

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Steven Nolan, P.E.
Project Manager
FDOT Central Office

Prepared by:

Raphael Kampmann, Ph.D.
Principal Investigator
Youneng Tang, Ph.D.
Co-Principal Investigator
Srichand Telikapalli, Ph.D., E.I.
Postdoctoral Researcher
Sarajeen Saima Hoque
Graduate Research Assistant

FAMU-FSU College of Engineering
Department of Civil and Environmental Engineering
2525 Pottsdamer Street
Tallahassee, FL 32310

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Unit Conversion to SI Units

Approximate conversion to SI units

Symbol	When you know	Multiply by	To find	Symbol
		Length		
in.	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		Area		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		Volume		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		Mass		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		Temperature		
°F	Fahrenheit	$\frac{5}{9}(\mathrm{F}-32)$	Celsius	°C
		Illumination		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	$\frac{\text{candela}}{\mathrm{m}^2}$	$\frac{\mathrm{cd}}{\mathrm{m}^2}$
		Stress/Pressure		
lbf	poundforce	4.45	newtons	N
$\frac{\mathrm{lbf}}{\mathrm{in}^2}$ (or psi)	$\frac{\text{poundforce}}{\text{square inch}}$	6.89	kilopascals	kPa

Unit Conversion to Imperial Units

Approximate conversion to imperial units

Symbol	When you know	Multiply by	To find	Symbol
		Length		
mm	millimeters	0.039	inches	in.
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		Area		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		Volume		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		Mass		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000 lb)	T
		Temperature		
°C	Celsius	$\frac{9}{5}C + 32$	Fahrenheit	°F
		Illumination		
lx	lux	0.0929	foot-candles	fc
$\frac{cd}{m^2}$	$\frac{\text{candela}}{\text{m}^2}$	0.2919	foot-Lamberts	fl
		Stress/Pressure		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	$\frac{\text{poundforce}}{\text{square inch}}$	$\frac{\text{lbf}}{\text{in}^2}$ (or psi)

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16. Abstract

This research was conducted to evaluate the performance of three commercially available BFRP rebar products and their individual raw material components, before and after exposure to nine different aggressive environments at 60°C for 300d and 600d, to development acceptance criteria specifically for basalt-based fiber reinforced polymer (BFRP) reinforcing bars which can further refine FDOT Specifications Section 932.
Three high-quality rebar products from different established FRP rebar producers were selected to evaluate two commonly used rebar sizes (# 3 and # 5) and to fully characterize the relevant material properties. A total of five different physical properties (cross- sectional dimensions, moisture absorption, fiber content, XRF analysis, and glass transition temperature) and four mechanical strength characteristics (transverse shear strength, apparent horizontal shear strength, tensile strength and elastic modulus, and bond-to-concrete strength) were experimentally quantified – for virgin materials, and compared to the aged constituent materials and BFRP rebars. Because acceptance criteria for basalt FRP rebars are not well established in the US, the findings were compared to the prevalent minimum criteria for glass FRP rebars and it was found that BFRP rebars are stronger and more durable than the minimum criteria set for GFRP bars. Performance differences were noted for rebar products from different manufacturers because of dissimilarities in material production and surface enhancement properties. However, basalt fiber rebar products appear to be a viable alternative as a non-corrosive rebar option. A standardized use of such rebars seem feasible based on appropriate acceptance criteria. While the development of acceptance criteria for BFRP rebars has been initiated through this project, and an implementation of this alternative reinforcing technology should be strongly considered by the FDOT, more critical BFRP-specific performance criteria can be developed in future projects to further differentiate the various fiber types and to take full advantage of the available material characteristics.
A long-term strength prediction model that estimates the strength retention of FRP bars regardless of exposure environment was developed based on the fib bulletin 40 model. Two new degradation terms, n_{Cl} and n_t, addressing chloride ion concentration of the exposure environment and exposure time were addressed to determine the environmental degradation factor (C_E) for FRP bars. The model was fed with empirical data from BFRP rebar testing in virgin and conditioned state and long-term strength retention was predicted. An interim approach for acceptance of BFRP reinforcing using the current environmental exposure factor C_E = 0.7 in design, and a modified Alkaline Resistance test under ASTM D 7957 was proposed.

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In addition, the authors would like to thank Dr. Chase Knight (former State Corrosion & Composite Materials Engineer), who provided valuable insight and was extraordinary help throughout the earlier stages and the experimental phases. Chase Knight was always available when his expertise was needed and his contributions to this research are greatly appreciated.

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Executive Summary

Florida is a coastal state with bridge infrastructure exposed to aggressive environments through direct and indirect contact with saline solutions. Due to this exposure, conventional black steel reinforcement that is traditionally used for bridges is corroding prematurely, resulting in early structural deterioration which in-turn may cause huge financial and personal losses. In a successful effort to overcome such corrosion and deteriorating effects, reinforcing bars (rebars) made from fiber reinforced polymers (FRP) were developed. FRP rebars are composite materials, in which fibers, resin, and sizing (interface material between fibers and resin) are the main constituent materials. Different fiber types are used to produce such rebars, and the most common type in the US is glass fiber. In the former Soviet Bloc, continuous fibers made from basalt rock were favored and since the collapse of the Union of Soviet Socialist Republics (USSR), previously proprietary/military technologies have been made public and continuous basalt fibers (CBF) have entered the world market as a viable alternative to glass fibers. CBF are now used to produce basalt fiber reinforced polymers (BFRP) in rebar applications and these rebars are now imported or produced in the North America. Various types of BFRP rebars with dissimilar sizes, physical and strength properties, are currently produced to be used for civil engineering construction. In this project, representative and commonly available BFRP rebars were tested to evaluate various physical properties (cross-sectional properties, fiber content, and moisture absorption properties) and different strength characteristics (horizontal and transverse shear, tensile strength, elastic modulus, and bond-to-concrete properties) according to ASTM standards, in an effort to develop basalt specific acceptance criteria for FDOT Specifications Section 932, which governs the use of non-metallic auxiliary materials for civil engineering construction.

BFRP rebars from three different manufacturers, two different production lots, and two commonly used rebar sizes (# 3 and # 5) were included in this study. The obtained results were used to evaluate the performance of each rebar type in a relativistic comparison to existing benchmark values for virgin glass FRP (GFRP) rebars — without the consideration of accelerated ageing. The fiber content test proved that all tested samples had consistent and nearly identical results with acceptable performance. Moisture absorption property of the rebars varied significantly based on the manufacturers, type of raw materials used, and the production techniques. Tensile strength, transverse shear strength, and horizontal shear strength measurements were consistent for all rebar types and the recorded values surpassed the strengths generally reported for GFRP rebars. The bond-to-concrete strength of the tested BFRP rebars were not significantly different from bond-to-concrete strength commonly reported for GFRP rebars because similar surface enhancement techniques are used for either rebar type. Long term (300 and 600 day) accelerated ageing tests using a range of pH and saline solutions at 60 °C, were conducted on rebars and constituent components. Results from these test indicated significant degradation of the tensile properties of the BFRP rebar under combined high alkalinity and saline conditions. These results need to be further investigated to refine the degradation model under more representative conditions for BFRP rebars embedded in concrete and submerged in seawater. Based on the obtained results it was noted that the tested BFRP rebars surpassed the strength related acceptance criteria for GFRP rebars. While the manufacturer reported properties varied and each rebar

type performed different, the tested BFRP rebars were generally stronger (higher performance) than GFRP rebars. Ultimately, it was found that BFRP rebars are a suitable and viable alternative for construction in Florida and that those materials should be considered for FDOT Specification 932.

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Chapter 1

Introduction

1.1 Introduction

Major bridge infrastructure in coastal areas are directly exposed to sea water resulting in corrosion of steel and concrete spalling. One of the major concerns of structural engineers is early deterioration of structural components due to corrosion issues inherent to steel in reinforced concrete and prestressed concrete elements. The chloride ions in seawater react with the traditional black steel in reinforced concrete structures, which ultimately leads to pitting corrosion. Pitting corrosion leads to volumetric expansion of steel reinforcement, which ultimately leads to structural failure. Corrosion also leads to concrete spalling, which is caused by the increased internal pressure in structural components. The pressure increase is caused by the volumetric expansion of structural steel affected by corrosion. The failure caused by the corrosion of traditional steel reinforcement can be eliminated by using noncorrosive Fiber Reinforced Polymer (FRP) rebars as internal reinforcement for concrete.

FRP rebars are made from the fibers made out of different material. Over the past two decades, use of FRP in the bridge engineering industry has increased. Several types of FRP rebars made from different materials are used as reinforcement material in the bridge structures replacing the traditional steel reinforcement. Some of the most common FRP are made out of Glass fibers (GFRP), Aramid fibers (AFRP), Carbon fibers (CFRP) and Basalt fibers (BFRP). These material have a promising future in the replacement of traditional black steel for reinforcing concrete (De Caso et al., 2012). Some of the major advantages of FRP are, magnetic transparency, lightness in weight, and durability in saline environments which help in increasing structural health and therefore extending the life period of structures.

Rebars made from basalt fibers were widely studied in the former soviet union during the cold war period and hence, they are widely used in countries like Russia and Ukraine. Manufacturers in the US preferred glass fiber research over basalt fiber research in the early 1900s because of economical reason and ease in production. To use any material in civil engineering structures, they have to satisfy a material acceptance criteria and standard specifications designed by the country it is used in. The standard specifications for BFRP rebars are not yet developed in the U.S. Though the BFRP rebars have desirable strength properties, and can compete with other FRP rebars, the lack of standards and material defining criteria impede the broader adoption. Nonetheless, due to serviceability requirements, need for resilient structures, and economical factors, FRP manufacturers started manufacturing BFRP rebars because they perform well and have better strength properties in comparison to some other FRP rebars.

The load-bearing capacity of the rebar depends substantially on the strength of fibers, the resin matrix and the resin to fiber interface. The resin-fiber matrix also plays an important role in increasing the chemical durability of rebar. The production process of rebars also plays a key role in strength and durability criteria.

If the quality of production is not maintained, it results in the formation of pores within the resin matrix and on the rebar surface which lead to increased moisture absorption, ultimately reducing the strength of rebar. Although many well experienced manufacturers work assiduously to maintain production quality by duplicating GFRP manufacturing criteria, inferior BFRP products are reportedly available on the world market now. If such low-grade products enter the U.S. market or are used for infrastructure projects, the traveling public could be at risk.

A wide range of BFRP products developed by different manufacturers are available in the industry. They have variation in physical and mechanical characteristics. These attributes vary based on raw materials used for production, material mix proportions, manufacturing philosophy, geometrical structure, and shape of rebar. The material properties of various raw materials as well as the characteristics of the final rebar products from different manufacturers have to be analyzed and compared. A proper material categorization helps in improving the raw material, and rebar characteristics ultimately helping in the standardization of material criteria and rebar design requirements.

1.2 Problem Statement

Rebars made of FRPs are now a viable replacement for traditional black steel rebars. Because of its good strength characteristics, and assumed durability, the use of BFRP rebar in the construction industry is increasing. But, a number of BFRP products with inferior quality are available in the global market as material standards are not available. Standardizing the BFRP rebar products helps in eliminating the products of inferior quality and protecting the general public safety. Because FRP materials are composite materials, the material characterization and standardization has to begin with raw materials. The specifications for each individual component should be clearly defined before those materials can be combined into a composite rebar. The main raw material in BFRP rebar manufacture is, basalt rock. Because basalt rock is a mineral, various types of basalt rocks with different chemical properties are available in the market. To achieve a chemically durable BFRP rebar product, mineral composition of raw materials (basalt rock) should be required to follow a standardized limit.

After the basalt fibers are produced, a protective layer called sizing is applied to the fibers, which also helps improve the bond with resin matrix. Sizing protects fiber from chemical attacks. Because sizing is a protective layer on the fibers, properties of sizing must be studied well under harsh environments to increase the resistance of sized fibers towards chemical attacks and to increase the rebar durability. Suitable standards must be defined to make sure the quality of sizing is maintained throughout the production process.

The resin is the binding material that holds the sized fibers together and helps form a resin-fiber matrix. It is because the resin-fiber bonding is the key factor that affects the strength characteristics of rebar, and because the resin protects the fiber from external chemical attacks and increases the durability of reinforcement, in turn prolonging the service life of structural components. The chemical reliance of the resin, and the physical and durable properties under chemical attack must be studied and standardized before implementing them in the manufacturing process of the rebar.

Because rebars are used intended to be used in high pH and saline environments, a wide range of raw materials and rebar products should be exposed to several combinations of aggressive conditions and their long-term strength and durability characteristics should be experimentally studied. Experimental evaluations on the fiber, sizing, and resin level are needed to promote the standardization process of BFRP Rebars.

1.3 Research Objective

This research aimed to analyze the characteristics and long-term chemical durability of raw materials used in the production process of BFRP rebars and to quantify the material properties and limit states of the individual and combined materials for the final rebar product. The chemical composition of the basalt mineral plays an important role to achieve the required strength and durability of the final fiber. Therefore, the first objective in this research was to qualify the basalt fibers based on the chemical composition and purity to provide minimum requirements for strength and durability related characteristics. Likewise, it was the goal to quantify the characteristics of the raw resin materials that were used in the production of the evaluated rebars to gain insight on the durability properties. The final goal in this research was to study the combined aspects of the individual material in the form of rebar by analyzing the a wide array of physical and mechanical rebar properties. While this research project aimed to classify the virgin material properties, it also targeted the long-term durability properties of BFRP rebars through accelerated ageing in a variety of combined pH and saline environments. This was necessary to ultimately define the strength retention properties for BFRP rebars in various exposure conditions and to classify or mathematically predict the long-term behavior of the evaluated materials to offer recommendations for implementing this type of emerging materials in future guidelines and design guides.

1.4 Research Scope

For the purpose of this project, a wide range of BFRP rebars and raw materials used to produce these rebars, which include fibers, sizing, and resin, were tested within their virgin state and after exposure to a variety of chemical environments. Tests included durability and strength tests on fibers (sized and non-sized) and resin coupons. Independent variables were the chemical compositions of each raw material and the exposure conditions (OH^- and Cl^-) as well as the material responses via tensile tests, shear tests, SEM, Raman spectroscopy, pH, alkalinity, salinity, anions, metals, bisphenol, and volume change analyses. Based on the findings during the raw material characterization tasks, BFRP rebars from three manufacturers in two sizes were selected and tested for performance evaluation. Ultimately, this research was concluded by recommending BFRP rebar specifications to be included in the FDOT Standard Specifications for Road & Bridge Construction.

Chapter 2

Background

2.1 Introduction

This chapter provides an overview of the history of Basalt fiber and uses in the construction industry in the form of Basalt Fiber Reinforced Polymer (BFRP) reinforcement bars (rebars), from the raw material to the final rebar product. To provide context and to offer a comprehensive state-of-the-art review of the alternative rebar industry, general FRP rebar materials are reviewed because clear commonalities exist between the constituent materials and the production methods of the most common FRP materials (basalt, glass, carbon, aramid, etc.). However, this chapter is mostly focused on techniques and materials use for the production of BFRP rebars. To facilitate an initial overview, a typical basalt rock, sized fibers, and a BFRP rebar can be seen in Figure 2.1. Like all fiber reinforced polymer materials, BFRP rebars are composite products.

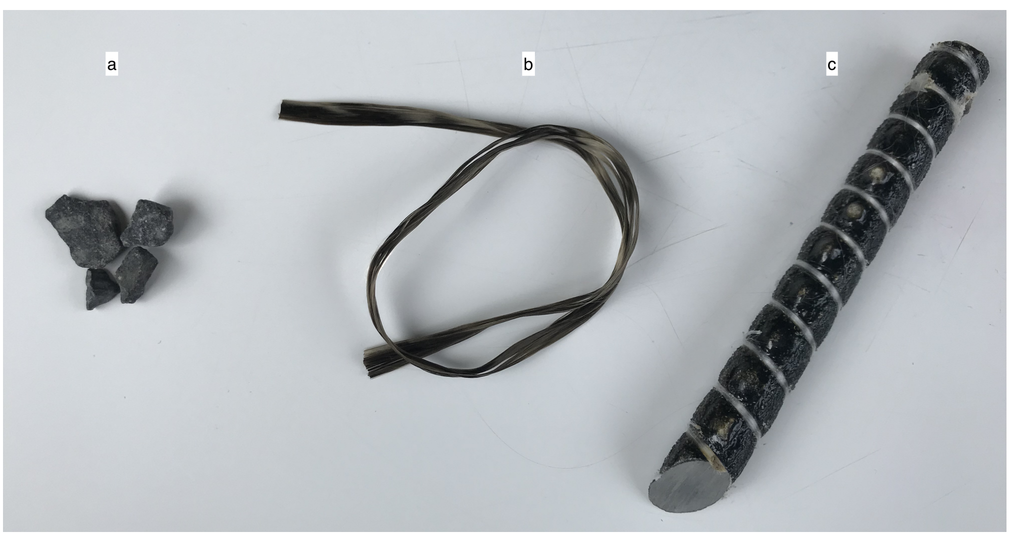


Figure 2.1: (a) Basalt rock, (b) Fiber, and (c) Rebar

A French researcher Paul Dhé invented basalt fibers in the year 1923 (Dhé, 1923). Manufacturers did not concentrate on basalt fibers due to the production difficulties and because the manufacturing of glass fibers was more profitable (Faruk et al., 2017). But the research on basalt fibers was continued for military purposes in the former soviet union during the Cold War period (Jamshaid and Mishra, 2016). Research findings were released for the use of civilians in 1995 after the collapse of the soviet union in 1991. Due to the confidentiality of the research until 1995, the use of basalt fibers in the construction industry is a developing technology.

Though BFRP rebars are believed to have a promising future in replacing traditional black steel (De Caso et al., 2012), carbon FRP, and glass FRP, the durability of BFRP rebar in response to chemical attacks has not been well established, yet. Because BFRP rebar is a recently developed technology, a study of long-term saline and alkaline durability of BFRP rebars has yet to be performed. Accordingly, a detailed literature review about the individual constituent materials and their currently documented behavior is presented in this chapter.

2.2 Fiber Types

This section describes the fiber types which are used in the manufacturing process of FRP rebars. Four major fiber types are used in FRP manufacturing: glass, basalt, carbon, and aramid fibers. Glass FRP are the predominantly used reinforced plastics in structural engineering due to the available research knowledge and low production cost. But, for engineering purposes, the mechanical properties of basalt FRP are comparatively better than the mechanical properties of glass FRP (Zych and Wojciech, 2012). Rebars made of other fibers are abundantly available in Asian countries (ACI Committee 440, 2007). A brief introduction to the four major fibers is given in the following subsections.

2.2.1 Carbon Fibers

Carbon fiber composites are fibers made from polyacrylonitrile (PAN) classified as high-modulus carbon fiber. Carbon fibers have the highest tensile strength and elastic modulus compared to other fibers. They have high resistance to alkali or acid attacks, and a high electrical conductivity. Carbon fibers are the most expensive fibers available in market (Nanni et al., 2014). Due to their high strength and elastic properties, they perform well in prestressing applications for bridge structures.

2.2.2 Aramid Fibers

Aramid fibers are polyamide-based fibers (Bagherpour, 2012), with Kevlar 29, 49 and 149 are the most predominantly used fiber grades for applications in structural engineering. Aramid fibers are in general strong in tension and have a higher elastic modulus in comparison to glass fibers (Bagherpour, 2012). They have higher resistance to fatigue and creep, the fibers are magnetically transparent and do not conduct electricity or heat. Due to its high resistance to heat, they are used for applications in furnaces. They are weak in high humid and chemical environments. Due to their high cost, these fibers are not widely used in construction (Nanni et al., 2014).

2.2.3 Glass Fibers

Glass fibers are the most common fibers used for structural applications, and specifically in bridge applications. The most common fibers are AR(Alkaline Resistant)-glass, E(Electrical)-glass, and S(High Strength)-glass. E-glass fibers are predominantly used in civil and industrial structures (Bagherpour, 2012). The glass fibers are highly resistant to moisture and have higher strength. The lime-alumina-borosilicate in sand is the major ingredient for the fiber manufacture (Bagherpour, 2012). S-glass is more expensive than E-glass and is less preferred by manufacturers. AR-glass does not have a proper sizing (see Section 2.6) compatibility for FRP manufacturing (Nanni et al., 2014). Unlike basalt fibers, the glass fiber manufacturing process includes additives like borax to achieve better chemical resistance (Aubourg et al., 1991). The major ingredient in the manufacturing of glass fibers is silica, while lime stone and soda ash are additives to lower the melting temperature.

Table 2.1: Mechanical and physical properties of fibers (Singha, 2012)

		Fiber Type			
		Continuous Basalt	Carbon	Glass	
Properties	unit			E- glass	S- glass
Breaking Strength	MPa	3000 – 4840	3500 – 6000	3100 – 3800	4020 – 4650
Elastic Modulus	GPa	79.3 – 93.1	230 – 600	72.5 – 75.5	83 – 86
Breaking Extension	%	3.1	1.5 – 2.0	4.7	5.3
Fiber Diameter	µm	6 – 21	5 – 15	6 – 21	6 – 21
Linear Density	tex	60 – 4200	60 – 2400	40 – 4200	40 – 4200
Temperature Withstand	°C	−260 – 700	−50 – 700	−50 – 380	−50 – 380

2.2.4 Basalt Fibers

The concept of basalt fibers was first invented in the year 1953 at the Moscow Research Institute (Morova, 2013). The fibers were initially used in bulletproof vests for military purposes and the research was kept classified. Use of BFRP rebar in construction engineering has started after the collapse of the soviet union in the year 1991, when the research was allowed to be published for civilian use. Some manufacturers claim that the performance of basalt fibers is comparable to the performance of expensive carbon fibers and glass fibers (Singha, 2012). Similar to basalt rock, the basalt fibers are categorized based on the acidic modulus (M_a), and the acidic modulus is defined as the ratio of acidic to basic oxides. In the construction industry, basalt fibers with M_a ranging from 1.2 to 1.5 are used (Singha, 2012). In a direct comparison, basalt fibers have a higher elastic modulus than glass fibers. They have excellent heat resistance and perform well in heat intensive environments while also providing good acoustic damping (Singha, 2012). The density of the fibers are much lower ($2.8\,\frac{\text{g}}{\text{cm}^3}$) in comparison to steel. The moisture absorption of basalt fibers is approximately 1 % and they can withstand an alkaline environment with pH levels between 13 and 14. Although basalt fibers are less stable in strong acids, they retain 92 % and 75 % of their properties by only losing 5 % and 2 % of their weight when tested in 2(M) NaOH and 2(M) HCl, respectively (Singha, 2012).

2.2.5 Summary of Fiber Types

In this subsection, the typical mechanical, and physical properties of different fibers are summarized and compared. Important fiber properties according to Singha (2012) are shown in Table 2.1. The thermal properties of s-glass and basalt fibers are compared in Table 2.2 as determined by Singha (2012). It can be seen in that basalt fibers have better thermal properties in comparison to glass fibers. Table 2.3 lists mechanical properties of different fibers according to Nanni et al. (2014). The data in the table shows that basalt fibers have better mechanical properties in comparison to other fibers.

Table 2.2: Thermal properties of fibers (Singha, 2012)

Thermal Properties	unit	Fiber Type	
		Basalt	E-glass
Maximum Operating Temperatures	°C	980	650
Sustained Operating Temperatures	°C	700	480
Minimum Operating Temperatures	°C	-2.6	-60
Thermal Conductivity	W/mK	$0.031 - 0.038$	$0.034 - 0.04$
Melting Temperature	°C	1280	1120
Thermal Expansion Coefficient	ppm/°C	8.0	5.4

Table 2.3: Typical mechanical properties of fibers (Nanni et al., 2014)

Type of Fiber	Density		Tensile strength		Tensile modulus		Tensile strain
	lb/yd^3	kg/m^3	ksi	N/mm^2	10^6 psi	10^6 N/m^2	%
Basalt	4720	2800	700	4827	12.9	88.95	3.1
E-glass	4215	2450	500	3448	10.5	72.40	2.4
S-glass	4215	2450	660	4550	12.4	85.50	3.3
AR-glass	3800	2250	260 - 500	1793 - 3448	10.1 - 11.0	69.64 - 75.85	2.0 - 3.0
High-modulus carbon	3290	1950	360 - 580	2482 - 4000	50.7 - 94.3	349.50 - 650.20	0.5
Low-modulus carbon	2950	1750	507	3496	34.8	239.90	1.1
Aramid (Kevlar 29)	2428	1440	400	2758	9.0	62.06	4.4
Aramid (Kevlar 49)	2428	1440	525	3620	18.0	124.11	2.2
Aramid (Kevlar 149)	2428	1440	500	3448	25.4	175.13	1.4

2.3 Source Material for Basalt Fibers

To produce basalt fibers, the source material from which the fibers are manufactured must be thoroughly studied because the physical, and the mechanical properties of the rebar (end product) depends on the physical, and durable properties of basalt rock (Singha, 2012). The physical, mechanical, and durability properties of the source material play a key role in the production as they determine the characteristics of the final fibers.

Basalt fibers are made from molten basalt rock, which is a fine-grained igneous rock. Igneous rocks are one of the three major classification of rocks, with the other two being sedimentary and metamorphic rocks and more than 90 % of all igneous rocks are basalt. Igneous rocks are classified into volcanic rocks and plutonic rocks (Best, 2003), dependent on the the exposure conditions during cooling and hardening. Volcanic rocks are formed when magma solidifies under the earth surface, while plutonic rocks are formed when the lava solidifies on the surface of the earth. Basalt rock is formed only from solidified lava (Singha, 2012); when magnesium-rich and iron-rich lava is exposed to a rapid cooling process, it forms into basalt rock. The melting temperature of basalt ranges from 1500 °C to 1700 °C (2732 °F to 3092 °F). Almost 80% of Basalts are made from two minerals, Plagioclase and Pyroxene. Plagioclase is a series of tectosilicate minerals within the feldspar group. Pyroxene (P_x) are a group of rock forming inosilicate minerals found in igneous and metamorphic rocks. Two of the main constituents of basalt are SiO_2 and Al_2O_3 (Militkỳ et al., 2002). Table 2.4 shows the composition of a typical basalt rock according to Militkỳ et al. (2002) and Deák and Czigány (2009). Because basalt is a mineral, the chemical composition of the core rock varies widely depending

Table 2.4: Typical Basalt components

	Content Wt %	
Constituent	Militky2002a	Deak2009a
SiO_2	43.3–47	42.43–55.69
Al_2O_3	11–13	14.21–17.97
Fe_2O_3	5	10.80–11.68
CaO	10–12	7.43–8.88
MgO	8–11	4.06–9.45
Na_2O	5	2.38–3.79
TiO_2	5	1.10–2.55
K_2O	5	1.06–2.33

on the place of origin. Basalts with a wide range of chemical composition is used in the manufacturing of stone castings, ties, and staple fibers (Singha, 2012). But the fibers used for civil engineering purposes, which are continuous basalt fibers (CBF), have to fall within a very narrow range of chemical composition to form a chemically durable and desirable final product (Vasil'eva et al., 2014; Tatarintseva et al., 2012b). Most fiber manufacturers around the world are using the Andesitic basalt rock with 50 % SiO_2 by weight (Novitskii and Efremov, 2013; Morozov et al., 2001). Basalt rock has to satisfy specific criteria to be accepted as a source for manufacture of continuous basalt fiber (Johannesson et al., 2017), and Table 2.5 lists the acceptance limits according to Stekloplastics (2014); Toni Schneider (2015); Kochergin et al. (2013). It can be seen in

Table 2.5: Limits for chemical composition of basalt for CBF production

	Content Wt %			
Oxide	Stekloplastics (2014)	Toni Schneider (2015)	www.bavoma.com	Kochergin et al. (2013)
SiO_2	50-54(48-56)	45-60	47.5-55.0	38-55
Al_2O_3	7.5-15.0	12-19	14-20	3-20
FeO-Fe_2O_3	7.0-15	5-15	7-13	2-18
MgO	3-7	3-7	3-8.5	1-24
TiO_2	0.1-2	0.1-2	0.2-2	–
$NaO+K_2O+CaO$	0.1-18	–	2.5-7.5(Na+K)	–
CaO	–	6-12	7-11	17
MnO	–	–	< 0.25	0.3
SO_3	–	–	< 0.2	–

Table 2.5 that the limits according to Kochergin et al. (2013) have much wider ranges then the ones listed by others, because these limits are applicable to a large range of applications which includes, for example, slag wool. The limits specified in the first, second, and third columns are narrower and are used in manufacture of continuous basalt fiber. The combination of alkali (Na_2O+K_2O) and silica content in volcanic rock is used to classify them through total alkali silica (TAS), which can be seen in Figure 2.2. It is important to study alkali and silica content of the rock because the limiting states and purity of rock depends on the mineral composition. The most important properties of basalt rock to be analyzed before using it for the production of fibers are acidity modulus, viscosity modulus, and surface tension.

2.3.1 Acidity Modulus (M_a)

Acidity modulus is the most important parameter considered in the manufacture of basalt fibers (Tatarintseva et al., 2012b,a). It is the ratio of acidic oxides to the basic oxides in the basalt rock as represented in equation 2.1.

$$M_a = \frac{\mathrm{SiO_2} + \mathrm{Al_2O_3}}{\mathrm{CaO} + \mathrm{MgO}} \tag{2.1}$$

The equation relies on the weight percentage of the included oxides. If M_a is less than 1.2, the fibers are considered slag wool, which is very brittle with poor chemical durability (Johannesson et al., 2017; Kochergin et al., 2013). If the acidic modulus ranges from 1.2 to 1.5, the fibers are considered mineral wool, which is good for insulation purposes. But the mineral wool fibers are very brittle in nature. If M_a of the fibers is greater than 1.5, they are considered rock wool or basalt fiber. Table 2.6 lists the values of acidic modulus for different production forms. King et al. (2014) classified basalt rock based on SiO_2 content, and states that the rock is considerably alkaline if SiO_2 is less than 42 %. Basalt rock is considered mildly acidic if SiO_2 % ranges between 43 % and 46 %, and acidic if SiO_2 is over 46 %.

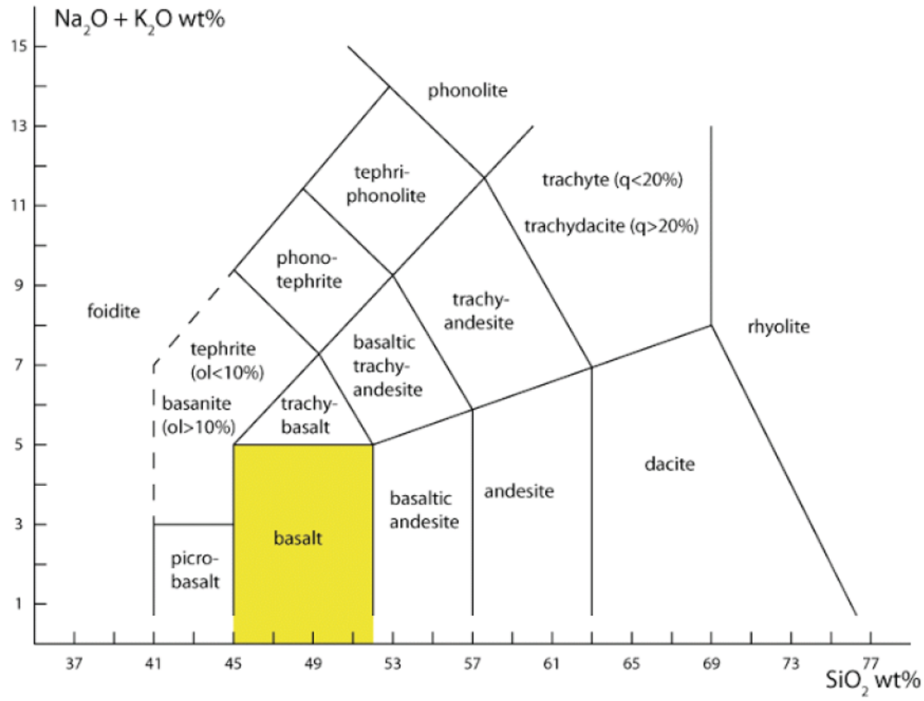


Figure 2.2: Total alkali silica

Table 2.6: Classification of acidity modulus (Johannesson et al., 2017)

References	Acidity Modulus (M_a)
Kochergin et al. (2013)	0.8-1.3 Slag
Singha (2012)	$<$ 1.2 Slag wool
	1.2-1.5 Mineral wool
	$>$ 1.5 Rock Wool, Basalt Fiber
Pisciotta et al. (2015)	$<$ 1.8 Mineral wool
	$>$ 1.8 Rock wool, Basalt fiber
Tatarintseva and Khodakova (2010)	$>$ 1.2 Staple and continuous fiber optimal for CBF

2.3.2 Viscosity Modulus (M_v)

The viscosity modulus is defined as the ratio of the molar fractions of the acidic oxides to all other oxides. For the production of continuous fibers, Toni Schneider (2015) defined the limits of viscosity modulus to be 2 to 3. Pisciotta et al. (2015),Pico et al. (2011), and Perevozchikova et al. (2014) defined the viscosity modulus through Equation 2.2.

$$M_v = \frac{x_{SiO_2} + x_{Al_2O_3}}{2x_{Fe_2O_3} + x_{FeO} + x_{CaO} + x_{MgO} + x_{K_2O} + x_{Na_2O}} \tag{2.2}$$

In this equation, x is defined as the molar ratio of the oxides.

Viscosity (η)

To produce basalt fibers, the rock has to be melted down and the molten material requires a specific liquidity. The stiffness of the molten material is described by the viscosity. Viscosity is one of the properties that determines the suitability for the basalt in the production process of fibers. Based on empirical analysis, the viscosity range for molten basalt rock must be between 10 Pa to 30 Pa to form a continuous basalt fiber (Tatarintseva et al., 2012a; Tatarintseva and Khodakova, 2012; Dzhigiris et al., 1983). These limits were derived from experimental analysis, and these limits were obtained at the melting temperatures ranging between 1300 °C and 1400 °C (Tatarintseva and Khodakova, 2012). The oxides that facilitate an increased viscosity (liquid stiffness) are silica (SiO_2), alumina (Al_2O_3), magnesium oxide (MgO), and trivalent iron (Fe_2O_3), while alkali metal oxides like potassium oxide (K_2O), sodium oxide (Na_2O), and divalent iron (FeO) contribute in decreasing the viscosity (Tatarintseva et al., 2012a). The viscosity of one particular basalt with composition shown in Table 2.7 can be calculated by using Equation 2.3 (Tatarintseva et al., 2012a).

$$\eta(T) = 3.26\left(\frac{SiO_2^{3.07} + (FeO + Fe_2O_3)^{1.34}}{Al_2O_3^{0.16} CaO^{0.4} (T - 1100\,°C)^{2.58}}\right)(M_a)^{1.25} \tag{2.3}$$

The oxides in this equation are supplied in weight percentage, T represents the temperature in °C, and the variables on the oxides are acidic modulus (M_a).

Table 2.7: Composition of basalt used in the viscosity equation (Tatarintseva et al., 2012a)

Oxide	Weight (%)
SiO_2	60.60
Al_2O_3	18.20
TiO_2	0.95
MnO	0.048
$FeO+Fe_2O_3$	7.2
MgO	2.20
Na_2O	2.30
K_{20}	3.45
P_2O_5	0.18
Other	4.70

Surface Tension (σ)

Surface tension is an important property, which must be determined in the production process of basalt fibers (Pisciotta et al., 2015). In continuous silicate fiber manufacture process, this property is known as fibreizability. The temperature at which the production process takes place depends on the ratio of the viscosity to the surface tension (η/σ). The stability of manufacturing process is directly proportional to this ratio. High modulus fibers are made from molten aluminosilicate glasses (Tatarintseva and Khodakova, 2012), and the η/σ ratio for these glasses is 100 Pa.

2.4 Basalt Fiber Production

The only raw ingredient used in the production process of basalt fibers is basalt rock (Zych and Wojciech, 2012), hence physical and mechanical properties of the fibers depend on the chemical composition of the rock. The basalt fibers are non-carcinogenic and non-toxic, and therefore, they are considered eco-friendly (Zych and Wojciech, 2012). Basalt fibers are made from molten basalt rock, which has a melting temperature of 1300 °C to 1450 °C (DIN SPEC 25714, 2017). Figure 2.3 depicts the production process of the basalt fiber, and it is shown that the crushed, washed basalt rock is transported to the furnace, first. Basalt rock absorbs

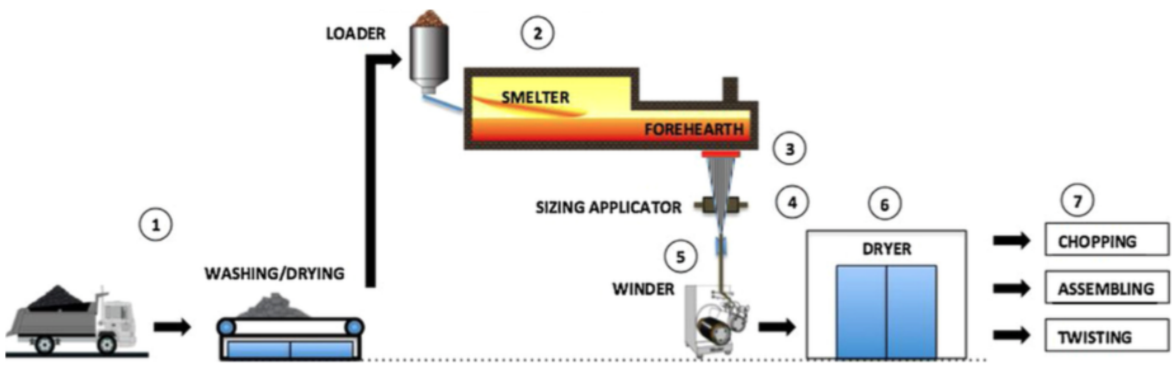
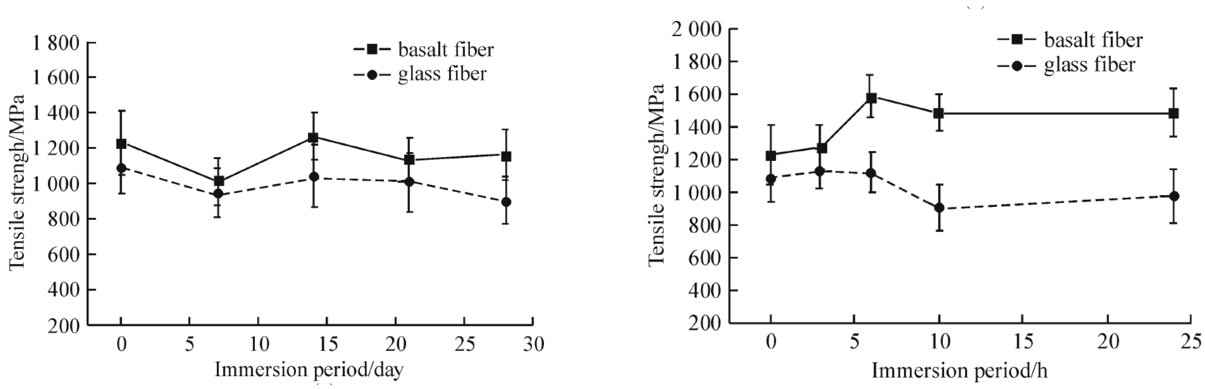


Figure 2.3: Basalt fiber production process (Ipbüker et al., 2014)

the infrared energy, and therefore, it is kept in the smelter until it reaches a homogeneous temperature throughout the entire molten mass (Ipbüker et al., 2014). Molten basalt flows into the forehearth and is then forced through a platinum/rhodium crucible, which has a 9 µm to 24 µm opening, and continuous fibers are extracted. Starch, oil, gelatin, or wax is applied to the extracted fibers as sizing for fiber protection and to improve bond within the fiber-resin matrix (Bagherpour, 2012; Zych and Wojciech, 2012). The fibers are then shaped and stored in desired forms depending on specific final purpose (Pavlovski et al., 2007).

2.5 Chemical Durability Studies on Basalt Fibers

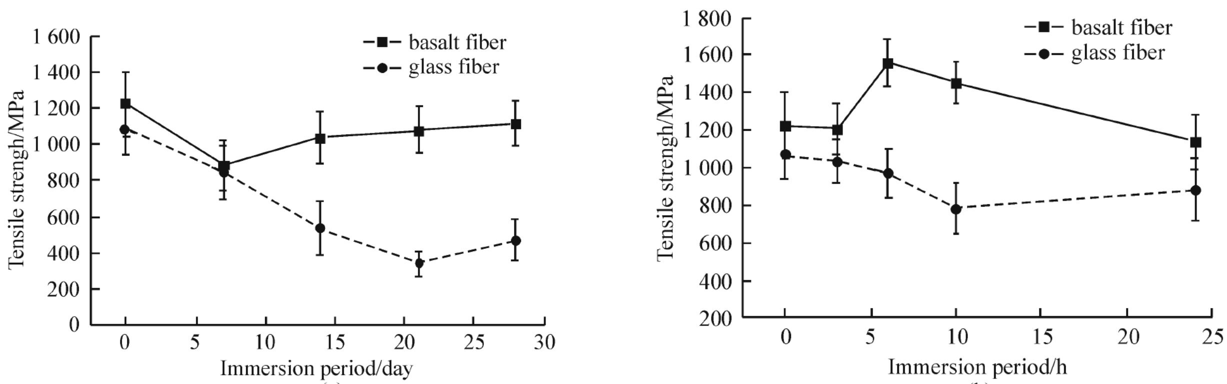
Ying and Zhou (2013) tested thermal stability of basalt, carbon and glass fibers in high temperature environments. The fibers were tested in tension after treating them with high temperatures (300 °C –600 °C). The corrosion properties of basalt fiber were also tested by Ying and Zhou (2013), for which the fibers were calcined at 300 °C for 3 h and 400 °C for 2 h before immersing them in water, acidic (hydrochloric acid) and alkali (sodium hydroxide) environments. The fibers were immersed for 24 h at 0 °C and 100 °C in all test solutions and weight retention of basalt fiber after 24 h immersion in boiling water, HCl (1mol/L), NaOH (1mol/L), NaOH (2mol/L) was 99 %, 97 %, 95 %, 92 %. The results of tensile strength of fibers after immersion period were plotted by (Ying and Zhou, 2013) and are shown in Figures 2.4, 2.5, and 2.6.



(a) Room temperature

(b) 100 °C

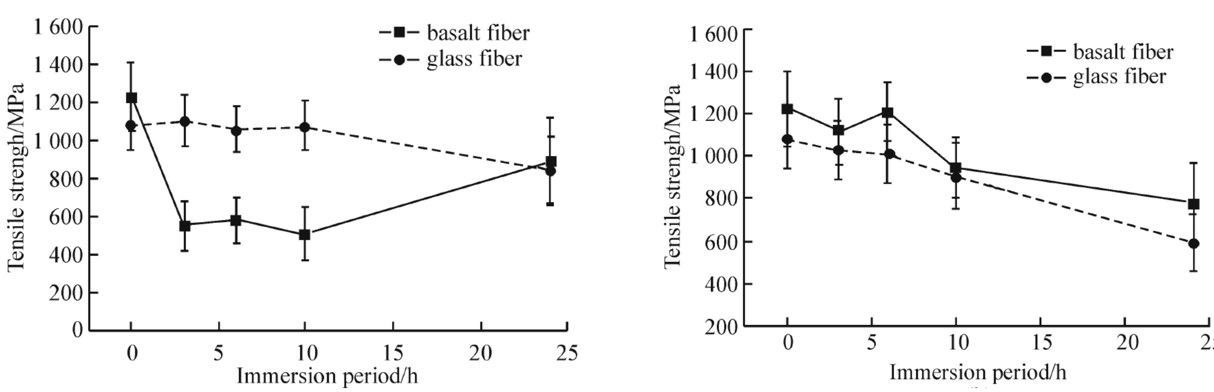
Figure 2.4: Tensile strength retention of water treated fibers (up to 24 h)



(a) Room temperature

(b) 100 °C

Figure 2.5: Tensile strength of fibers in 1mol/L HCl for 24 h



(a) 1mol/L NaOH

(b) 2mol/L NaOH

Figure 2.6: Tensile strength of fibers exposed to NaOH solution for 24 h at 100 °C

Nasir et al. (2012) studied the corrosion behavior and the crack formation mechanism of basalt fiber in sulphuric acid and compared the result to the documented performance of E-glass fiber studied by Shokrieh et al. (2012). Nasir et al. (2012) kept the basalt fiber bundles in 5 % sulphuric acid for 720 h and tested the tensile strength of the fibers. The fibers were cleaned with deionized water and air dried before examining them by XRF (X-ray fluorescence) based on ASTM standards. The strength of basalt fibers decreased by 58.5 % and the modulus decreased by 31.5 % after 720 h of immersion time. The glass fibers strength reduced by 37 % as compared to the strength measured in the virgin state, and the modulus reduced by 32 % after exposure period of 192 h. The comparison showed that the strain and the fracture mechanism of both fiber types were approximately the same but the basalt fiber strength was higher than the strength of the tested glass fibers after degradation. For the glass fibers, high content of the Fe^{3+} ions were noted around the generated micro-cracks, while Fe^{3+} ions were seen between separated basalt fibers. The Al^{3+} and Ca^{2+} ions were leached out on the surface of both fiber types throughout immersion, resulting in formation of thick Si layer on the surface.

Wei et al. (2010) studied the tensile behavior of basalt and glass fibers after treating them with 2M HCl (hydrochloric acid) and NaOH (sodium hydroxide) solutions for 0.5 h-3 h. The fibers were first washed in acetone, before treating them with the test solutions and then dried at 105 °C (221 °F) for 3 h. After the treatment, the fibers were soaked in distilled water for 24 h and then dried again. The tensile strengths of fiber bundles were measured before and after treatment. Results showed that the fibers were damaged in both the solutions. Tensile strength of the fibers was inversely proportional to the immersion time, while the effect of acidic solution on basalt fibers was not as high as it was for glass fibers with increased immersion time. The durability of basalt fibers was better in acidic environment than it was in alkaline environment while the durability of glass fibers was identical for both test solutions (Wei et al., 2010).

In a research completed by Mingchao et al. (2008), chemical durability and mechanical properties of alkali-proof basalt fibers and epoxy resin matrix were analyzed. In addition, the mechanical properties of BFRP were studied. First the densities of basalt fibers were measured by using the suspension method (Mingchao et al., 2008). The specimen were then impregnated with resin, and then the tensile properties of the samples were analyzed. The seven day water absorption of the fibers was measured at room temperature. The chemical durability of fiber yarns were tested by boiling them in distilled water, 2 mol/L NaOH and 2 mol/L HCl for 3 h. The mass loss of the fibers was measured and the tensile properties were determined. The BFRP flexural specimen were stored in eight different chemical media (30 % vitriol, 5 % hydrochloric acid, 5 % nitric acid, 110 % sodium hydroxide, saturated sodium carbonate solution, 10 % ammonia, acetone and distilled water) for 15 d, 30 d, and 90 d at room temperature. The results showed that the chemical durability of fibers after 3 h period in hydrochloric acid was much less in comparison to sodium hydroxide. The mass of fibers, and their tensile strength decreased more after exposing them to hydrochloric acid in comparison to exposure in sodium hydroxide. The flexural strength of the BFRP specimen kept lowering while the flexural modulus was steady in alkaline media, but both the flexural strength and modulus decreased after exposure in acid media(Mingchao et al., 2008).

A study on structure and properties of basalt fiber was performed by Shi (2012). Chemical composition, crystal structure, thermal properties, flammability, mechanical properties and morphology of the fiber were investigated. The elements comprising the basalt fibers, especially metals were quantitatively analyzed by X-ray Fluorescence Spectrometry (XRF). It was found that the main elements comprising basalt fibers were Fe, Si, Ca, Al, K, and Mo and the sum of the elements Fe, Si, Ca, and Al make up to 87 %. The composition of the basalt fiber varies with its place of origin. Main compositions of the fiber are listed in table in Figure 2.7.

The characteristic diffraction pattern for every substance does not change although a material may be composed of a variety of substances mixed together. Shi (2012) performed the X-ray diffraction spectroscopy (XRD) of basalt fiber to study the correspondence between the structure and diffraction pattern for every crystal. It can be seen in Figure 2.8 that there is no diffraction peak but only a characteristic peak of a glass substance. This proves that basalt fibers are amorphous in nature and there is no long range order crystal

Analyte	Result (%)	Analyte	Result (%)	Analyte	Result (%)
Fe	36.020	Mo	2.066	S	0.429
Si	26.304	Ti	1.778	Cr	0.094
Ca	17.239	Ba	1.303	Zr	0.090
Al	7.432	Mn	0.610	Cu	0.080
K	6.028	Sr	0.479	Zn	0.049

Figure 2.7: Quantitative result of basalt fiber (Shi, 2012)

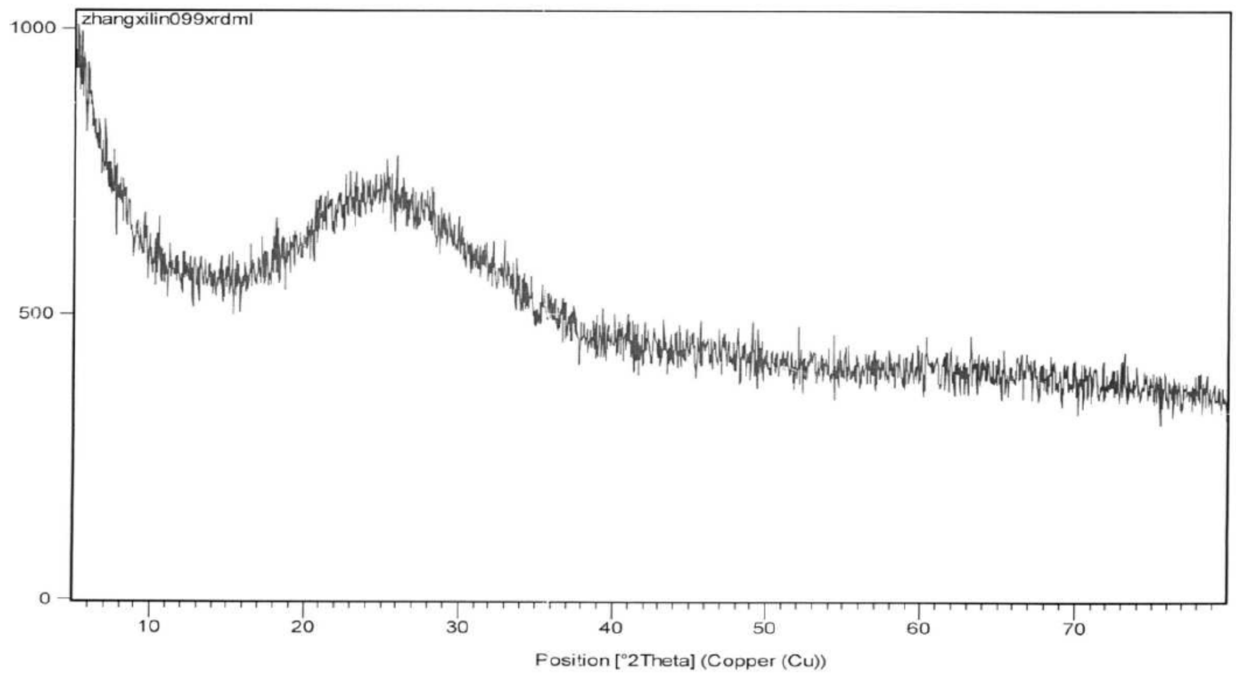


Figure 2.8: The X-ray diffraction spectroscopy of basalt fiber (Shi, 2012)

structure in the fiber but only with short range order.

XRD analysis on basalt fibers was also conducted by Gutnikov et al. (2013); Lipatov et al. (2015); Iorio et al. (2018). Results obtained by the researchers can be seen in graphs in Figures 2.9, 2.10, and 2.11. It can be seen that the results obtained are very similar to results obtained by Shi (2012).

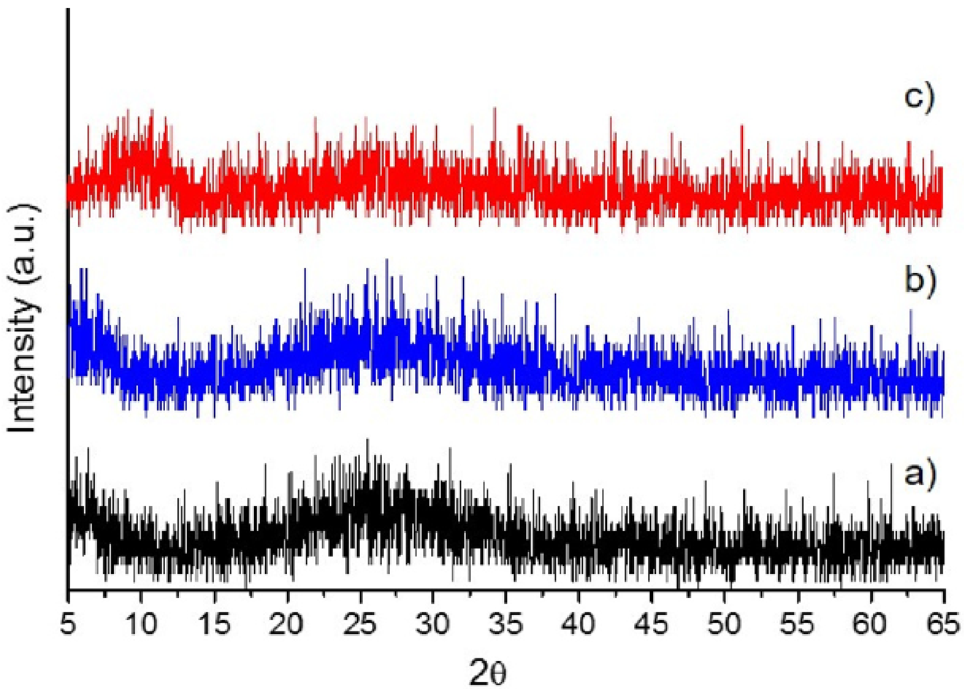


Figure 2.9: The X-ray diffraction spectroscopy of basalt fiber (Iorio et al., 2018)

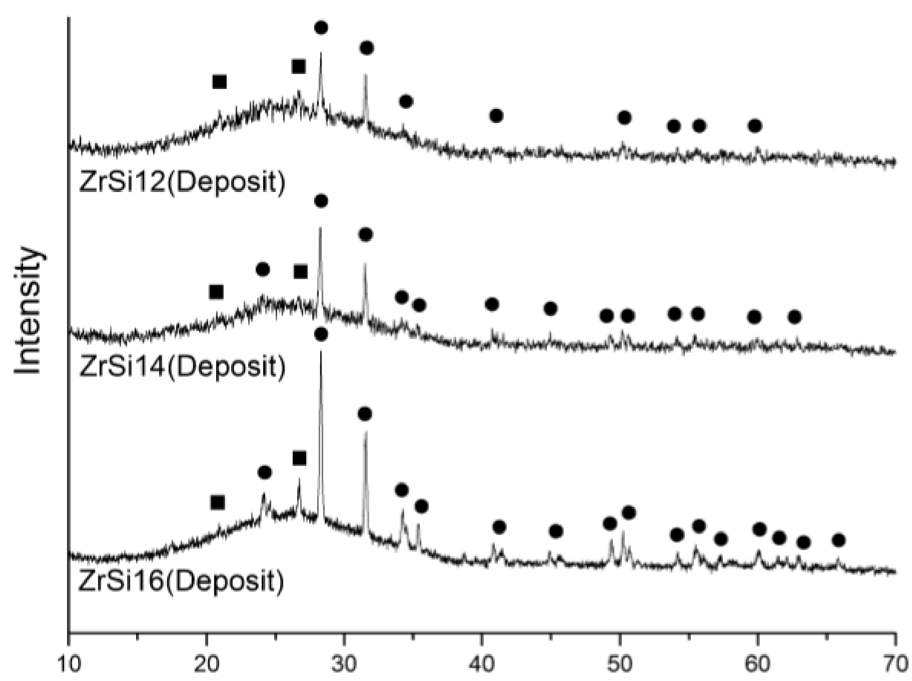


Figure 2.10: The X-ray diffraction spectroscopy of basalt fiber (Lipatov et al., 2015)

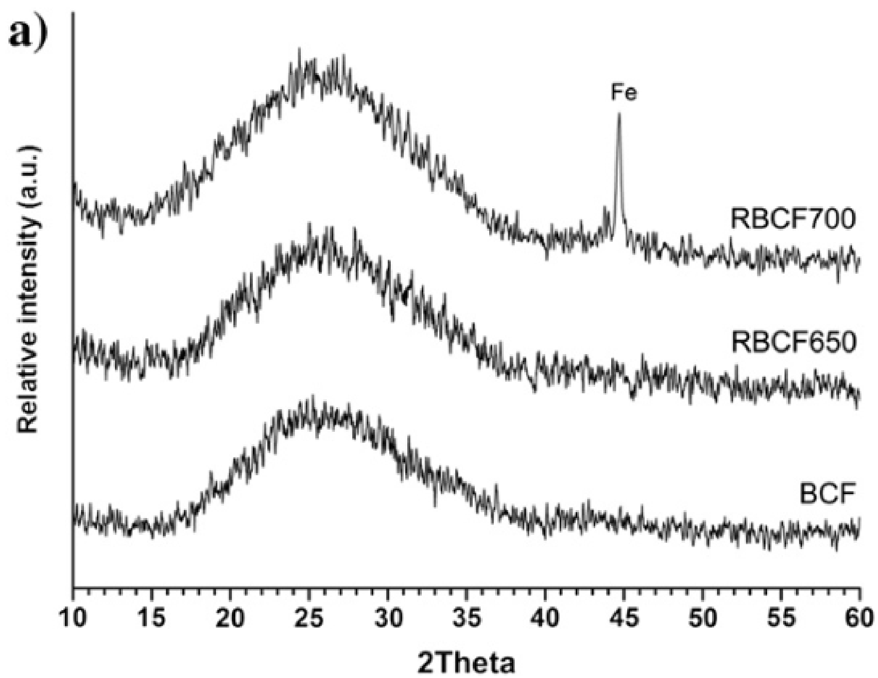


Figure 2.11: The X-ray diffraction spectroscopy of basalt fiber (Gutnikov et al., 2013)

2.6 Sizing

The sizing is a protective layer that is applied to the virgin fibers at the end of the manufacturing process. Sizing forms a strong protective layer, which shields each fiber from chemical attacks in aggressive environments and mechanical damage, but it also increases the resin adhesion to the fiber (Ivashchenko, 2009). A number of studies were conducted to improve the alkali resistance throughout the application of different sizing agents and to match it properly to the fibers (Rybin et al., 2016). Some of the methods researchers developed are: modifying the makeup of fibers by addition of alkali resistant components such as ZrO_2 to the raw materials (Lipatov et al., 2015), applying alkali resistant coating to the fibers (Jung and Subramanian, 1994; Rybin et al., 2013), and modifying cement matrices by using special additives (Lipatov et al., 2012).

2.7 Chemical Durability Studies on Sizing

Rybin et al. (2013), conducted a study to compare the tensile strength characteristics of virgin basalt fibers to Zirconia-coated basalt fibers. The fibers were coated with Zirconyl Chloride Octahydrate ($ZrCl_2 \cdot 8\,H_2O$ [0.1–0.4M]) and heated in a furnace at 550 °C (1022 °F) for half an hour in argon atmosphere and then cooled in air. The fibers were then exposed to alkali solution for a duration of eight days. According to this study the Zircona coting helped improve the corrosion resistance of the fibers. The tensile strength of virgin fibers and 0.4M zirconia-coated fibers immersed in alkali for eight days was 4.5 GPa and 4.4 GPa, respectively which is a 0.1 GPa difference. But the 0.1M zirconia coated fibers reached only 2.6 GPa after eight-day exposure (Rybin et al., 2013). Further, the uncoated and coated fibers were tested in a cement matrix, and zirconia coating made the fibers more resistant to corrosion from the alkali environment.

Rybin et al. (2016) coated basalt fibers with zirconium dioxide and titanium dioxide, and studied the corrosion behavior after exposing the coated fibers to 2M NaOH (sodium hydroxide, pH14) and saturated 0.02M Ca(OH) 2 (calcium hydroxide) for 16 d and 64 d. Zirconyl-chloride octahydrate ($ZrOCl_2 \cdot 8\,H_2O$) was dissolved in ethanol water to form a 0.4M ZrO_2 solution, which was aged for three days before it was used to coat the fibers. Titanium tetrachloride ($TiCl_4$) was added to frozen water to form 0.8M TiO_2 solution. The basalt fibers were immersed into the solutions for 1 min and then air dried before aging them in a preheated furnace at 550 °C, which prevented degradation of mechanical properties of fiber. The specimens were cleaned twice with distilled water after the exposure period and dried at room temperature. The cleaned dry specimens were scanned using scanning electron microscope (SEM), and energy-dispersive X-ray method (EDS). Rybin et al. (2016) found that the degradation of coated fibers was less than the degradation of non-coated fibers. TiO_2 coating helped protecting fibers from early degradation in $CaOH_2$ solution, and ZrO_2 coating protected fibers in both solutions.

In research projects performed by Wei (Wei et al. (2011) and Wei et al. (2011)), the surface of basalt fibers were modified by organic/inorganic nano hybrid sizing synthesized using sol-gel technology. The infrared (IR) and atomic force microscopy (AFM) analyses were performed to confirm that the epoxy/SiO_2 nano-hybrid material synthesis was successful. Wei et al. (2011) analyzed the surface morphology of modified fibers and studied the multifilament yarn tensile strength as well as the inter-layer shear strength (ILSS). The predominant method of synthesizing nano SiO_2 is called stöber method (Van Blaaderen et al., 1992). E-51 epoxy resin and 3-Aminopropyltriethoxysilane (KH-550) — at the material ratio of 100:3.55 — were mixed to prepare a modified epoxy resin and stirring at 50 °C-55 °C for 4 h (Wei et al., 2011). Nano-hybrid composite was prepared by mixing nano-SiO_2 solutions with modified epoxy solutions. The ultimate slurry that was used to modify the basalt fiber was made by mixing the epoxy/SiO_2 nano-hybrid material and acetone at a mass ratio of 2:100 (Wei et al., 2011). The results showed that the tensile strength of basalt fiber multifilament yarn was increased by 15 %-30 % after modification (Wei et al. (2011) and Wei et al.

(2011)). Surface modification performed well when the SiO_2 content was set to 5 %. A 10 % to 15 % increase in the ILSS of basalt fiber composite was noted (Wei et al. (2011) and Wei et al. (2011)).

2.8 Binder Materials and Types

Resin is the binding material used in the manufacture of FRP to guarantee a unified behavior of the combined fibers. Resin helps to hold the sized fibers together and plays an important role in the load transfer. The resin also protects the fiber from chemical attacks and protects the filaments from mechanical damages (Benmokrane et al., 2002). Resins are classified into two types, Thermosetting resins and Thermoplastic resins. The thermosetting resins are used to manufacture FRP materials for civil structures because after they are cured at high temperatures and hardened, they cannot be returned into a liquid state (Bagherpour, 2012). Thermoplastic resins are not used in civil structures because, they can be returned to their original state by applying heat (reheating). The most common resins used in FRP manufacturing are Epoxy resin, Polyester resin, and Vinyl-Ester resin (ACI Committee 440, 2007). Figure 2.12 shows thermoset resin in its virgin

Figure 2.12: Thermoset resin used in FRP

state. The thermoset resins are usually liquid at room temperature and solid with a low melting point in their virgin state. Heat treatment and catalysts are used in the curing process to expedite hardening and set. Table 2.8 shows the properties of typical resin matrices according to Nanni et al. (2014). The following subsections below provide a brief description of the three common resins used in FRP manufacture.

2.8.1 Epoxy

Epoxy resins are used in high performance composite materials because of the desired mechanical properties of these resins. Epoxies are generally durable and resist chemical attacks and corrosive liquids. The shrinkage characteristic of epoxy is very low, which facilitates its use in civil structures. Epoxy resins are highly viscous

Table 2.8: Typical properties of resins (Nanni et al., 2014)

Resin Type	Density kg/m^3	Tensile Strength kN/mm^2	Longitudinal Modulus kN/mm^2	Poissons's Ratio	CTE $10^{-6}/^{\circ}C$	Moisture Content %	Glass Transition Temperature $^{\circ}C$
Epoxy	1186 −1423	34.5−103.5	2067−3445	0.35 −0.39	2.88 −5.4	0.15 −0.60	95 −175
Polyester	1186 −1423	48.3 −130.9	2756 −4134	0.38 −0.40	2.34 −3.42	0.08 −0.15	70 −100
Vinyl-ester	1127 −1364	68.9 −75.8	2997.2 −3445	0.36 −0.39	2.7 −3.96	0.14 −0.30	70 −165

$Notes : 1kg/m^3 = 1.686lb/yd^3; 1N/mm^2 = 0.145ksi;$ °C = (°F − 32) $* 5/9; 1/^{\circ}C(CTE) = 0.556/^{\circ}F$

and need post curing at elevated temperatures (ACI Committee 440, 2007). Carbas et al. (2013) analyzed the effects of post curing on the mechanical properties (yield strength, Young's modulus, and failure strain) of these resins. The glass transition temperature (T_g) was measured by a dynamic mechanical analysis apparatus developed by Carbas et al. (2013). If epoxy resins are exposed to elevated temperature less than that of glass transition temperature for longer periods, the mass density of the resins increases, which is termed physical aging (Carbas et al., 2013). For the use of resins in civil engineering purposes, the degradation due to decrease in the T_g is not critical if the glassy state is maintained (Arias et al., 2018). Epoxy resins are manufactured by using bisphenol A (BPA), a compound that can be synthesized as a chemical oestrogen (Dodds and Lawson, 1936). BPA leads to a negative impact on the environment, and therefore, researchers started studying the materials that can substitute BPA and allowing the synthesis of epoxy thermoset resins without BPA (Aouf et al., 2013). These types of resins are called bio-epoxies, and are favored by the manufacturers in the production of FRP rebars which make them eco-friendly rebars. The cost of these resins is high compared to other resins and these are widely used in FRP for concrete repair because of high strength performances (Bagherpour, 2012).

2.8.2 Vinyl-Ester

Vinyl esters are corrosion resistant themoset resins with good mechanical properties (Nouranian et al., 2013; McConnell, 2010; ACI Committee 440, 2007). They are polymeric resins that can be cured faster than epoxy resins, and can be cured in both room temperature and at elevated temperatures (Cook et al., 1997). The flexural properties of a neat vinyl ester resin depends on the curing atmosphere (Nouranian et al., 2013). Figure 2.13 shows the chemical structure of a vinyl ester prepolymer. These resins are used in civil engineering structures not only because of their good mechanical properties but also because of their good toughness and low shrinkage properties when cured (Alia et al., 2013). The mechanical properties of these resins, and their viscoelastic properties are affected by post-curing temperature (Alía et al., 2015). These resins are cheaper and have better physical and mechanical properties in comparison to other resins. The glass fiber industry uses vinyl-ester resin predominantly while epoxy resins are used in basalt fiber industry (Nanni et al., 2014).

2.8.3 Polyester

Polyesters are unsaturated reins with good mechanical performance, low material density, and high chemical resistance (Fink, 2017). One of the main reasons to use these low cost resins in the civil engineering industry is, they are adaptable into large composite structures (Baley et al., 2006). The curing process involves dissolving resin in the monomer, which reacts with unsaturated polymer to form thermoset structure (ACI

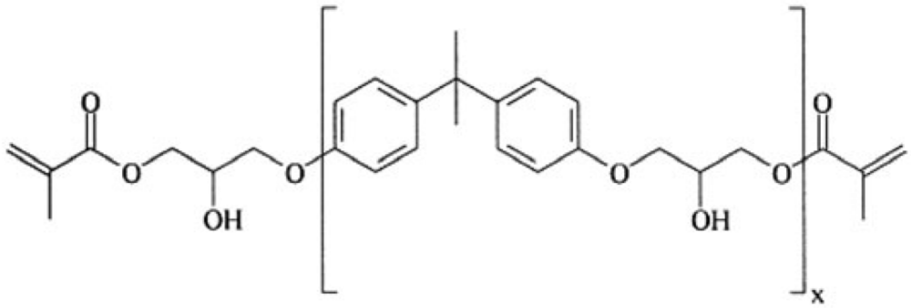


Figure 2.13: Structure of a vinyl-ester

Committee 440, 2007). These resins shrink about 7 % during the curing process leading to problems such as surface distortion, or inability to mold to close parts, etc. (Kinkelaar et al., 1994). Low profile additives like thermoplastic polymers are added to overcome such problems with curing (Huang and Liang, 1996). However, different types of resins exist to satisfy different desirable requirements such as dimensional stability, cost efficiency, etc.

2.9 Chemical Durability Studies on Resins

In a study completed by Benmokrane et al. (2017), the durability of glass fiber rebars made with vinyl-ester, isophthalic polyester, and epoxy resins after alkaline exposure for 1000, 3000 and 5000 h at elevated temperatures (60 °C [140 °F]) was evaluated. GFRP rebars with a 12 mm diameter were tested for this study because small sized specimen suffer more severely from chemical attacks. The physical and mechanical properties of the rebar were measured according to ASTM standards before and after the immersion period. Then, they were compared to one another. The comparison between rebars made with three different types of resin showed that the rebar made from polyester resin had the lowest virgin and conditioned physical and mechanical properties. The epoxy and vinyl-ester GFRP bars had higher fiber-resin bond, flexural strength, flexural modulus of elasticity, and inter-laminar-shear strength while having the least moisture uptake. The flexural strength reduction of polyester, vinyl-ester, and epoxy resin were 25 %, 17 %, and 23 %, respectively. The inter-laminar shear strength of rebars made with polyester resin was reduced by 21 % while the strength of rebars made from vinyl-ester, and epoxy resin was reduced by only 13 %. Finally, the polyester GFRP absorbed 18 % more water in comparison to other rebars.

In a research conducted by Kajorncheappunngam et al. (2002), glass reinforced epoxy coupons were immersed in four different liquid media at two different temperatures, and the durability of coupons was evaluated. Epoxy compatible E-glass fibers were woven with epoxy resin and soaked in distilled water, saturated salt solution (30 g/ 100 cc NaCl), 5M NaOH solution, and a 1M hydrochloric acid (HCl) solution for 5 months, and aged at room temperature and at 60 °C (140 °F). The tensile and durability properties of the coupons were analyzed, and SEM analysis of aged coupons was performed. The results of tensile strength tests on the epoxy neat resin and the fiber-resin coupons are listed in Tables 2.9, 2.10, 2.11, and 2.12. Tables 2.9 and 2.10 show the tensile strength results of the epoxy resin exposed to liquid media in room temperature and at elevated temperature. The tensile test results of the fiber-resin coupons can be found in Tables 2.11, and 2.12. It can be seen that the strength retention of GFRP rebars made from epoxy resin in alkali environment was high at both room temperature and elevated temperature. Results of this study demonstrated that the epoxy resins are durable in alkali environment and the durability of GFRP coupons

Table 2.9: Effect of liquid media at room temperature on the tensile properties of epoxy neat resin (Kajorncheappunngam et al., 2002)

		Solutions												
		Saturated Salt (NaCl)			5M NaOH			Distilled Water			1M HCl			Control Sample
		Aging Time (month)			Aging Time (month)			Aging Time (month)			Aging Time (month)			Aging Time(month)
Properties	Unit.	1	3	5	1	3	5	1	3	5	1	3	5	0
Maximum Stress at Failure	psi	6707	5336	5057	8572	7229	5821	5915	6706	5677	6159	4551	4564	5558
Strain at Failure	microstrain	22329	11899	10585	28823	24619	13647	13261	20649	15426	10024	9335	9516	11730
Young's Modulus	msi	0.45	0.48	0.52	0.44	0.41	0.47	0.53	0.44	0.42	0.66	0.52	0.51	0.51
Percent Maximum Stress Reduction [a]	%	-20.68(120.68)	4.00(96.00)	9.00(91.00)	-54.22(154.22)	-30.07(130.07)	-4.74(104.74)	-6.43(106.43)	-20.66(120.66)	-2.14(102.14)	-10.81(110.81)	18.12(81.88)	17.88(82.12)	–
Percent Ultimate Strain Reduction	%	-90.89	-1.44	9.76	-145.71	-109.87	-16.34	-13.05	-76.03	-31.51	14.54	20.41	18.87	–

Table 2.10: Effect of liquid media at elevated temperature on the tensile properties of epoxy neat resin (Kajorncheappunngam et al., 2002)

		Solutions												
		Saturated Salt (NaCl)			5M NaOH			Distilled Water			1M HCl			Control Sample
		Aging Time (month)			Aging Time (month)			Aging Time (month)			Aging Time (month)			Aging Time(month)
Properties	Unit.	1	3	5	1	3	5	1	3	5	1	3	5	0
Maximum Stress at Failure	psi	5554	5013	4783	6719	5001	4713	5801	5312	5332	4492	5335	5670	5558
Strain at Failure	microstrain	14458	12543	11518	18251	12519	11132	15600	14379	13413	10107	10424	12929	11730
Young's Modulus	msi	0.44	0.45	0.47	0.42	0.43	0.47	0.43	0.43	0.45	0.49	0.52	0.49	0.51
Percent Maximum Stress Reduction [b]	%	0.08(99.92)	9.81(90.19)	13.94(86.06)	-20.88(120.88)	10.02(89.98)	15.20(84.80)	-4.37(104.37)	4.43(95.57)	4.06(95.94)	19.17(80.83)	104244.01(95.99)	-2.01(102.01)	–
Percent Ultimate Strain Reduction	%	-23.25	-6.94	1.81	-55.59	-6.73	5.09	-32.99	-22.58	-14.34	13.83	11.13	-10.22	–

[a] Parentheses indicate the percentage retention of tensile strength.
[b] Parentheses indicate the percentage retention of tensile strength.

Table 2.11: Effect of liquid media at room temperature on the tensile properties of glass/epoxy composite (Kajorncheappunngam et al., 2002)

		Solutions												
		Saturated Salt (NaCl)			5M NaOH			Distilled Water			1M HCl			Control Sample
		Aging Time (month)			Aging Time (month)			Aging Time (month)			Aging Time (month)			Aging Time(month)
Properties	Unit.	1	3	5	1	3	5	1	3	5	1	3	5	0
Maximum Stress at Failure	psi	54368	56640	59688	43900	46851	41825	58413	47333	44458	29007	17711	15324	57920
Strain at Failure	microstrain	19452	20092	20649	17125	16352	14916	19226	16025	15288	11005	7431	6284	20664
Young's Modulus	msi	2.90	3.00	3.00	3.04	3.23	3.04	3.17	3.05	2.97	2.83	2.49	2.52	3.05
Percent Maximum Stress Reduction [a]	%	6.1(93.87)	2.21(97.79)	-3.05(103.50)	24.12(75.79)	19.11(80.89)	27.79(72.21)	-0.85(100.85)	18.28(81.72)	23.24(76.76)	49.94(50.08)	69.42(30.58)	73.54(26.46)	–
Percent Ultimate Strain Reduction	%	5.87	2.77	0.07	17.13	20.86	27.81	6.96	22.45	26.02	46.74	64.04	69.59	–

Table 2.12: Effect of liquid media at elevated temperature on the tensile properties of glass/epoxy composite (Kajorncheappunngam et al., 2002)

		Solutions												
		Saturated Salt (NaCl)			5M NaOH			Distilled Water			1M HCl			Control Sample
		Aging Time (month)			Aging Time (month)			Aging Time (month)			Aging Time (month)			Aging Time(month)
Properties	Unit.	1	3	5	1	3	5	1	3	5	1	3	5	0
Maximum Stress at Failure	psi	54196	57721	46735	27172	15591	15363	29405	30503	30262	37350	37771	30087	57920
Strain at Failure	microstrain	20158	20429	17314	11425	7099	6191	10205	10043	10122	16223	12846	13437	20664
Young's Modulus	msi	2.82	3.15	2.80	2.79	2.76	2.79	2.94	3.09	3.07	2.55	2.33	2.46	3.05
Percent Maximum Stress Reduction [b]	%	6.43(93.57)	0.34(99.66)	19.31(80.69)	53.03(46.91)	73.08(26.92)	73.47(26.53)	49.23(50.77)	47.34(52.66)	47.75(52.25)	35.51(64.49)	34.79(65.21)	48.05(51.95)	–
Percent Ultimate Strain Reduction	%	2.32	1.13	16.21	44.71	65.64	70.04	50.61	51.39	51.02	21.49	37.83	34.97	–

[a] Parentheses indicate the percentage retention of tensile strength.
[b] Parentheses indicate the percentage retention of tensile strength.

depends on the resistance of glass fiber to aggressive environments.

2.10 BFRP Rebar Production

By analyzing the SEM pictures of the surface of FRP rebars, manufactures believe that numerous properties are influenced by the production process (Borges et al., 2015). Based on this, FRP rebar manufacturers developed several processes to help increase the efficiency and quality of production. Because the production process for FRP rebars is not standardized yet, many different BFRP rebar products are available in the market with dissimilar physical and mechanical properties (Borges et al., 2015; Joshi et al., 2003). The most predominant methods are pultrusion, wet-layup, and braiding or weaving. In the BFRP rebar industry, the most common manufacturing methods are pultrusion and wet-layup, while the manufacturers seem to prefer pultrusion process due to the efficiency and economical factors. Braiding is an old production process for FRPs and manufacturers seem to not use this process due to the inconsistency in surface properties of the rebar. Because pultrusion and wet-layup processes are the most common techniques for the production of FRP materials, they are described in the following subsections.

2.10.1 Wet-Layup

The wet-layup process was invented because of the increasing demand for the FRP rebars in the infrastructure rehabilitation (Saadatmanesh et al., 2010). Manufacturers believe that this process is economical in comparison to the traditional pultrusion process. It is a recently developed process and has not been widely researched, yet. Figure 2.14 schematically represents the wet-layup process to show how the fibers are guided through a resin bath in which the wetting of fibers in resin and impregnation occurs. A programmable arm

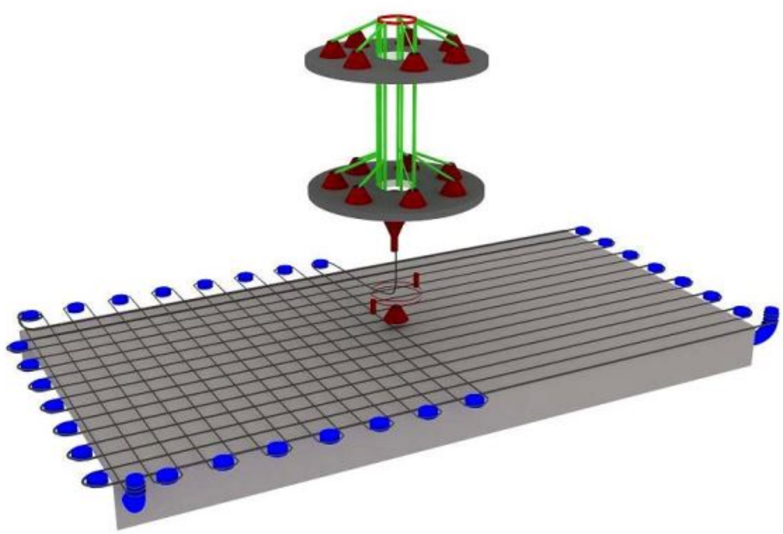


Figure 2.14: Schematic of wet-layup process (Banibayat and Patnaik, 2014)

with three degrees of freedom in orthogonal direction helps in rebar manufacturing. Though this process is economical, manufacturers do not prefer this method because of potential inconsistencies in rebar dimensions and surface properties. The rebar manufactures who use this process generally produce rebars with wavy surface, which helps to improve the bond-to-concrete strength but reduces the tensile strength of the rebar (You et al., 2015).

2.10.2 Pultrusion

Pultrusion is the most predominant method that manufacturers use to produce FRP rebars. It is a fully automated process, and hence the most economical and time-saving method. The fibers and the resin are molded in a continuous process that helps maintain a consistent rebar cross section. Figure 2.15 schematically represents the pultrusion process (Borges et al., 2015), in which the fibers are first cleaned and parallelized

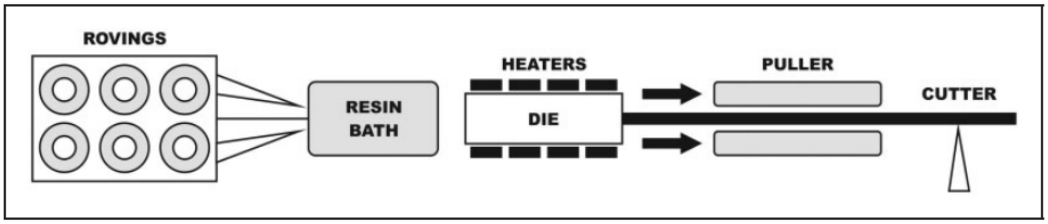


Figure 2.15: Schematic representation of the pultrusion process (Borges et al., 2015)

in the rovings before entering the resin bath. In the resin bath, the fibers are impregnated with resin at suitable temperatures between 30 °C to 50 °C (86 °F to 122 °F) range (Borges et al., 2015). The viscosity of the resin increases as the temperature increases, possibly resulting in improper impregnation. The wet fibers then enter into the heating die with multiple heating zones which activates the curing process, to ensure that the resin hardens and bonds the fibers together, producing a uniform FRP rebar. In a research conducted by Joshi et al. (2003), the authors claimed that the recommended curing temperature is 177 °C (350 °F). An exothermic reaction helps the liquid resin to form into a gel, which later harden into a fiber-resin matrix. The fiber-resin composite is then pulled out of the machine and cooled to room temperature. Following this process, a surface enhancement (sand coating, ribs, and surface lugs) is applied to the outer part of the rebars, which increases the bond-to-concrete strength (You et al., 2015). Quality of the rebar is affected by the resin quality, production time, curing temperature, fiber content and other factors.

2.11 Chemical Durability Studies on FRP Rebar

In a study performed by Guo et al. (2018), the durability of CFRP, GFRP, and BFRP immersed in various chemically active solutions at 60 °C (140 °F) was analyzed. The solutions used and their chemical composition are listed in Table 2.13. The results obtained from samples immersed in the distilled water were used as a reference. The alkaline content of SWSS concrete solutions was low in comparison to normal concrete because of added slag that replaced Portland cement. FRP coupons were stored in sealed containers to prevent calcium hydroxide from interacting with carbon dioxide in the air. The specimen were immersed in solutions for 90 d, and the moisture uptake of all the rebars in the various solutions was as follows: NC > SWSSNC > DW > HPC > SWSSHPC. The FRP in HPC and SWSSHPC followed a distinct trend, which indicated that the alkali content play an important role in the durability of FRP. The moisture uptake of FRP in SWSSHPC and SWSSNC was lower than that of NC and HPC , which indicated that the seawater and sea sand played a beneficial role in resisting water uptake or degradation. However, the water uptake of BFRP rebars in NC was lower than SWSSNC at the end of 90 d, which showed that NaCl present in SWSSNC plays a key role in preventing the deterioration of BFRP. CFRP had the better durability in comparison to other FRP.

Benmokrane et al. (2015) performed an experimental analysis of physical, mechanical, and durability properties of BFRP rebar manufactured with vinyl ester resin, GFRP-vinyl ester resin, and BFRP-epoxy resin. The physical and mechanical properties of the unconditioned rebars were first measured. These results

Table 2.13: Chemical composition of accelerated solutions (Guo et al., 2018)

	Quantities(g/Ll)				
Simulated Environment	NaOH	KOH	$Ca(OH_2)$	NaCl	pH
SWSSNC[1]	2.4	19.6	2.0	35	13.4
NC[2]	2.4	19.6	2.0	–	13.4
SWSSHPC[3]	0.6	1.4	0.037	35	12.7
HPC[4]	0.6	1.4	0.037	–	12.7
DW[5]	–	–	–	–	7.5

were used as the reference results to compare the properties of the rebars after exposure to alkaline environments that simulated the concrete pore solution at 60 °C (140 °F) for 1000 h, 3000 h, and 5000 h. Differential scanning calorimetry (DSC) was used to measure the glass transition temperature and Fourier transform infrared spectroscopy (FTIR) was used to measure the chemical composition of the rebars. Scanning electron microscope (SEM) was used to evaluate the micro structure of the un-aged and the aged samples. The results showed that the moisture absorption of both types of unconditioned basalt rebars was almost twice as much as the GFRP rebar. GFRP rebars also had a higher inter-laminar shear strength, flexural strength, flexural modulus of elasticity, and had a good fiber-resin bond in comparison to BFRP rebars. BFRP-Vinyl ester, unconditioned rebars had the lowest transverse shear strength, flexural strength, inter-laminar shear strength, and weak fiber/resin interface (Benmokrane et al., 2015). The transverse strength of conditioned BFRP-vinyl ester bars reduced by 33 %, while GFRP-vinyl ester and BFRP-epoxy bars decreased by 9 % and 10 % , respectively. In addition, the flexural strength of both the BFRP rebars decreased by 37 % and GFRP rebars by 7 %. Interlaminar shear strength of BFRP-vinyl ester bars decreased by 22 %, BFRP-epoxy reabrs decreased by 14 % and GFRP rebars decreased by 5 %. Ultimately, the GFRP rebar showed the better durability in alkaline environment in comparison to BFRP rebars.

Chapter 3

Existing Standards for FRP Rebars

In this chapter, the existing standards and acceptance criteria for GFRP and BFRP rebars in concrete structures according to various national and international regulations are presented in table format. Table 3.1 lists the various codes and standards for countries/nations that provide acceptance criteria for FRP rebars with various sizes.

Table 3.1: Codes and standards for FRP in different countries

Code	Country	Year
FDOT 932-3	USA (Florida)	2017
AC454	USA	2017
ASTM D 7957	USA	2017
CAN/CSA S807	Canada	2010 (R2015)
FIB Bulletin 40	Europe	2007
GOST 31938	Russia	2012

3.1 Typical Fiber Properties

Typical properties of basalt, E-glass, and S-glass fibers according to FIB Bulletin 40 are listed in Table 3.2, and 3.3 in imperial and metric units (rounded to the nearest two decimal values).

Table 3.2: Acceptance criteria for properties of fibers for the production of FRP rebars (Imperial Units)

		Fiber Type (FIB Bulletin 40)		
		Basalt	Glass	
Properties	unit		E- glass	S- glass
Density	lbs./ft^3	174.8	156.07	156.07
Tensile Strength	ksi	701.98	500.38	664.26
Young's Modulus	ksi	12 908.4	10 500.73	12 400.73
Ultimate Tensile Strain	%	3.1	2.5	3.3
Coefficient of Thermal Expansion	10^{-6}/°C	8	5	2.9
Poisson's Coefficient	–	–	0.22	0.22

Table 3.3: Acceptance criteria for properties of fibers for the production of FRP rebars (Metric Units)

		Fiber Type (European)		
		Basalt	Glass	
Properties	unit		E- glass	S- glass
Density	kg/m^3	2800	2500	2500
Tensile Strength	MPa	4840	3450	4580
Young's Modulus	GPa	89	72.4	85.5
Ultimate Tensile Strain	%	3.1	2.5	3.3
Coefficient of Thermal Expansion	10^{-6}/°C	8	5	2.9
Poisson's Coefficient	–	–	0.22	0.22

3.2 Typical Resin Properties

Typical properties of polyester, epoxy, and vinyl ester resins according to FIB Bulletin 40 are listed in the Tables 3.4 and 3.5 in imperial and metric units (rounded to the nearest two decimal values), respectively.

Table 3.4: Acceptance criteria for properties of resins for the production of FRP rebars (Imperial Units)

		Resin Type (FIB Bulletin 40)		
Properties	unit	Polyester	Epoxy	Vinyl ester
Density	lbs./ft^3	74.91 – 87.4	74.91 – 87.4	71.79 – 84.28
Tensile Strength	ksi	5.00 – 15.08	7.98 – 18.85	10.59 – 11.75
Longitudinal Modulus	ksi	304.58 – 513.43	398.85 – 594.66	435.11 – 507.63
Poisson's Coefficient	–	0.35 – 0.39	0.38 – 4.0	0.36 – 0.39
Coefficient of Thermal Expansion	10^{-6}/°C	55 – 100	45 – 65	50 – 75
Moisture Content	%	0.15 – 0.60	0.08 – 0.15	0.14 – 0.30

Table 3.5: Acceptance criteria for properties of resins for the production of FRP rebars (Metric Units)

		Resin Type (European)		
Properties	unit	Polyester	Epoxy	Vinyl ester
Density	kg/m^3	1200 – 1400	1200 – 1400	1150 – 1350
Tensile Strength	MPa	34.50 – 104	55 – 130	73 – 81
Longitudinal Modulus	GPa	2.10 – 3.45	2.75 – 4.10	3.00 – 3.50
Poisson's Coefficient	–	0.35 – 0.39	0.38 – 4.0	0.36 – 0.39
Coefficient of Thermal Expansion	10^{-6}/°C	55 – 100	45 – 65	50 – 75
Moisture Content	%	0.15 – 0.60	0.08 – 0.15	0.14 – 0.30

3.3 Cross Sectional Properties of Rebar

Tables 3.6, and 3.7 show the required cross section diameter and the cross-sectional areas for the rebars of different sizes in imperial units. Tables 3.8, and 3.9 list the same data in metric units (rounded to the nearest two decimal values). The first column of the tables represents the rebar number. While standards in Europe, Canada and Russia follow a different numbering system for rebars, the converted dimensions are given in the table for ease of comparison.

Table 3.6: Acceptance criteria for cross section measurements of GFRP rebar (Imperial Units)

	GFRP											
	FDOT 932-3/2017		AC454		ASTM D 7957		CAN/CSA S807		FIB Bulletin 40		GOST 31938 -2012	
	Diameter	Area	Diameter	Area	Diameter	Area	Diameter	Area	Diameter	Area	Diameter	Area
Bar Size	in.	in.^{2}	in.	in.^{2}	in.	in.^{2}	in.	in.^{2}	in.	in.^{2}	in.	in.^{2}
1	n/a	n/a	n/a	n/a	n/a	n/a	0.24	0.05	0.24	0.04	0.24	n/a
2	0.25	0.046 - 0.085	0.25	0.046 - 0.085	0.25	0.046 - 0.085	0.31	50.08	0.31	0.08	0.31	n/a
3	0.370	0.104 - 0.161	0.370	0.104 - 0.161	0.370	0.104 - 0.161	0.39	0.11	0.39	0.12	0.39	n/a
4	0.500	0.185 - 0.263	0.500	0.185 - 0.263	0.500	0.185 - 0.263	0.51	0.2	0.47	0.18	0.47	n/a
5	0.625	0.288 - 0.388	0.625	0.288 - 0.388	0.625	0.288 - 0.388	0.59	0.31	0.55	0.24	0.55	n/a
6	0.750	0.415 - 0.539	0.750	0.415 - 0.539	0.750	0.415 - 0.539	0.79	0.44	1.00	0.31	1.00	n/a
7	0.875	0.565 - 0.713	0.875	0.565 - 0.713	0.875	0.565 - 0.713	0.87	0.6	0.79	0.49	0.7	n/a
8	1.000	0.738 - 0.913	1.000	0.738 - 0.913	1.000	0.738 - 0.913	0.98	0.79	0.98	0.65	0.79	n/a
9	1.128	0.934 - 1.137	1.128	0.934 - 1.137	1.128	0.934 - 1.137	1.18	1.0	1.1	0.95	0.98	n/a
10	1.270	1.154 - 1.385	1.270	1.154 - 1.385	1.270	1.154 - 1.385	1.26	1.27	1.26	1.25	1.1	n/a
11	n/a	n/a	n/a	n/a	n/a	n/a	1.42	1.56	1.56	1.95	1.26	n/a

Table 3.7: Acceptance criteria for cross section measurements of BFRP rebar (Imperial Units)

	BFRP											
	FDOT 932-3/2017		AC454		ASTM D 7957		CAN/CSA S807		FIB Bulletin 40		GOST 31938 -2012	
	Diameter	Area	Diameter	Area	Diameter	Area	Diameter	Area	Diameter	Area	Diameter	Area
Bar Size	in.	in.^{2}	in.	in.^{2}	in.	in.^{2}	in.	in.^{2}	in.	in.^{2}	in.	in.^{2}
1	n/a	n/a	n/a	n/a	n/a	n/a	0.24	0.05	0.24	0.04	0.24	n/a
2	n/a	n/a	n/a	n/a	n/a	n/a	0.31	0.08	0.31	0.08	0.31	n/a
3	n/a	n/a	n/a	n/a	n/a	n/a	0.39	0.11	0.39	0.12	0.39	n/a
4	n/a	n/a	n/a	n/a	n/a	n/a	0.51	0.2	0.47	0.18	0.47	n/a
5	n/a	n/a	n/a	n/a	n/a	n/a	0.59	0.31	0.55	0.24	0.55	n/a
6	n/a	n/a	n/a	n/a	n/a	n/a	0.79	0.44	1.00	0.31	1.00	n/a
7	n/a	n/a	n/a	n/a	n/a	n/a	0.87	0.6	0.79	0.49	0.7	n/a
8	n/a	n/a	n/a	n/a	n/a	n/a	0.98	0.79	0.98	0.65	0.79	n/a
9	n/a	n/a	n/a	n/a	n/a	n/a	1.18	1.0	1.1	0.95	0.98	n/a
10	n/a	n/a	n/a	n/a	n/a	n/a	1.26	1.27	1.26	1.25	1.1	n/a
11	n/a	n/a	n/a	n/a	n/a	n/a	1.42	1.56	1.56	1.95	1.26	n/a

Table 3.8: Acceptance criteria for nominal diameters and cross section measurements of GFRP rebar (Metric Units)

	GFRP											
	FDOT 932-3/2017		AC454		ASTM D 7957		CAN/CSA S807		European		GOST 31938 -2012	
	Diameter	Area	Diameter	Area	Diameter	Area	Diameter	Area	Diameter	Area	Diameter	Area
Bar Size	in.	in.^{2}	in.	in.^{2}	in.	in.^{2}	mm	mm^2	mm	mm^2	mm	mm^2
1	n/a	n/a	n/a	n/a	n/a	n/a	6	32	6	28.3	6	n/a
2	6.35	29.68 - 54.84	0.025	0.046 - 0.085	0.025	0.046 - 0.085	8	50	8	50.3	8	n/a
3	9.4	67.1 - 103.87	0.370	0.104 - 0.161	0.370	0.104 - 0.161	10	71	10	78.5	10	n/a
4	12.7	119.35 - 152.26	0.500	0.185 - 0.263	0.500	0.185 - 0.263	13	129	12	113	12	n/a
5	15.88	185.81 - 250.32	0.625	0.288 - 0.388	0.625	0.288 - 0.388	15	199	14	154	14	n/a
6	19.05	267.74 - 347.74	0.750	0.415 - 0.539	0.750	0.415 - 0.539	20	284	16	201	16	n/a
7	22.23	364.52 - 463.87	0.875	0.565 - 0.713	0.875	0.565 - 0.713	22	387	20	314	18	n/a
8	25.4	507.74 - 589.03	1.000	0.738 - 0.913	1.000	0.738 - 0.913	25	510	25	419	20	n/a
9	28.65	602.58 - 733.55	1.128	0.934 - 1.137	1.128	0.934 - 1.137	30	645	28	616	25	n/a
10	32.26	744.51 - 893.55	1.270	1.154 - 1.385	1.270	1.154 - 1.385	32	819	32	804	28	n/a
11	n/a	n/a	n/a	n/a	n/a	n/a	36	1006	40	1257	32	n/a

Table 3.9: Acceptance criteria for nominal diameters and cross section measurements of BFRP rebar (Metric Units)

	BFRP											
	FDOT 932-3/2017		AC454		ASTM D 7957		CAN/CSA S807		European		GOST 31938 -2012	
	Diameter	Area	Diameter	Area	Diameter	Area	Diameter	Area	Diameter	Area	Diameter	Area
Bar Size	in.	in.^{2}	in.	in.^{2}	in.	in.^{2}	mm	mm^2	mm	mm^2	mm	mm^2
1	n/a	n/a	n/a	n/a	n/a	n/a	6	32	6	28.3	6	n/a
2	n/a	n/a	n/a	n/a	n/a	n/a	8	50	8	50.3	8	n/a
3	n/a	n/a	n/a	n/a	n/a	n/a	10	71	10	78.5	10	n/a
4	n/a	n/a	n/a	n/a	n/a	n/a	13	129	12	113	12	n/a
5	n/a	n/a	n/a	n/a	n/a	n/a	15	199	14	154	14	n/a
6	n/a	n/a	n/a	n/a	n/a	n/a	20	284	16	201	16	n/a
7	n/a	n/a	n/a	n/a	n/a	n/a	22	387	20	314	18	n/a
8	n/a	n/a	n/a	n/a	n/a	n/a	25	510	25	419	20	n/a
9	n/a	n/a	n/a	n/a	n/a	n/a	30	645	28	616	25	n/a
10	n/a	n/a	n/a	n/a	n/a	n/a	32	819	32	804	28	n/a
11	n/a	n/a	n/a	n/a	n/a	n/a	36	1006	40	1257	32	n/a

3.4 Minimum Guaranteed Tensile Strength of Rebar

Tables 3.10, and 3.11, list the required minimum guaranteed tensile strength of the rebars in imperial and metric units (rounded to the nearest two decimal values) respectively . The criteria listed in the Canadian standards change for different grades, but the listed information is given for grade I bars.

Table 3.10: Acceptance criteria for tensile strength (Imperial Units)

	GFRP						BFRP					
	FDOT 932-3/2017	AC454	ASTM D 7957	CAN/CSA S807	GOST 31938 -2012	FIB Bulletin 40	FDOT 932-3/2017	AC454	ASTM D 7957	CAN/CSA S807	GOST 31938 -2012	FIB Bulletin 40
Bar Size	ksi	ksi	ksi	ksi	ksi	ksi	ksi	ksi	ksi	ksi	ksi	ksi
1	n/a		n/a	108.78			n/a		n/a	TBD		n/a
2	6.1		6.1	108.78			n/a		n/a	TBD		n/a
3	13.2		13.2	108.78			n/a		n/a	TBD		n/a
4	21.6		21.6	94.27			n/a		n/a	TBD		n/a
5	29.1		29.1	94.27			n/a		n/a	TBD		n/a
6	40.9		40.9	87.02	116.	27–23	n/a		n/a	TBD	116.	n/a
7	54.1		54.1	79.77			n/a		n/a	TBD		n/a
8	66.8		66.8	79.77			n/a		n/a	TBD		n/a
9	82.0		82.0	72.52			n/a		n/a	TBD		n/a
10	98.2		98.2	65.27			n/a		n/a	TBD		n/a
11	n/a		n/a	65.27			n/a		n/a	TBD		n/a

Table 3.11: Acceptance criteria for tensile strength (Metric Units)

	GFRP						BFRP					
	FDOT 932-3/2017	AC454	ASTM D 7957	CAN/CSA S807	GOST 31938 -2012	FIB Bulletin 40	FDOT 932-3/2017	AC454	ASTM D 7957	CAN/CSA S807	GOST 31938 -2012	FIB Bulletin 40
Bar Size	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa
1	n/a		n/a	750			n/a		n/a	TBD		n/a
2	42.06		42.06	750			n/a		n/a	TBD		n/a
3	91.01		91.01	750			n/a		n/a	TBD		n/a
4	148.92		148.92	650			n/a		n/a	TBD		n/a
5	200.63		200.63	650			n/a		n/a	TBD		n/a
6	281.99		281.99	600	$\geq$ 80	0–16	n/a		n/a	TBD	$\geq$ 80	n/a
7	373.00		373.00	550			n/a		n/a	TBD		n/a
8	460.56		460.56	550			n/a		n/a	TBD		n/a
9	565.37		565.37	500			n/a		n/a	TBD		n/a
10	677.06		677.06	450			n/a		n/a	TBD		n/a
11	n/a		n/a	450			n/a		n/a	TBD		n/a

3.5 Physical and Mechanical Properties of Rebar

The required physical and mechanical properties of the rebars are tabulated in the Table 3.12, and Table 3.13. The first column of the table lists the test methods used to determine those properties in the U.S. and Canada. The criteria listed in the Canadian standards are given for grade I bars (criteria changes for different grades).

Table 3.12: Acceptance criteria for physical and mechanical characteristics of GFRP rebar (Imperial Units)

			GFRP					
			FDOT 932-3/2017	AC454	ASTM D 7957	CAN/CSA S807	FIB Bulletin 40	GOST 31938 -2012
Test Method	Test Description	Unit	Criteria	Criteria	Criteria	Criteria	Criteria	Criteria
ASTM D 2584	Fiber Content	% wt.	$\geqslant 70$	$\geqslant 70$	$\geqslant 70$	$\geqslant 55$	$\geqslant 0.55$	n/a
ASTM D 570	Moist. Absorption short term @50 °C	%	$\leqslant 0.25$	$\leqslant 0.25$	$\leqslant 0.25$	$\leqslant 0.35$	n/a	n/a
ASTM D 570	Moist. Absorption long term @50 °C	%	$\leqslant 1.0$	n/a	$\leqslant 1.0$	$\leqslant 1.0$	n/a	n/a
ASTM D 7617	Min. Guaranteed Transverse Shear	ksi	$\geqslant 22$	$\geqslant 22$	$\geqslant 19$	$\geqslant 23.21$	$\geqslant 39$	n/a
ASTM D 4475	Horizontal Shear Stress	ksi	n/a	$\geqslant 5.5$	n/a	TBD	$\geqslant 12.9$	n/a
ACI440. 3 R,B.3	Bond-to-concrete strength	ksi	$\geqslant 1.1$	$\geqslant 1.1$	$\geqslant 1.1$	> 1.16	n/a	$\geqslant 1.74$

Table 3.13: Acceptance criteria for physical and mechanical characteristics of BFRP rebar (Imperial Units)

			BFRP					
			FDOT 932-3/2017	AC454	ASTM D 7957	CAN/CSA S807	FIB Bulletin 40	GOST 31938 -2012
Test Method	Test Description	Unit	Criteria	Criteria	Criteria	Criteria	Criteria	Criteria
ASTM D 2584	Fiber Content	% wt.	n/a	n/a	n/a	TBD	n/a	n/a
ASTM D 570	Moist. Absorption short term @50 °C	%	n/a	n/a	n/a	TBD	n/a	n/a
ASTM D 570	Moist. Absorption long term @50 °C	%	n/a	n/a	n/a	TBD	n/a	n/a
ASTM D 7617	Min. Guaranteed Transverse Shear	ksi	n/a	n/a	n/a	TBD	n/a	n/a
ASTM D 4475	Horizontal Shear Stress	ksi	n/a	n/a	n/a	TBD	n/a	n/a
ACI440. 3 R,B.3	Bond-to-concrete strength	ksi	n/a	n/a	n/a	TBD	n/a	$\geqslant 1.74$

3.6 Required Chemical Durability of Rebar

The maximum strength reduction of rebars exposed to alkaline environment with a dead load is listed in Table 3.14.

Table 3.14: Acceptance criteria for chemical durability of rebar

		Reduction of strength after alkaline exposure with load					
		FDOT 932-3/2017	AC454	ASTM D 7957	CAN/CSA S807	FIB Bulletin 40	GOST 31938 -2012
Rebar Type	Unit	Criteria	Criteria	Criteria	Criteria	Criteria	Criteria
GFRP	%	$\leqslant 30$	$\leqslant 30$	$\leqslant 30$	$\leqslant 40$	n/a	$\leqslant 25$
BFRP	%	n/a	n/a	n/a	TBD	n/a	$\leqslant 25$

Chapter 4

Experimental Program

4.1 Introduction

The research methodology and all experiments that were conducted on BFRP rebar constituent materials and BFRP rebar products are described in this chapter. Several physical, mechanical, and chemical tests were conducted on rebar samples, raw materials, and exposure solutions, both before and after exposure to various combinations of saline and alkaline environments. Accordingly, this chapter targets four major aspects: 1) the general experimental concept, 2) the characterization of BFRP constituent materials, 3) the characterization of BFRP rebar specimens, and 4) the characterization of exposure solutions. It was the aim to analyze the characteristics and long-term chemical durability of raw materials used for the production of BFRP rebars and to quantify the material properties and limit states of the individual constituents as well as the performance of the final rebar products.

Before studying the deterioration characteristics of BFRP rebars, the durability properties of the raw constituent materials was studied because the resilience of BFRP rebars depends on the durability of the raw materials. Therefore, a study of the physical properties of basalt fibers was conducted to qualify the fibers based on the chemical composition, to provide minimum requirements for strength and durability related characteristics. Then, sizing and resins materials were characterized based on chemical composition and in view of the durability properties. With the obtained durability results, this research aimed to provide recommendations for suitable fiber-resin compositions to target high quality BFRP rebars.

FRP rebars are typically thought off as a resilient alternative in harsh environments, but several studies (c.f. previous chapter) have shown that BFRP rebars are susceptible to degradation when exposed to a combination of alkaline and saline environments (Guo et al., 2018; Kochergin et al., 2013; Altalmas et al., 2015). Accordingly, the durability of FRP rebar was an important property, which needs to be further studied because degradation caused by chemical attacks may lead to strength reduction, which in-turn causes structure failure that may ultimately lead to personal and financial losses. To minimize the risk and to prevent failure due to actual degradation, strength reduction factors are applied to decrease the design strength of concrete structures in harsh environments, when designing according to AASHTO-LRFD Bridge Design Guide Specifications for GFRP Reinforced Concrete or ACI 440.1R Guide for the Design and Construction of Structural Concrete Reinforced with Fiber-Reinforced Polymer (FRP) Bars. For example, the guaranteed strength (f^*_{fu}) of FRP rebars has to be reduced by applying the environmental factor (C_E) (ACI Committee 440, 2015). Likewise, to avoid premature failure due to creep and fatigue, creep rupture factor (C_c) and fatigue reduction factor (C_f) are applied to the design strength for FRP rebars under sustained load and cyclic load (ACI Committee 440, 2015; du Béton, 2007). Such factors vary and depend on the actual fiber type (glass, carbon, basalt, etc.) and resin materials. Because the environmental factor, C_E, has not been fully developed for BFRP rebars and this factor is an important consideration for the design of infrastructure elements in Florida, it was the goal of this experimental program to systematically expose different BFRP rebar components to various harsh environments, such that the effective degradation could be quantified and data for the development of environmental factors under Florida conditions can be provided.

To standardize BFRP rebars with appropriate quality, the chemistry of raw materials and rebars in alkaline and saline environments was studied through systematic testing. To evaluate the potential material degradation of BFRP rebars and their components, a test matrix was developed to target various specimen characteristics in the virgin state and after exposure in harsh conditions after 300 day and 600 day. Mass transfer between the exposed materials (fibers, resin, and BFRP rebar) and the aggressive solution was quantified. Specific experiments were conducted to quantify the chemical compounds that were exchanged between the exposed solids and the storage solution. The impact of chemical mass transfer on the physical and mechanical properties of conditioned specimens (fiber, resin, and rebars) and the effect of exposure conditions (salinity and alkalinity) on basalt based FRPs was quantified.

4.2 Experimental Concept Overview

Because BFRP composites are potentially affected by saline and alkaline environments (Benmokrane et al., 2015), a major goal of the experimental program was to simulate a combination of these two environments (factorial expeiments) with varying pH content and chloride ions to systematically study the impact of each chemical environment and the combined effect. Figure 4.1 depicts the various combinations of the exposure conditions, in which the alkalinity and the salinity are systematically increased. In the test matrix, gray filled squares indicate BFRP rebar samples for mechanical strength tests, while open squares identify raw material samples for chemical durability tests, and finally the open circles represent chemical analysis conducted on the exposure solutions in which the BFRP components were stored. As seen in the figure, the salinity of the exposure solutions ranged from 0 $mgCl^-/L$ (deionized water), to 200 $mgCl^-/L$ (fresh water), and 20 000 $mgCl^-/L$ (synthetic and real seawater), while the range of pH value varied from 4pH (acidic water) to 13pH (high alkaline water). These exposure solutions were developed synthetically to eliminate potential contamination and to precisely study the degradation caused by the main factors. Along with the synthetic solutions, control samples were stored in real seawater collected from the Florida State University Coastal and Marine Laboratory before testing, to study the degradation properties under real world conditions. The exposure temperature for ageing FRP in alkaline solutions according to ASTM International (2012) is 60 °C, and it is the most commonly used temperature suggested by Chen et al. (2007); and Benmokrane et al. (2017). Therefore, a constant temperature of 60 °C was maintained throughout the conditioning period to accelerate the chemical degradation process. Chemical baseline values for the virgin materials as well as for the virgin exposure solutions were taken before ageing (0 days) was initiated, and ultimately compared to the measurements after each exposure duration (300 days and 600 days). Table 4.1 lists different types of tests that were performed on the conditioned raw materials (naked fibers, sized fibers and resin (epoxy, polyester, and vinyl-ester)) and BFRP rebar samples, before and after the exposure periods. To expand the general experimental concept and for additional clarification, the individual aspects of the test program (constituent materials, BFRP rebars, and exposure solutions) are separately discussed below.

4.2.1 Characterization of BFRP Constituent Materials

FRP rebars are a product of composites made from sized fibers and resin matrices. The durability of these rebar products significantly depends on the resilience of the raw materials. Therefore, it was important to test the chemical durability of raw materials before analyzing the chemical durability of the composite rebars. For

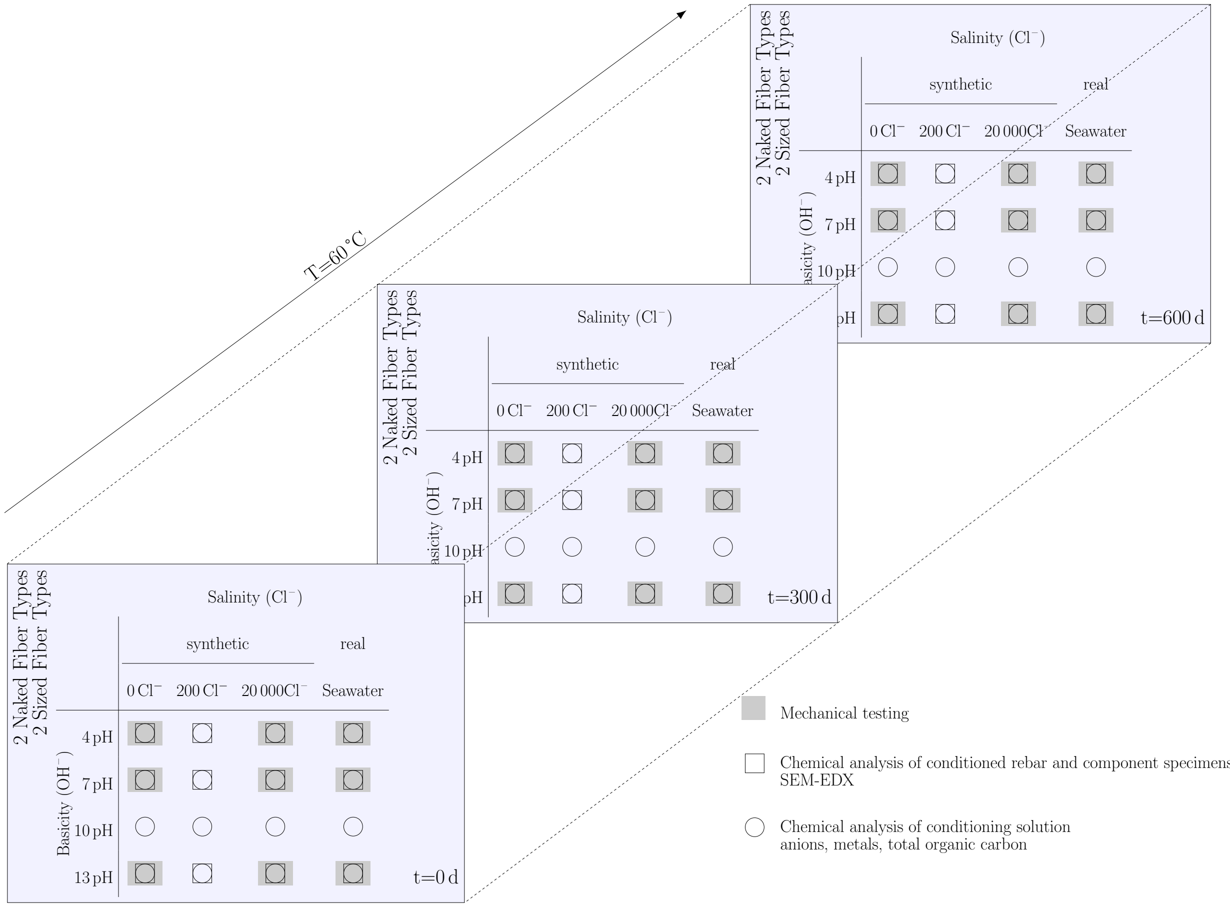


Figure 4.1: Test concept for chemical exposure

Table 4.1: Test matrix

	Specimen type			
	Constituent Material			
Test type	Naked Fibers†	Sized Fibers	Resin	BFRP Rebar
Strength test	✓	✓	✓	✓
Chemical analysis of material solids	✓	✓	✓	✓
Chemical analysis of exposure solution	✓	✓	✓	✓

reliability of test results and to obtain representative values for the BFRP rebar product as a whole, the tests were repeated five times for samples taken from different sections of the production lot — average values were assigned and statistics (min, max, CV, etc.) for each sample were documented. Specimens from up to three different production lots per manufacturer and three different manufacturers were tested. Accordingly, a total of 45 tests were conducted — for virgin materials as well as after each aging period — for each test procedure that targeted the characterization of constituent materials. Table 4.2 lists the tests that were performed on fiber samples and resin samples. Basic material properties of basalt fibers, such as diameter and unit weight,

Table 4.2: Tests on individual components of BFRP rebar

	Test type	Test method	Specimen count: Per sample	Specimen count: Total†
Naked and sized fibers	Diameter of fibers	ASTM D6466	3	15
	Micro-structure observation	SEM and Raman Spectroscopy	2	72
	Mass transfer between solution and fibers	Based on chemical analysis results	1	80
Resin	Micro-structure observation	SEM and Raman Spectroscopy	2	72
	Tensile strength	ASTM D638	5	160
	Mass transfer between solution and resin	Based on chemical analysis results	2	72

were studied before measuring the tensile strength. The fiber material (that has not been tested) were then exposed to harsh environments as shown above. After each individual conditioning period, a battery of tests were conducted on the specimens as listed in table 4.2. Likewise, the virgin material properties of resin were tested and characterized before the resin specimens were exposed to harsh environments. Change in physical properties were quantified by performing an array of test procedures as shown in table 4.2 to evaluate the retention of the properties. Chemical mass transfer between the fiber/resin specimen and the exposure solutions were studied through chemical analysis of the individual components and the exposure solutions.

4.2.2 Characterization of BFRP Rebar Specimens

To use FRP rebars in infrastructure projects, they have to meet or exceed specific test criteria (e.g.: Florida Specifications Section 932). Typical physical properties such as the cross-sectional area, fiber content, moisture absorption; mechanical properties such as tensile strength, horizontal shear strength, transverse shear strength, bond-to-concrete strength; and chemical durability properties were studied. This section provides a general overview of these tests and details how these tests were superimposed with the test concept shown in Figure 4.1.

All physical and mechanical tests that were conducted on BFRP rebars are listed in Table 4.3. Two commonly used rebar sizes — # 3 and # 5 — were tested in this project. For reliability of test results and to obtain representative values for the BFRP rebar product as a whole, the tests were repeated five times for specimens taken from different sections of the production lot and the average values were assigned (while monitoring statistics of each sample). Three different rebar products (each produced by a different manufacturer) were chosen and up to three different production lots per manufacturer were tested. The physical and mechanical tests were conducted on virgin rebars or on rebar specimens that have not been exposed to harsh environments. In addition, the mechanical tests were conducted on conditioned rebar specimens after multiple exposure durations to evaluate and quantify the strength retention properties in harsh environments.

The variation of cross-sectional properties largely depends on the proprietary production methods and the surface enhancement features. Therefore, the cross-sectional area was measured according to the ASTM D 792-13 to benchmark the physical property and to study the relative differences between the tested rebar products. The fiber content percentage of FRP rebar plays a crucial role for the load transfer, ductility, elastic modulus, and the ultimate strength of a rebar product. Accordingly, the fiber-to-resin ratio of the BFRP rebars was quantified in agreement with ASTM D 2584 (ASTM-International, 2011). Because FRP rebars are intended for use in coastal areas and other harsh environments, moisture infiltration is a critical characteristic

Table 4.3: Tests on BFRP rebars

	Test type	Test method	Specimen count	
			Per sample	Total†
Physical	Cross-sectional area	ASTM D792	5	60
	Fiber content	ASTM D2584	5	60
	Moisture absorption	ASTM D570	5	60
	Micro-structure observation	SEM and Raman Spectroscopy	1	216
Mechanical	Tensile strength	ASTM D7205	5	540
	Transverse shear strength	ASTM D7617	5	540
	Apparent horizontal shear strength	ASTM D4475	3	250
	Bond-to-concrete	ACI440.3R,B.3	3	300
	Mass transfer from solution to rebar	Based on chemical analysis results	5	90

that relates to the durability properties of FRP rebars. Moisture can damage the rebar structure and deposit contaminates that decreases the strength of the composite material and compromise the overall rebar integrity. Therefore, the moisture absorption property of the BFRP rebar samples was characterized according to ASTMD 5229/ D 5229M (ASTM, 2014). Chemical analysis on the rebars and porosity analysis were conducted via SEM methods to study the deterioration of the BFRP rebars due to exposure. The glass transition temperature (T_g) of the rebar samples was evaluated via differential scanning calorimetry according to ASTM E 1356 (ASTM International, 2014a). Because the T_g of a resin system defines when a thermoset polymer transitions from an amorphous rigid state to a more flexible state, it is an important rebar property that defines the nature (rigid and glassy or flexible and rubbery) of the polymer at its service temperature. ASTM D 7617 (ASTM-International, 2012b) was used in the process of testing and analyzing the transverse shear properties. In addition, the BFRP rebar products were tested for horizontal shear properties according to ASTM D 4475 (ASTM-International, 2012a) to evaluate the quality and strength of the resins when use for the production of BFRP rebars. The tensile properties (strength and elastic modulus) of the rebars were evaluated according to the ASTM D 7205 (ASTM-International, 2015a). Bond-to-concrete strength of the rebars was tested in accordance with ASTM D 7913 (ASTM International, 2014b) to quantify the bond strength variations based on the different surface enhancement features.

4.2.3 Characterization of Exposure Solutions

To maintain the designed exposure conditions of the storage solutions, the conditioning environments were monitored and analyzed at defined time interval. Different chemical characterization tests were conducted to quantify and report the chemical properties. All chemical analysis tests — conducted on the exposure solutions — are listed in Table 4.4, along with the standard procedures that were followed for each test. To monitor and maintain the designed exposure conditions, pH values, alkalinity, and salinity of the exposure solutions were regularly measured. The anions and metals transferred from the fibers to the solutions and from the solution to fibers were measured because these quantities are needed to determine the acidity modulus of basalt, which is an important property that characterizes the suitability of the raw materials for fiber production. In addition, it is needed as a quality control indicator during basalt fiber production.

Table 4.4: Tests on exposure solutions

Test Type	Property	Standard
Electrometric method	pH	SM4500-H+
Electrical conductivity	Salinity	SM2520-B
Titration method	Alkalinity	SM2320-B
Ion chromatography	Anions	SM4100
Atomic emission spectrometry	Metals	Agilent 4100 MP-AES
Gas chromatographic/mass spectometric method	Biphenol A	SM6040
DO meter	Dissolved oxygen	ASTM D888 - 18
TOC analyzer	Total Organic Carbon	ASTM D7573 - 18ae1

Bisphenol A (BPA) was measured because this organic synthetic compound is used in the manufacturing of resins and it may transfer from the resin to the exposure solution as a result of rebar degradation.

Chapter 5

Aggressive Environments — Solution Properties

According to the test matrix, 16 different solutions—with various pH-values and salinity levels—were generated to expose the raw constituents and composite basalt rebar materials to aggressive environments. While each specific solution (with a defined ph-value and salinity-level) was eventually distributed over various bottles and containers, the entire required amount for each solution was created in a single (well mixed) batch to guarantee identical exposure conditions across the various materials and components within each particular solution type (c.f. test matrix). This chapter specifies how the solutions were tested and evaluated for various chemical properties. This step was necessary for quality control purposes and to generate baseline values, before the rebar materials were submerged in the corresponding solution.

5.1 Introduction

The measurement of pH, salinity, dissolved oxygen and anions were determined according to the 'Standard Methods' for examining water and wastewater properties (Rice, Eugene W and Baird, Rodger B and Eaton, Andrew D and Clesceri, Lenore S and others, 2012). For each parameter, triplicate samples were measured and the corresponding minimum, maximum, and average concentrations were recorded. These measurements were completed immediately before the unsized fiber, sized fiber, resin plates and rebars were exposed to the solutions. Therefore, the results presented in the following section (Section 6.2.2) are the representation of baseline data (i.e., the 0 day data). By examining the changes of the exposure solution water chemistry, affects of the different exposure solutions on the fibers, resins and rebars after 300 days and 600 days were studied.

5.2 Results

Results for pH and salinity are summarized in Table 6.3. All pH and salinity results were very close to the target values (theoretical values in the first two columns). The variation between the triplicate measurements were minimal.

The results for dissolved oxygen and anions are summarized in Table 5.2. The concentrations for dissolved oxygen did not vary for the 16 mixes and they were close to the saturated concentration. All measured chloride concentrations were similar to the target concentrations. For the exposure solutions with a pH-value of 4, sulfate concentrations were measured due to the addition of H_2SO_4 to lower the pH to 4.

Table 5.1: pH and Salinity results of exposure solutions

Exposure Solution		pH			Salinity		
pH	cl^-				mg/L		
	ppm	$\wedge$	$\vee$	μ	$\wedge$	$\vee$	μ
4	0	3.99	4.00	3.99	9.70	9.80	9.73
4	200	3.99	4.00	4.00	343.00	344.00	343.33
4	20000	3.98	3.99	3.99	32970.00	32980.00	32976.70
4	Seawater	4.01	4.02	4.02	33690.00	33710.00	33696.70
7	0	7.01	7.02	7.02	5.50	5.50	5.50
7	200	7.00	7.01	7.00	335.00	336.00	335.67
7	20000	7.00	7.01	7.01	32950.00	32960.00	32953.30
7	Seawater	7.01	7.03	7.02	33710.00	33730.00	33723.30
10	0	10.00	10.01	10.00	6.90	6.90	6.90
10	200	10.01	10.02	10.01	338.00	339.00	338.70
10	20000	9.99	10.00	10.00	32960.00	32970.00	32966.70
10	Seawater	10.01	10.02	10.02	34540.00	34560.00	34546.70
13	0	12.99	13.00	12.99	4005.00	4010.00	4008.33
13	200	13.01	13.03	13.02	4333.00	4336.00	4334.30
13	20000	13.00	13.01	13.00	36970.00	36980.00	36973.30
13	Seawater	12.98	12.99	12.99	36600.0	36610.00	36596.70

Table 5.2: Dissolved oxygen and Anions results of exposure solutions

Exposure Solution		DissolvedOxygen			Anions					
					Chloride			Sulfate		
pH	cl$^-$	mg/L			mg/L			mg/L		
	ppm	$\wedge$	$\vee$	μ	$\wedge$	$\vee$	μ	$\wedge$	$\vee$	μ
4	0	8.89	8.90	8.89	Below 0.08	Below 0.08	Below 0.08	6.01	6.04	6.02
4	200	8.81	8.82	8.82	201.09	201.12	201.10	6.17	6.21	6.20
4	20000	8.76	8.80	8.77	20008.10	20010.24	20008.81	6.35	6.36	6.36
4	Seawater	8.57	8.60	8.58	19948.70	19950.34	19949.25	2653.95	2658.31	2655.40
7	0	8.86	8.87	8.87	Below 0.08	Below 0.08	Below 0.08	Below 0.5	Below 0.5	Below 0.5
7	200	8.80	8.81	8.82	201.11	201.11	201.11	Below 0.5	Below 0.5	Below 0.5
7	20000	8.74	8.78	8.76	20007.97	20010.43	20009.61	Below 0.5	Below 0.5	Below 0.5
7	Seawater	8.55	8.57	8.56	19947.90	19951.67	19949.42	2646.85	2648.89	2647.78
10	0	8.85	8.87	8.86	Below 0.08	Below 0.08	Below 0.08	Below 0.5	Below 0.5	Below 0.5
10	200	8.78	8.81	8.79	201.12	201.14	201.13	Below 0.5	Below 0.5	Below 0.5
10	20000	8.73	8.75	8.74	20009.35	20011.49	20010.06	Below 0.5	Below 0.5	Below 0.5
10	Seawater	8.55	8.56	8.56	19952.89	19955.78	19954.82	2647.59	2651.11	2649.94
13	0	8.83	8.84	8.84	Below 0.08	Below 0.08	Below 0.08	Below 0.5	Below 0.5	Below 0.5
13	200	8.75	8.79	8.77	201.13	201.14	201.14	Below 0.5	Below 0.5	Below 0.5
13	20000	8.70	8.71	8.70	20008.19	20011.67	20009.35	Below 0.5	Below 0.5	Below 0.5
13	Seawater	8.52	8.54	8.53	19948.96	19953.71	19950.54	2647.25	2651.89	2648.79

Chapter 6

Chemical, Material and Physical Properties of Rebar and Components Before Exposure to Aggressive Environments

6.1 Virgin Component Properties

6.1.1 Resin Moisture Absorption

The moisture absorption property of resin was tested in accordance with ASTM D 5229 (ASTM, 2014). The graph plotted in Figure 6.1 represents weight change of all tested resin types stored in distilled water over a test period of 84 d. It can be seen in the graph that all resin types showed comparable moisture absorption behavior.

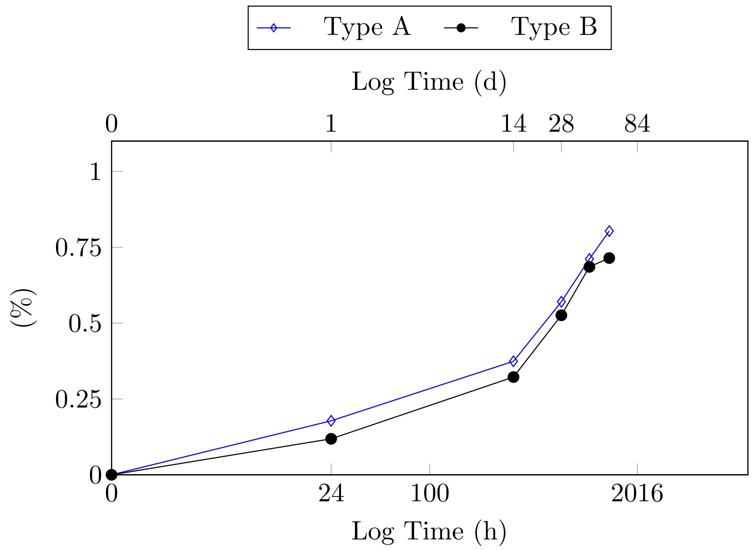


Figure 6.1: Moisture absorption results of all types of resin

6.1.2 X-Ray Fluorescence (XRF) Analysis on Fibers

The XRF Analysis was conducted with X-Ray fluorescence spectrometer. The results are tabulated in Table 6.1.

Table 6.1: XRF analysis on virgin naked and sized fibers

Analyte	Result (%)				
	Manf1-Sized	Manf1-Unsized	Manf2-Sized	Manf2-Unsized	Manf3-Sized
Fe	44.96	44.09	43.90	38.83	38.61
Si	19.10	18.99	19.35	19.98	18.81
Ca	20.05	20.28	20.33	23.06	21.79
Al	4.84	5.28	5.08	5.12	5.94
K	4.36	4.54	4.54	5.02	4.84
Mo	0.03	0.02	0	0	0.13
Ti	3.03	3.04	3.07	3.50	3.29

6.1.3 Diameter of Fibers

The diameter of fibers was measured using SEM. The measured diameter of all naked and sized fibers is listed in the following table.

Table 6.2: Diameter of virgin sized and un-sized fibers

Type	Diameter (µm)		
	Specimen 1	Specimen 2	Specimen 3
A-Sized	16.41	16.37	16.70
B-Sized	19.34	19.30	19.24
C-Sized	21.07	21.53	21.34
A-Un-sized	15.62	15.66	15.52
B-Un-sized	18.14	18.35	18.37

6.1.4 SEM Images of Fibers, Unsized Fibers, and Resins

The SEM analysis of the sized fibers, unsized fibers, and the resins for all rebar types at day 0 (before exposure) are shown in Figures 6.2, 6.3, and 6.4. Images with various magnifications were recorded to study different details of the raw materials. Figure 6.2 further illustrates that different manufacturers (different Types) use fibers of different sizes to produce their rebars. While Type A measured the smallest fiber diameters, Type C had the largest diameter fibers.

As it is difficult to obtain unsized fibers (some manufacturers claim it to be impossible), such fibers could not be acquired for all rebar types. However, two manufacturers were able to produce fibers without sizing, and those fibers are shown in Figure 6.3. It can be seen that the fibers for Type A rebars appeared to have a more uniform and continuous surface, whereas the surface for Type B rebars appeared to be more spiky.

Similar to the unsized fibers, not all manufacturers were able to share resin samples (neither in liquid form to produce specimens in the laboratory, nor in prepared and hardened form). Accordingly, Figure 6.4 shows images of the SEM-analysis for resins for rebars Type A and Type B. As it can bee seen, the resin surfaces for both materials appeared mostly smooth and without significant pores. In fact, the surfaces appeared densely sealed.

All SEM images of the raw materials at day 0 (virgin state) are provided for relative comparison with the SEM images of the the raw materials that were recorded after exposure to aggressive environments for 300 and 600 days (see following two chapters).

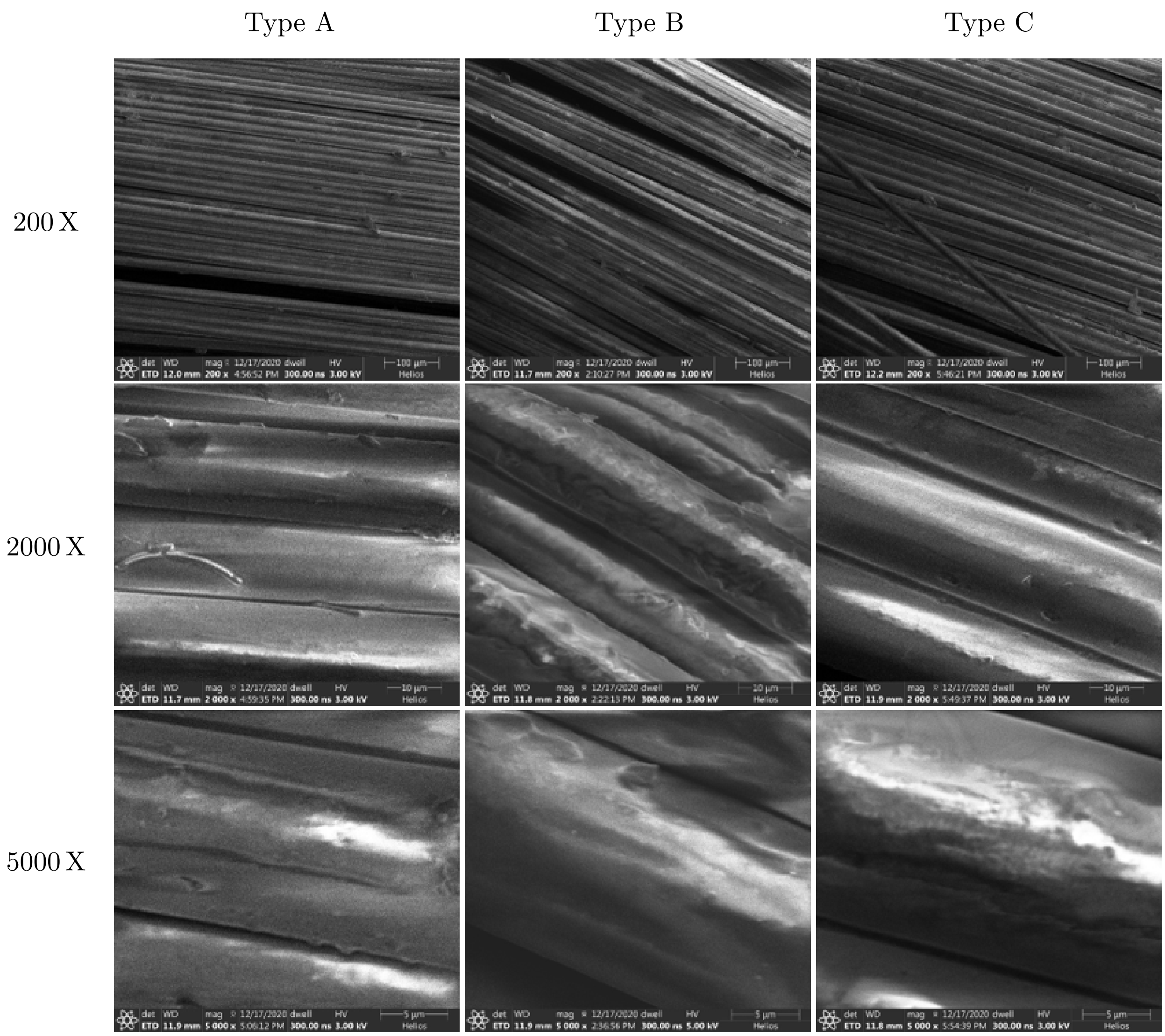


Figure 6.2: All types of sized fibers at different magnifications

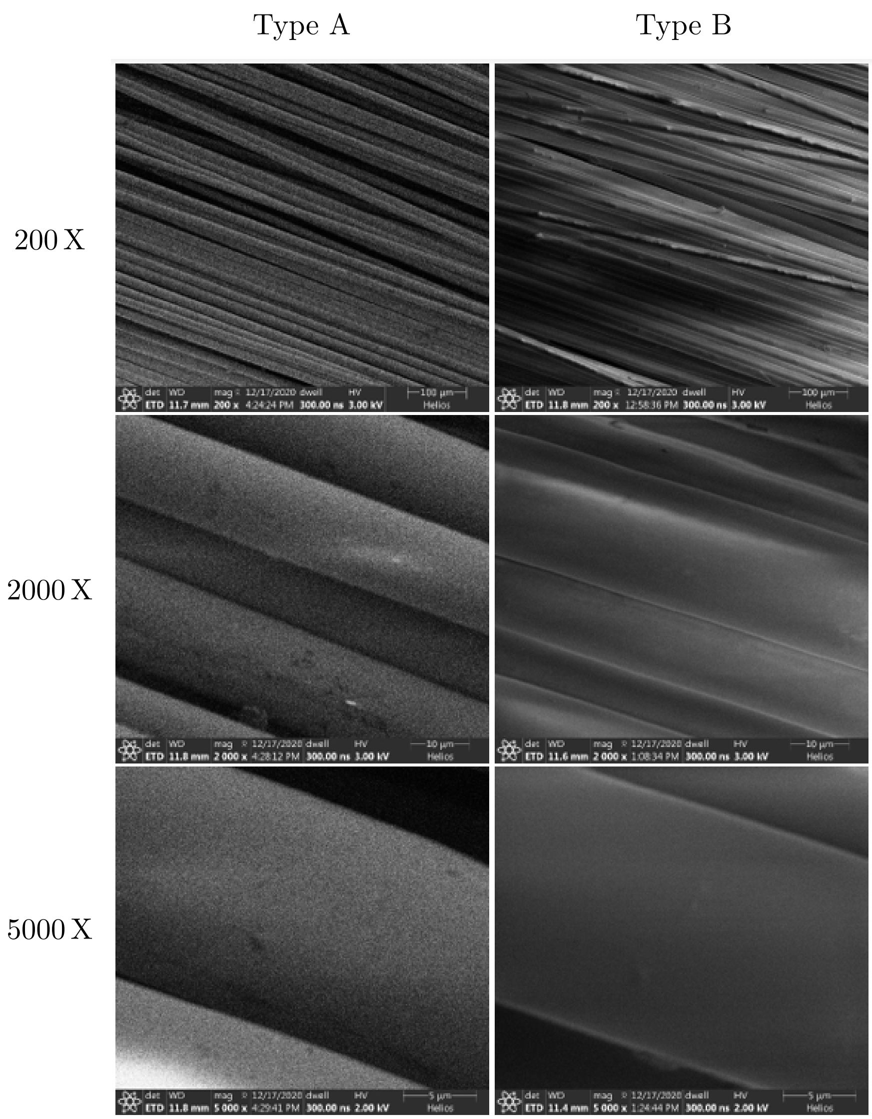


Figure 6.3: All types of unsized fibers at different magnifications

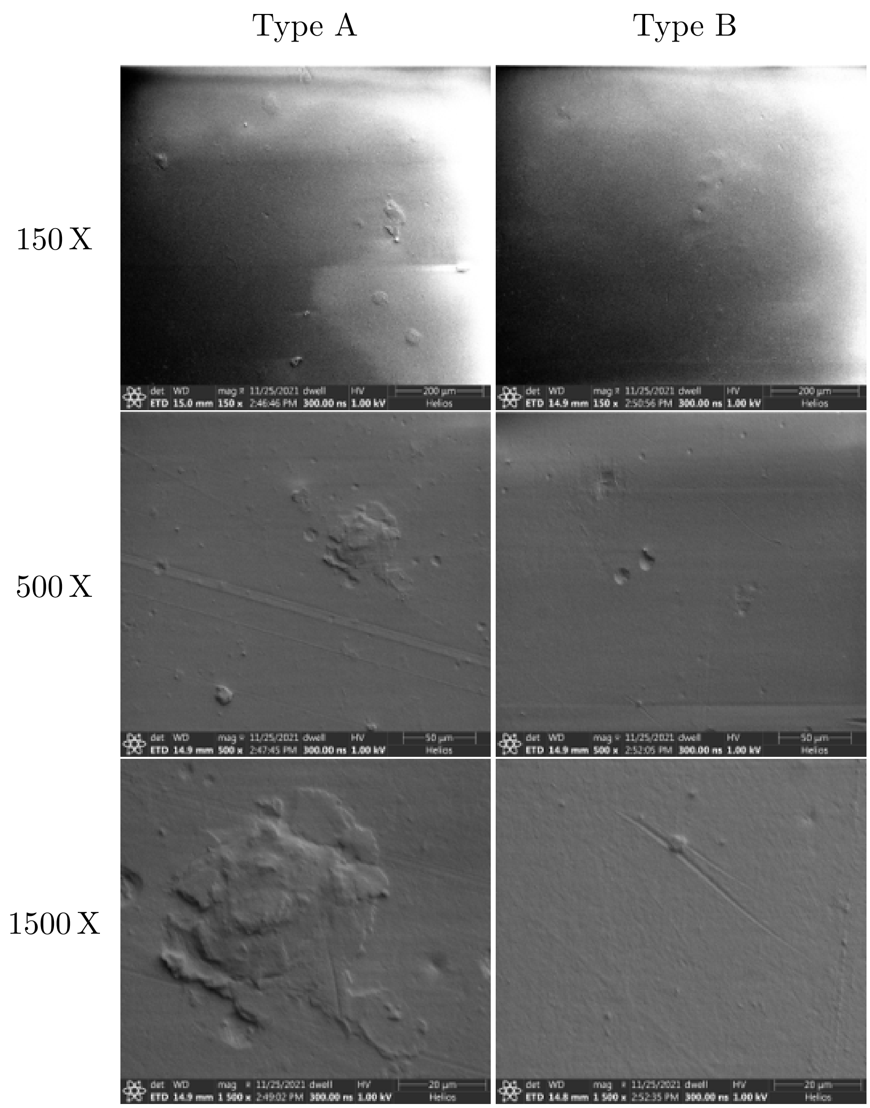


Figure 6.4: All types of resins at different magnifications

6.2 Chemical Properties of Exposure Environments

6.2.1 Introduction

According to the test matrix, 16 different solutions—with various pH-values and salinity levels—were generated to expose the raw constituents and composite basalt rebar materials to aggressive environments. While each specific solution (with a defined ph-value and salinity-level) was eventually distributed over various bottles and containers, the entire required amount for each solution was created in a single (well mixed) batch to guarantee identical exposure conditions across the various materials and components within each particular solution type (c.f. test matrix). The actual mixing process is detailed in the previous chapter, but this chapter specifies how the solutions were tested and evaluated for various chemical properties. This step was necessary for quality control and to generate baseline values, before the rebar materials were submerged in the corresponding solution.

6.2.2 Aggressive Environments — Solution Properties

The measurement of pH and salinity were determined according to the 'Standard Methods' for examining water and wastewater properties (Rice, Eugene W and Baird, Rodger B and Eaton, Andrew D and Clesceri, Lenore S and others, 2012). For each parameter, triplicate samples were measured and the corresponding minimum, maximum, and average concentrations were recorded. These measurements were completed immediately before the unsized fiber, sized fiber, resin plates and rebars were exposed to the solutions. Therefore, the results presented in the following section (Section 6.2.2) are the representation of baseline data (i.e., the 0 day data). By examining the changes of the exposure solution water chemistry, affects of the different exposure solutions on the fibers, resins and rebars after 300 days was studied.

Results for pH and salinity are summarized in Table 6.3. All pH and salinity results were very close to the target values (theoretical values in the first two columns). The variation between the triplicate measurements were minimal.

Table 6.3: pH and salinity results of exposure solutions

Exposure Solution		pH			Salinity		
pH	cl$^-$				mg/L		
	ppm	$\wedge$	$\vee$	μ	$\wedge$	$\vee$	μ
4	0	3.99	4.00	3.99	9.70	9.80	9.73
4	200	3.99	4.00	4.00	343.00	344.00	343.33
4	20000	3.98	3.99	3.99	32970.00	32980.00	32976.70
4	Seawater	4.01	4.02	4.02	33690.00	33710.00	33696.70
7	0	7.01	7.02	7.02	5.50	5.50	5.50
7	200	7.00	7.01	7.00	335.00	336.00	335.67
7	20000	7.00	7.01	7.01	32950.00	32960.00	32953.30
7	Seawater	7.01	7.03	7.02	33710.00	33730.00	33723.30
10	0	10.00	10.01	10.00	6.90	6.90	6.90
10	200	10.01	10.02	10.01	338.00	339.00	338.70
10	20000	9.99	10.00	10.00	32960.00	32970.00	32966.70
10	Seawater	10.01	10.02	10.02	34540.00	34560.00	34546.70
13	0	12.99	13.00	12.99	4005.00	4010.00	4008.33
13	200	13.01	13.03	13.02	4333.00	4336.00	4334.30
13	20000	13.00	13.01	13.00	36970.00	36980.00	36973.30
13	Seawater	12.98	12.99	12.99	36600.0	36610.00	36596.70

6.3 Physical Properties of Rebars

6.3.1 Introduction

The performance evaluation of virgin basalt fiber reinforced polymer (BFRP) rebars is summarized in this chapter. The following results were obtained at the FAMU-FSU College of Engineering in the Structures and Materials laboratories. All tests were conducted in accordance with the relevant American Society for Testing and Materials (ASTM) test protocol. The collected raw data were analyzed with the engineering software R-statistics[1] and R-Studio[2]. The results in this chapter are presented in graphs to visualize individual specimen

[1]R.app GUI 1.70 (7434 El Capitan build), S. Urbanek & H.-J. Bibiko, © R Foundation for Statistical Computing, 2016
[2]Version 1.1.383 © 2009-2017 RStudio, Inc.

data, while tables are used to summarize the statistical data of each test sample (rebar type). For clarity, each property was individually studied; accordingly, each material characteristic is presented separately.

6.3.2 Cross-Sectional Properties

The effective rebar diameter was measured according to the ASTM D 792-13. Due to the variety of FRP rebars on the market and depending on the proprietary production methods, rebars with different surface enhancement may vary significantly and deviate from the given nominal diameter. Table 6.4 below lists the results of water displacement method according to the ASTM D 792-13 of all the rebar products.

Table 6.4: Statistical evaluation of diameter measurements for rebar size # 3 and # 5

Rebar			$\wedge$	$\vee$	μ	σ	CoV†
Type	Size	Lot	mm	mm	mm	mm	%
A	# 3	1	10.67	10.93	10.76	0.11	0.99
B	# 3	1	9.84	10.47	10.31	0.26	2.56
A	# 3	2	10.41	10.94	10.70	0.20	1.89
B	# 3	2	10.57	10.83	10.72	0.11	1.05
A	# 5	1	16.66	16.79	16.71	0.05	0.30
B	# 5	1	17.52	17.59	17.56	0.03	0.19
A	# 5	2	16.26	16.52	16.43	0.10	0.60
B	# 5	2	17.53	17.65	17.57	0.05	0.30

† Coefficient of Variation

6.3.3 Fiber Content

The fiber content by weight of the rebars was calculated according to ASTM D 2584 -11 (ASTM-International, 2011). The measured fiber content results are plotted in Figure 6.5. The bar chart was generated to compare the different rebar types against each other and to compare the different rebar sizes. Each row in the plot indicates a specific rebar size, while each column represents a different rebar type. The bars represent individual specimens. The red hatched part of the bars indicates the fiber content in percentage, the blue crosshatched part represents the percentage of resin, and the black part represents the amount of sand that was applied to the rebar surface to increase the bond-to-concrete performance. Since the weight of the sand surface enhancement has a relative higher contribution (percentage wise) on smaller specimens, the percentage weight on # 3 rebars is higher than # 5 rebars as presented in bar chart. The 100 % values for these rebars are based on total specimen weight minus the sand content. The dashed line at the 70 % mark shows the AC454 and FDOT currently accepted minimum fiber content for FRP rebars. It can be seen that all individual rebar specimens met the minimum requirement for the fiber content. Overall, the measured fiber content results show that the production quality was consistent for all rebar types and sizes (within each rebar product). The following Figure 6.6 presents typical closeup pictures for individual test specimens of rebar types A and B. These pictures show # 3 rebar from Type A and # 5 rebar from Type B.

6.3.4 Moisture Absorption

The moisture absorption property of rebars was tested in accordance with ASTM D 5229 (ASTM, 2014). The graph plotted in Figure 6.7 represents weight change of all tested rebar types stored in distilled water over a test period of 98 d. It can be seen in the graph that all rebar types showed comparable moisture absorption

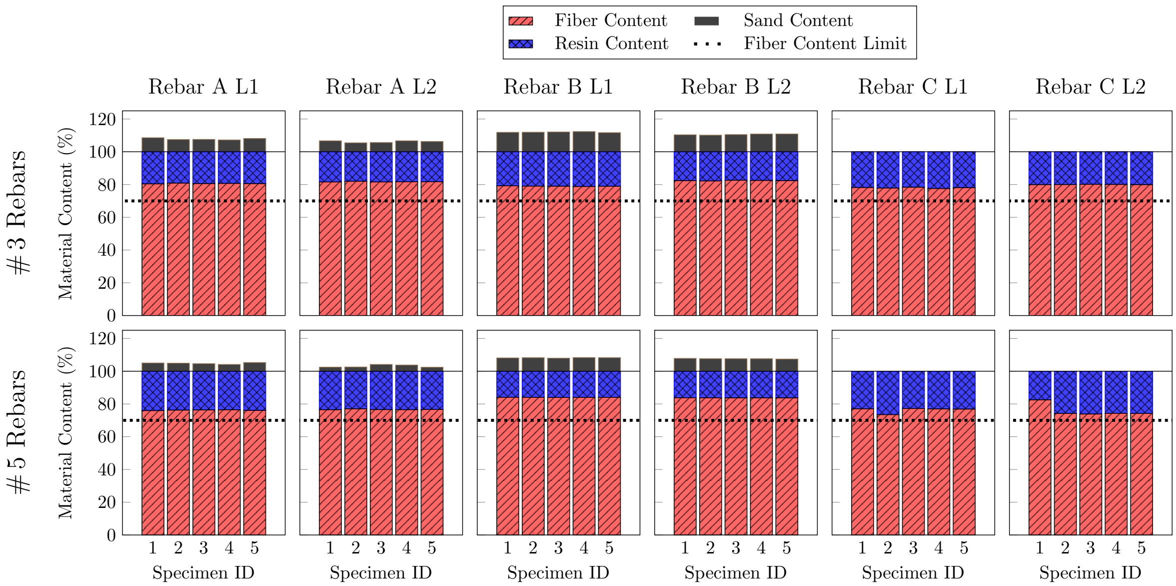


Figure 6.5: Fiber content percentage of rebars from all manufacturers

(a) Type A

(b) Type B

Figure 6.6: Fiber content specimen of rebars after test

behavior. All the rebar types satisfied the AC454 limitations for the absorption limit of 0.25 % in first 24 hours of exposure.

6.3.5 X-Ray Fluorescence (XRF) Analysis on Rebars

The XRF Analysis on rebar samples was conducted with X-Ray fluorescence spectrometer. The results are tabulated in Table 6.5.

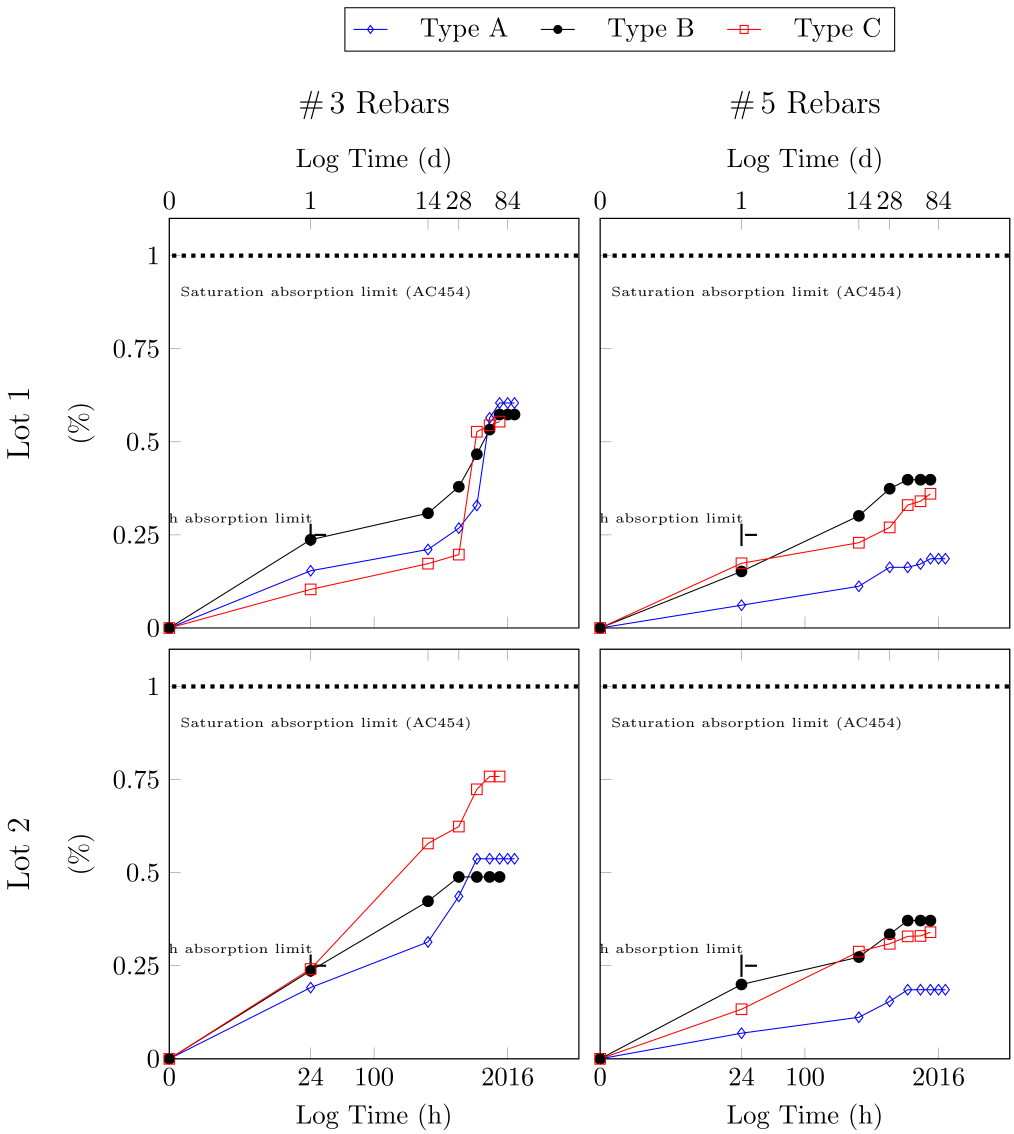


Figure 6.7: Moisture absorption results of rebars from all manufacturers

Table 6.5: XRF results of virgin rebars

Type	Lot	Ca %	Ti %	Cr PPM	Mn %	Fe %	Cu PPM	Zn %	Sr %	Zr %	Mo PPM	Ag %	Ba %	Eu %	Mg %	Al %	Si %	P %	S %	Cl %	K %
A	1	18.46	2.82	559.8	0.62	43.91	412.9	0.24	0.33	0.16	0.2	1.32	0.29	0.32	0.59	5.35	18.52	0.32	0	1.43	3.95
A	2	18.98	2.88	347.4	0.62	43.62	291.8	977.4	0.33	0.15	0.21	1.28	0.23	0.3	0.66	5.07	20.1	0.28	0	0.42	4.09
B	1	18.94	2.83	252	0.63	43.34	357.6	939.5	0.32	0.2	0	1.27	0.26	0.28	0.55	5	20.04	0.36	0	0.28	4.07
B	2	18.84	2.66	483.4	0.61	41.96	0.25	0.14	0.33	0.21	0	1.96	0	0.28	0.3	3.42	22.93	0.81	0	0.63	3.93
C	1	18.97	2.75	425.8	0.62	41.46	0.1	0.25	0.76	0.39	0.44	2.51	0	0.26	0.49	5.05	20.68	0	0	0.56	3.94
C	2	18.63	2.82	360.8	0.65	45.89	0	0.11	0.34	0.18	0.34	1.46	0.26	0.29	0.51	4.51	17.94	0.37	0	0.84	4.28

6.4 Mechanical Properties

6.4.1 Transverse Shear Test

ASTM D 7617 (ASTM-International, 2012b) was used in the process of testing and analyzing the transverse shear strength of the rebars. Tested and processed data are plotted in the following sections 6.4.1 and 6.4.1.

Load-Displacement

The graphs plotted in Figures 6.8, 6.9, 6.10, 6.11, 6.12, and 6.13 show the load-displacement behavior recorded during the transverse shear tests of # 3 and # 5 rebars for all rebar types tested in this study. The x-axis of the graph represents the cross-head extension or the relative displacement between the edges of the directly sheared specimen, while the y-axis shows the measured force throughout the load application period. The Graph in figure 6.8 shows a linear behavior until it reaches the ultimate failure load. It can be seen that # 5 sized rebar sustained higher load in comparison with # 3 rebars. All the # 3 rebars sustained a consistent load while # 5 rebars sustained same peak load but the extension of the rebars varied. The graph in Figure 6.9 shows a comparison between the load and the displacement for transverse shear strength of # 3 and # 5 rebars Lot 1 from Type B rebar. It can be seen that the graph had a linear behavior until it reached the ultimate failure load. All the rebars sizes sustained a consistent load with similar extension. The Graph in Figure 6.10 shows the load - displacement behavior of Type C rebars. Linearity can be seen until it reaches the ultimate failure load. It can be seen that # 5 sized rebar sustained higher load in comparison with # 3 rebars. The graph in Figure 6.11 presents a comparison between the load and the displacement for of transverse shear strength of # 3 and # 5 rebars from Type A from Lot 2. The graph shows a linear behavior until it reached approximately 90% of the ultimate failure load. The visualized data in Figure 6.12 show the load-displacement behavior for transverse shear strength of # 3 and # 5 rebars Lot 2 from Type B rebar. It can be seen that the material behaved linearly until approximately 90 % of the ultimate failure load was reached. All the # 3 rebars sustained a consistent load while # 5 rebars sustained same peak load but the extension of the rebars varied. The graph in Figure 6.13 shows a comparison between the load and the displacement for transverse shear strength of # 3 and # 5 rebars from Lot 2. The graph shows a linear behavior until it reached approximately 90% of the ultimate failure load.

Stress-Displacement

The results obtained from the transverse test was properly reduced and analyzed. These results are shown via graphs and table. The graphs in Figures 6.14, 6.15, 6.16, 6.17, 6.18, and 6.19 compare the stress-displacement behavior of transverse shear test of # 3 and # 5 rebars from all rebar types that were tested for this research project. The data along the x-axis represents the cross-head extension or the direct shear displacement, while the y-axis signifies the measured shear stress.

The data in Figure 6.14 show that the material behaved nearly linearly until the ultimate failure load was reached.

It can be seen in Figure 6.14 that the stress-strain behavior of all rebars was close but not identical—specifically, it varied significantly for rebar number # 5. The graph in Figure 6.15 presents the stress-displacement behavior of transverse shear test of rebar Type B Lot 1. From the stress-strain behavior of rebar Type B as shown in Figure 6.15, it can be seen that the rebars underwent similar failure behavior. The graph in Figure 6.16 compares the stress - strain behavior of Type C rebar from Lot 1. It shows the linearity of tested rebar until the ultimate failure load was reached. It can be seen in Figure 6.16 that the stress-strain behavior of all rebars was close but not identical—specifically, it varied significantly for rebar number # 5. The graph in Figure 6.17 presents the stress-displacement behavior of transverse shear test of

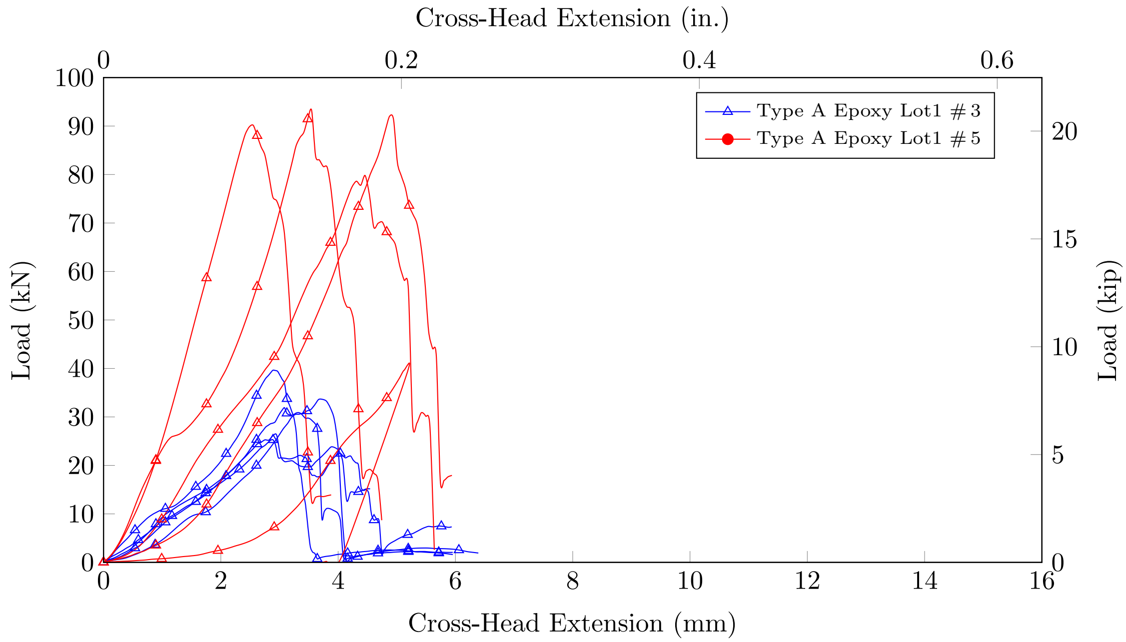


Figure 6.8: Extension-transverse shear load behavior of Type A rebars Lot 1 size 3 and 5

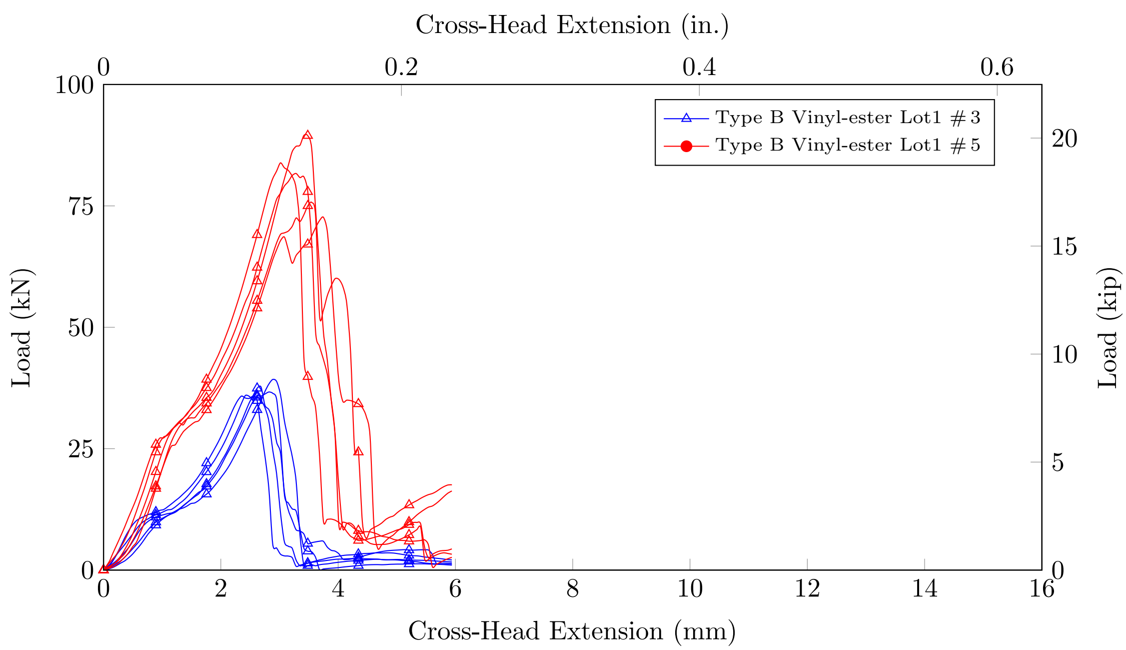


Figure 6.9: Extension-transverse shear load behavior of Type B rebars Lot 1 size 3 and 5

rebar Type A Lot 2. The graphs display a mostly linear behavior until the ultimate failure load was reached. Figure 6.18 shows the stress-displacement behavior of transverse shear test of rebar Type B Lot 2. It can be seen that the data represented a nearly linear behavior until the ultimate failure load was attained. The stress-displacement behavior of failed rebar specimen from both types from Lot 2 in Figures 6.17 and 6.18 show that, although the ultimate failure capacity of the rebars varied significantly, all the rebar samples failed in a identical manner. The graph in Figure 6.19 presents the stress-displacement behavior of transverse shear test of Lot 2 rebars from Type C manufacturer. From the stress-displacement behavior of rebar as shown in

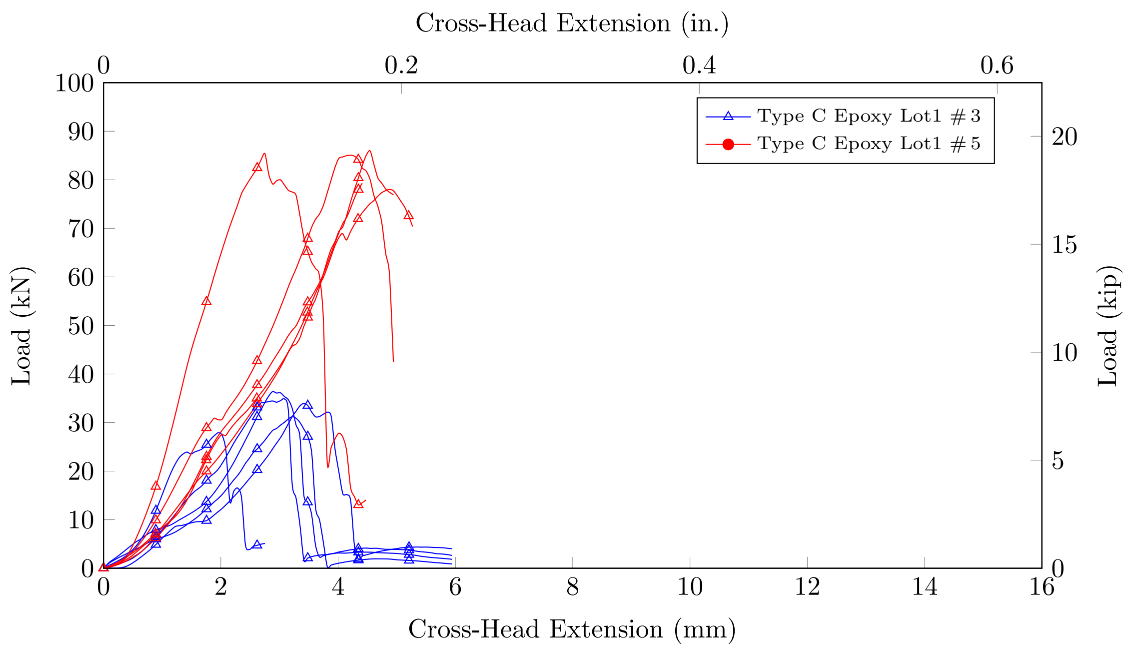


Figure 6.10: Extension-transverse shear load behavior of Type C rebars Lot 1 size 3 and 5

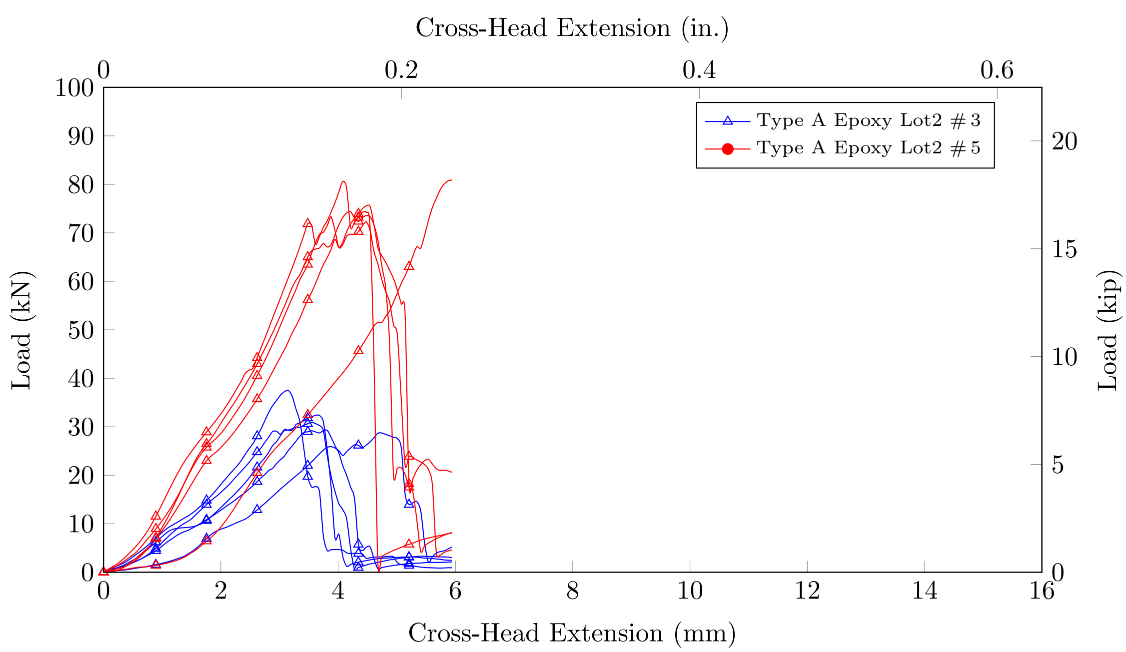


Figure 6.11: Extension-transverse shear load behavior of Type A rebars Lot 2 size 3 and 5

Figure 6.19, it can be seen that the rebars underwent similar failure behavior.

6.4.2 Modes of Failure

To study the failure process, the failed BFRP rebars were analyzed in detail to observe the failure pattern of outer fibers and inner fibers. Figure 6.20 exemplifies the failure patterns of the tested BFRP specimen in response to the applied transverse shear loads. Figure 6.20 shows that the failure mode for all rebars was

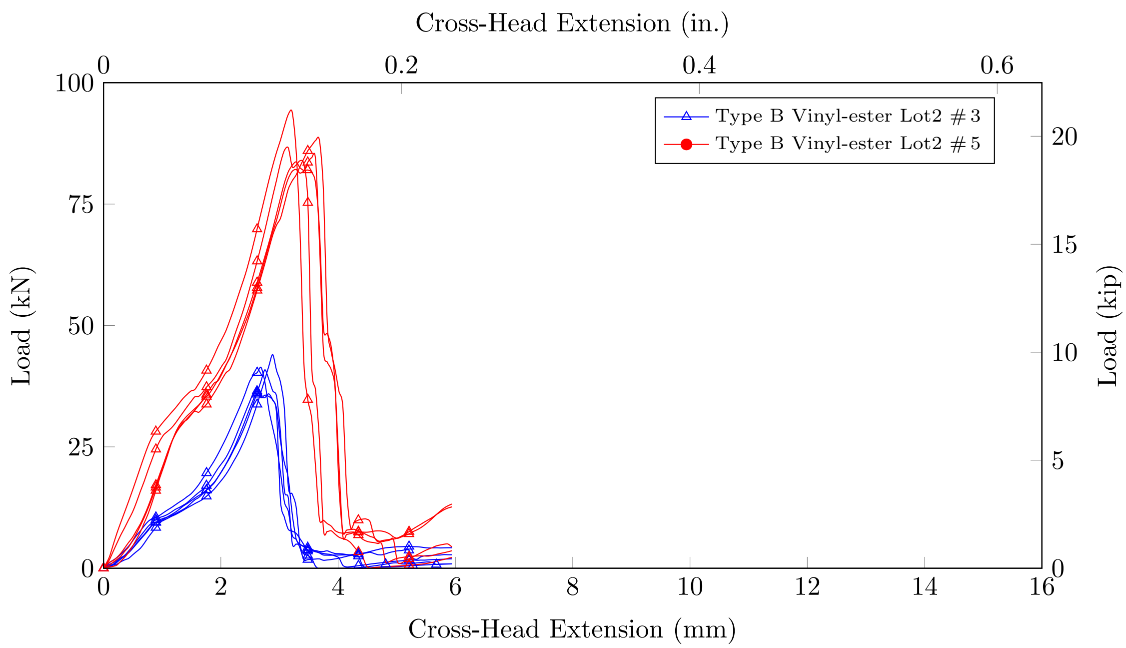


Figure 6.12: Extension-transverse shear load behavior of Type B rebars Lot 2 size 3 and 5

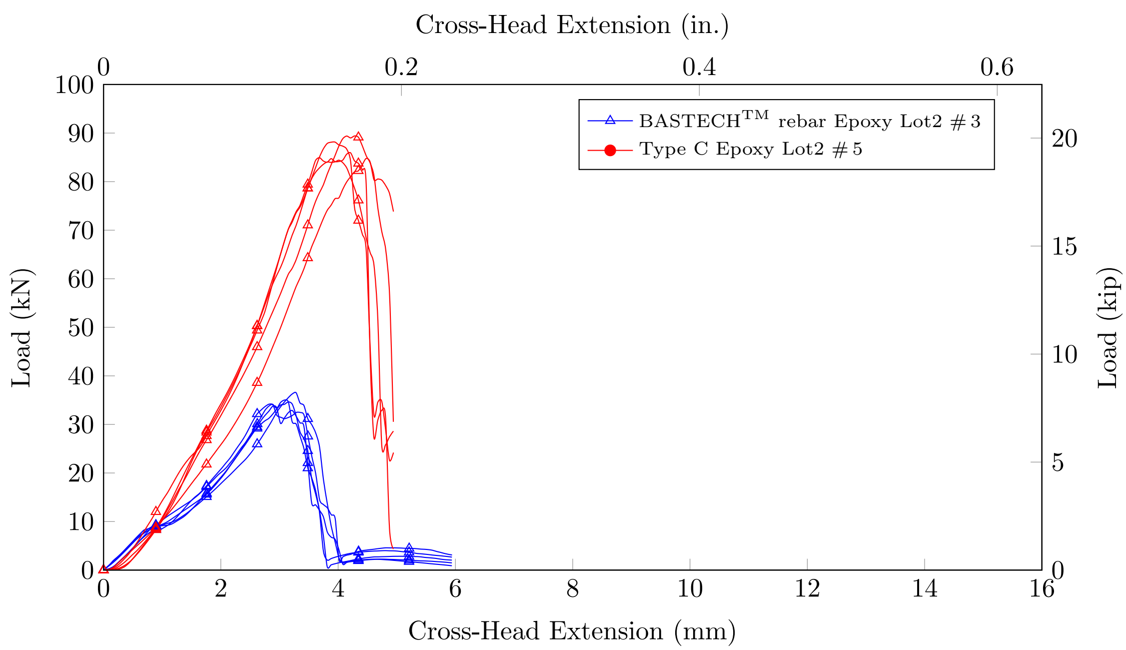


Figure 6.13: Extension-transverse shear load behavior of Type C rebars Lot 2 size 3 and 5

identical irrespective of the sizes and types.

6.4.3 Summary of Transverse Shear Properties

The results of the statistical evaluation for the transverse shear strength properties of the tested products are listed in the following Table 7.41. A total of 60 specimen, five for each rebar type, size and lot were tested. The average and all other statistical values were calculated based on a sample size of five specimen, and the

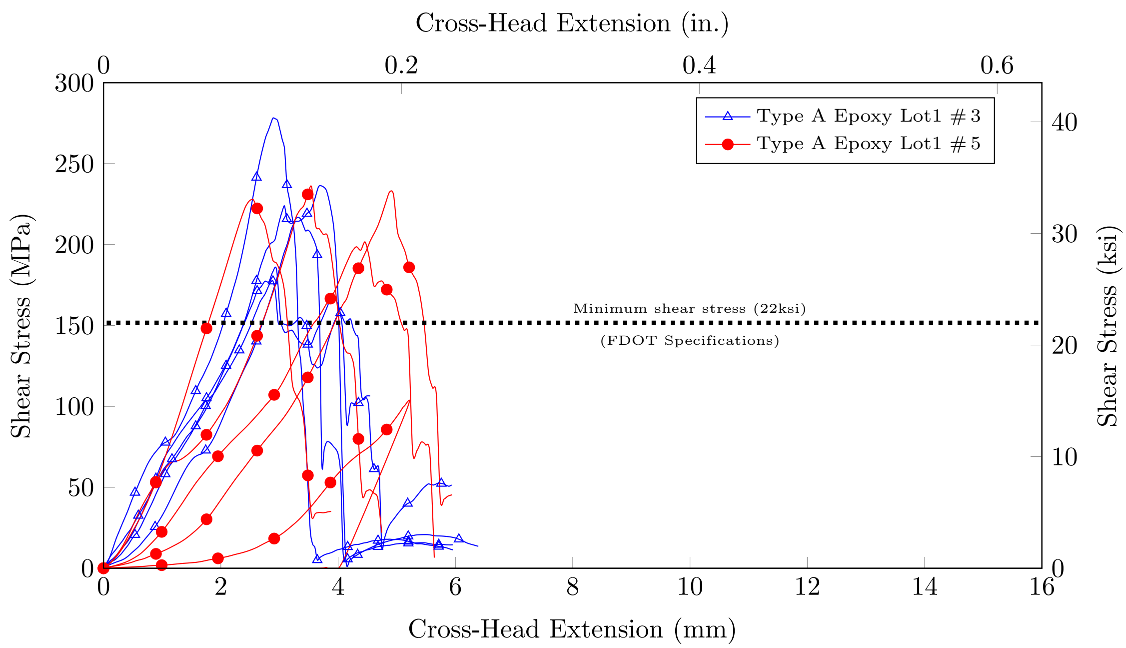


Figure 6.14: Transverse shear stress-extension behavior of rebar Type A Lot 1 size 3 and 5

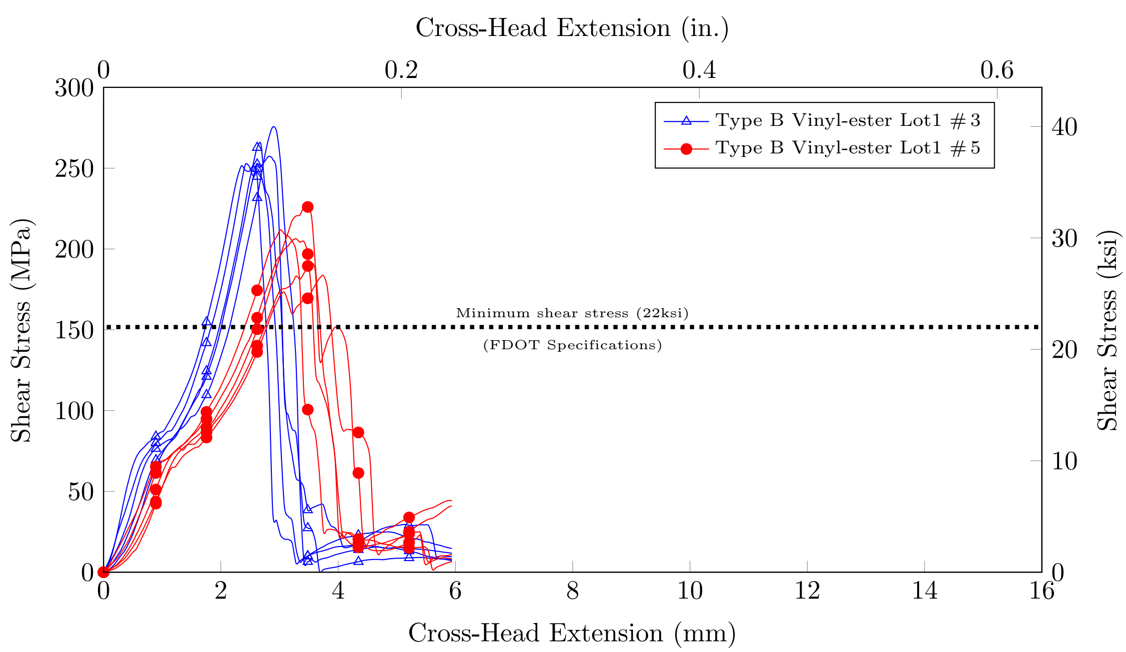


Figure 6.15: Transverse shear stress-extension results of rebar Type B Lot 1 size 3 and 5

corresponding results are shown in the table. For numerical comparison and concluding values, Table 7.41 lists the minimum shear stress ($\wedge$), the maximum shear stress ($\vee$), the average shear stress (μ), the standard deviation (σ), and the coefficient of variation (CV) for each individual test sample.

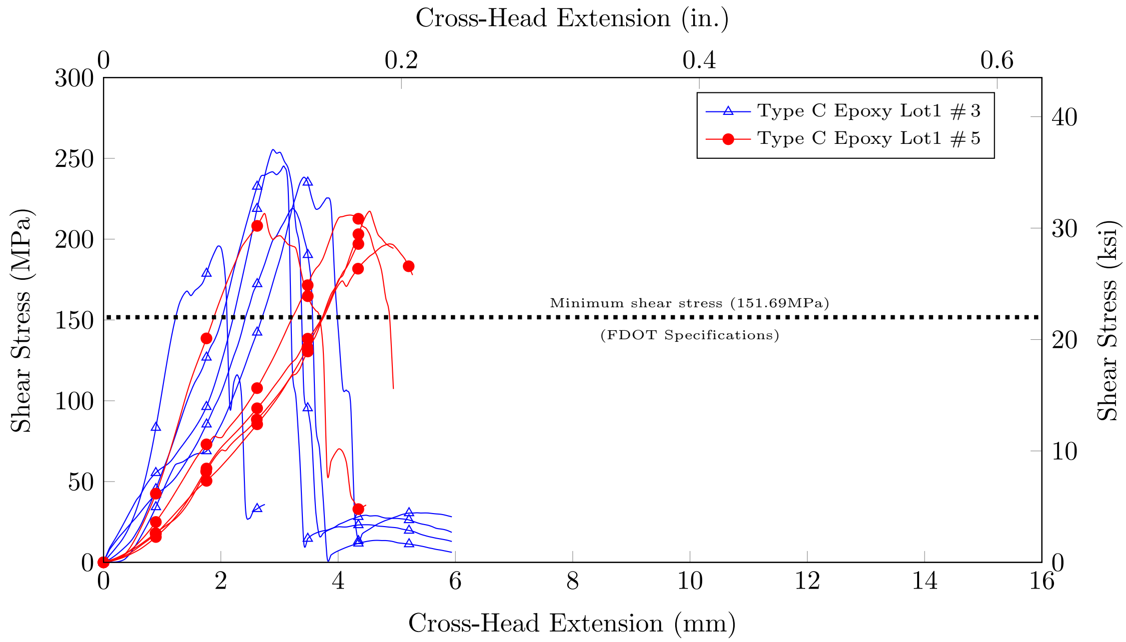


Figure 6.16: Transverse shear stress-extension results of Type C rebar Lot 1 size 3 and 5

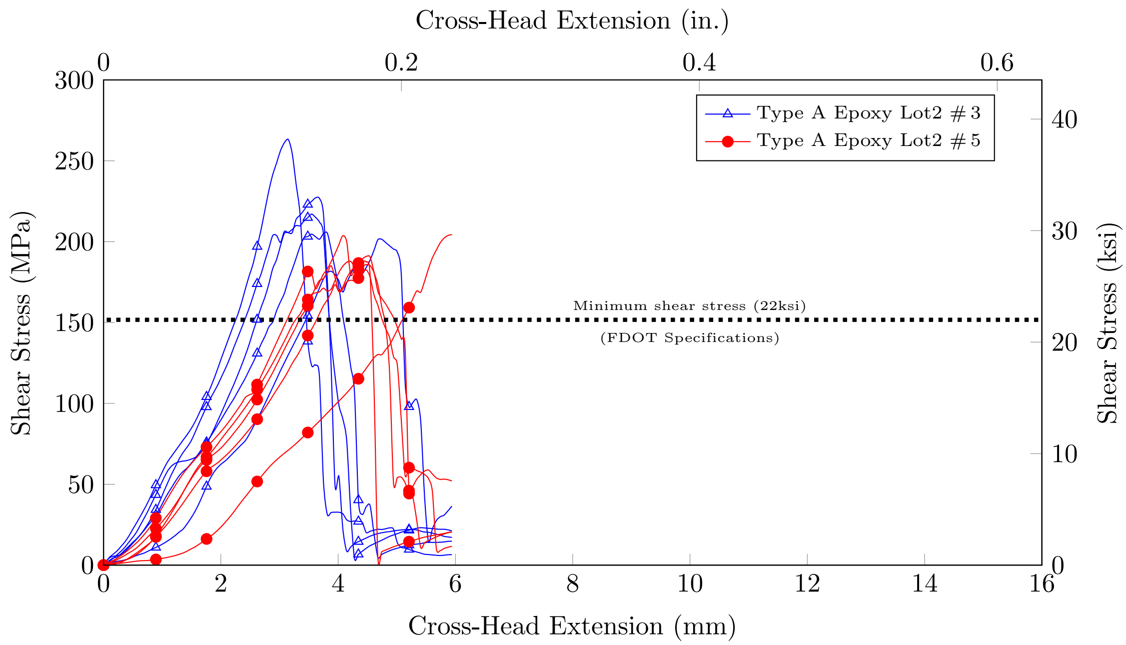


Figure 6.17: Transverse shear stress-extension behavior of rebar Type A Lot 2 size 3 and 5

6.4.4 Apparent Horizontal Shear Test

The FRP rebar products were tested for horizontal shear properties. The horizontal shear test was conducted according to the ASTM D 4475 (ASTM-International, 2012a) standards.

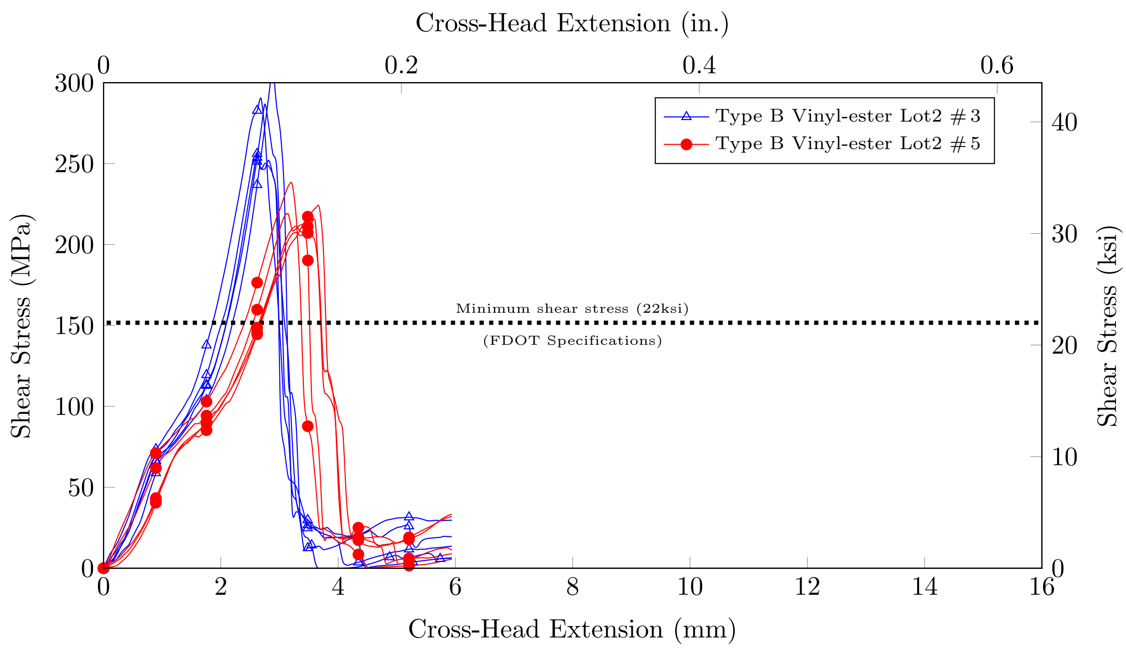


Figure 6.18: Transverse shear stress-extension results of rebar Type B Lot 2 size 3 and 5

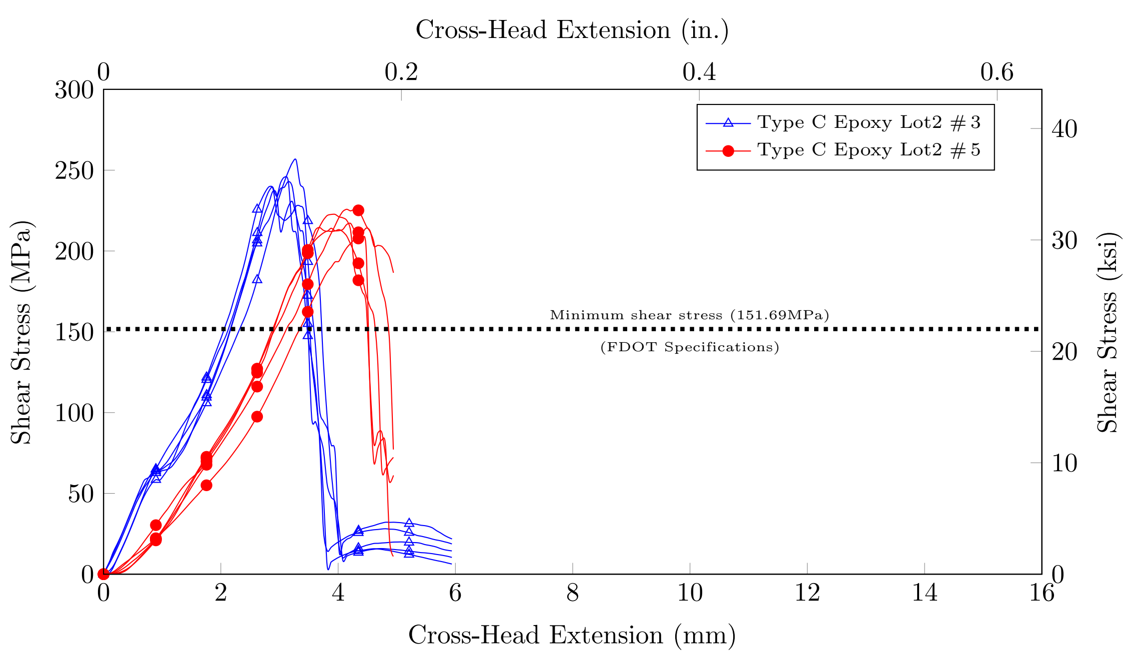
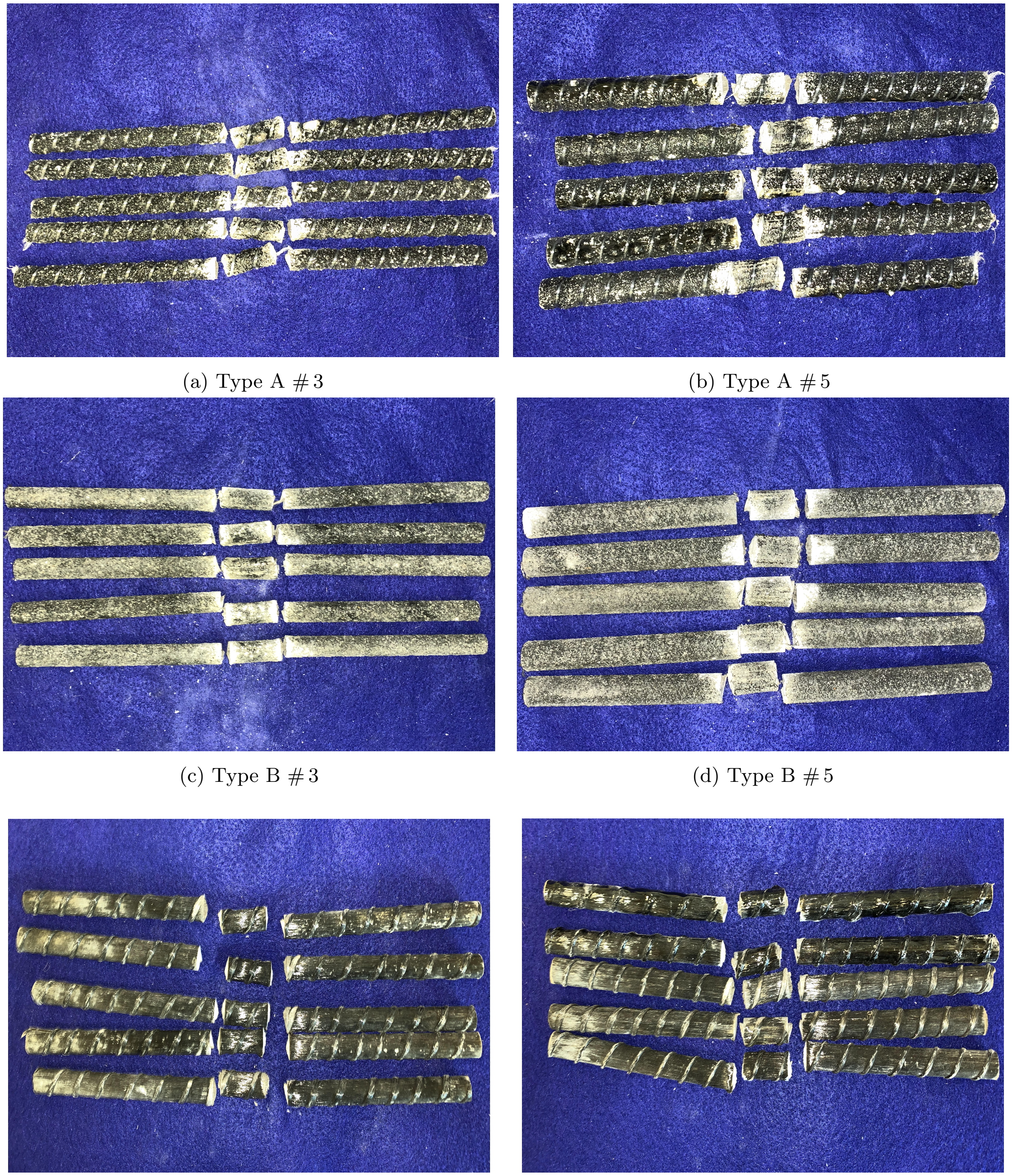


Figure 6.19: Transverse shear stress-extension results of Type C rebar Lot 2 size 3 and 5

Load-Displacement

The graphs in Figures 6.21, 6.22, 6.23, 6.24, 6.25, and 6.26 plot the load-displacement behavior of short span 3 point bending. Each rebar type is shown individually—and every specimen within the relevant sample is displayed—to compare # 3 and # 5 from the same type. The x-axis of the graph represents the cross-head frame displacement, and the y-axis represents the applied load.

The graph in Figure 6.21 shows a nearly linear behavior until it reached the ultimate failure load. Following



(a) Type A # 3 (b) Type A # 5

(c) Type B # 3 (d) Type B # 5

(e) Type C # 3 (f) Type C # 5

Figure 6.20: Failure pattern for tested rebar after transverse shear test

the peak load, a descending branch proceeds with individual local peaks and drops. The peaks and drops represent individual layers of fibers engaged and failing in tension located in the lower part of the specimen experiencing pure tension, while the upper part is in compression. Extension-Horizontal shear behavior of rebar Type B can be seen in the graph in Figure 6.22. Similar to Type A, # 5 Type B rebar sustained more load in comparison with # 3 rebars. The failure pattern of # 3 and # 5 Type B rebars was similar and identical to Type A rebar failure pattern. The load - displacement graph of Type C rebar in Figure 6.23 shows a nearly linear behavior until it reached the ultimate failure load. Following the peak load, a descending branch proceeds with individual local peaks and drops. The peaks and drops represent individual layers of fibers engaged and failing in tension located in the lower part of the specimen experiencing pure tension, while the upper part is in compression. The graphs shown in Figures 6.24, 6.25, and 6.26 show the load-displacement behavior of Lot 2 Type A, Type B, and Type C rebars. The graphs show a linear behavior until it reached approximately 90 % of the ultimate failure load. It can be seen in Figures 6.24 and 6.25 that the failure behavior of Type A and Type B rebars is identical irrespective of production lot and rebar size. Extension-Horizontal shear behavior of Lot 2 Type C rebars can be seen in the graph in Figure 6.26. Similar to Lot 1, # 5 Lot 2 rebars sustained more load in comparison with # 3 rebars. The failure pattern of # 3 and # 5 Lot 2 rebars was similar and identical to the failure pattern of rebars from Lot 1.

Stress-Displacement

To provide clarity and to compare the horizontal shear strength performance of the two rebar sizes, stress-strain behavior of rebar is shown in this section via graphs. The following graphs in Figures 6.27, 6.28, 6.29, 6.30, 6.31, and 6.32 show the comparison of the stress - cross-head behavior for the tested BFRP rebars. The x-axis of graph represents the cross-head extension, while the y-axis signifies the measured shear stresses. As expected, a significant difference in peak load between rebar sizes of Type A rebar was observed. Nevertheless, the resultant horizontal shear stress is approximately the same regardless of the rebar size. The stress-displacement behavior of rebar Type B shows that the failure pattern was identical for both the sizes but # 5 rebars sustained more stress in comparison to # 3 rebars. As expected, a significant difference in peak load between rebar sizes of Type C Lot 1 rebar was observed. Nevertheless, the resultant horizontal shear stress is approximately the same regardless of the rebar size. The graphs in Figures 6.30, 6.31, and 6.32 are used to compare the stress-displacement behavior of horizontal shear test of # 3 and # 5 rebars from Type A, Type B, and Type C from Lot 2. The stress-strain behavior of rebars from Lot 2 show that the failure pattern was identical for both the sizes but # 5 rebars sustained more stress in comparison to # 3 rebars. Figures 6.30 and 6.31 show that all the rebars of Type A and Type B underwent similar stress and strain irrespective of lot and size.

Table 6.6: Transverse Shear test statistical values for each sample group (US Customary Units)

Sample Group				Statistical Values				
				Shear Stress				
Manuf. Type	Resin Type	Size #	Lot No.	$\wedge$ ksi	$\vee$ ksi	μ ksi	σ ksi	CV %
Type A	Epoxy	3	1	25.8	40.4	32.0	5.9	18.51
Type A	Epoxy	5	1	15.3	34.3	29.3	8.1	27.62
Type B	Vinyl-ester	3	1	36.7	40.3	38.1	1.5	3.89
Type B	Vinyl-ester	5	1	30.8	32.9	31.7	0.8	2.62
Type C	Epoxy	3	1	28.5	37.3	33.6	3.5	10.30
Type C	Epoxy	5	1	34.9	37.5	35.8	1.1	3.01
Type A	Epoxy	3	2	29.4	38.3	32.5	3.6	10.94
Type A	Epoxy	5	2	26.7	33.1	29.7	2.5	8.58
Type B	Vinyl-ester	3	2	37.0	45.5	41.0	3.6	8.72
Type B	Vinyl-ester	5	2	30.8	34.7	32.2	1.5	4.73
Type C	Epoxy	3	2	28.6	31.5	30.5	1.3	4.29

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Table 6.6: Transverse Shear test statistical values for each sample group (US Customary Units)

Sample Group				Statistical Values				
				Shear Stress				
Manuf. Type	Resin Type	Size #	Lot No.	∧ ksi	∨ ksi	μ ksi	σ ksi	CV %
Type C	Epoxy	5	2	31.0	32.8	31.8	0.8	2.40
TypeA	Epoxy	3	1	28.6	32.3	30.1	1.4	4.70
TypeA	Epoxy	5	1	28.7	31.0	30.0	0.8	2.75
TypeB	VinylEster	3	1	28.1	30.6	29.3	1.0	3.40
TypeB	VinylEster	5	1	27.6	29.3	28.2	0.6	2.30
TypeC	Epoxy	3	1	28.2	31.9	30.0	1.3	4.44
TypeC	Epoxy	5	1	22.9	25.7	24.5	1.2	4.95
TypeA	Epoxy	3	1	29.4	33.7	31.1	1.7	5.45
TypeA	Epoxy	5	1	25.8	29.3	27.8	1.4	4.92
TypeB	VinylEster	3	1	29.8	34.1	31.8	1.7	5.45
TypeB	VinylEster	5	1	28.0	29.1	28.7	0.4	1.48
TypeC	Epoxy	3	1	24.8	28.2	27.0	1.3	4.74
TypeC	Epoxy	5	1	20.8	28.6	26.6	3.3	12.35
TypeA	Epoxy	3	1	27.3	31.4	29.2	1.8	6.24
TypeA	Epoxy	5	1	25.8	28.8	27.3	1.3	4.79
TypeB	VinylEster	3	1	30.0	33.2	31.4	1.5	4.85
TypeB	VinylEster	5	1	27.7	29.5	28.5	0.7	2.44
TypeC	Epoxy	3	1	28.9	31.5	30.2	1.1	3.74
TypeC	Epoxy	5	1	20.8	25.6	23.2	2.1	9.25
TypeA	Epoxy	3	2	25.1	31.4	27.5	2.6	9.58
TypeA	Epoxy	5	2	28.1	29.6	28.7	0.6	2.15
TypeB	VinylEster	3	2	30.7	32.5	31.8	0.8	2.47
TypeB	VinylEster	5	2	27.6	29.8	28.5	0.9	3.17
TypeC	Epoxy	3	2	29.0	31.4	30.5	0.9	2.98
TypeC	Epoxy	5	2	20.3	24.5	21.9	1.6	7.40
TypeA	Epoxy	3	2	18.8	26.3	22.0	3.3	14.82
TypeA	Epoxy	5	2	25.2	28.7	27.1	1.5	5.59
TypeB	VinylEster	3	2	31.9	36.9	33.5	2.0	6.09
TypeB	VinylEster	5	2	29.8	30.8	30.1	0.4	1.30
TypeC	Epoxy	3	2	29.5	32.9	30.7	1.3	4.16
TypeC	Epoxy	5	2	20.4	25.0	23.5	1.9	7.89
TypeA	Epoxy	3	2	21.4	25.8	23.6	2.0	8.58
TypeA	Epoxy	5	2	25.8	29.9	28.3	1.7	5.85
TypeB	VinylEster	3	2	32.6	35.8	34.6	1.3	3.67
TypeB	VinylEster	5	2	26.9	28.2	27.5	0.6	2.09
TypeC	Epoxy	3	2	29.9	32.7	31.4	1.2	3.84
TypeC	Epoxy	5	2	19.3	21.7	20.2	1.0	5.04
TypeA	Epoxy	3	1	24.8	31.5	28.2	2.8	9.99
TypeA	Epoxy	5	1	29.3	30.9	30.2	0.6	1.95
TypeB	VinylEster	3	1	28.3	34.1	31.1	2.2	7.10
TypeB	VinylEster	5	1	26.6	27.7	27.0	0.4	1.58
TypeC	Epoxy	3	1	28.8	31.9	30.1	1.2	4.06

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Table 6.6: Transverse Shear test statistical values for each sample group (US Customary Units)

Sample Group				Statistical Values				
				Shear Stress				
Manuf. Type	Resin Type	Size #	Lot No.	$\wedge$ ksi	$\vee$ ksi	μ ksi	σ ksi	CV %
TypeC	Epoxy	5	1	14.5	21.3	19.6	2.8	14.54
TypeA	Epoxy	3	1	28.7	34.4	31.8	2.3	7.20
TypeA	Epoxy	5	1	27.7	31.4	29.6	1.7	5.81
TypeB	VinylEster	3	1	29.8	34.6	31.6	1.9	6.07
TypeB	VinylEster	5	1	26.6	30.1	28.6	1.3	4.39
TypeC	Epoxy	3	1	30.2	33.1	31.5	1.3	4.11
TypeC	Epoxy	5	1	15.7	20.8	18.3	1.9	10.62
TypeA	Epoxy	3	1	29.2	33.9	31.7	1.7	5.40
TypeA	Epoxy	5	1	28.7	30.3	29.6	0.7	2.26
TypeB	VinylEster	3	1	26.7	30.7	29.1	1.5	5.10
TypeB	VinylEster	5	1	25.8	29.0	27.4	1.3	4.69
TypeC	Epoxy	3	1	28.6	31.8	29.9	1.1	3.81
TypeC	Epoxy	5	1	13.4	16.4	14.6	1.5	9.95
TypeA	Epoxy	3	2	21.8	27.5	24.6	2.5	10.17
TypeA	Epoxy	5	2	26.9	29.9	28.0	1.1	3.99
TypeB	VinylEster	3	2	31.3	35.4	32.6	1.6	4.97
TypeB	VinylEster	5	2	26.6	27.3	27.0	0.3	1.16
TypeC	Epoxy	3	2	27.8	33.4	30.7	2.1	6.86
TypeC	Epoxy	5	2	18.0	23.2	21.0	2.2	10.51
TypeA	Epoxy	3	2	25.3	29.2	27.6	1.7	6.05
TypeA	Epoxy	5	2	28.1	32.3	30.4	1.6	5.17
TypeB	VinylEster	3	2	32.3	40.5	36.7	3.2	8.75
TypeB	VinylEster	5	2	26.9	28.8	28.0	0.8	2.83
TypeC	Epoxy	3	2	28.5	31.4	30.1	1.3	4.29
TypeC	Epoxy	5	2	18.2	22.0	19.9	1.9	9.48
TypeA	Epoxy	3	2	21.8	26.4	24.2	1.6	6.81
TypeA	Epoxy	5	2	28.3	30.2	29.0	0.8	2.81
TypeB	VinylEster	3	2	32.2	35.6	34.2	1.3	3.90
TypeB	VinylEster	5	2	28.0	29.3	28.4	0.5	1.92
TypeC	Epoxy	3	2	24.5	27.0	26.0	1.1	4.19
TypeC	Epoxy	5	2	11.6	14.5	13.1	1.0	7.97
TypeA	Epoxy	5	1	7.2	27.7	21.8	8.5	39.14
TypeB	VinylEster	3	1	28.0	34.4	30.0	2.6	8.73
TypeB	VinylEster	5	1	25.0	27.5	26.3	1.1	4.13
TypeC	Epoxy	5	1	12.8	14.8	13.7	0.7	5.30
TypeB	VinylEster	3	1	30.5	36.9	33.3	2.3	7.00
TypeB	VinylEster	5	1	20.9	27.4	24.5	3.0	12.34
TypeB	VinylEster	3	1	12.8	14.4	13.8	0.6	4.54
TypeB	VinylEster	5	1	16.8	19.1	17.9	1.0	5.62
TypeA	Epoxy	5	2	18.8	29.1	26.0	4.8	18.58
TypeB	VinylEster	3	2	16.5	38.7	30.5	9.4	30.85
TypeB	VinylEster	5	2	16.7	26.2	23.4	4.0	17.27

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Table 6.6: Transverse Shear test statistical values for each sample group (US Customary Units)

Sample Group				Statistical Values				
				Shear Stress				
Manuf. Type	Resin Type	Size #	Lot No.	∧ ksi	∨ ksi	μ ksi	σ ksi	CV %
TypeC	Epoxy	5	2	13.8	29.7	20.6	6.1	29.51
TypeB	VinylEster	3	2	23.0	34.4	29.4	4.5	15.27
TypeB	VinylEster	5	2	26.5	29.4	27.6	1.1	3.89
TypeB	VinylEster	3	2	12.9	16.4	14.9	1.4	9.53
TypeB	VinylEster	5	2	17.6	21.6	19.8	1.4	7.28

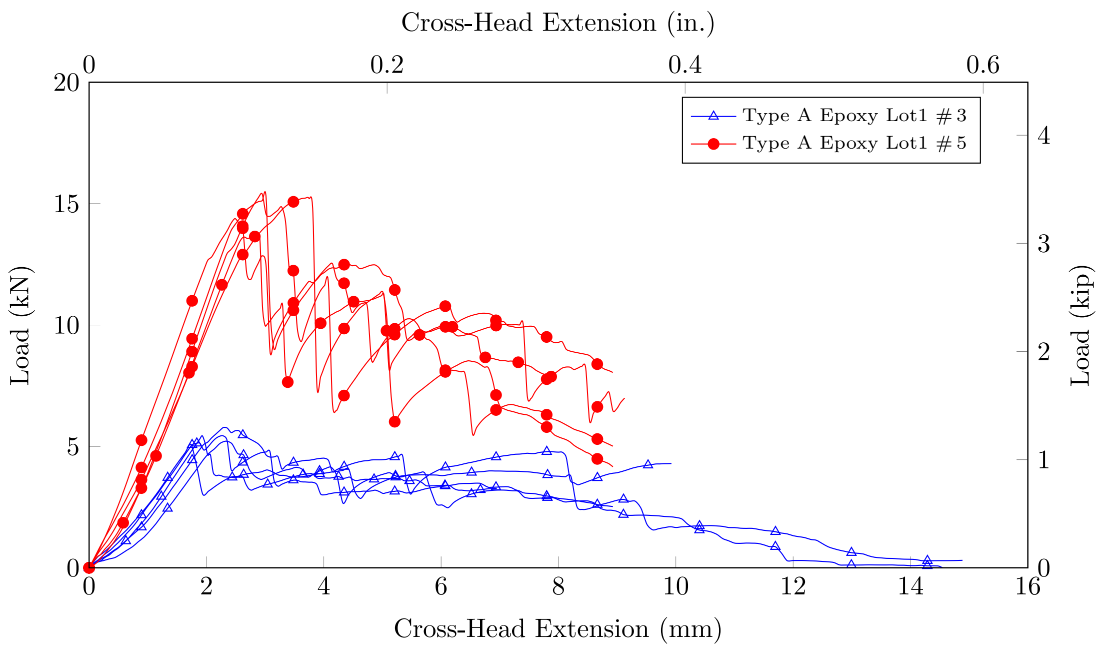


Figure 6.21: Extension-horizontal shear load behavior of rebar Type A Lot 1 size 3 and 5

6.4.5 Modes of Failure

To study the failure pattern of BFRP rebars, failure modes of the tested rebars were analyzed. Figure 6.33 shows the failed BFRP specimen after completion of the horizontal shear test. All tested specimens failed due to the apparent horizontal shear force, resulting in horizontal failure planes as observed from the perpendicular cracks to the applied load, through the depth of the cross section. After the peak load, secondary cracks were generated representing the horizontal shear failure plane as each inter-laminar layer of fibers is engaged in tension and then failing in fiber-matrix interface which occurred due to the three point bending load on a short span, that formed a horizontal failure plane, as shown in Figure 6.33. All the tested specimens had more than one failure plane. To study the post failure behavior of rebars, the bending test was continued although the load peak was reached. The tests were performed until three or four additional load drops was observed, which means additional three or four additional failure planes appeared.

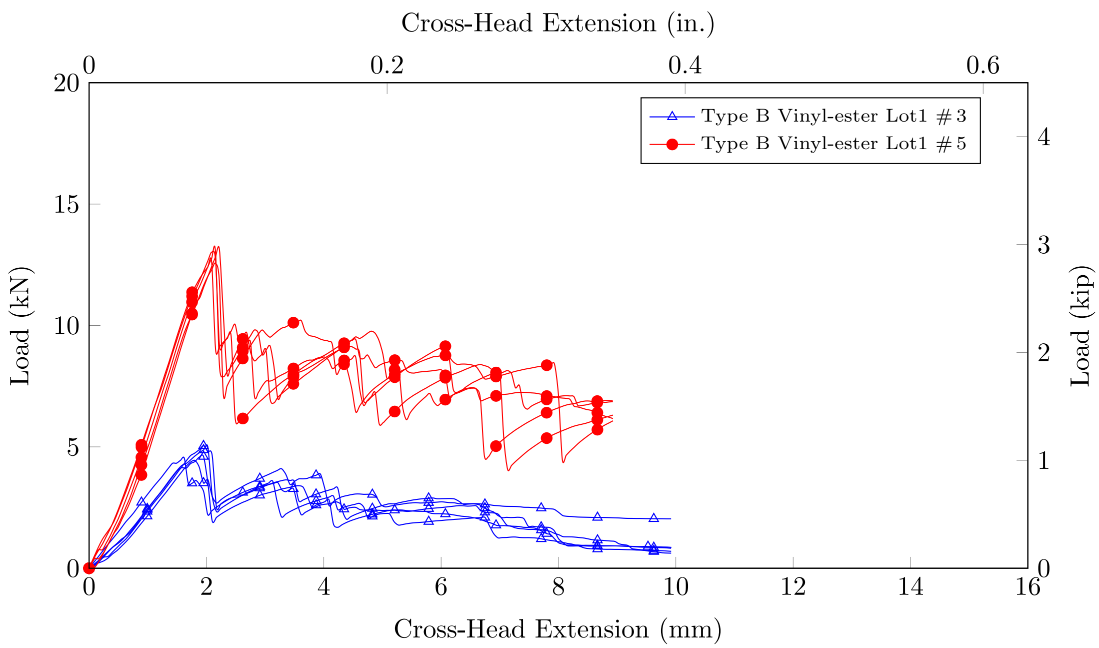


Figure 6.22: Extension-horizontal shear load behavior of rebar Type B Lot 1 size 3 and 5

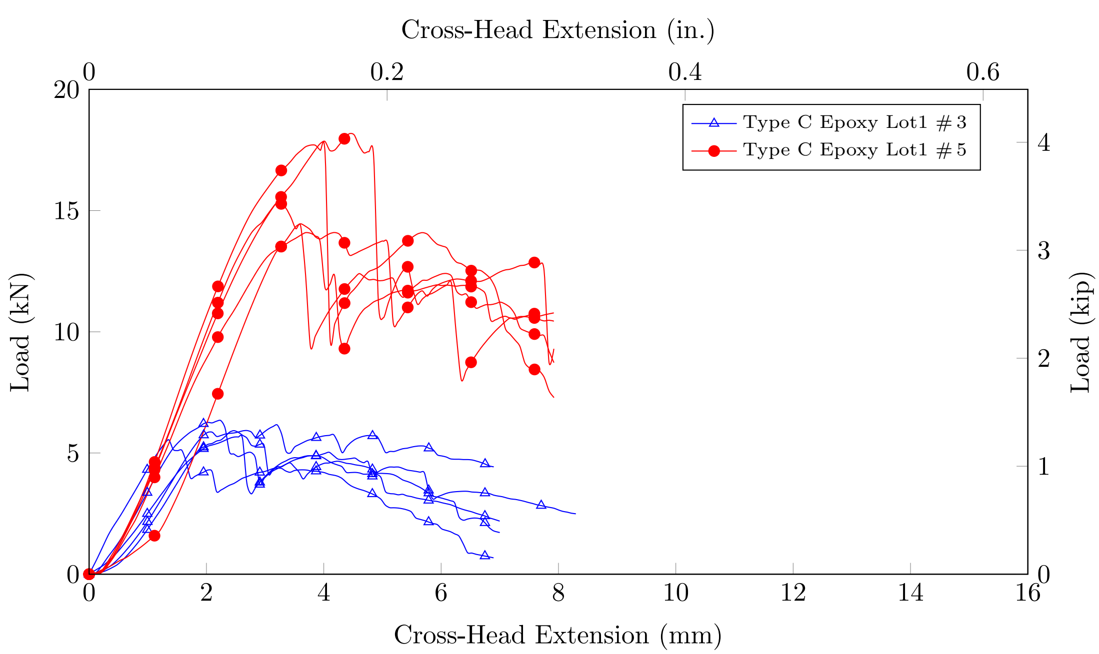


Figure 6.23: Extension-horizontal shear load behavior of Type C rebar Lot 1 size 3 and 5

6.4.6 Summary of Horizontal Shear Strength Properties

The statistical values for the horizontal shear strength properties of the tested products are listed in the following Table 7.42. A total of 60 specimens, five for each type, each size and lot were tested in total. The average of five specimens was assigned to each sample (specimen group) as shown in the table. For numerical comparison and concluding values, Table 7.42 lists the minimum shear stress ($\wedge$), the maximum shear stress ($\vee$), the average shear stress (μ), the standard deviation (σ), and the coefficient of variation (CV) for each

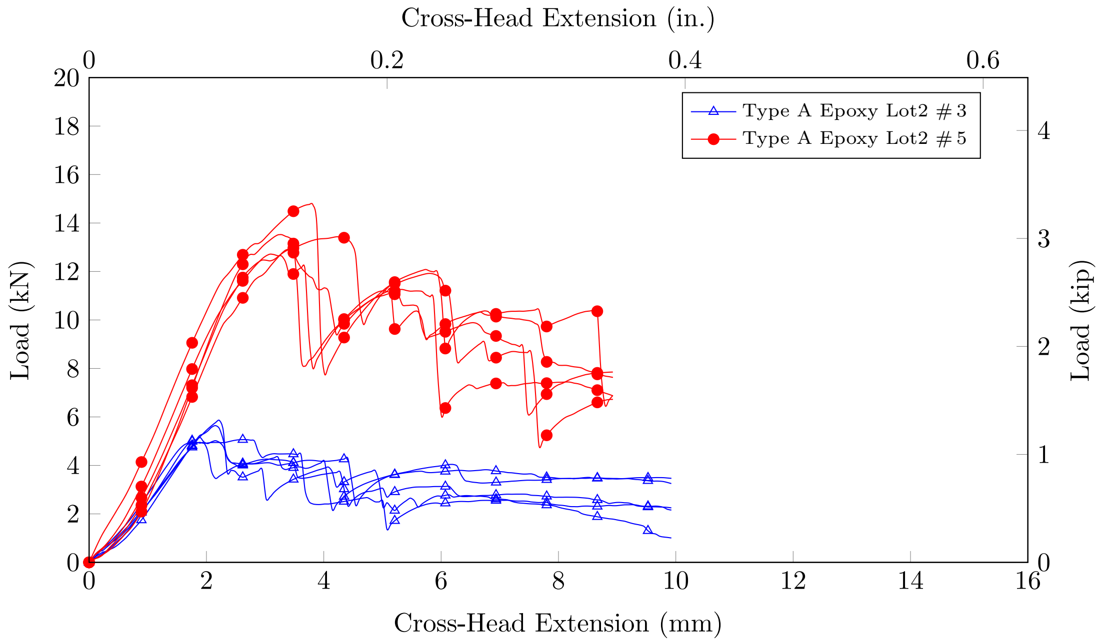


Figure 6.24: Extension-horizontal shear load behavior of rebar Type A Lot 2 size 3 and 5

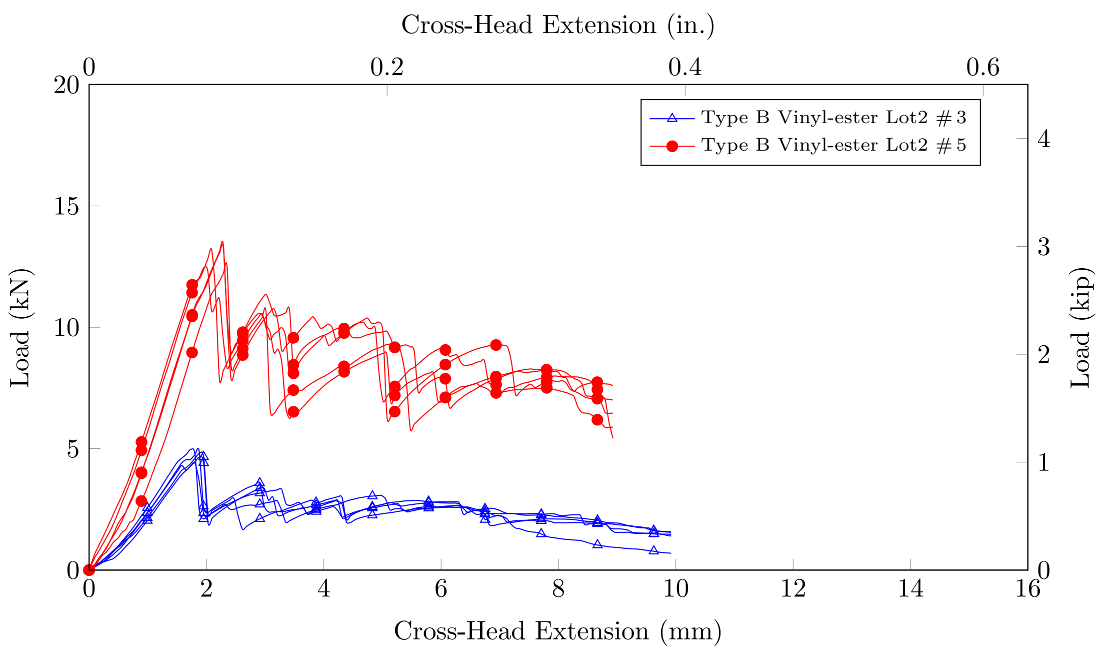


Figure 6.25: Extension-horizontal shear load behavior of rebar Type B Lot 2 size 3 and 5

individual test sample.

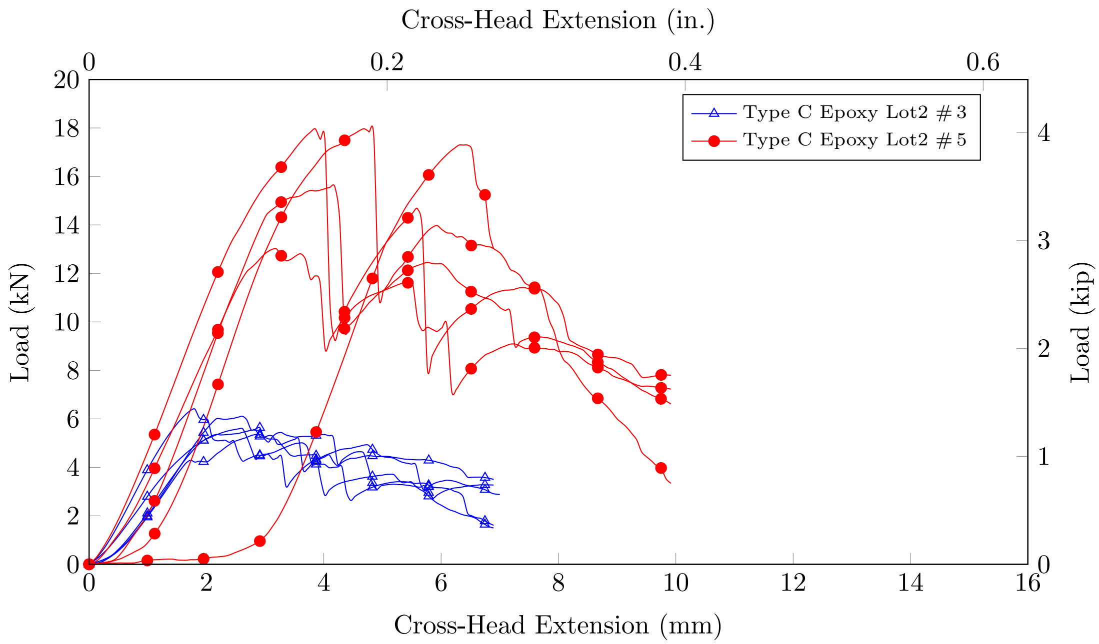


Figure 6.26: Extension-horizontal shear load behavior of Type C rebar Lot 2 size 3 and 5

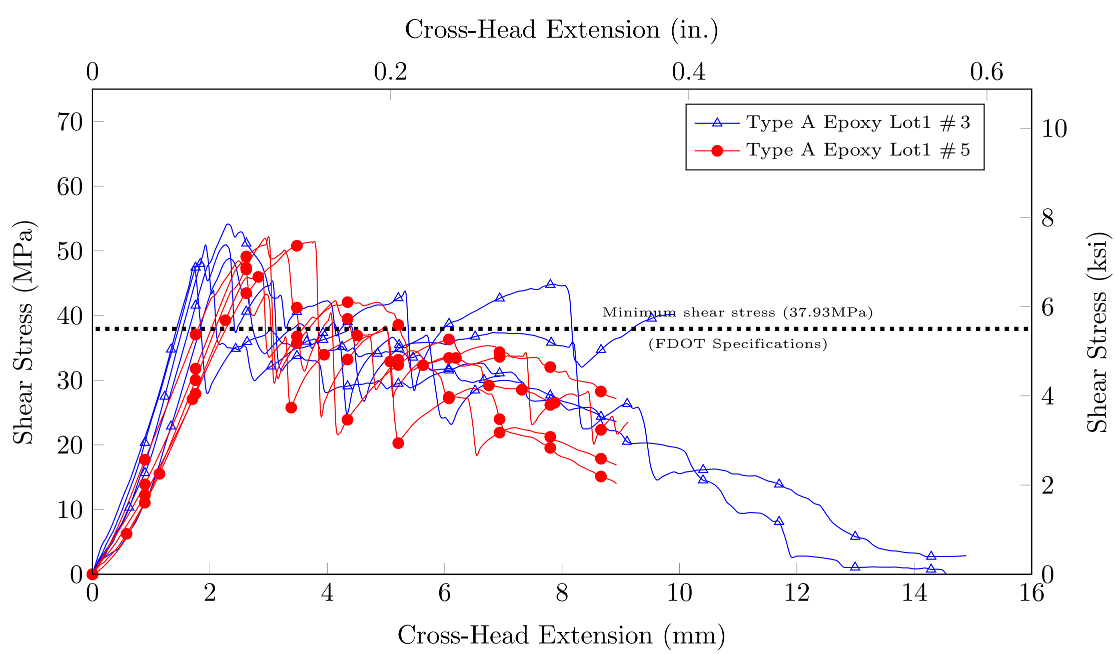


Figure 6.27: Horizontal shear stress - extension behavior of rebar Type A Lot 1 size 3 and 5

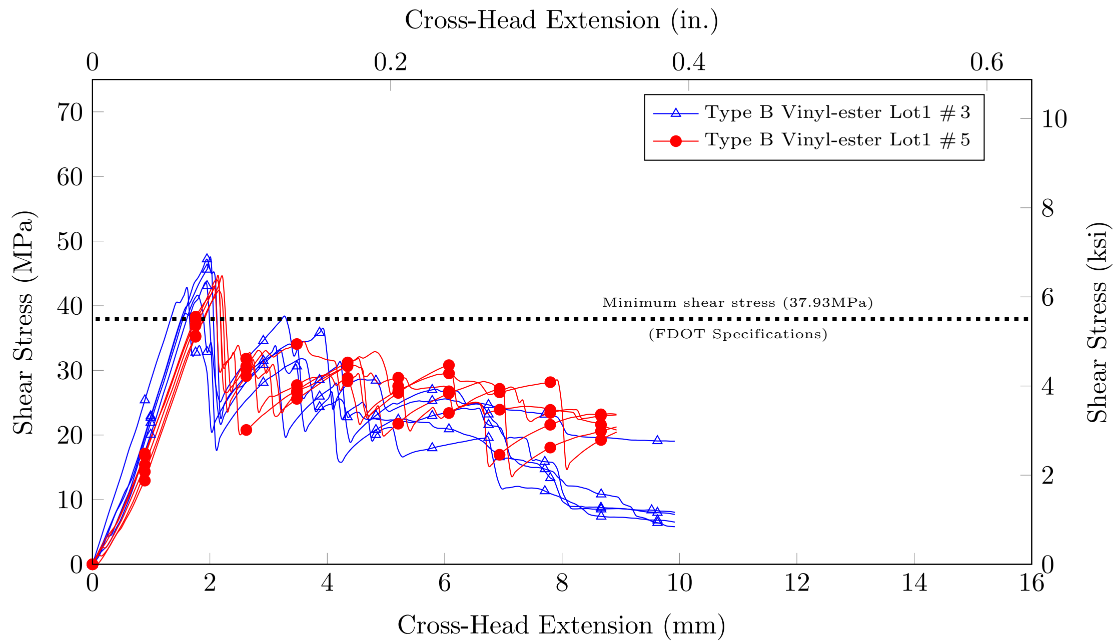


Figure 6.28: Horizontal shear stress - extension behavior of rebar Type B Lot 1 size 3 and 5

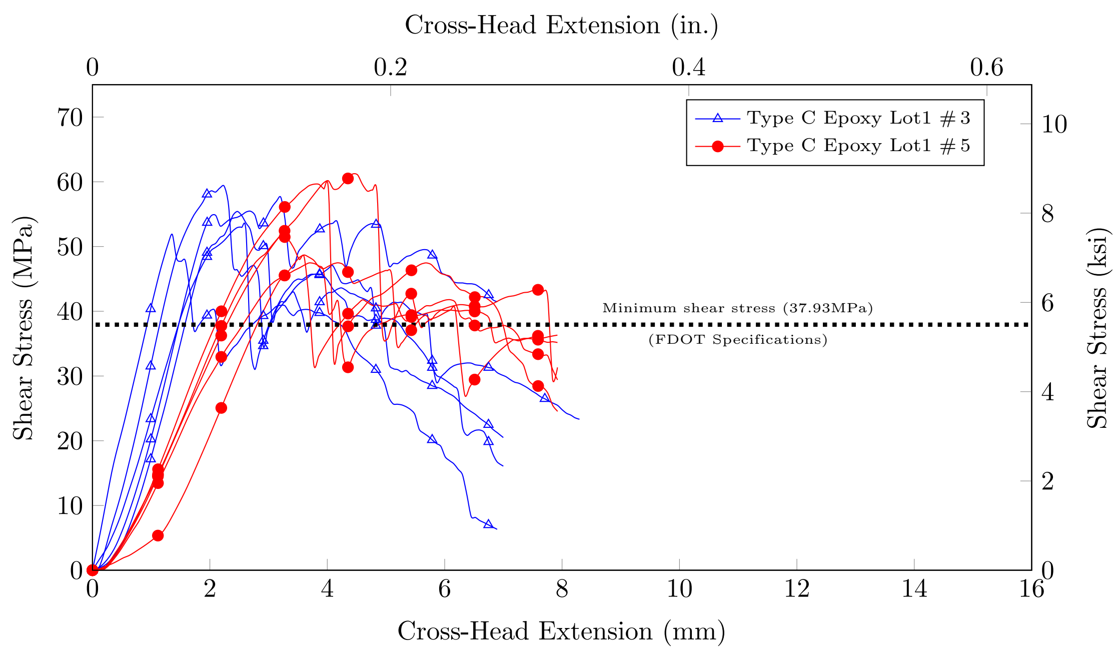


Figure 6.29: Horizontal shear stress-extension behavior of Type C rebar Lot 1 size 3 and 5

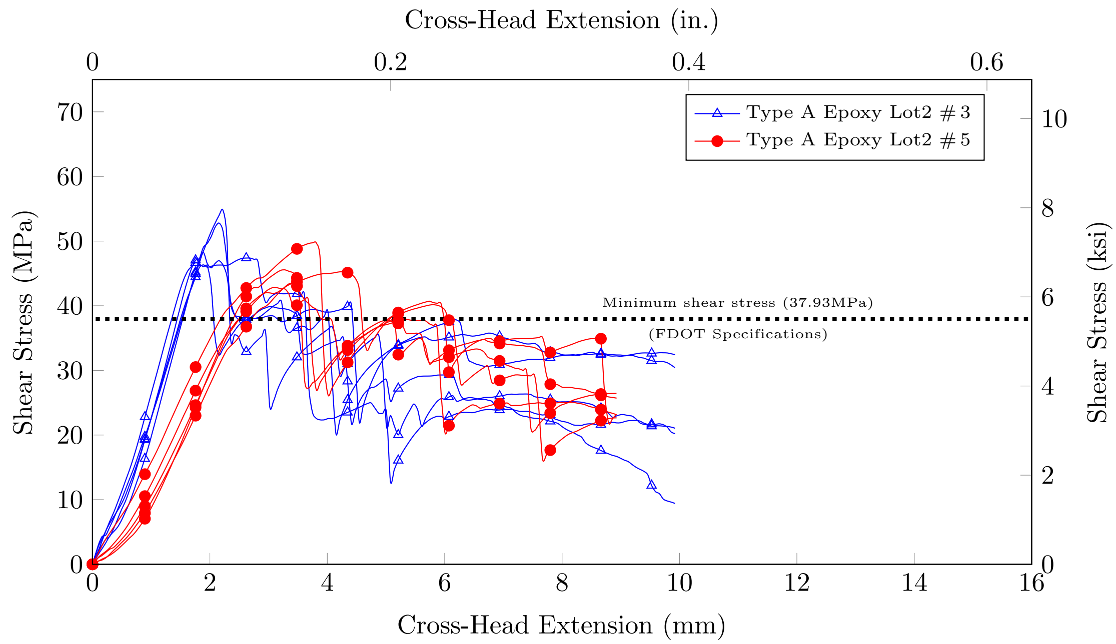


Figure 6.30: Horizontal shear stress - extension behavior of rebar Type A Lot 2 size 3 and 5

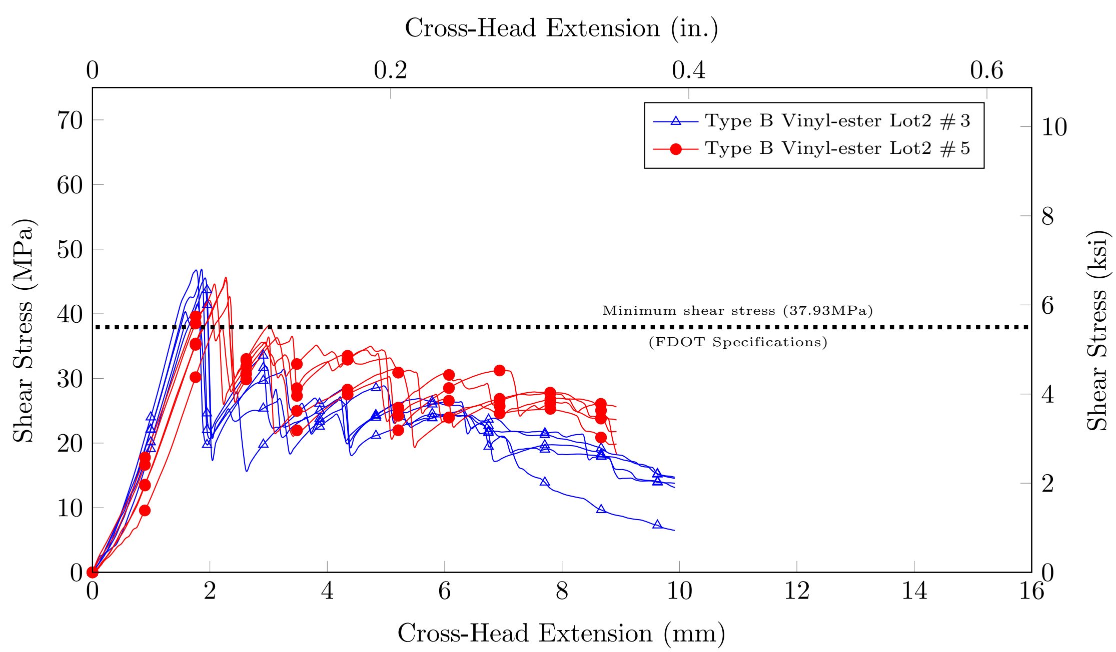


Figure 6.31: Horizontal shear stress - extension behavior of rebar Type B Lot 2 size 3 and 5

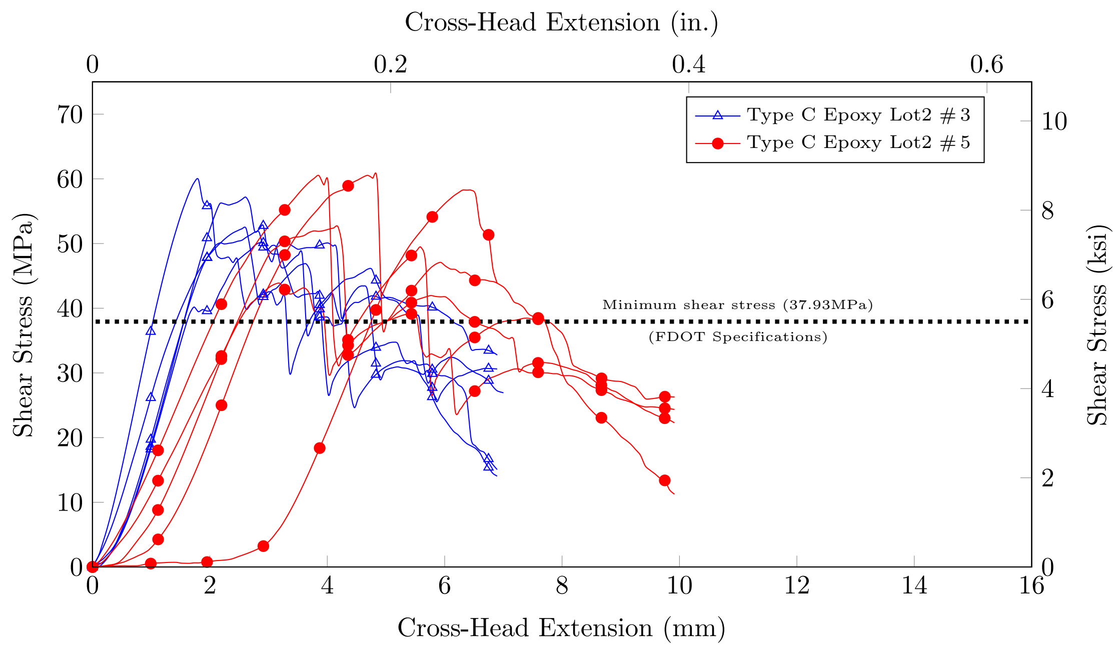
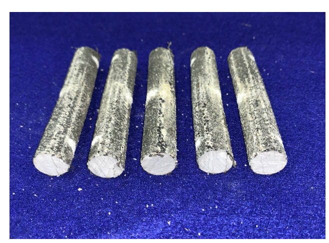


Figure 6.32: Horizontal shear stress-extension behavior of Type C rebar Lot 2 size 3 and 5

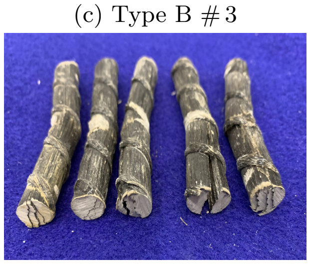
(a) Type A #3

(b) Type A #5

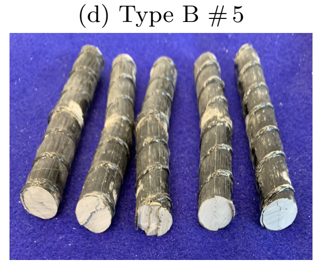
(c) Type B #3



(d) Type B #5



(e) Type C #3



(f) Type C #5

Figure 6.33: Failure pattern for tested rebar after horizontal shear test

Table 6.7: Horizontal Shear test statistical values for each sample group (US Customary Units)

Sample Group				Statistical Values				
				Shear Stress				
Manuf. Type	Resin Type	Size #	Lot No.	∧ ksi	∨ ksi	μ ksi	σ ksi	CV %
TypeA	Epoxy	3	1	7.3	8.0	7.5	0.3	3.91
TypeA	Epoxy	5	1	6.7	7.5	7.2	0.4	5.10
TypeB	Vinyl-ester	3	1	6.1	6.9	6.5	0.4	5.82
TypeB	Vinyl-ester	5	1	6.2	6.5	6.4	0.2	2.51
TypeC	Epoxy	3	1	7.6	8.6	8.1	0.4	5.45
TypeC	Epoxy	5	1	7.3	8.7	7.9	0.6	7.71
TypeA	Epoxy	3	2	6.8	8.0	7.3	0.5	7.34
TypeA	Epoxy	5	2	6.2	7.2	6.6	0.4	5.91
TypeB	Vinyl-ester	3	2	6.0	6.9	6.6	0.4	5.61
TypeB	Vinyl-ester	5	2	6.2	6.6	6.4	0.2	3.47
TypeC	Epoxy	3	2	6.9	8.9	7.8	0.9	11.79
TypeC	Epoxy	5	2	6.4	8.8	8.0	1.0	12.92

6.4.7 Tensile Test

The rebars were tested according to the ASTM D 7205 (ASTM-International, 2015a) to evaluate the tensile properties. The recorded and processed data of the tensile strength test are shown in this section via graphs and table.

Load-Displacement Behavior

To compare the load-displacement behavior of the different rebar samples and specimens, the graphs in Figures 6.34, 6.35, 6.36, 6.37, 6.38, and 6.39 plot the recorded test data. As shown, the x-axis of the graph represents the cross-head extension—which has to be interpreted with care because it includes the elastic deformation of the load frame and the test fixtures—and the y-axis indicates the applied and measured load. Figure 6.40 shows that # 5 rebar Type A sustained higher failure load in comparison with # 3 rebars and the extension of rebar # 5 was almost thrice that of the # 3 rebars extension. Figure 6.41 shows that the extension of # 5 was more than twice in comparison with # 3 rebars and the peak load was much higher. All the rebars failed in similar fashion. The following graph in Figure 6.36 illustrate the test results for the # 3 and # 5 Type C rebars from Lot 1. After comparing Figures 6.37, 6.38, and 6.36 it can be seen that the rebars of the same size from both the lots of all rebar types sustained the same peak load and failed in the same mode. The extension of rebars from lot 2 of both types was similar to rebars from lot 1 for both sizes. The specimens demonstrated a linear characteristic at around 10 kN until the peak load. The common behavior after the maximum load was overcome was a stepwise loss of load with little inclines until the next load loss occurred. With increasing cross-head extension in the post-failure region, the load decreased slightly, but then stagnated or even regained some strength throughout further extension, multiple times, until the specimen failed completely. During testing, it was observed that after the maximum load was reached, the rebars delaminated and flared out more and more, as these load-drops occurred (ultimately producing the failure patterns detailed in Section 6.4.8).

Stress-Strain Behavior

The stress-strain behavior of the failed rebars of all types was plotted to quantify and compare the elastic moduli of the tested BFRP rebars. The data in Figures 6.40, 6.41, 6.42, 6.43, 6.44, and 6.45 were plotted to compare the stress-strain behavior of the different rebar types. Accordingly, the x-axis shows the applied stress while the y-axis represents the outermost surface strain that was measured with an external extensometer. The results plotted in the graph in Figure 6.40 show that though the load capacities of the different sized rebars vary widely, the slope of the stress-strain curve was identical for all the rebars. It can be seen in Figure 6.41 that stress-strain behavior of rebar Type B are identical for both the rebar sizes. The stress-strain behavior of rebars from lot 2 as shown in Figures 6.43, 6.44, and 6.45 show that the slopes of bars from Lot 1 and Lot 2 were identical.

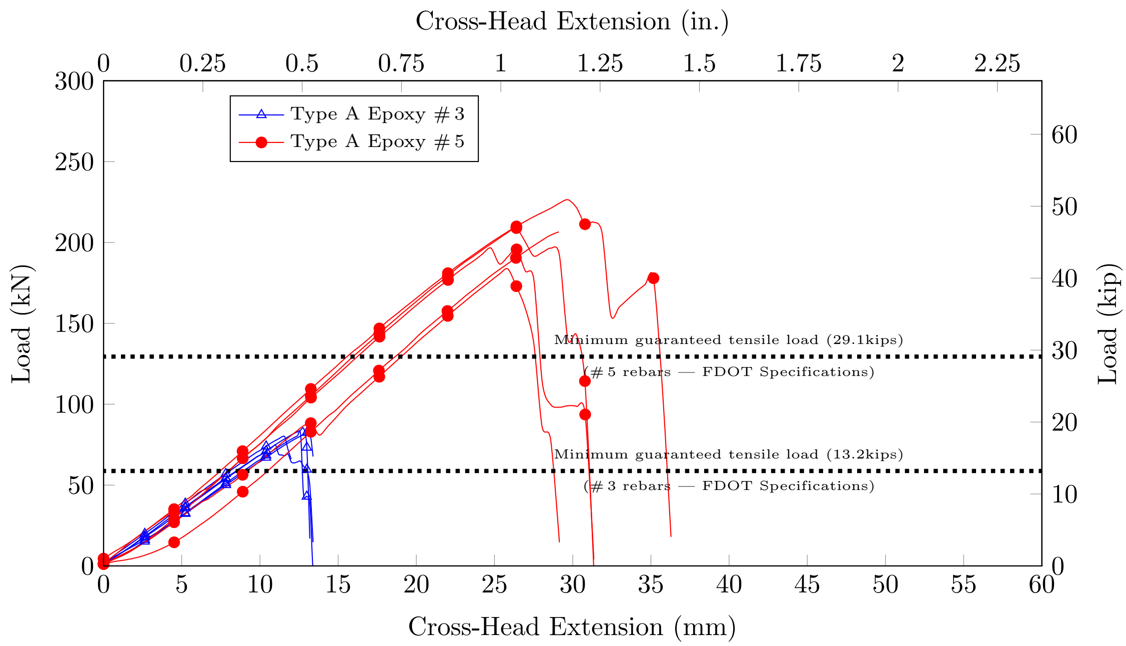


Figure 6.34: Tensile strength-displacement behavior of rebar Type A Lot 1 size 3 and 5

6.4.8 Modes of Failure

According to ASTM D 7205, three different failure modes may occur during a tensile strength test. The first and expected one is the tensile rupture outside of the anchor pipes. Due to insufficient sample preparation or test procedure issues, two more failure modes may occur. The rebar could slip within the grouted anchor (rebar slippage) or the anchor could slip out of the fixture/grips (anchor slippage). Therefore, the last two described failure modes lead to unusable results when defining the material characteristics. However, for this research project, no specimen failed due to rebar or anchor slippage. Hence, tensile rupture of the BFRP rebar was the recorded failure mode for each bar that was tested. Figure 6.46a and 6.47a show the failed specimens of Type A rebars. It can be seen that all specimens, regardless of their diameter, displayed similar failure pattern. The fibers formed a brush type of failure and all specimens suffered fiber delamination throughout the entire free specimen length. Figure 6.46b and 6.47b present the post failure pattern of Type B rebar specimens. It is shown that all the rebar sizes had an identical failure. The fibers were delaminated and a distinct brush-like failure was observed. Figure 6.46c and 6.47c show the failed specimens of # 3 and # 5 Type C rebars. All the specimens failed in a similar manner. After the peak load was reached, an abrupt

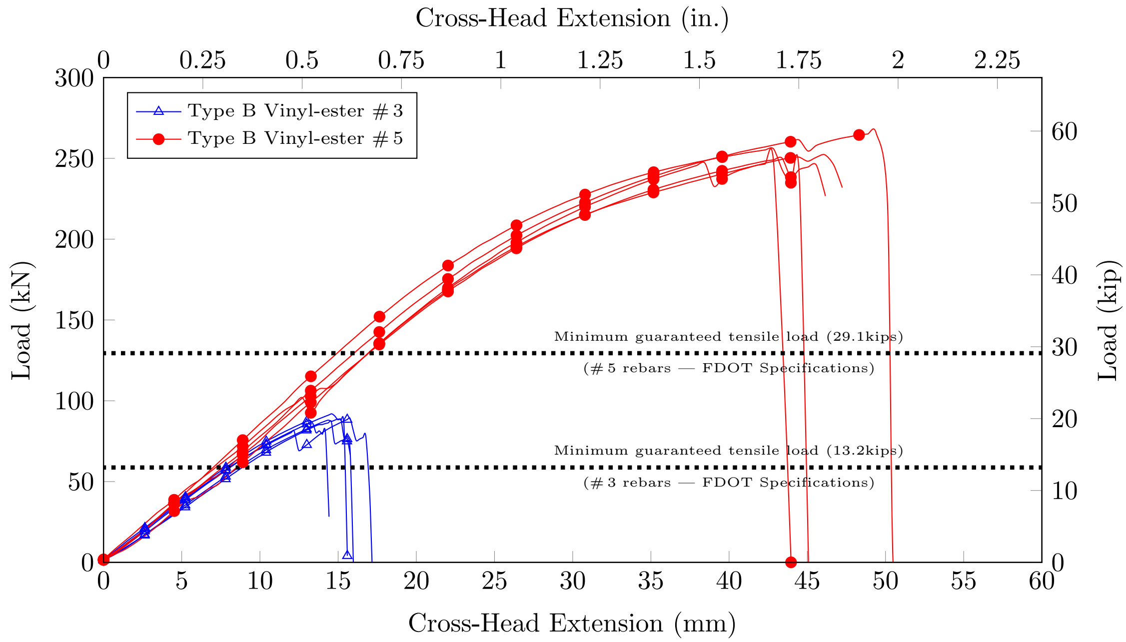


Figure 6.35: Tensile strength-displacement behavior of rebar Type B Lot 1 size 3 and 5

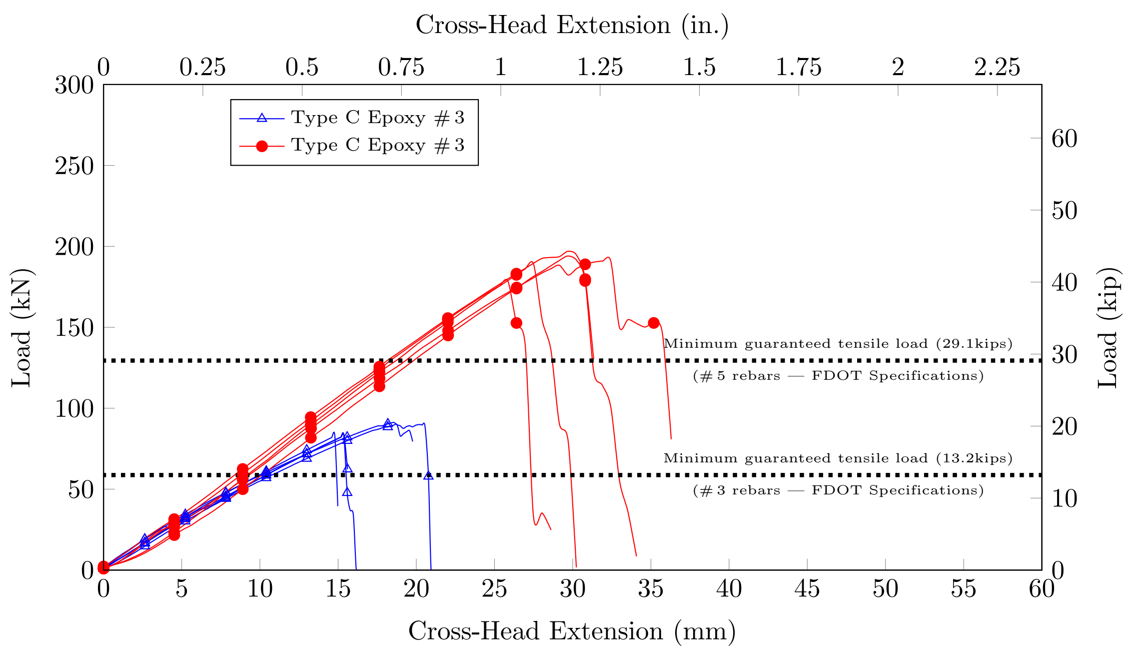


Figure 6.36: Tensile strength-displacement behavior of Type C rebar Lot 1 size 3 and 5

brittle failure of the rebar was observed close to the anchor.

6.4.9 Summary of Tensile Properties

The results of the statistical evaluation for the measured tensile properties of all products along with the elastic modulus property are listed in the following Table 6.8. A total of 60 specimen, 5 per rebar size, type and lot, were tested and analyzed to determine the results shown in the table. For numerical comparison

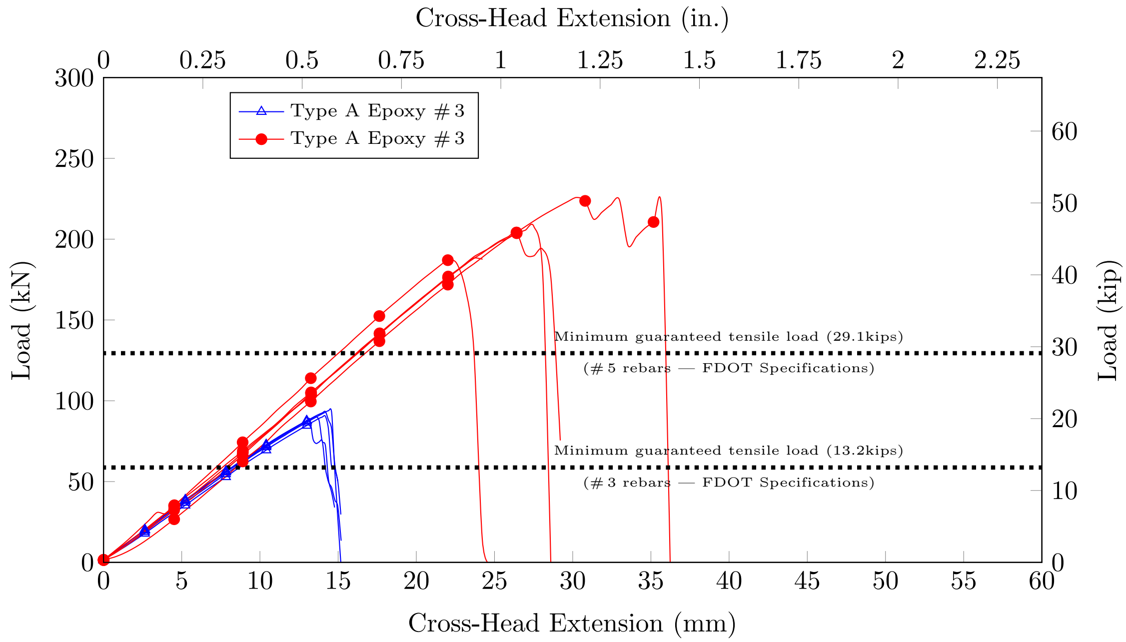


Figure 6.37: Tensile strength-displacement behavior of rebar Type A Lot 2 size 3 and 5

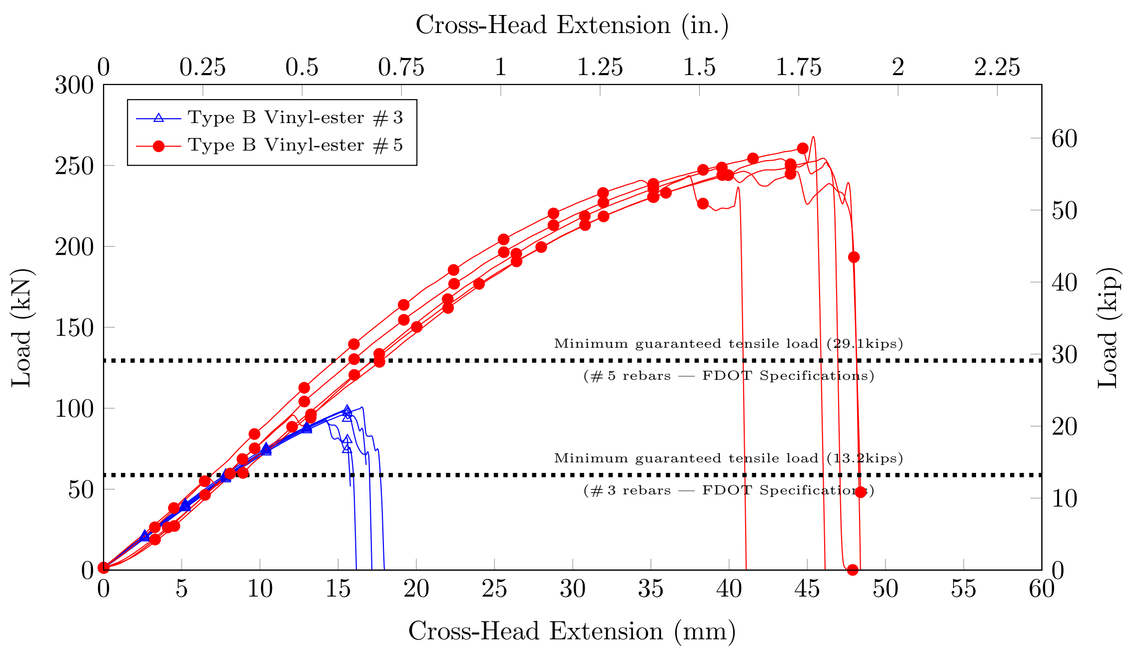


Figure 6.38: Tensile strength-displacement behavior of rebar Type B Lot 2 size 3 and 5

and concluding values, Table 6.8 lists the minimum tensile stress ($\wedge$), the maximum tensile stress ($\vee$), the average tensile stress (μ), the standard deviation (σ), and the coefficient of variation (CV) for each individual test sample.

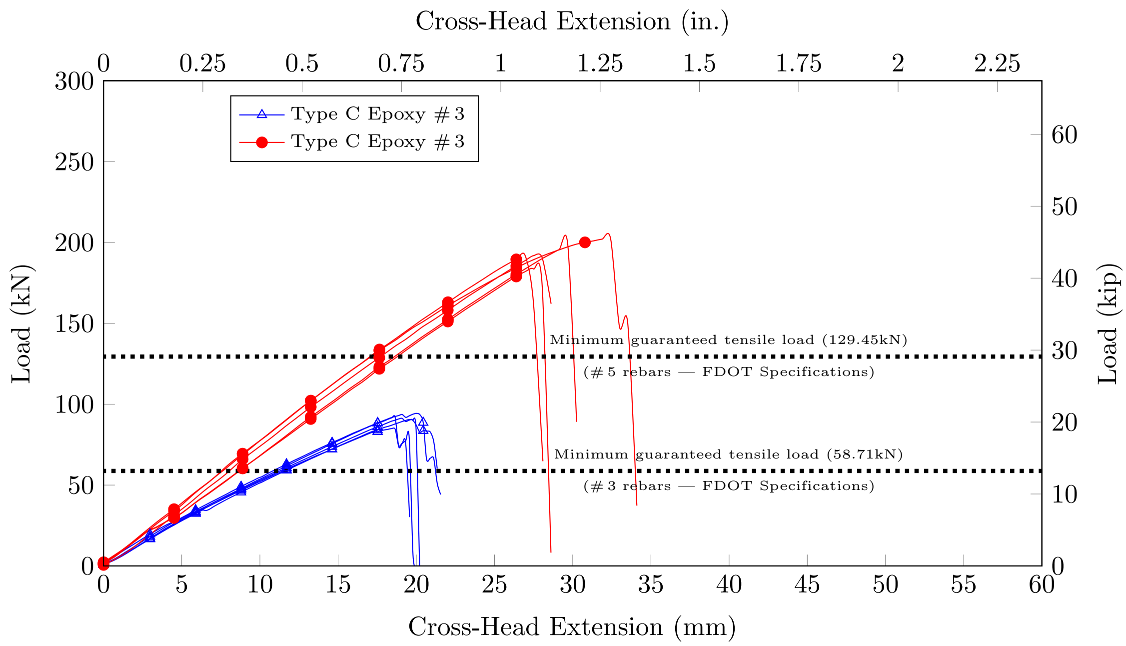


Figure 6.39: Tensile strength-displacement behavior of Type C rebar Lot 2 size 3 and 5

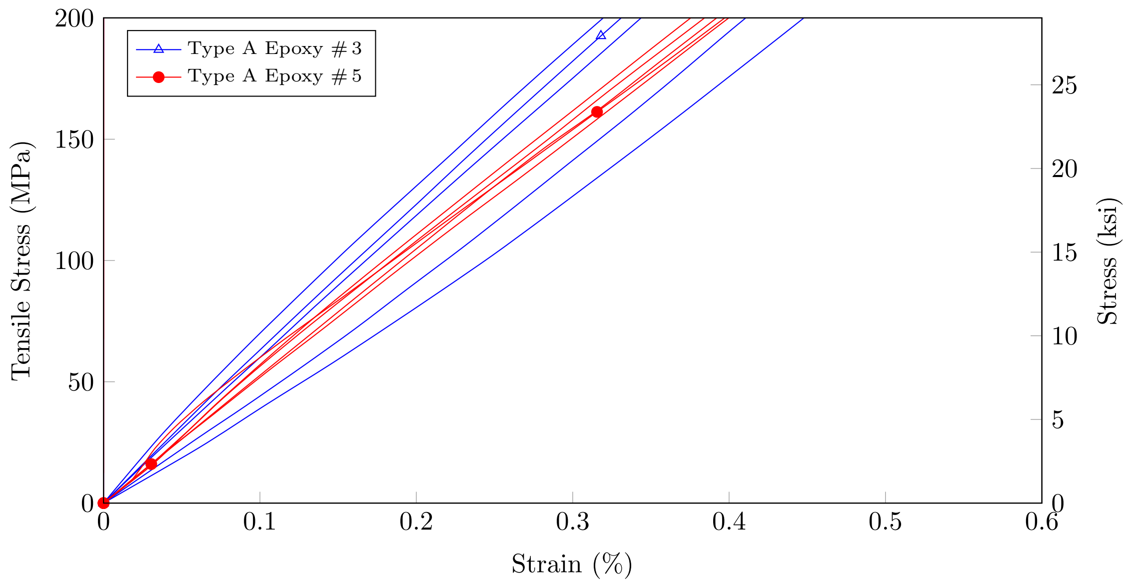


Figure 6.40: Tensile stress-strain behavior of rebar Type A Lot 1 rebar size 3 and 5

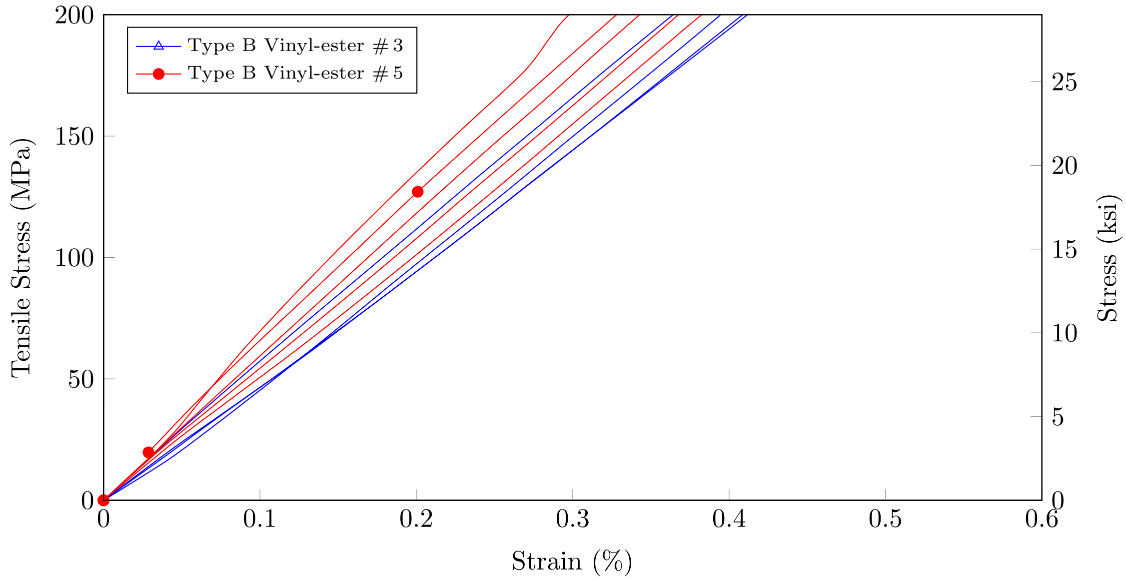


Figure 6.41: Tensile stress-strain behavior of rebar Type B Lot 1 rebar size 3 and 5

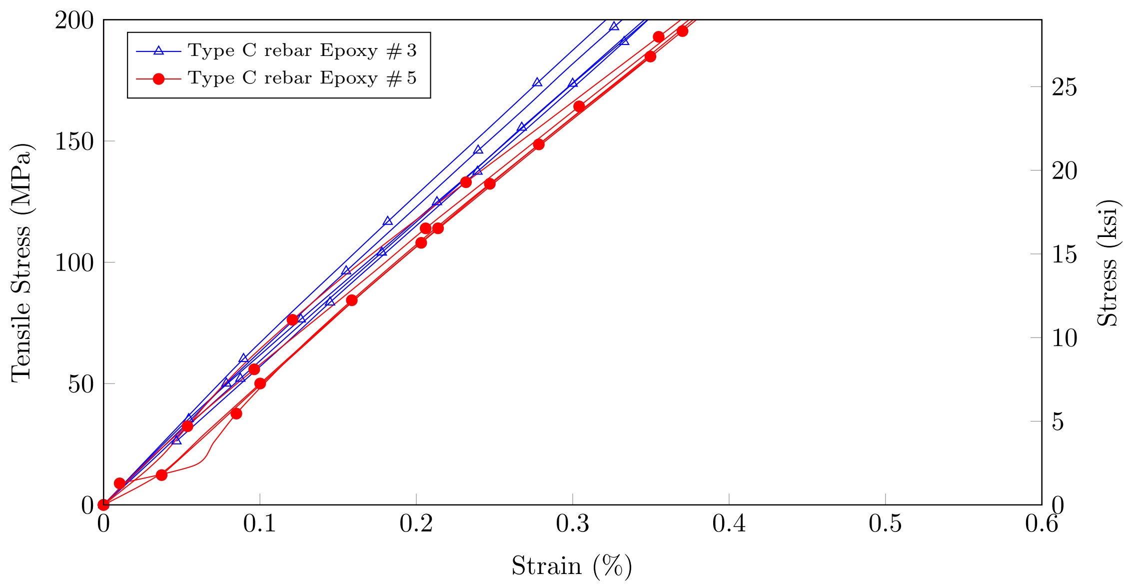


Figure 6.42: Tensile stress-strain behavior of Type C rebar Lot 1 rebar size 3 and 5

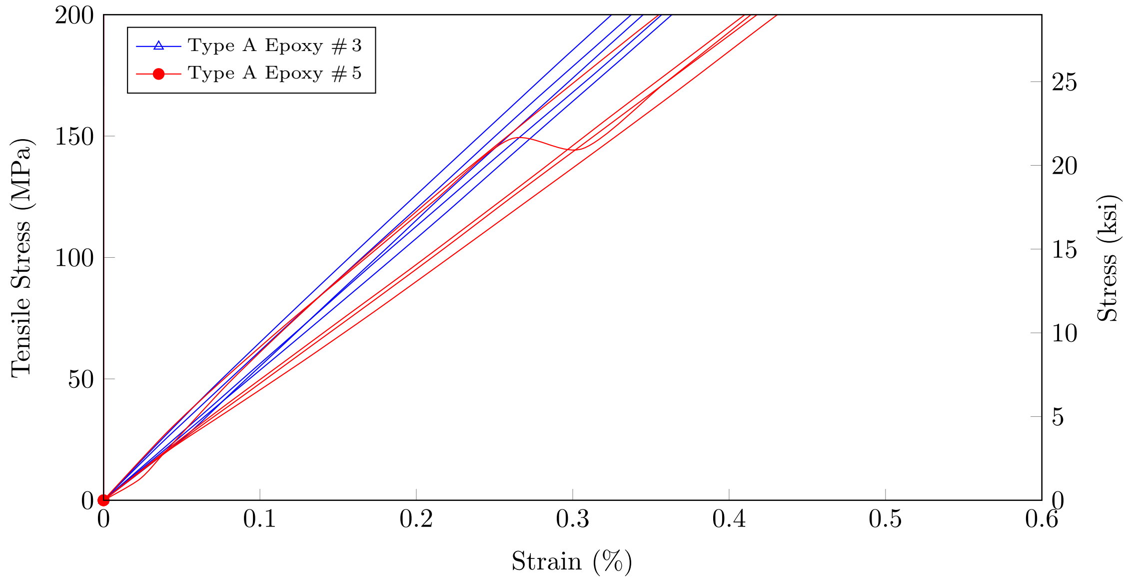


Figure 6.43: Tensile stress-strain behavior of rebar Type A Lot 2 rebar size 3 and 5

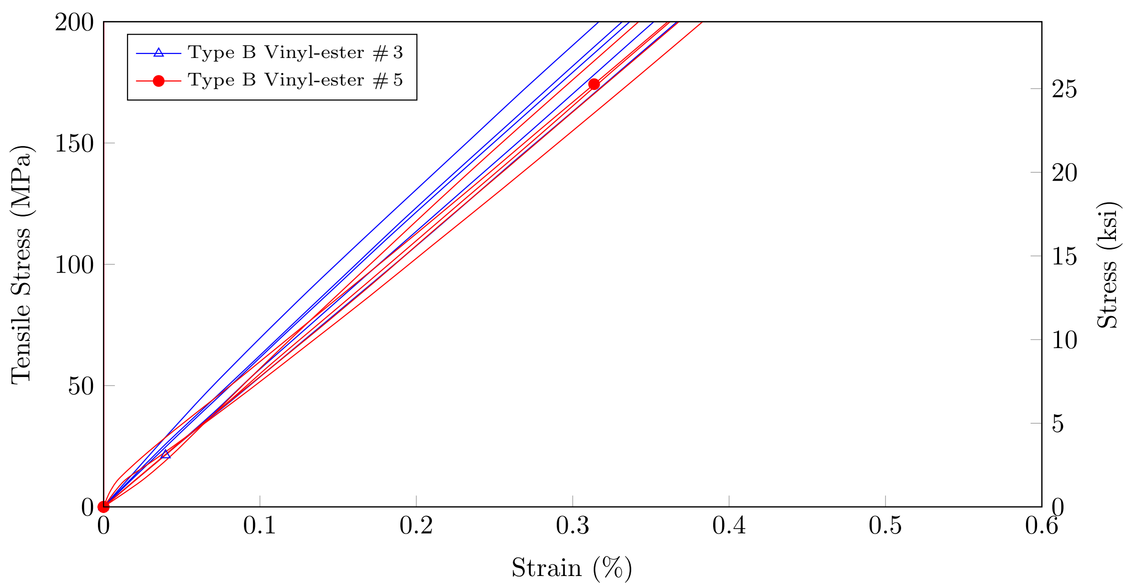


Figure 6.44: Tensile stress-strain behavior of rebar Type B Lot 2 rebar size 3 and 5

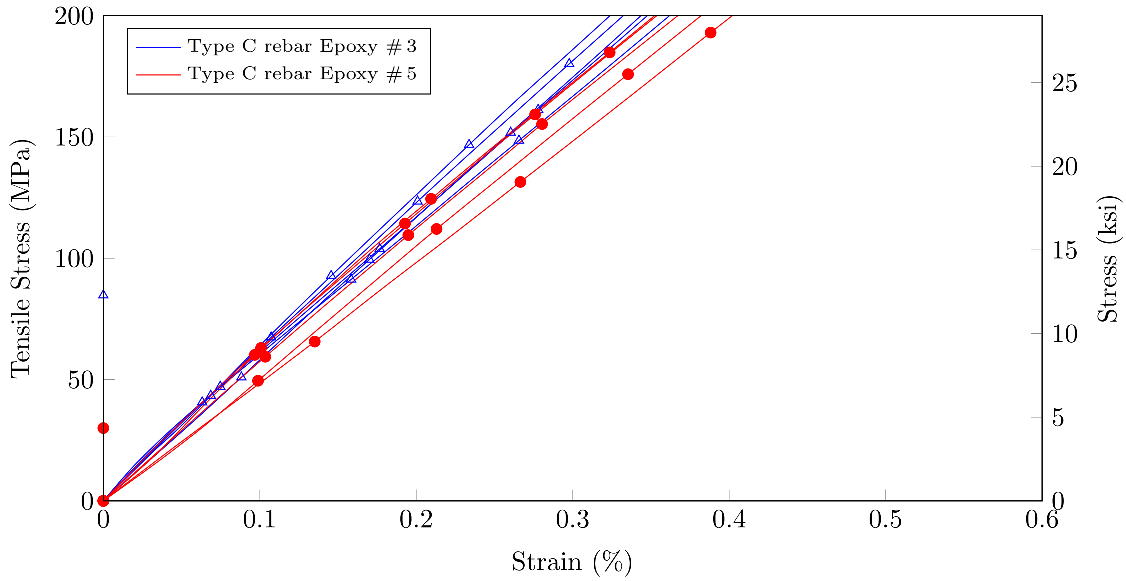
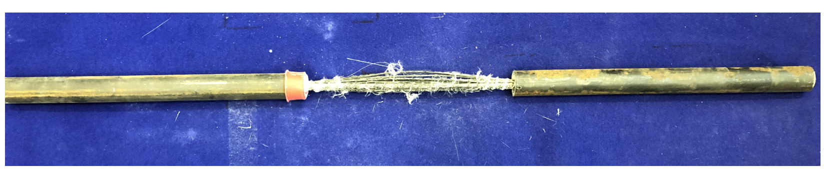


Figure 6.45: Tensile stress-strain behavior of Type C rebar Lot 2 size 3 and 5

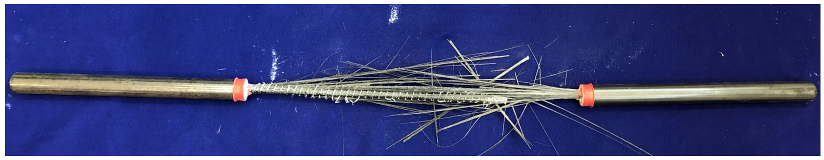


(a) Type A

(b) Type B

(c) Type C

Figure 6.46: # 3 rebar final failure pattern after tensile test



(a) Type A

(b) Type B

(c) Type C

Figure 6.47: # 5 rebar final failure pattern after tensile test

Table 6.8: Tensile strength test statistical values for each sample group (US Customary Units)

Sample group				Statistical values									
				Tensile Strength					Elastic Modulus				
Manf. Type	Resin Type	Size #	Lot No.	∧ ksi	∨ ksi	μ ksi	σ ksi	CoV %	∧ ksi	∨ ksi	μ ksi	σ ksi	CoV %
Rebar A	Epoxy	3	1	149.3	170.9	162.3	8.2	5.05	6358	8638	7788	1030	13.21
Rebar A	Epoxy	5	1	134.1	162.8	149.1	10.7	7.20	6825	7575	7241	277	3.81
Rebar A	Epoxy	3	2	178.7	188.9	183.5	4.3	2.37	8011	11 460	8958	1430	15.96
Rebar A	Epoxy	5	2	137.9	166.5	148.9	11.7	7.87	5352	8036	6780	961	14.17
Rebar B	Vinly-ester	3	1	174.5	184.9	178.3	3.9	2.18	7050	7888	7441	364	4.89
Rebar B	Vinly-ester	5	1	180.1	194.0	185.6	5.1	2.75	7563	9134	8319	615	7.39
Rebar B	Vinly-ester	3	2	186.1	200.1	193.7	6.7	3.48	7938	8796	8425	348	4.13
Rebar B	Vinly-ester	5	2	177.6	190.1	183.8	4.9	2.68	7513	8619	7955	412	5.18

6.5 Bond-to-Concrete Strength

The bond stress τ_{max} (MPa or lbs./in.^{2}) for a circular bar diameter d (mm or in.) is given by Equation 8.1, in which F represents the recorded pullout load (N or lbs.) and L is the accurately measured bond length.

$$\tau_{max} = \frac{F}{d\pi L} \qquad [in\text{MPa } or \text{ psi}] \tag{6.1}$$

This formula was used to determine the bond behavior development and is the basis for the following graphs; Figure 6.48, 6.49, 6.50, 6.51, 6.52, and 6.53 depict the measured bond stresses along the rebar surfaces relative to the rebar slip at the free end. For clarity, the post failure measurements (at the onset of a 50 % load drop) were removed from these graphs. All tested specimens failed at the rebar-concrete interface in bond slip, without splitting the concrete open or without tensile failure. The bond capacity and the failure behavior of the BFRP rebar-concrete interface were affected by the surface enhancement features.

6.6 Bond Stress vs. Slip at Free End

The graphs in this section compare the bond stress vs. slip at free end of rebar. Graphs in Figure 6.48, 6.49, 6.50, 6.51, 6.52, and 6.53 portray bond stresses vs slip at free end of the rebars of both the sizes. The x-axis of the graph signifies the measured bond stress, while the y-axis represents the slip of rebar at the free end.

Generally, from the graphs in Figure 6.48, 6.49, and 6.50 it can be seen that each rebar type resulted in a consistent but distinct failure mode with ultimate stresses that were characteristic for each rebar type. All of the sand-coated rebars (Type B) showed a soft failure while the rebars with a deformed surface (Type A and C) failed suddenly with abrupt pullout. After graphically presenting the virgin rebar characteristics in this chapter, the following chapter details aged rebar characteristics in the form of graphs and tables.

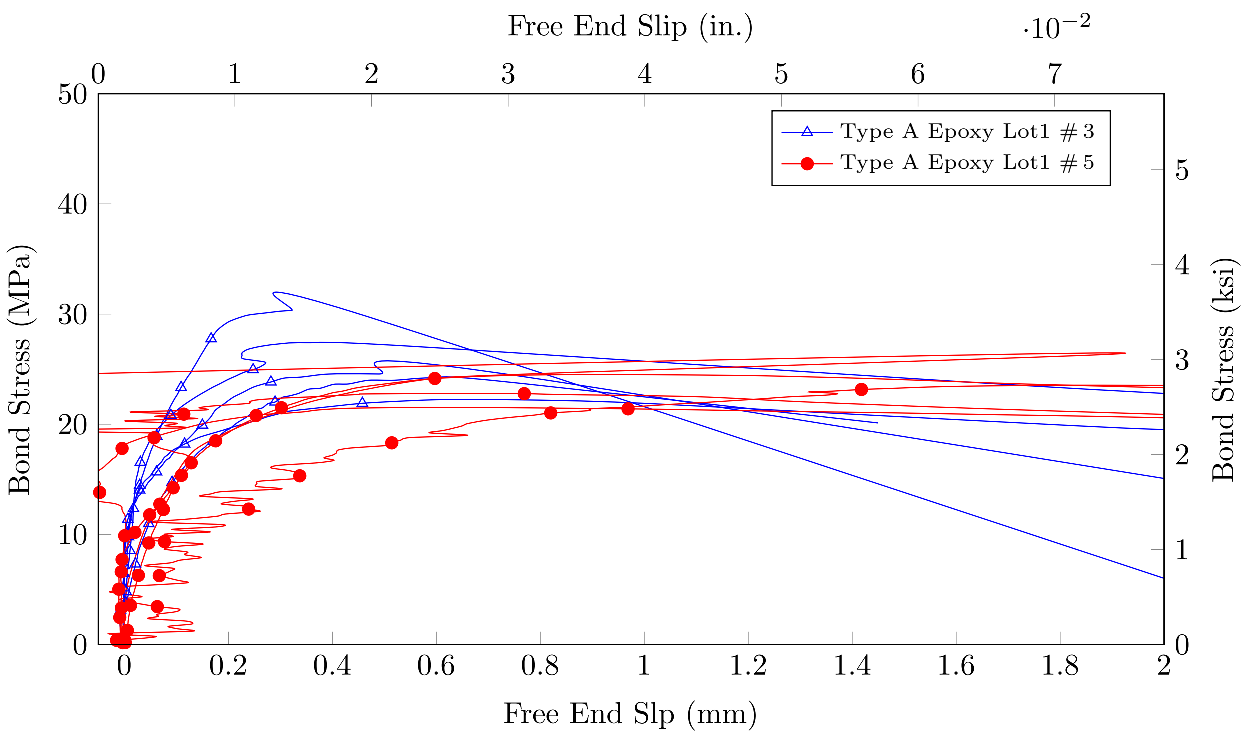


Figure 6.48: Free end slip behavior of the tested rebar Type A Lot 1

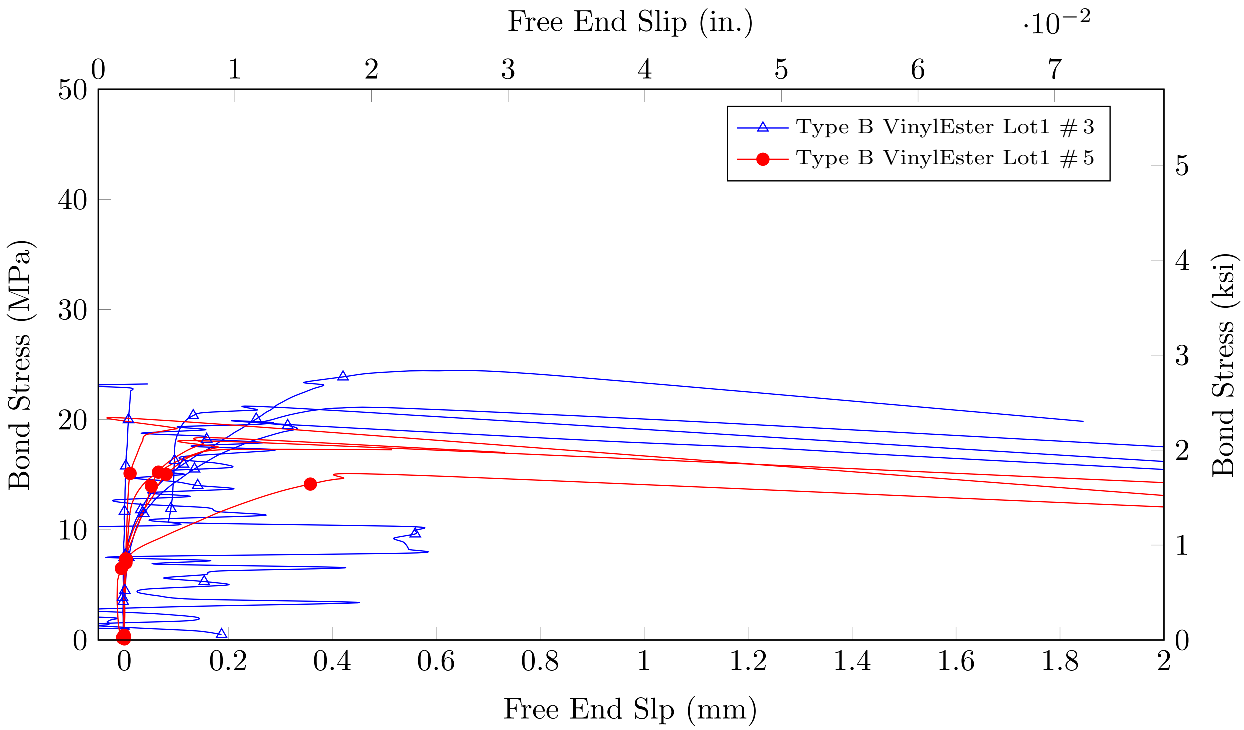


Figure 6.49: Free end slip behavior of the tested rebar Type B Lot 1

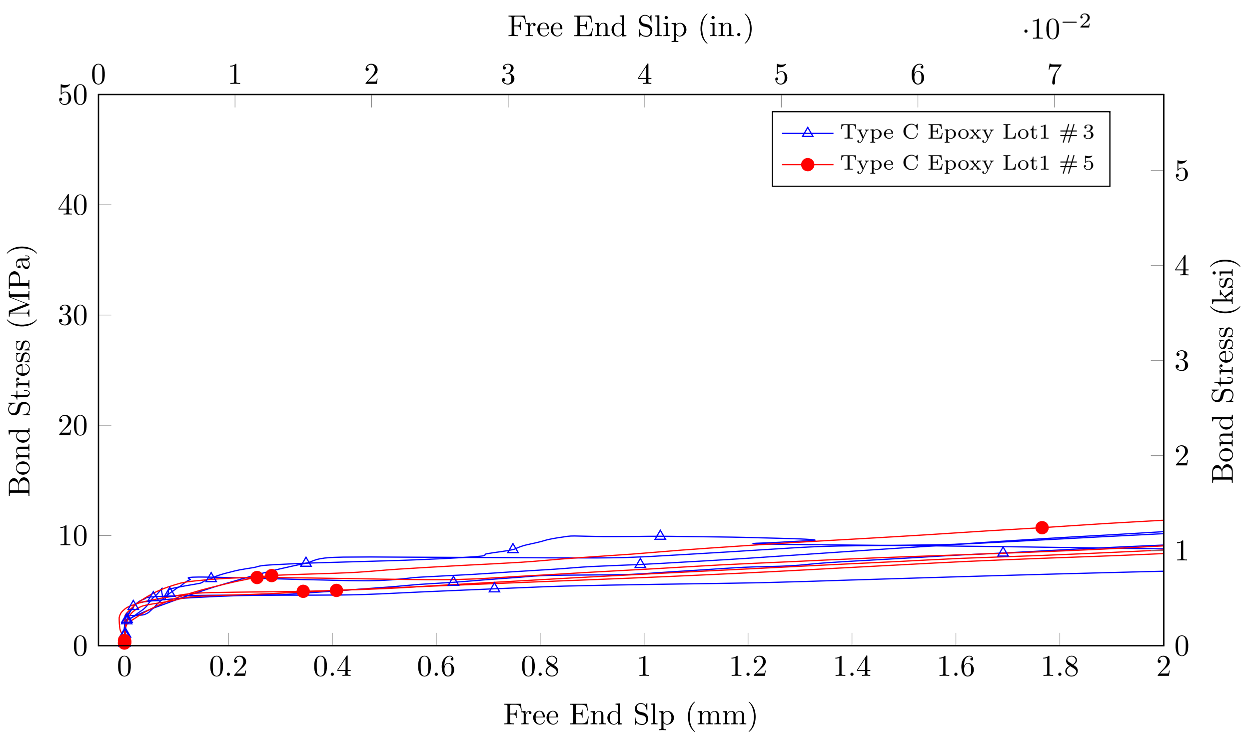


Figure 6.50: Free end slip behavior of the tested rebar Type C Lot 1

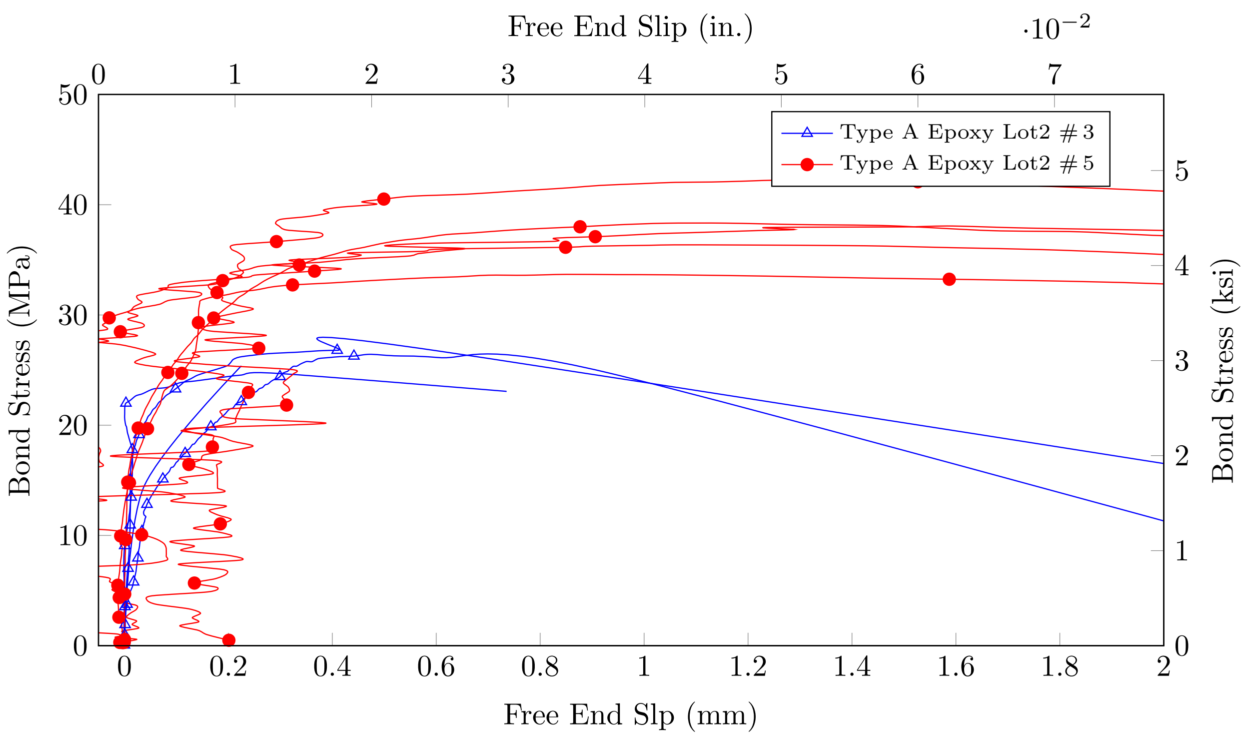


Figure 6.51: Free end slip behavior of the tested rebar Type A Lot 2

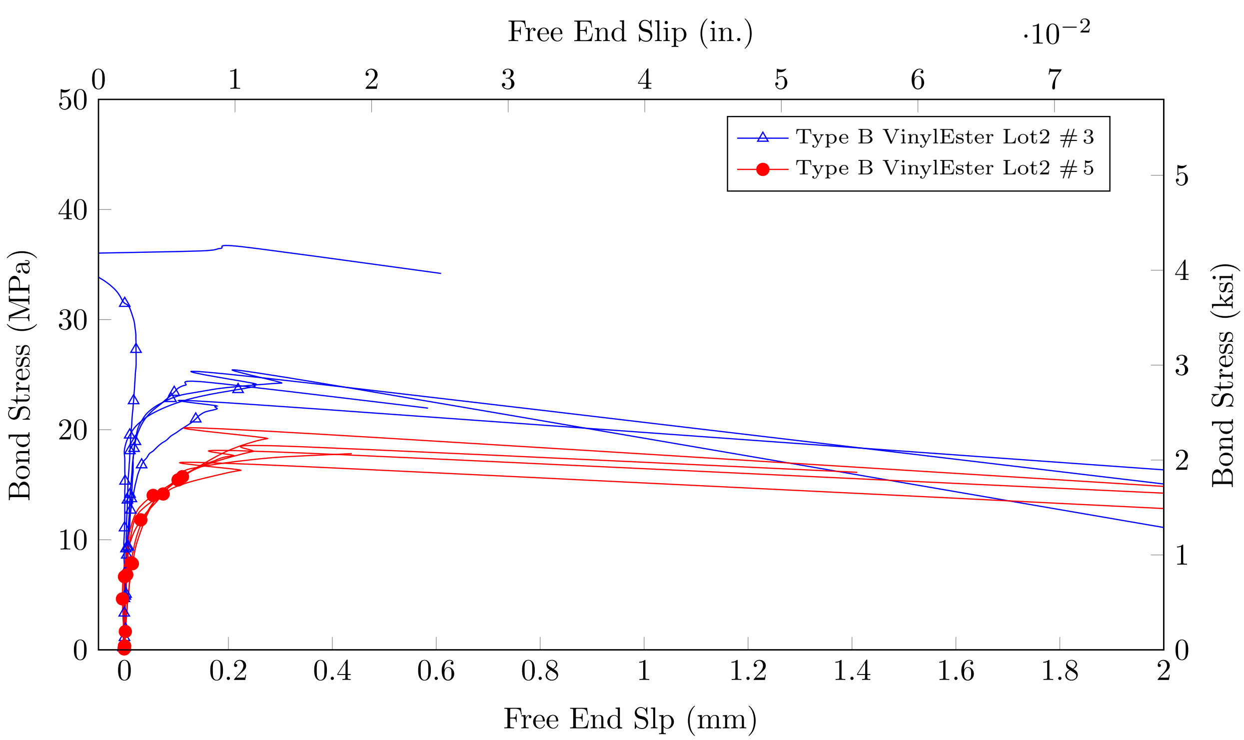


Figure 6.52: Free end slip behavior of the tested rebar Type B Lot 2

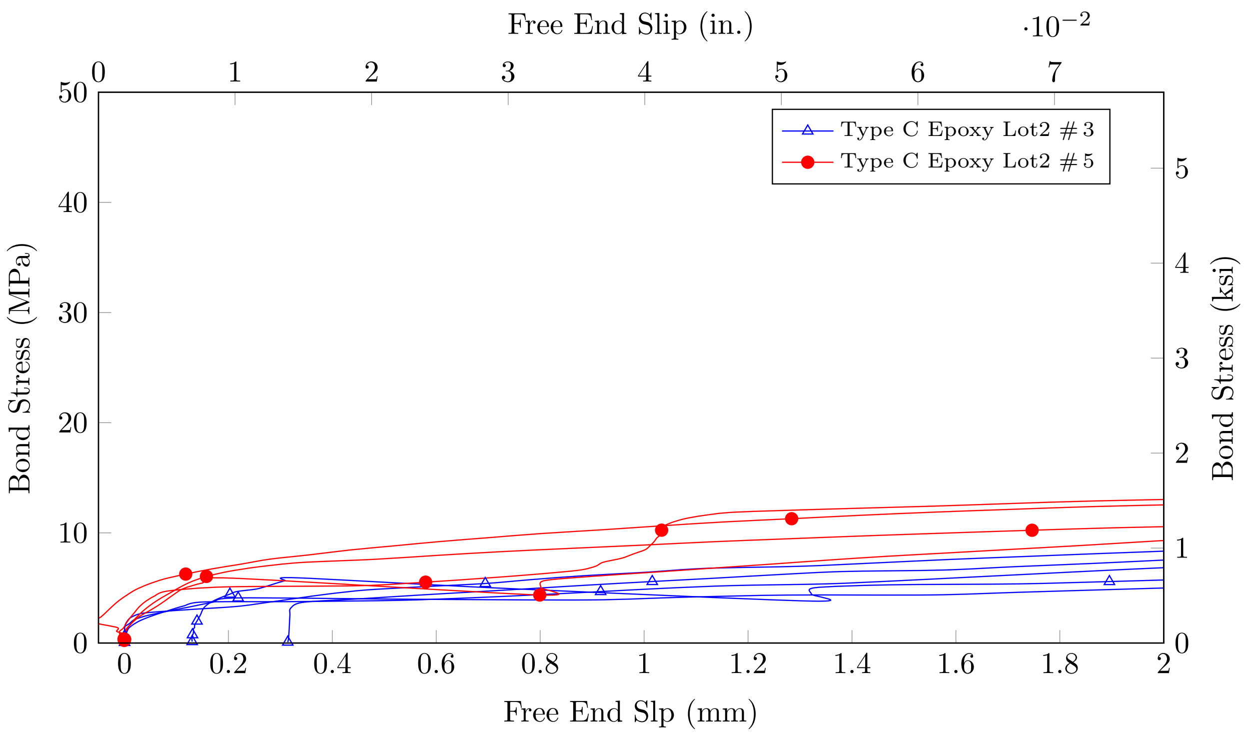


Figure 6.53: Free end slip behavior of the tested rebar Type C Lot 2

Chapter 7

Chemical, Physical, and Material Properties of Rebar and Components After Exposure to Aggressive Environments for 300 Days

7.1 Introduction

The performance evaluations of BFRP rebars after exposing them to aggressive environments for 300 days at 60 °C are listed throughout this chapter. Several physical, mechanical, and chemical tests were executed for each rebar sample, raw material, and exposure solution after exposure to various combinations of saline and alkaline environments. Accordingly, this chapter addresses three major aspects: 1) the characterization of exposure solutions, 2) the characterization of BFRP rebar components, and 3) the characterization of BFRP rebar specimens.

7.2 Properties of Exposure Environments after 300 Day Exposure

This section presents the chemical properties of all exposure environments used in the research to expose rebars and rebar components.

7.2.1 pH

The pH of the chemical environments was measured after 300 days of exposure. Tables 7.1, shows the pH data of environments in which rebars, resins, and fibers were exposed.

Table 7.1: pH Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						pH			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$	$\vee$	μ	σ
A	Epoxy	1	300	4	0	3.52	3.58	3.55	0.03
B	Vinyl Ester	1	300	4	0	4.25	4.29	4.27	0.02
C	Epoxy	1	300	4	0	3.80	3.82	3.81	0.01
A	Epoxy	1	300	4	200	3.48	3.52	3.50	0.02
B	Vinyl Ester	1	300	4	200	4.26	4.32	4.29	0.03
C	Epoxy	1	300	4	200	3.71	3.75	3.73	0.02
A	Epoxy	1	300	4	20000	3.46	3.52	3.49	0.03
B	Vinyl Ester	1	300	4	20000	4.35	4.41	4.38	0.03
C	Epoxy	1	300	4	20000	3.66	3.68	3.67	0.01
A	Epoxy	1	300	4	SeaWater	3.41	3.45	3.43	0.02
B	Vinyl Ester	1	300	4	SeaWater	4.47	4.48	4.47	0.01
C	Epoxy	1	300	4	SeaWater	3.57	3.59	3.58	0.01
A	Epoxy	2	300	4	0	3.39	3.45	3.42	0.03
B	Vinyl Ester	2	300	4	0	4.30	4.34	4.32	0.02
C	Epoxy	2	300	4	0	3.72	3.75	3.74	0.02
A	Epoxy	2	300	4	200	3.42	3.48	3.45	0.03
B	Vinyl Ester	2	300	4	200	4.31	4.35	4.33	0.02
C	Epoxy	2	300	4	200	3.65	3.66	3.65	0.01
A	Epoxy	2	300	4	20000	3.51	3.55	3.53	0.02
B	Vinyl Ester	2	300	4	20000	4.34	4.36	4.35	0.01
C	Epoxy	2	300	4	20000	3.58	3.65	3.62	0.04
A	Epoxy	2	300	4	SeaWater	3.46	3.49	3.47	0.02
B	Vinyl Ester	2	300	4	SeaWater	4.42	4.43	4.42	0.01
C	Epoxy	2	300	4	SeaWater	3.52	3.58	3.55	0.03
A	Epoxy	1	300	7	0	6.72	6.78	6.75	0.03
B	Vinyl Ester	1	300	7	0	7.15	7.21	7.18	0.03
C	Epoxy	1	300	7	0	6.80	6.82	6.81	0.01
A	Epoxy	1	300	7	200	6.61	6.65	6.63	0.02
B	Vinyl Ester	1	300	7	200	7.18	7.24	7.21	0.03
C	Epoxy	1	300	7	200	6.77	6.79	6.78	0.01
A	Epoxy	1	300	7	20000	6.60	6.62	6.61	0.01
B	Vinyl Ester	1	300	7	20000	7.26	7.32	7.29	0.03
C	Epoxy	1	300	7	20000	6.65	6.70	6.68	0.02
A	Epoxy	1	300	7	SeaWater	6.43	6.51	6.47	0.04
B	Vinyl Ester	1	300	7	SeaWater	7.34	7.40	7.37	0.03
C	Epoxy	1	300	7	SeaWater	6.56	6.59	6.57	0.02
A	Epoxy	2	300	7	0	6.53	6.55	6.54	0.01
B	Vinyl Ester	2	300	7	0	7.40	7.46	7.43	0.03
C	Epoxy	2	300	7	0	6.55	6.61	6.58	0.03
A	Epoxy	2	300	7	200	6.31	6.33	6.32	0.01
B	Vinyl Ester	2	300	7	200	7.43	7.51	7.47	0.04

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Table 7.1: pH Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						pH			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$	$\vee$	μ	σ
C	Epoxy	2	300	7	200	6.53	6.54	6.53	0.01
A	Epoxy	2	300	7	20000	6.25	6.26	6.26	0.01
B	Vinyl Ester	2	300	7	20000	7.53	7.57	7.55	0.02
C	Epoxy	2	300	7	20000	6.33	6.37	6.35	0.02
A	Epoxy	2	300	7	SeaWater	6.21	6.25	6.23	0.02
B	Vinyl Ester	2	300	7	SeaWater	7.61	7.65	7.63	0.02
C	Epoxy	2	300	7	SeaWater	6.29	6.33	6.31	0.02
A	Epoxy	1	300	10	0	9.83	9.89	9.86	0.03
B	Vinyl Ester	1	300	10	0	10.29	10.37	10.33	0.04
C	Epoxy	1	300	10	0	9.86	9.89	9.88	0.02
A	Epoxy	1	300	10	200	9.71	9.78	9.74	0.04
B	Vinyl Ester	1	300	10	200	10.45	10.51	10.48	0.03
C	Epoxy	1	300	10	200	9.76	9.78	9.77	0.01
A	Epoxy	1	300	10	20000	9.61	9.64	9.62	0.02
B	Vinyl Ester	1	300	10	20000	10.56	10.60	10.58	0.02
C	Epoxy	1	300	10	20000	9.67	9.71	9.69	0.02
A	Epoxy	1	300	10	SeaWater	9.44	9.50	9.47	0.03
B	Vinyl Ester	1	300	10	SeaWater	10.60	10.66	10.63	0.03
C	Epoxy	1	300	10	SeaWater	9.54	9.55	9.54	0.01
A	Epoxy	2	300	10	0	9.72	9.74	9.73	0.01
B	Vinyl Ester	2	300	10	0	10.29	10.35	10.32	0.03
C	Epoxy	2	300	10	0	9.74	9.78	9.76	0.02
A	Epoxy	2	300	10	200	9.50	9.54	9.52	0.02
B	Vinyl Ester	2	300	10	200	10.35	10.39	10.37	0.02
C	Epoxy	2	300	10	200	9.71	9.72	9.71	0.01
A	Epoxy	2	300	10	20000	9.45	9.47	9.46	0.01
B	Vinyl Ester	2	300	10	20000	10.46	10.47	10.46	0.01
C	Epoxy	2	300	10	20000	9.46	9.50	9.48	0.02
A	Epoxy	2	300	10	SeaWater	9.36	9.43	9.39	0.04
B	Vinyl Ester	2	300	10	SeaWater	10.48	10.56	10.52	0.04
C	Epoxy	2	300	10	SeaWater	9.42	9.45	9.43	0.02
A	Epoxy	1	300	13	0	11.38	11.44	11.41	0.03
B	Vinyl Ester	1	300	13	0	12.25	12.29	12.27	0.02
C	Epoxy	1	300	13	0	11.81	11.82	11.82	0.01
A	Epoxy	1	300	13	200	11.35	11.39	11.37	0.02
B	Vinyl Ester	1	300	13	200	12.40	12.48	12.44	0.04
C	Epoxy	1	300	13	200	11.74	11.75	11.74	0.01
A	Epoxy	1	300	13	20000	11.28	11.36	11.32	0.04
B	Vinyl Ester	1	300	13	20000	12.44	12.46	12.45	0.01
C	Epoxy	1	300	13	20000	11.53	11.56	11.55	0.02
A	Epoxy	1	300	13	SeaWater	11.24	11.30	11.27	0.03
B	Vinyl Ester	1	300	13	SeaWater	12.59	12.67	12.63	0.04

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Table 7.1: pH Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						pH			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$	$\vee$	μ	σ
C	Epoxy	1	300	13	SeaWater	11.50	11.54	11.52	0.02
A	Epoxy	2	300	13	0	11.29	11.32	11.31	0.02
B	Vinyl Ester	2	300	13	0	12.42	12.46	12.44	0.02
C	Epoxy	2	300	13	0	11.76	11.78	11.77	0.01
A	Epoxy	2	300	13	200	11.23	11.29	11.26	0.03
B	Vinyl Ester	2	300	13	200	12.45	12.49	12.47	0.02
C	Epoxy	2	300	13	200	11.67	11.71	11.69	0.02
A	Epoxy	2	300	13	20000	11.14	11.20	11.17	0.03
B	Vinyl Ester	2	300	13	20000	12.53	12.55	12.54	0.01
C	Epoxy	2	300	13	20000	11.23	11.26	11.25	0.02
A	Epoxy	2	300	13	SeaWater	11.09	11.15	11.12	0.03
B	Vinyl Ester	2	300	13	SeaWater	12.58	12.65	12.61	0.04
C	Epoxy	2	300	13	SeaWater	11.44	11.47	11.46	0.02

The change in pH of exposure environments after the exposure period was calculated and the data was plotted in the following Figures 7.1, 7.2, and 7.3. From Table 1.1 it can be noticed that the pH drops significantly more for the Epoxy rebars in Lots A and C than the vinyl-ester rebar in Lots B. Resin is generally a composition carbon (C), hydrogen (H) and oxygen (O). The pH will decrease when more C and O is released into the solution. For epoxy rebars, it is anticipated that the resin has degraded more into the solution which has led to more release of C and O that has ultimately resulted in more pH drop than the vinyl-ester rebar.

7.2.2 Salinity

Salinity of the chemical environments was measured after 300 days of exposure. Tables 7.2, 7.3, and 7.4 below shows the salinity data of environments in which rebars, resins, and fibers were exposed.

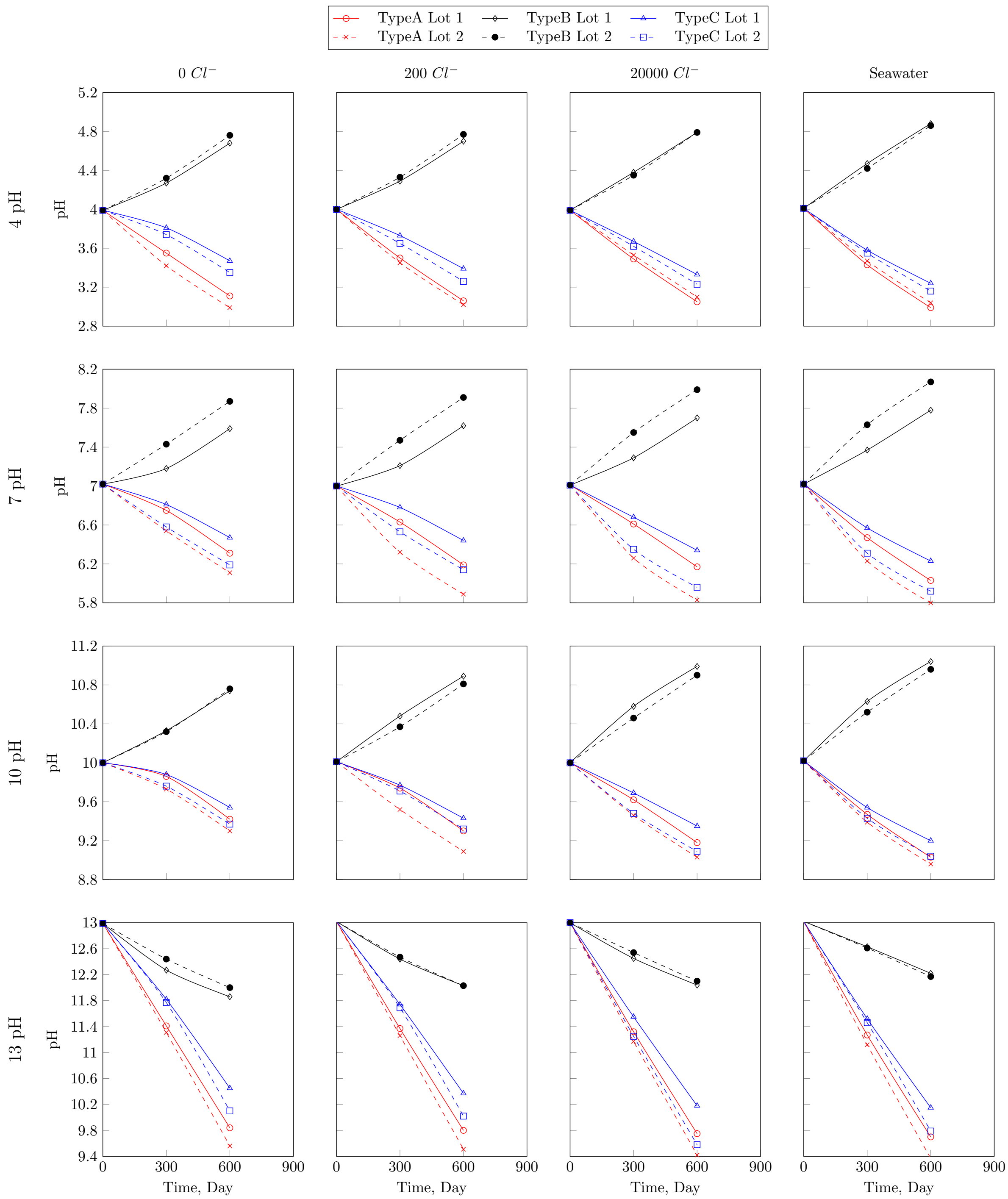

Figure 7.1: pH of environments after exposure of rebars

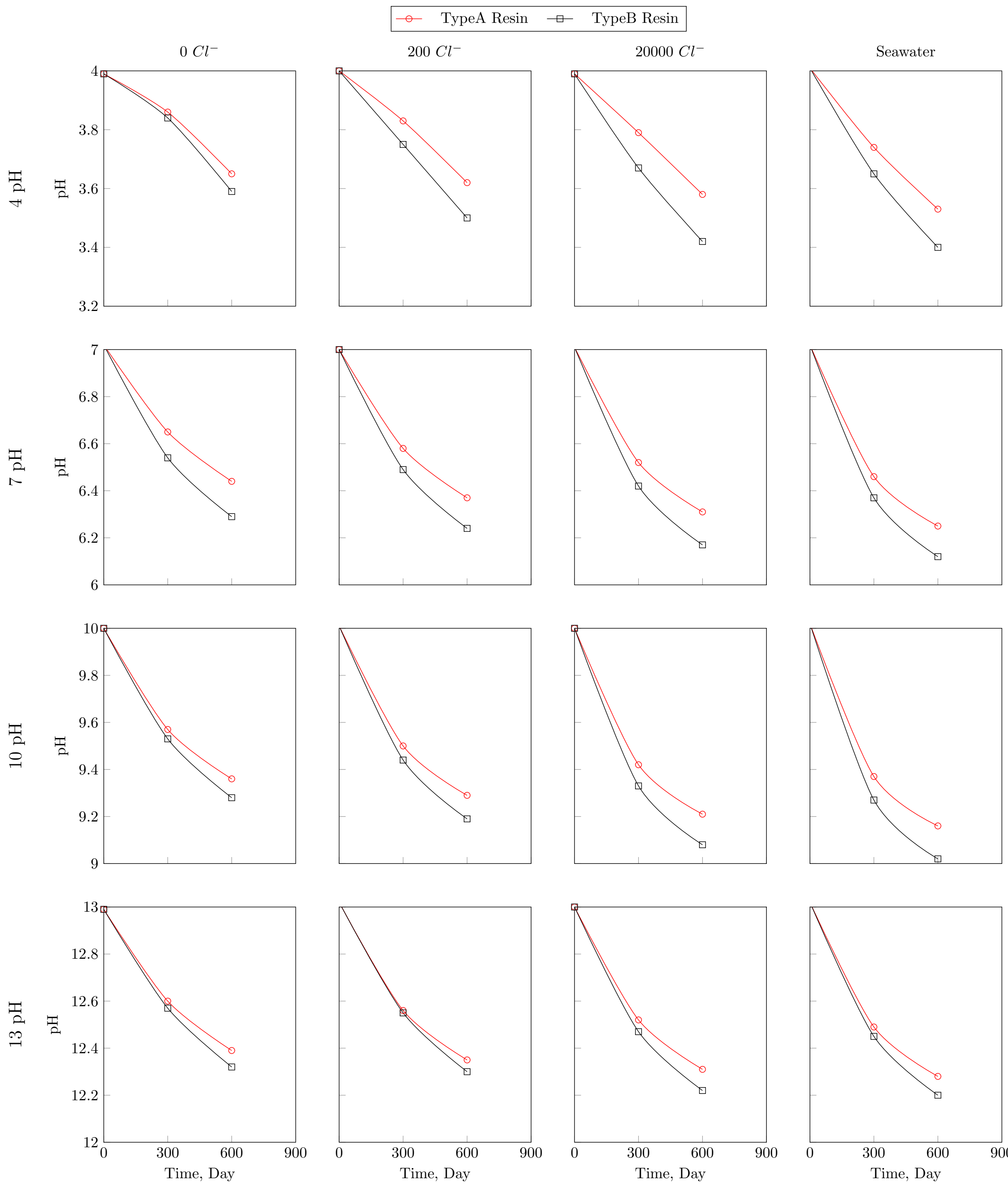

Figure 7.2: pH of environments after exposure of resins

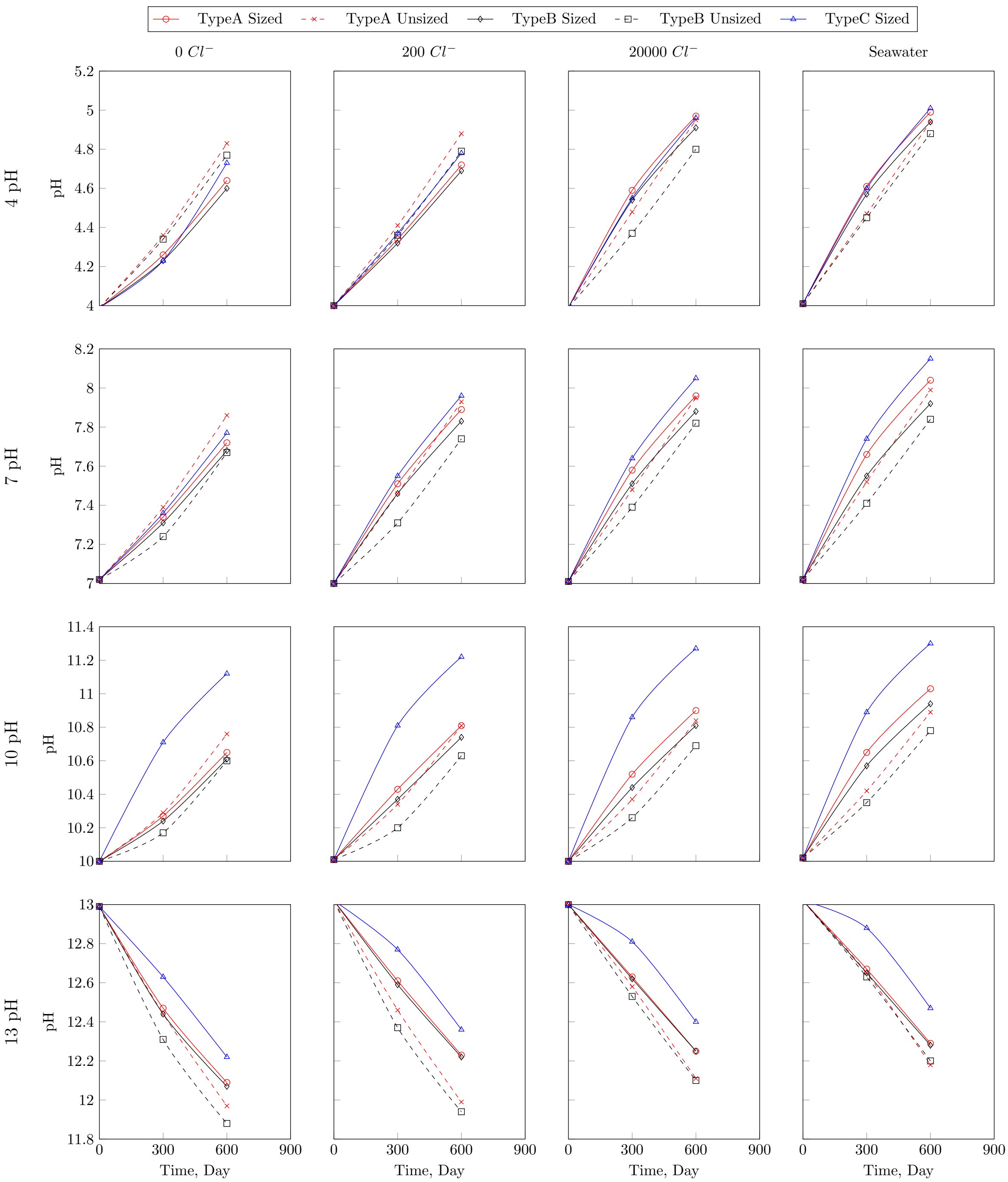

Figure 7.3: pH of environments after exposure of sized and unsized fibers

Table 7.2: Salinity Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Salinity			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	4	0	30.09	31.24	30.67	0.58
B	Vinyl Ester	1	300	4	0	55.51	57.82	56.67	1.15
C	Epoxy	1	300	4	0	45.09	46.24	45.67	0.58
A	Epoxy	1	300	4	200	360.14	363.19	361.67	1.53
B	Vinyl Ester	1	300	4	200	371.00	375.00	373.00	2.00
C	Epoxy	1	300	4	200	380.14	383.19	381.67	1.53
A	Epoxy	1	300	4	20000	33 400.00	33 420.00	33 410.00	10.00
B	Vinyl Ester	1	300	4	20000	33 407.56	33 419.11	33 413.33	5.77
C	Epoxy	1	300	4	20000	33 590.00	33 610.00	33 600.00	10.00
A	Epoxy	1	300	4	SeaWater	34 218.17	34 268.50	34 243.33	25.17
B	Vinyl Ester	1	300	4	SeaWater	35 708.06	35 738.61	35 723.33	15.28
C	Epoxy	1	300	4	SeaWater	34 408.17	34 458.50	34 433.33	25.17
A	Epoxy	2	300	4	0	20.59	24.75	22.67	2.08
B	Vinyl Ester	2	300	4	0	69.09	70.24	69.67	0.58
C	Epoxy	2	300	4	0	54.27	57.73	56.00	1.73
A	Epoxy	2	300	4	200	349.51	351.82	350.67	1.15
B	Vinyl Ester	2	300	4	200	349.51	351.82	350.67	1.15
C	Epoxy	2	300	4	200	410.35	415.65	413.00	2.65
A	Epoxy	2	300	4	20000	33 010.00	33 030.00	33 020.00	10.00
B	Vinyl Ester	2	300	4	20000	33 282.68	33 317.32	33 300.00	17.32
C	Epoxy	2	300	4	20000	33 153.54	33 206.46	33 180.00	26.46
A	Epoxy	2	300	4	SeaWater	33 128.17	33 178.50	33 153.33	25.17
B	Vinyl Ester	2	300	4	SeaWater	34 495.85	34 537.48	34 516.67	20.82
C	Epoxy	2	300	4	SeaWater	34 023.54	34 076.46	34 050.00	26.46
A	Epoxy	1	300	7	0	41.51	43.82	42.67	1.15
B	Vinyl Ester	1	300	7	0	42.27	45.73	44.00	1.73
C	Epoxy	1	300	7	0	56.51	58.82	57.67	1.15

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Table 7.2: Salinity Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Salinity			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	7	200	372.81	375.86	374.33	1.53
B	Vinyl Ester	1	300	7	200	387.00	389.00	388.00	1.00
C	Epoxy	1	300	7	200	392.81	395.86	394.33	1.53
A	Epoxy	1	300	7	20000	33 218.06	33 248.61	33 233.33	15.28
B	Vinyl Ester	1	300	7	20000	33 413.54	33 466.46	33 440.00	26.46
C	Epoxy	1	300	7	20000	33 408.06	33 438.61	33 423.33	15.28
A	Epoxy	1	300	7	SeaWater	34 292.52	34 334.15	34 313.33	20.82
B	Vinyl Ester	1	300	7	SeaWater	34 420.00	34 440.00	34 430.00	10.00
C	Epoxy	1	300	7	SeaWater	34 482.52	34 524.15	34 503.33	20.82
A	Epoxy	2	300	7	0	32.51	34.82	33.67	1.15
B	Vinyl Ester	2	300	7	0	29.09	30.24	29.67	0.58
C	Epoxy	2	300	7	0	65.36	69.98	67.67	2.31
A	Epoxy	2	300	7	200	362.81	365.86	364.33	1.53
B	Vinyl Ester	2	300	7	200	363.81	366.86	365.33	1.53
C	Epoxy	2	300	7	200	454.25	458.41	456.33	2.08
A	Epoxy	2	300	7	20000	33 241.79	33 264.88	33 253.33	11.55
B	Vinyl Ester	2	300	7	20000	32 963.54	33 016.46	32 990.00	26.46
C	Epoxy	2	300	7	20000	33 301.79	33 324.88	33 313.33	11.55
A	Epoxy	2	300	7	SeaWater	33 402.52	33 444.15	33 423.33	20.82
B	Vinyl Ester	2	300	7	SeaWater	34 267.56	34 279.11	34 273.33	5.77
C	Epoxy	2	300	7	SeaWater	34 312.68	34 347.32	34 330.00	17.32
A	Epoxy	1	300	10	0	34.36	38.98	36.67	2.31
B	Vinyl Ester	1	300	10	0	58.81	61.86	60.33	1.53
C	Epoxy	1	300	10	0	49.36	53.98	51.67	2.31
A	Epoxy	1	300	10	200	371.14	374.19	372.67	1.53
B	Vinyl Ester	1	300	10	200	379.25	383.41	381.33	2.08
C	Epoxy	1	300	10	200	391.14	394.19	392.67	1.53

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Table 7.2: Salinity Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Salinity			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	10	20000	33 261.39	33 291.94	33 276.67	15.28
B	Vinyl Ester	1	300	10	20000	33 630.00	33 670.00	33 650.00	20.00
C	Epoxy	1	300	10	20000	33 451.39	33 481.94	33 466.67	15.28
A	Epoxy	1	300	10	SeaWater	35 021.79	35 044.88	35 033.33	11.55
B	Vinyl Ester	1	300	10	SeaWater	35 091.79	35 114.88	35 103.33	11.55
C	Epoxy	1	300	10	SeaWater	35 211.79	35 234.88	35 223.33	11.55
A	Epoxy	2	300	10	0	34.51	36.82	35.67	1.15
B	Vinyl Ester	2	300	10	0	27.14	30.19	28.67	1.53
C	Epoxy	2	300	10	0	49.18	51.49	50.33	1.15
A	Epoxy	2	300	10	200	370.25	374.41	372.33	2.08
B	Vinyl Ester	2	300	10	200	362.09	363.24	362.67	0.58
C	Epoxy	2	300	10	200	450.59	454.75	452.67	2.08
A	Epoxy	2	300	10	20000	33 506.08	33 600.59	33 553.33	47.26
B	Vinyl Ester	2	300	10	20000	33 308.17	33 358.50	33 333.33	25.17
C	Epoxy	2	300	10	20000	33 805.12	33 828.21	33 816.67	11.55
A	Epoxy	2	300	10	SeaWater	33 831.39	33 861.94	33 846.67	15.28
B	Vinyl Ester	2	300	10	SeaWater	35 151.79	35 174.88	35 163.33	11.55
C	Epoxy	2	300	10	SeaWater	35 380.00	35 400.00	35 390.00	10.00
A	Epoxy	1	300	13	0	2529.59	2533.75	2531.67	2.08
B	Vinyl Ester	1	300	13	0	1564.51	1566.82	1565.67	1.15
C	Epoxy	1	300	13	0	2769.59	2773.75	2771.67	2.08
A	Epoxy	1	300	13	200	3333.25	3337.41	3335.33	2.08
B	Vinyl Ester	1	300	13	200	1937.27	1940.73	1939.00	1.73
C	Epoxy	1	300	13	200	3335.25	3339.41	3337.33	2.08
A	Epoxy	1	300	13	20000	22 400.00	22 440.00	22 420.00	20.00
B	Vinyl Ester	1	300	13	20000	28 981.79	29 004.88	28 993.33	11.55
C	Epoxy	1	300	13	20000	22 590.00	22 630.00	22 610.00	20.00

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Table 7.2: Salinity Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Salinity			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	13	SeaWater	25 572.52	25 614.15	25 593.33	20.82
B	Vinyl Ester	1	300	13	SeaWater	29 822.78	29 883.88	29 853.33	30.55
C	Epoxy	1	300	13	SeaWater	25 762.52	25 804.15	25 783.33	20.82
A	Epoxy	2	300	13	0	2384.55	2392.12	2388.33	3.79
B	Vinyl Ester	2	300	13	0	1801.00	1805.00	1803.00	2.00
C	Epoxy	2	300	13	0	2969.59	2973.75	2971.67	2.08
A	Epoxy	2	300	13	200	3330.25	3334.41	3332.33	2.08
B	Vinyl Ester	2	300	13	200	2299.14	2302.19	2300.67	1.53
C	Epoxy	2	300	13	200	3221.59	3225.75	3223.67	2.08
A	Epoxy	2	300	13	20000	22 230.00	22 250.00	22 240.00	10.00
B	Vinyl Ester	2	300	13	20000	28 708.06	28 738.61	28 723.33	15.28
C	Epoxy	2	300	13	20000	23 911.39	23 941.94	23 926.67	15.28
A	Epoxy	2	300	13	SeaWater	25 291.39	25 321.94	25 306.67	15.28
B	Vinyl Ester	2	300	13	SeaWater	31 518.06	31 548.61	31 533.33	15.28
C	Epoxy	2	300	13	SeaWater	27 143.54	27 196.46	27 170.00	26.46

Table 7.3: Salinity Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Salinity			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	300	4	0	17.76	18.91	18.33	0.58
B	Vinyl Ester	300	4	0	24.81	27.86	26.33	1.53
A	Epoxy	300	4	200	351.76	352.91	352.33	0.58
B	Vinyl Ester	300	4	200	345.81	348.86	347.33	1.53
A	Epoxy	300	4	20000	33 681.39	33 711.94	33 696.67	15.28
B	Vinyl Ester	300	4	20000	33 590.00	33 610.00	33 600.00	10.00
A	Epoxy	300	4	SeaWater	34 761.39	34 791.94	34 776.67	15.28
B	Vinyl Ester	300	4	SeaWater	35 018.06	35 048.61	35 033.33	15.28
A	Epoxy	300	7	0	17.00	19.00	18.00	1.00
B	Vinyl Ester	300	7	0	23.76	24.91	24.33	0.58
A	Epoxy	300	7	200	358.00	360.00	359.00	1.00
B	Vinyl Ester	300	7	200	359.09	360.24	359.67	0.58
A	Epoxy	300	7	20000	33 728.06	33 758.61	33 743.33	15.28
B	Vinyl Ester	300	7	20000	34 100.89	34 112.44	34 106.67	5.77
A	Epoxy	300	7	SeaWater	35 090.89	35 102.44	35 096.67	5.77
B	Vinyl Ester	300	7	SeaWater	34 558.06	34 588.61	34 573.33	15.28
A	Epoxy	300	10	0	6.81	9.86	8.33	1.53
B	Vinyl Ester	300	10	0	7.09	8.24	7.67	0.58
A	Epoxy	300	10	200	349.14	352.19	350.67	1.53
B	Vinyl Ester	300	10	200	346.18	348.49	347.33	1.15
A	Epoxy	300	10	20000	33 695.12	33 718.21	33 706.67	11.55
B	Vinyl Ester	300	10	20000	33 595.85	33 637.48	33 616.67	20.82
A	Epoxy	300	10	SeaWater	36 258.06	36 288.61	36 273.33	15.28
B	Vinyl Ester	300	10	SeaWater	34 970.00	34 990.00	34 980.00	10.00
A	Epoxy	300	13	0	4340.89	4352.44	4346.67	5.77
B	Vinyl Ester	300	13	0	4257.56	4269.11	4263.33	5.77
A	Epoxy	300	13	200	4664.51	4666.82	4665.67	1.15

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Table 7.3: Salinity Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Salinity			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	300	13	200	4628.09	4629.24	4628.67	0.58
A	Epoxy	300	13	20000	39 978.06	40 008.61	39 993.33	15.28
B	Vinyl Ester	300	13	20000	37 941.39	37 971.94	37 956.67	15.28
A	Epoxy	300	13	SeaWater	43 713.94	43 786.06	43 750.00	36.06
B	Vinyl Ester	300	13	SeaWater	38 703.94	38 776.06	38 740.00	36.06

Table 7.4: Salinity Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Salinity			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Sized	300	4	0	15.02	19.64	17.33	2.31
B	Sized	300	4	0	28.76	29.91	29.33	0.58
C	Sized	300	4	0	19.02	23.64	21.33	2.31
A	Sized	300	4	200	342.59	346.75	344.67	2.08
B	Sized	300	4	200	350.09	351.24	350.67	0.58
C	Sized	300	4	200	344.59	348.75	346.67	2.08
A	Sized	300	4	20000	33 251.39	33 281.94	33 266.67	15.28
B	Sized	300	4	20000	33 425.12	33 448.21	33 436.67	11.55
C	Sized	300	4	20000	33 361.39	33 391.94	33 376.67	15.28
A	Sized	300	4	SeaWater	34 221.39	34 251.94	34 236.67	15.28
B	Sized	300	4	SeaWater	33 932.78	33 993.88	33 963.33	30.55
C	Sized	300	4	SeaWater	34 331.39	34 361.94	34 346.67	15.28
A	Unsized	300	4	0	11.76	12.91	12.33	0.58
B	Unsized	300	4	0	15.14	18.19	16.67	1.53
A	Unsized	300	4	200	344.81	347.86	346.33	1.53
B	Unsized	300	4	200	346.81	349.86	348.33	1.53
A	Unsized	300	4	20000	33 305.85	33 347.48	33 326.67	20.82
B	Unsized	300	4	20000	33 417.56	33 429.11	33 423.33	5.77
A	Unsized	300	4	SeaWater	34 482.68	34 517.32	34 500.00	17.32
B	Unsized	300	4	SeaWater	34 198.06	34 228.61	34 213.33	15.28
A	Sized	300	7	0	11.09	12.24	11.67	0.58
B	Sized	300	7	0	22.00	24.00	23.00	1.00
C	Sized	300	7	0	15.09	16.24	15.67	0.58
A	Sized	300	7	200	352.00	354.00	353.00	1.00
B	Sized	300	7	200	354.09	355.24	354.67	0.58
C	Sized	300	7	200	354.00	356.00	355.00	1.00
A	Sized	300	7	20000	33 785.85	33 827.48	33 806.67	20.82
B	Sized	300	7	20000	33 381.55	33 451.79	33 416.67	35.12
C	Sized	300	7	20000	33 895.85	33 937.48	33 916.67	20.82
A	Sized	300	7	SeaWater	34 000.89	34 012.44	34 006.67	5.77
B	Sized	300	7	SeaWater	34 575.47	34 651.19	34 613.33	37.86
C	Sized	300	7	SeaWater	34 110.89	34 122.44	34 116.67	5.77
A	Unsized	300	7	0	21.00	23.00	22.00	1.00
B	Unsized	300	7	0	24.76	25.91	25.33	0.58
A	Unsized	300	7	200	363.27	366.73	365.00	1.73
B	Unsized	300	7	200	354.76	355.91	355.33	0.58
A	Unsized	300	7	20000	33 630.00	33 650.00	33 640.00	10.00
B	Unsized	300	7	20000	33 731.39	33 761.94	33 746.67	15.28
A	Unsized	300	7	SeaWater	34 268.06	34 298.61	34 283.33	15.28
B	Unsized	300	7	SeaWater	34 308.06	34 338.61	34 323.33	15.28
A	Sized	300	10	0	7.81	10.86	9.33	1.53

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Table 7.4: Salinity Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Salinity			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^{-} ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Sized	300	10	0	12.25	16.41	14.33	2.08
C	Sized	300	10	0	11.81	14.86	13.33	1.53
A	Sized	300	10	200	351.51	353.82	352.67	1.15
B	Sized	300	10	200	352.76	353.91	353.33	0.58
C	Sized	300	10	200	353.51	355.82	354.67	1.15
A	Sized	300	10	20000	34 160.89	34 172.44	34 166.67	5.77
B	Sized	300	10	20000	34 032.52	34 074.15	34 053.33	20.82
C	Sized	300	10	20000	34 270.89	34 282.44	34 276.67	5.77
A	Sized	300	10	SeaWater	35 002.68	35 037.32	35 020.00	17.32
B	Sized	300	10	SeaWater	35 331.55	35 401.79	35 366.67	35.12
C	Sized	300	10	SeaWater	35 112.68	35 147.32	35 130.00	17.32
A	Unsized	300	10	0	13.14	16.19	14.67	1.53
B	Unsized	300	10	0	11.76	12.91	12.33	0.58
A	Unsized	300	10	200	355.81	358.86	357.33	1.53
B	Unsized	300	10	200	352.09	353.24	352.67	0.58
A	Unsized	300	10	20000	33 827.56	33 839.11	33 833.33	5.77
B	Unsized	300	10	20000	33 870.24	33 916.43	33 893.33	23.09
A	Unsized	300	10	SeaWater	35 865.85	35 907.48	35 886.67	20.82
B	Unsized	300	10	SeaWater	35 511.79	35 534.88	35 523.33	11.55
A	Sized	300	13	0	3677.56	3689.11	3683.33	5.77
B	Sized	300	13	0	3268.17	3318.50	3293.33	25.17
C	Sized	300	13	0	3797.56	3809.11	3803.33	5.77
A	Sized	300	13	200	4001.27	4004.73	4003.00	1.73
B	Sized	300	13	200	3830.15	3837.18	3833.67	3.51
C	Sized	300	13	200	4010.27	4013.73	4012.00	1.73
A	Sized	300	13	20000	34 140.00	34 160.00	34 150.00	10.00
B	Sized	300	13	20000	34 724.52	34 788.81	34 756.67	32.15
C	Sized	300	13	20000	34 250.00	34 270.00	34 260.00	10.00
A	Sized	300	13	SeaWater	35 306.41	35 393.59	35 350.00	43.59
B	Sized	300	13	SeaWater	35 826.12	35 887.22	35 856.67	30.55
C	Sized	300	13	SeaWater	35 416.41	35 503.59	35 460.00	43.59
A	Unsized	300	13	0	3080.24	3126.43	3103.33	23.09
B	Unsized	300	13	0	3397.56	3409.11	3403.33	5.77
A	Unsized	300	13	200	3535.00	3541.00	3538.00	3.00
B	Unsized	300	13	200	3835.12	3841.55	3838.33	3.21
A	Unsized	300	13	20000	34 581.39	34 611.94	34 596.67	15.28
B	Unsized	300	13	20000	34 742.52	34 784.15	34 763.33	20.82
A	Unsized	300	13	SeaWater	35 484.00	35 582.66	35 533.33	49.33
B	Unsized	300	13	SeaWater	35 960.00	35 980.00	35 970.00	10.00

For a better understanding, change in the salinity content of the environments was plotted in graphs in

Figure 7.4, 7.5, and 7.6.

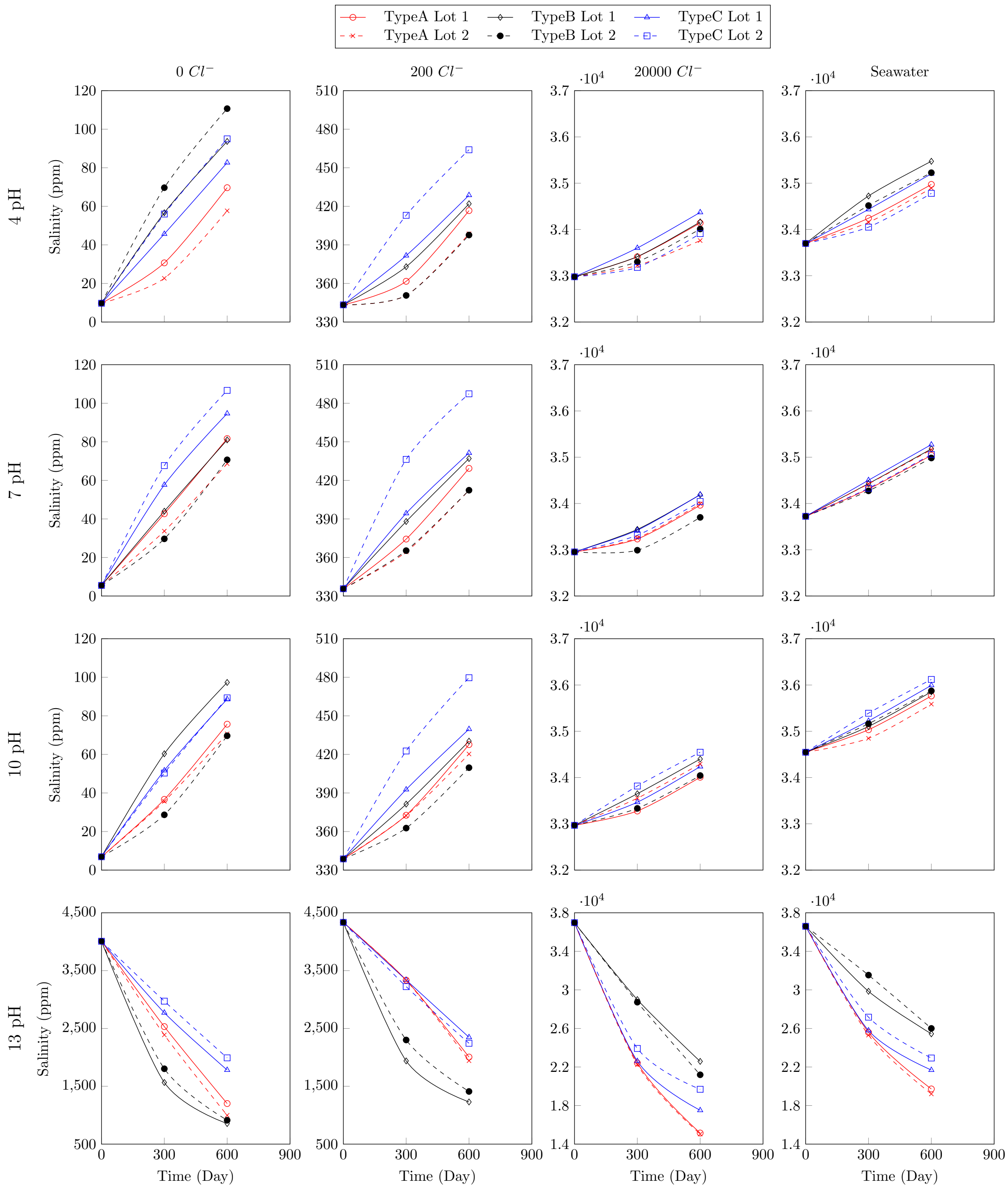

Figure 7.4: Salinity of environments after exposure of rebars

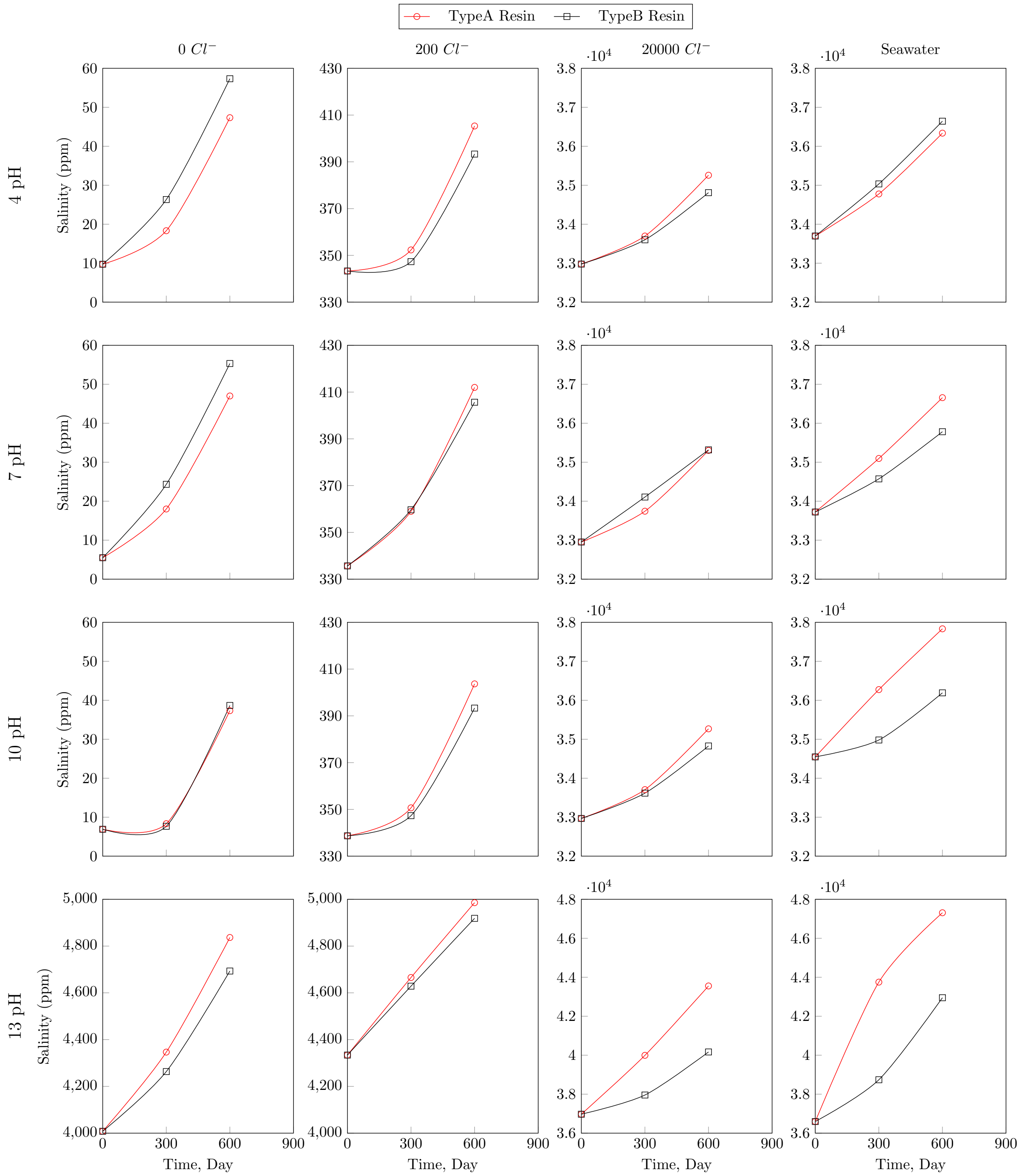

Figure 7.5: Salinity of environments after exposure of resins

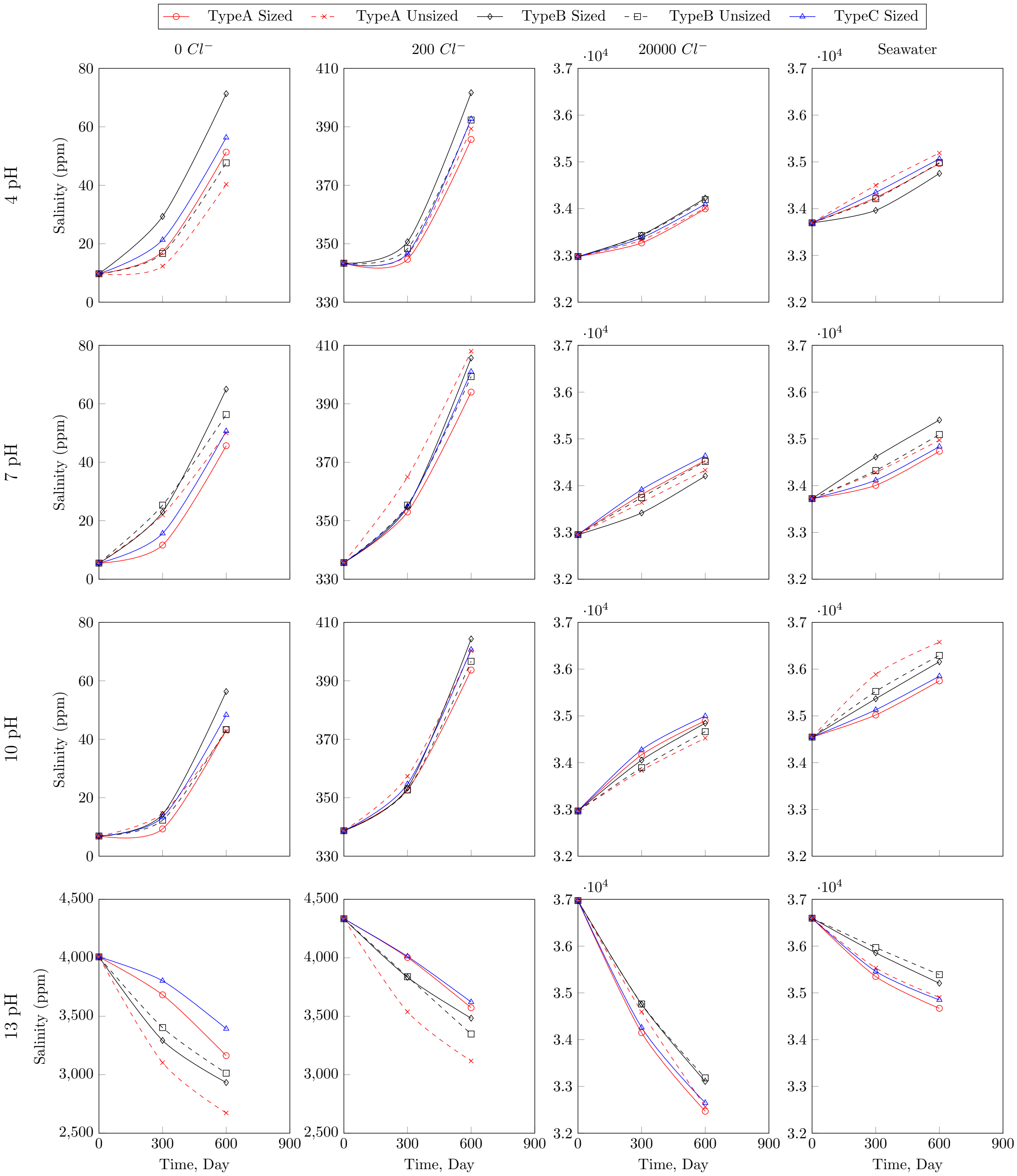

Figure 7.6: Salinity of environments after exposure of sized and unsized fibers

7.2.3 Dissolved oxygen (DO)

DO of the chemical environments was measured after 300 days of exposure. Tables 7.5, 7.6, and 7.7 below shows the DO data of environments in which rebars, resins, and fibers were exposed.

Table 7.5: Dissolved Oxygen Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Dissolved Oxygen			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	4	0	8.66	8.70	8.68	0.02
B	Vinyl Ester	1	300	4	0	8.70	8.73	8.72	0.02
C	Epoxy	1	300	4	0	8.65	8.71	8.68	0.03
A	Epoxy	1	300	4	200	8.60	8.64	8.62	0.02
B	Vinyl Ester	1	300	4	200	8.64	8.78	8.71	0.07
C	Epoxy	1	300	4	200	8.59	8.62	8.60	0.02
A	Epoxy	1	300	4	20000	8.51	8.52	8.52	0.01
B	Vinyl Ester	1	300	4	20000	8.65	8.66	8.65	0.01
C	Epoxy	1	300	4	20000	8.48	8.54	8.51	0.03
A	Epoxy	1	300	4	SeaWater	8.47	8.53	8.50	0.03
B	Vinyl Ester	1	300	4	SeaWater	8.50	8.56	8.53	0.03
C	Epoxy	1	300	4	SeaWater	8.40	8.42	8.41	0.01
A	Epoxy	2	300	4	0	8.51	8.59	8.55	0.04
B	Vinyl Ester	2	300	4	0	8.68	8.80	8.74	0.06
C	Epoxy	2	300	4	0	8.38	8.48	8.43	0.05
A	Epoxy	2	300	4	200	8.47	8.50	8.48	0.02
B	Vinyl Ester	2	300	4	200	8.70	8.71	8.71	0.01
C	Epoxy	2	300	4	200	8.41	8.43	8.42	0.01
A	Epoxy	2	300	4	20000	8.38	8.43	8.41	0.03
B	Vinyl Ester	2	300	4	20000	8.66	8.72	8.69	0.03
C	Epoxy	2	300	4	20000	8.38	8.39	8.39	0.01
A	Epoxy	2	300	4	SeaWater	8.26	8.29	8.28	0.02
B	Vinyl Ester	2	300	4	SeaWater	8.45	8.55	8.50	0.05
C	Epoxy	2	300	4	SeaWater	7.67	7.74	7.70	0.04
A	Epoxy	1	300	7	0	8.66	8.68	8.67	0.01
B	Vinyl Ester	1	300	7	0	8.67	8.77	8.72	0.05
C	Epoxy	1	300	7	0	8.60	8.64	8.62	0.02
A	Epoxy	1	300	7	200	8.57	8.61	8.59	0.02
B	Vinyl Ester	1	300	7	200	8.67	8.75	8.71	0.04
C	Epoxy	1	300	7	200	8.49	8.55	8.52	0.03
A	Epoxy	1	300	7	20000	8.52	8.53	8.52	0.01
B	Vinyl Ester	1	300	7	20000	8.62	8.64	8.63	0.01
C	Epoxy	1	300	7	20000	8.44	8.48	8.46	0.02
A	Epoxy	1	300	7	SeaWater	8.41	8.43	8.42	0.01
B	Vinyl Ester	1	300	7	SeaWater	8.51	8.52	8.51	0.01
C	Epoxy	1	300	7	SeaWater	8.33	8.35	8.34	0.01
A	Epoxy	2	300	7	0	8.46	8.52	8.49	0.03

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Table 7.5: Dissolved Oxygen Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Dissolved Oxygen			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	2	300	7	0	8.70	8.74	8.72	0.02
C	Epoxy	2	300	7	0	8.37	8.43	8.40	0.03
A	Epoxy	2	300	7	200	8.37	8.43	8.40	0.03
B	Vinyl Ester	2	300	7	200	8.68	8.71	8.70	0.02
C	Epoxy	2	300	7	200	8.34	8.43	8.39	0.05
A	Epoxy	2	300	7	20000	8.30	8.36	8.33	0.03
B	Vinyl Ester	2	300	7	20000	8.64	8.65	8.65	0.01
C	Epoxy	2	300	7	20000	8.31	8.33	8.32	0.01
A	Epoxy	2	300	7	SeaWater	8.20	8.23	8.21	0.02
B	Vinyl Ester	2	300	7	SeaWater	8.49	8.51	8.50	0.01
C	Epoxy	2	300	7	SeaWater	7.38	7.42	7.40	0.02
A	Epoxy	1	300	10	0	8.62	8.69	8.66	0.03
B	Vinyl Ester	1	300	10	0	8.68	8.74	8.71	0.03
C	Epoxy	1	300	10	0	8.47	8.54	8.50	0.04
A	Epoxy	1	300	10	200	8.56	8.61	8.58	0.03
B	Vinyl Ester	1	300	10	200	8.68	8.73	8.70	0.03
C	Epoxy	1	300	10	200	8.37	8.44	8.41	0.03
A	Epoxy	1	300	10	20000	8.41	8.49	8.45	0.04
B	Vinyl Ester	1	300	10	20000	8.55	8.67	8.61	0.06
C	Epoxy	1	300	10	20000	8.30	8.37	8.34	0.03
A	Epoxy	1	300	10	SeaWater	8.04	8.08	8.06	0.02
B	Vinyl Ester	1	300	10	SeaWater	8.48	8.52	8.50	0.02
C	Epoxy	1	300	10	SeaWater	8.20	8.24	8.22	0.02
A	Epoxy	2	300	10	0	8.35	8.42	8.38	0.04
B	Vinyl Ester	2	300	10	0	8.64	8.65	8.65	0.01
C	Epoxy	2	300	10	0	8.37	8.40	8.39	0.02
A	Epoxy	2	300	10	200	8.27	8.31	8.29	0.02
B	Vinyl Ester	2	300	10	200	8.64	8.65	8.65	0.01
C	Epoxy	2	300	10	200	8.35	8.36	8.36	0.01
A	Epoxy	2	300	10	20000	8.19	8.26	8.22	0.04
B	Vinyl Ester	2	300	10	20000	8.55	8.63	8.59	0.04
C	Epoxy	2	300	10	20000	8.22	8.34	8.28	0.06
A	Epoxy	2	300	10	SeaWater	8.05	8.12	8.09	0.04
B	Vinyl Ester	2	300	10	SeaWater	8.44	8.49	8.46	0.02
C	Epoxy	2	300	10	SeaWater	7.34	7.35	7.34	0.01
A	Epoxy	1	300	13	0	8.62	8.63	8.62	0.01
B	Vinyl Ester	1	300	13	0	8.67	8.68	8.68	0.01
C	Epoxy	1	300	13	0	7.88	7.92	7.90	0.02
A	Epoxy	1	300	13	200	8.44	8.48	8.46	0.02
B	Vinyl Ester	1	300	13	200	8.62	8.70	8.66	0.04
C	Epoxy	1	300	13	200	7.80	7.82	7.81	0.01
A	Epoxy	1	300	13	20000	8.13	8.16	8.14	0.02

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Table 7.5: Dissolved Oxygen Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Dissolved Oxygen			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	1	300	13	20000	8.56	8.64	8.60	0.04
C	Epoxy	1	300	13	20000	7.70	7.72	7.71	0.01
A	Epoxy	1	300	13	SeaWater	7.56	7.61	7.58	0.03
B	Vinyl Ester	1	300	13	SeaWater	8.44	8.50	8.47	0.03
C	Epoxy	1	300	13	SeaWater	7.52	7.58	7.55	0.03
A	Epoxy	2	300	13	0	7.74	7.80	7.77	0.03
B	Vinyl Ester	2	300	13	0	8.61	8.64	8.63	0.02
C	Epoxy	2	300	13	0	8.24	8.34	8.29	0.05
A	Epoxy	2	300	13	200	7.68	7.70	7.69	0.01
B	Vinyl Ester	2	300	13	200	8.56	8.57	8.57	0.01
C	Epoxy	2	300	13	200	8.25	8.28	8.27	0.02
A	Epoxy	2	300	13	20000	7.56	7.61	7.59	0.02
B	Vinyl Ester	2	300	13	20000	8.52	8.58	8.55	0.03
C	Epoxy	2	300	13	20000	8.13	8.16	8.14	0.02
A	Epoxy	2	300	13	SeaWater	7.46	7.51	7.49	0.03
B	Vinyl Ester	2	300	13	SeaWater	8.44	8.46	8.45	0.01
C	Epoxy	2	300	13	SeaWater	7.06	7.16	7.11	0.05

Table 7.6: Dissolved Oxygen Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Dissolved Oxygen			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	300	4	0	8.74	8.76	8.75	0.01
B	Vinyl Ester	300	4	0	8.67	8.75	8.71	0.04
A	Epoxy	300	4	200	8.66	8.74	8.70	0.04
B	Vinyl Ester	300	4	200	8.68	8.69	8.69	0.01
A	Epoxy	300	4	20000	8.65	8.67	8.66	0.01
B	Vinyl Ester	300	4	20000	8.63	8.68	8.66	0.03
A	Epoxy	300	4	SeaWater	8.47	8.48	8.47	0.01
B	Vinyl Ester	300	4	SeaWater	8.47	8.55	8.51	0.04
A	Epoxy	300	7	0	8.71	8.75	8.73	0.02
B	Vinyl Ester	300	7	0	8.67	8.68	8.67	0.01
A	Epoxy	300	7	200	8.66	8.69	8.68	0.02
B	Vinyl Ester	300	7	200	8.63	8.69	8.66	0.03
A	Epoxy	300	7	20000	8.63	8.66	8.64	0.02
B	Vinyl Ester	300	7	20000	8.64	8.67	8.65	0.02

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Table 7.6: Dissolved Oxygen Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Dissolved Oxygen			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	300	7	SeaWater	8.45	8.47	8.46	0.01
B	Vinyl Ester	300	7	SeaWater	8.45	8.55	8.50	0.05
A	Epoxy	300	10	0	8.65	8.70	8.67	0.03
B	Vinyl Ester	300	10	0	8.62	8.68	8.65	0.03
A	Epoxy	300	10	200	8.61	8.65	8.63	0.02
B	Vinyl Ester	300	10	200	8.65	8.68	8.66	0.02
A	Epoxy	300	10	20000	8.60	8.62	8.61	0.01
B	Vinyl Ester	300	10	20000	8.60	8.66	8.63	0.03
A	Epoxy	300	10	SeaWater	8.40	8.52	8.46	0.06
B	Vinyl Ester	300	10	SeaWater	8.46	8.48	8.47	0.01
A	Epoxy	300	13	0	8.66	8.67	8.67	0.01
B	Vinyl Ester	300	13	0	8.61	8.67	8.64	0.03
A	Epoxy	300	13	200	8.62	8.63	8.62	0.01
B	Vinyl Ester	300	13	200	8.60	8.66	8.63	0.03
A	Epoxy	300	13	20000	8.54	8.64	8.59	0.05
B	Vinyl Ester	300	13	20000	8.56	8.58	8.57	0.01
A	Epoxy	300	13	SeaWater	8.44	8.47	8.45	0.02
B	Vinyl Ester	300	13	SeaWater	8.45	8.49	8.47	0.02

Table 7.7: Dissolved Oxygen Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Dissolved Oxygen			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Sized	300	4	0	8.73	8.74	8.74	0.01
B	Sized	300	4	0	8.77	8.78	8.77	0.01
C	Sized	300	4	0	8.68	8.72	8.70	0.02
A	Sized	300	4	200	8.70	8.73	8.71	0.02
B	Sized	300	4	200	8.67	8.68	8.68	0.01
C	Sized	300	4	200	8.62	8.65	8.64	0.02
A	Sized	300	4	20000	8.68	8.70	8.69	0.01
B	Sized	300	4	20000	8.60	8.67	8.63	0.04
C	Sized	300	4	20000	8.59	8.61	8.60	0.01
A	Sized	300	4	SeaWater	8.51	8.54	8.52	0.02
B	Sized	300	4	SeaWater	8.52	8.54	8.53	0.01
C	Sized	300	4	SeaWater	8.55	8.57	8.56	0.01
A	Unsized	300	4	0	8.74	8.75	8.75	0.01

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Table 7.7: Dissolved Oxygen Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Dissolved Oxygen			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Unsized	300	4	0	8.72	8.76	8.74	0.02
A	Unsized	300	4	200	8.69	8.73	8.71	0.02
B	Unsized	300	4	200	8.71	8.73	8.72	0.01
A	Unsized	300	4	20000	8.63	8.70	8.67	0.04
B	Unsized	300	4	20000	8.67	8.71	8.69	0.02
A	Unsized	300	4	SeaWater	8.46	8.50	8.48	0.02
B	Unsized	300	4	SeaWater	8.50	8.52	8.51	0.01
A	Sized	300	7	0	8.73	8.75	8.74	0.01
B	Sized	300	7	0	8.67	8.73	8.70	0.03
C	Sized	300	7	0	8.68	8.69	8.68	0.01
A	Sized	300	7	200	8.66	8.69	8.68	0.02
B	Sized	300	7	200	8.65	8.69	8.67	0.02
C	Sized	300	7	200	8.59	8.61	8.60	0.01
A	Sized	300	7	20000	8.64	8.70	8.67	0.03
B	Sized	300	7	20000	8.60	8.64	8.62	0.02
C	Sized	300	7	20000	8.51	8.55	8.53	0.02
A	Sized	300	7	SeaWater	8.47	8.48	8.47	0.01
B	Sized	300	7	SeaWater	8.46	8.54	8.50	0.04
C	Sized	300	7	SeaWater	8.48	8.50	8.49	0.01
A	Unsized	300	7	0	8.74	8.75	8.74	0.01
B	Unsized	300	7	0	8.71	8.77	8.74	0.03
A	Unsized	300	7	200	8.68	8.69	8.69	0.01
B	Unsized	300	7	200	8.70	8.71	8.70	0.01
A	Unsized	300	7	20000	8.61	8.69	8.65	0.04
B	Unsized	300	7	20000	8.67	8.69	8.68	0.01
A	Unsized	300	7	SeaWater	8.42	8.47	8.45	0.03
B	Unsized	300	7	SeaWater	8.47	8.55	8.51	0.04
A	Sized	300	10	0	8.70	8.72	8.71	0.01
B	Sized	300	10	0	8.67	8.68	8.68	0.01
C	Sized	300	10	0	8.60	8.63	8.61	0.02
A	Sized	300	10	200	8.65	8.69	8.67	0.02
B	Sized	300	10	200	8.66	8.67	8.67	0.01
C	Sized	300	10	200	8.51	8.54	8.53	0.02
A	Sized	300	10	20000	8.62	8.70	8.66	0.04
B	Sized	300	10	20000	8.60	8.64	8.62	0.02
C	Sized	300	10	20000	8.47	8.49	8.48	0.01
A	Sized	300	10	SeaWater	8.44	8.48	8.46	0.02
B	Sized	300	10	SeaWater	8.46	8.50	8.48	0.02
C	Sized	300	10	SeaWater	8.37	8.41	8.39	0.02
A	Unsized	300	10	0	8.70	8.72	8.71	0.01
B	Unsized	300	10	0	8.69	8.77	8.73	0.04
A	Unsized	300	10	200	8.67	8.69	8.68	0.01

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Table 7.7: Dissolved Oxygen Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Dissolved Oxygen			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Unsized	300	10	200	8.67	8.72	8.70	0.03
A	Unsized	300	10	20000	8.63	8.67	8.65	0.02
B	Unsized	300	10	20000	8.66	8.67	8.66	0.01
A	Unsized	300	10	SeaWater	8.44	8.46	8.45	0.01
B	Unsized	300	10	SeaWater	8.48	8.53	8.51	0.02
A	Sized	300	13	0	8.65	8.66	8.66	0.01
B	Sized	300	13	0	8.65	8.69	8.67	0.02
C	Sized	300	13	0	8.57	8.59	8.58	0.01
A	Sized	300	13	200	8.64	8.67	8.66	0.02
B	Sized	300	13	200	8.65	8.68	8.66	0.02
C	Sized	300	13	200	8.48	8.51	8.49	0.02
A	Sized	300	13	20000	8.61	8.71	8.66	0.05
B	Sized	300	13	20000	8.58	8.61	8.60	0.02
C	Sized	300	13	20000	8.38	8.41	8.40	0.02
A	Sized	300	13	SeaWater	8.41	8.51	8.46	0.05
B	Sized	300	13	SeaWater	8.42	8.50	8.46	0.04
C	Sized	300	13	SeaWater	8.30	8.34	8.32	0.02
A	Unsized	300	13	0	8.67	8.69	8.68	0.01
B	Unsized	300	13	0	8.69	8.74	8.71	0.02
A	Unsized	300	13	200	8.63	8.67	8.65	0.02
B	Unsized	300	13	200	8.70	8.72	8.71	0.01
A	Unsized	300	13	20000	8.64	8.65	8.64	0.01
B	Unsized	300	13	20000	8.58	8.65	8.62	0.04
A	Unsized	300	13	SeaWater	8.42	8.45	8.43	0.02
B	Unsized	300	13	SeaWater	8.46	8.54	8.50	0.04

For a better understanding, change in the DO content of the environments was plotted in graphs in Figure 7.7, 7.8, and 7.9. It can be seen that dissolved oxygen content of environments has decreased overtime.

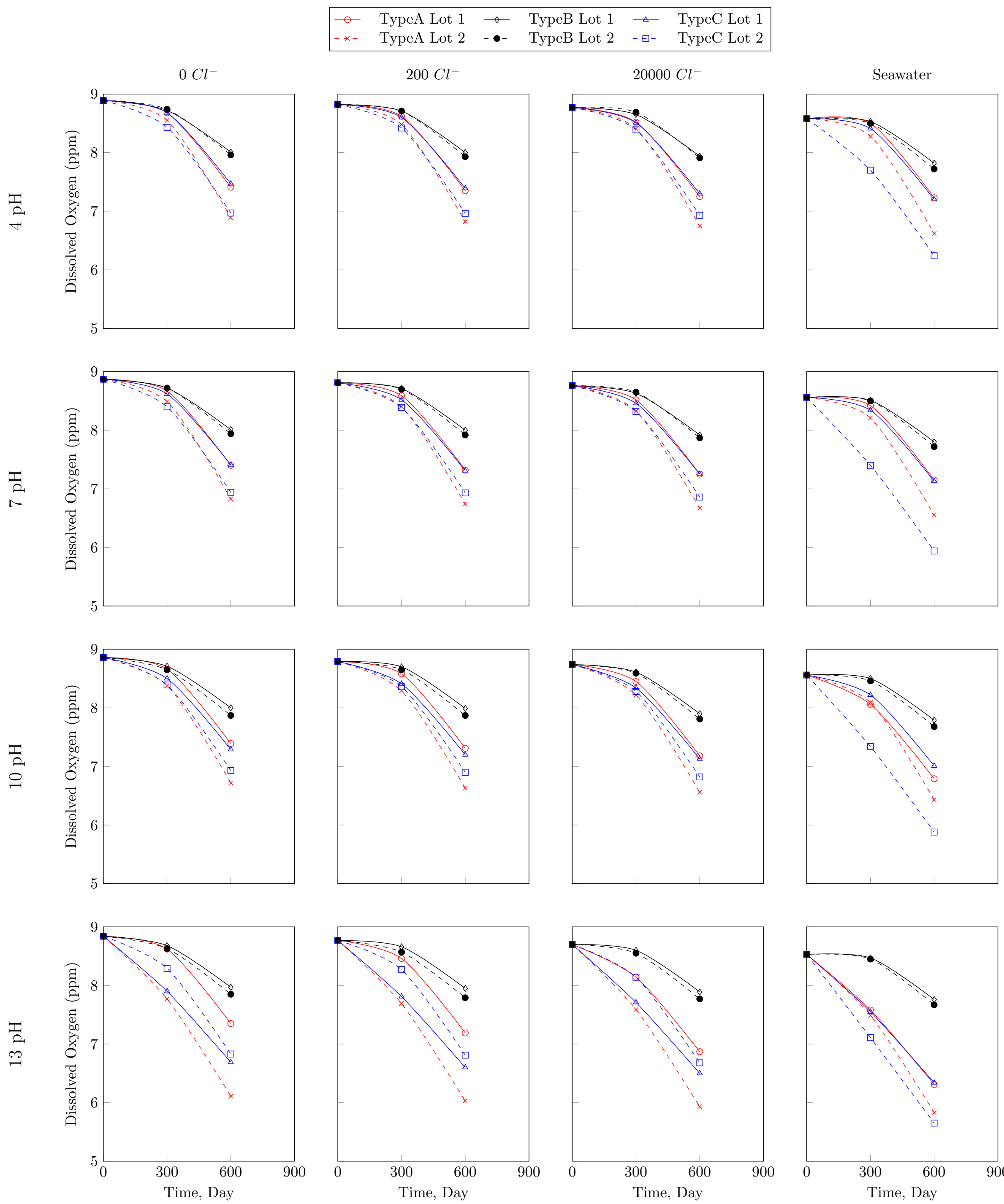

Figure 7.7: Dissolved oxygen concentration of environments after exposure of rebars

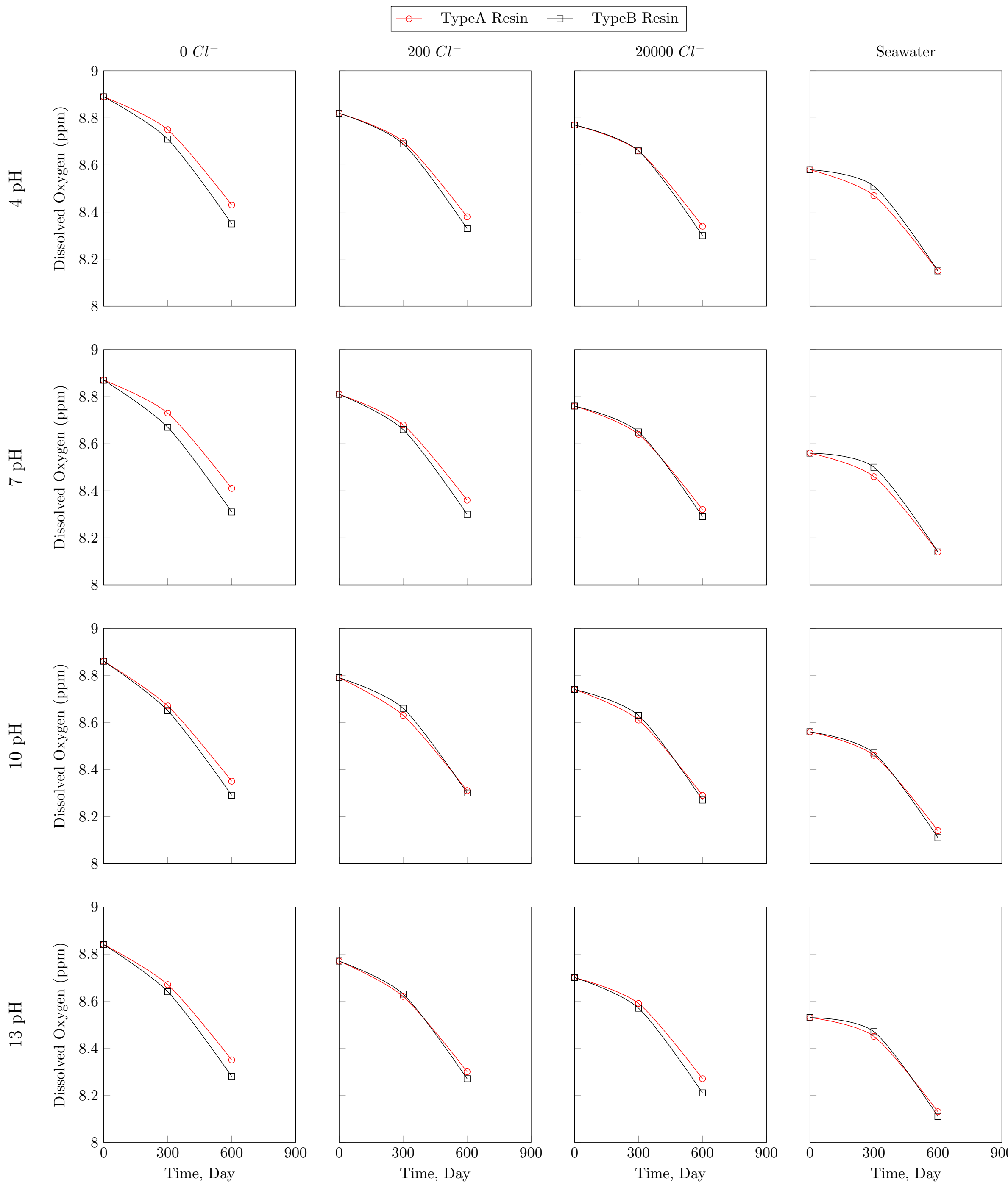

Figure 7.8: Dissolved oxygen concentration of environments after exposure of resins

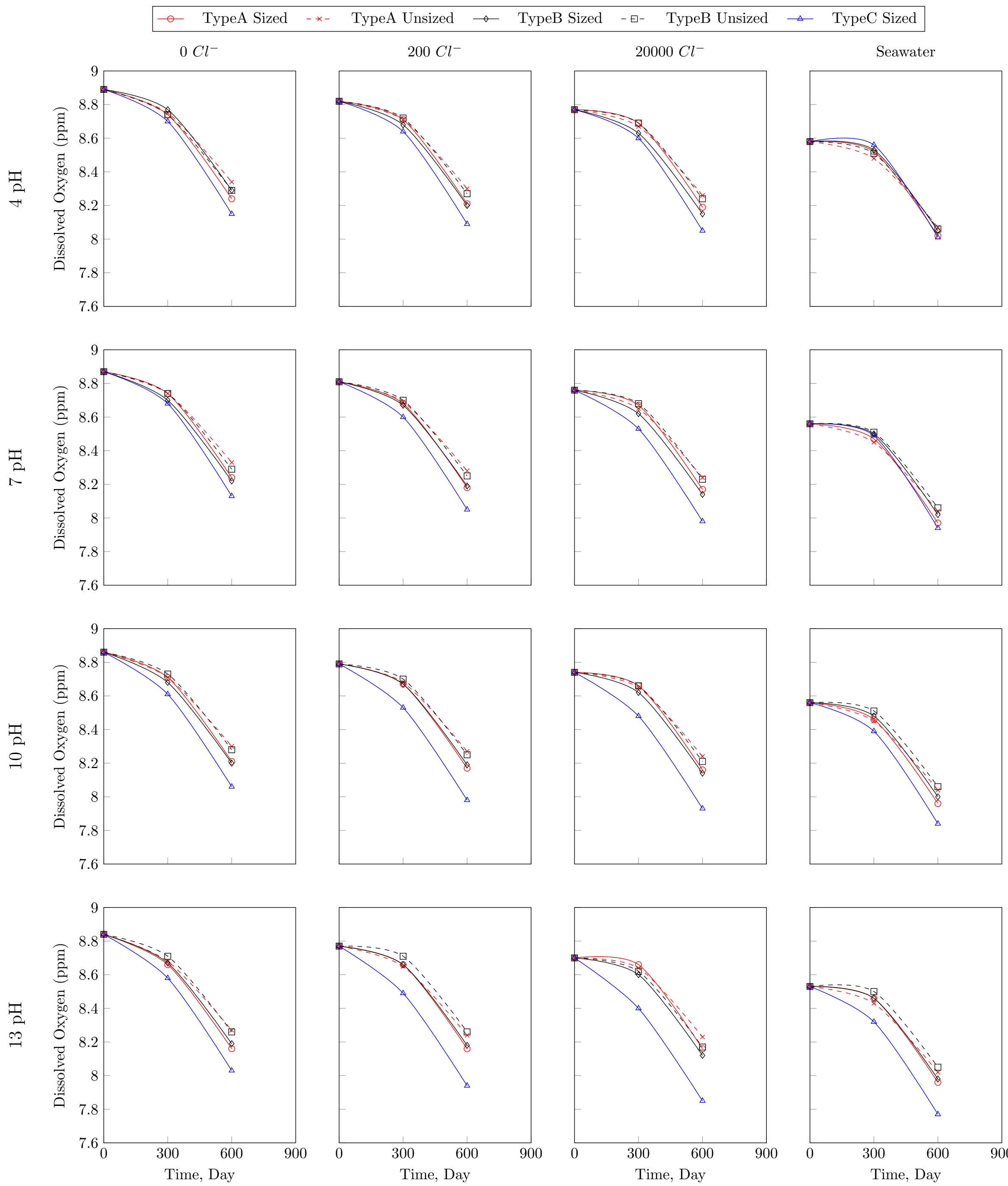

Figure 7.9: Dissolved oxygen concentration of environments after exposure of sized and unsized fibers

7.2.4 Alkalinity

Alkalinity of the chemical environments was measured after 300 days of exposure. Tables 7.8, 7.9, and 7.10 below shows the pH data of environments in which rebars, resins, and fibers were exposed.

Table 7.8: Alkalinity Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Alkalinity			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppmas$CaCO_3$	$\vee$ ppmas$CaCO_3$	μ ppmas$CaCO_3$	σ ppmas$CaCO_3$
A	Epoxy	1	300	4	0	−13.20	−13.01	−13.11	0.09
B	Vinyl Ester	1	300	4	0	−2.41	−2.35	−2.38	0.03
C	Epoxy	1	300	4	0	−11.62	−11.45	−11.53	0.08
A	Epoxy	1	300	4	200	−14.59	−14.45	−14.52	0.07
B	Vinyl Ester	1	300	4	200	−2.10	−2.06	−2.08	0.02
C	Epoxy	1	300	4	200	−12.84	−12.72	−12.78	0.06
A	Epoxy	1	300	4	20000	−16.32	−15.86	−16.09	0.23
B	Vinyl Ester	1	300	4	20000	−1.92	−0.48	−1.20	0.72
C	Epoxy	1	300	4	20000	−14.37	−13.96	−14.16	0.20
A	Epoxy	1	300	4	SeaWater	−19.03	−18.87	−18.95	0.08
B	Vinyl Ester	1	300	4	SeaWater	−0.75	−0.05	−0.40	0.35
C	Epoxy	1	300	4	SeaWater	−16.74	−16.60	−16.67	0.07
A	Epoxy	2	300	4	0	−23.64	−19.02	−21.33	2.31
B	Vinyl Ester	2	300	4	0	−2.22	−1.80	−2.01	0.21
C	Epoxy	2	300	4	0	−20.33	−16.36	−18.35	1.99
A	Epoxy	2	300	4	200	−20.23	−18.67	−19.45	0.78
B	Vinyl Ester	2	300	4	200	−2.00	−1.60	−1.80	0.20
C	Epoxy	2	300	4	200	−17.40	−16.06	−16.73	0.67
A	Epoxy	2	300	4	20000	−15.56	−15.16	−15.36	0.20
B	Vinyl Ester	2	300	4	20000	−2.13	−1.07	−1.60	0.53
C	Epoxy	2	300	4	20000	−13.38	−13.04	−13.21	0.17
A	Epoxy	2	300	4	SeaWater	−14.22	−13.76	−13.99	0.23
B	Vinyl Ester	2	300	4	SeaWater	−0.78	−0.55	−0.67	0.12
C	Epoxy	2	300	4	SeaWater	−12.23	−11.84	−12.03	0.20
A	Epoxy	1	300	7	0	0.71	1.92	1.31	0.60
B	Vinyl Ester	1	300	7	0	3.68	5.18	4.43	0.75
C	Epoxy	1	300	7	0	0.75	2.01	1.38	0.63

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Table 7.8: Alkalinity Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values: Alkalinity			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppmas$CaCO_3$	$\vee$ ppmas$CaCO_3$	μ ppmas$CaCO_3$	σ ppmas$CaCO_3$
A	Epoxy	1	300	7	200	0.99	1.45	1.22	0.23
B	Vinyl Ester	1	300	7	200	5.16	6.30	5.73	0.57
C	Epoxy	1	300	7	200	1.04	1.52	1.28	0.24
A	Epoxy	1	300	7	20000	0.80	1.28	1.04	0.24
B	Vinyl Ester	1	300	7	20000	6.07	6.57	6.32	0.25
C	Epoxy	1	300	7	20000	0.84	1.35	1.09	0.25
A	Epoxy	1	300	7	SeaWater	57.07	58.51	57.79	0.72
B	Vinyl Ester	1	300	7	SeaWater	73.21	74.17	73.69	0.48
C	Epoxy	1	300	7	SeaWater	59.92	61.44	60.68	0.76
A	Epoxy	2	300	7	0	0.66	1.43	1.05	0.38
B	Vinyl Ester	2	300	7	0	3.89	5.45	4.67	0.78
C	Epoxy	2	300	7	0	0.70	1.52	1.11	0.41
A	Epoxy	2	300	7	200	0.23	1.41	0.82	0.59
B	Vinyl Ester	2	300	7	200	5.44	6.62	6.03	0.59
C	Epoxy	2	300	7	200	0.24	1.50	0.87	0.63
A	Epoxy	2	300	7	20000	0.40	0.59	0.49	0.09
B	Vinyl Ester	2	300	7	20000	6.38	6.90	6.64	0.26
C	Epoxy	2	300	7	20000	0.42	0.62	0.52	0.10
A	Epoxy	2	300	7	SeaWater	52.28	52.96	52.62	0.34
B	Vinyl Ester	2	300	7	SeaWater	78.58	79.13	78.86	0.27
C	Epoxy	2	300	7	SeaWater	55.42	56.14	55.78	0.36
A	Epoxy	1	300	10	0	5.89	6.33	6.11	0.22
B	Vinyl Ester	1	300	10	0	14.90	15.30	15.10	0.20
C	Epoxy	1	300	10	0	6.19	6.65	6.42	0.23
A	Epoxy	1	300	10	200	5.20	5.26	5.23	0.03
B	Vinyl Ester	1	300	10	200	18.54	18.90	18.72	0.18
C	Epoxy	1	300	10	200	5.46	5.52	5.49	0.03

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Table 7.8: Alkalinity Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Alkalinity			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppmas$CaCO_3$	$\vee$ ppmas$CaCO_3$	μ ppmas$CaCO_3$	σ ppmas$CaCO_3$
A	Epoxy	1	300	10	20000	4.44	4.87	4.65	0.21
B	Vinyl Ester	1	300	10	20000	23.47	23.57	23.52	0.05
C	Epoxy	1	300	10	20000	4.66	5.11	4.89	0.22
A	Epoxy	1	300	10	SeaWater	98.97	100.57	99.77	0.80
B	Vinyl Ester	1	300	10	SeaWater	122.95	124.46	123.71	0.75
C	Epoxy	1	300	10	SeaWater	103.92	105.60	104.76	0.84
A	Epoxy	2	300	10	0	5.41	5.59	5.50	0.09
B	Vinyl Ester	2	300	10	0	14.90	15.03	14.97	0.06
C	Epoxy	2	300	10	0	5.73	5.93	5.83	0.10
A	Epoxy	2	300	10	200	4.31	4.47	4.39	0.08
B	Vinyl Ester	2	300	10	200	16.54	16.90	16.72	0.18
C	Epoxy	2	300	10	200	4.56	4.74	4.65	0.09
A	Epoxy	2	300	10	20000	3.64	4.07	3.85	0.21
B	Vinyl Ester	2	300	10	20000	19.07	19.17	19.12	0.05
C	Epoxy	2	300	10	20000	3.86	4.31	4.08	0.23
A	Epoxy	2	300	10	SeaWater	94.87	96.70	95.78	0.92
B	Vinyl Ester	2	300	10	SeaWater	120.24	122.21	121.22	0.98
C	Epoxy	2	300	10	SeaWater	100.56	102.50	101.53	0.97
A	Epoxy	1	300	13	0	166.25	182.42	174.33	8.08
B	Vinyl Ester	1	300	13	0	957.00	973.00	965.00	8.00
C	Epoxy	1	300	13	0	167.25	183.51	175.38	8.13
A	Epoxy	1	300	13	200	127.54	134.46	131.00	3.46
B	Vinyl Ester	1	300	13	200	1395.98	1407.35	1401.67	5.69
C	Epoxy	1	300	13	200	128.56	135.54	132.05	3.49
A	Epoxy	1	300	13	20000	117.18	119.49	118.33	1.15
B	Vinyl Ester	1	300	13	20000	1456.85	1477.15	1467.00	10.15
C	Epoxy	1	300	13	20000	118.35	120.68	119.52	1.17

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Table 7.8: Alkalinity Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Alkalinity			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppmas$CaCO_3$	$\vee$ ppmas$CaCO_3$	μ ppmas$CaCO_3$	σ ppmas$CaCO_3$
A	Epoxy	1	300	13	SeaWater	373.57	436.43	405.00	31.43
B	Vinyl Ester	1	300	13	SeaWater	4141.51	4195.82	4168.67	27.15
C	Epoxy	1	300	13	SeaWater	378.87	438.18	408.53	29.66
A	Epoxy	2	300	13	0	104.09	119.24	111.67	7.57
B	Vinyl Ester	2	300	13	0	1397.00	1413.00	1405.00	8.00
C	Epoxy	2	300	13	0	104.93	120.19	112.56	7.63
A	Epoxy	2	300	13	200	84.87	115.13	100.00	15.13
B	Vinyl Ester	2	300	13	200	1508.31	1520.36	1514.33	6.03
C	Epoxy	2	300	13	200	85.72	116.28	101.00	15.28
A	Epoxy	2	300	13	20000	79.25	83.41	81.33	2.08
B	Vinyl Ester	2	300	13	20000	1776.85	1797.15	1787.00	10.15
C	Epoxy	2	300	13	20000	80.20	84.42	82.31	2.11
A	Epoxy	2	300	13	SeaWater	320.02	383.31	351.67	31.64
B	Vinyl Ester	2	300	13	SeaWater	4093.19	4129.48	4111.33	18.15
C	Epoxy	2	300	13	SeaWater	324.50	388.68	356.59	32.09

Table 7.9: Alkalinity Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Alkalinity			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppmas$CaCO_3$	$\vee$ ppmas$CaCO_3$	μ ppmas$CaCO_3$	σ ppmas$CaCO_3$
A	Epoxy	300	4	0	−7.95	−7.59	−7.77	0.18
B	Vinyl Ester	300	4	0	−8.92	−7.96	−8.44	0.48
A	Epoxy	300	4	200	−8.59	−8.45	−8.52	0.07
B	Vinyl Ester	300	4	200	−10.20	−10.15	−10.17	0.02
A	Epoxy	300	4	20000	−11.13	−10.42	−10.77	0.36
B	Vinyl Ester	300	4	20000	−12.51	−12.37	−12.44	0.07
A	Epoxy	300	4	SeaWater	−12.91	−12.86	−12.89	0.02
B	Vinyl Ester	300	4	SeaWater	−14.73	−14.51	−14.62	0.11
A	Epoxy	300	7	0	0.71	1.78	1.25	0.53
B	Vinyl Ester	300	7	0	0.29	1.62	0.95	0.67
A	Epoxy	300	7	200	0.44	1.76	1.10	0.66
B	Vinyl Ester	300	7	200	0.04	1.36	0.70	0.66
A	Epoxy	300	7	20000	0.54	1.01	0.77	0.24
B	Vinyl Ester	300	7	20000	−0.39	0.90	0.25	0.64
A	Epoxy	300	7	SeaWater	55.27	55.93	55.60	0.33
B	Vinyl Ester	300	7	SeaWater	53.48	54.15	53.81	0.34
A	Epoxy	300	10	0	5.53	5.89	5.71	0.18
B	Vinyl Ester	300	10	0	5.08	5.44	5.26	0.18
A	Epoxy	300	10	200	3.95	4.37	4.16	0.21
B	Vinyl Ester	300	10	200	3.65	4.13	3.89	0.24
A	Epoxy	300	10	20000	3.64	4.07	3.85	0.21
B	Vinyl Ester	300	10	20000	3.30	3.58	3.44	0.14
A	Epoxy	300	10	SeaWater	94.67	95.84	95.25	0.58
B	Vinyl Ester	300	10	SeaWater	92.41	93.58	93.00	0.59
A	Epoxy	300	13	0	2137.00	2153.00	2145.00	8.00
B	Vinyl Ester	300	13	0	2085.56	2097.78	2091.67	6.11
A	Epoxy	300	13	200	2003.98	2015.35	2009.67	5.69

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Table 7.9: Alkalinity Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Alkalinity			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppmas$CaCO_3$	$\vee$ ppmas$CaCO_3$	μ ppmas$CaCO_3$	σ ppmas$CaCO_3$
B	Vinyl Ester	300	13	200	1943.98	1955.35	1949.67	5.69
A	Epoxy	300	13	20000	1887.37	1915.96	1901.67	14.29
B	Vinyl Ester	300	13	20000	1847.37	1875.96	1861.67	14.29
A	Epoxy	300	13	SeaWater	3954.43	3992.24	3973.33	18.90
B	Vinyl Ester	300	13	SeaWater	3927.76	3965.57	3946.67	18.90

Table 7.10: Alkalinity Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Alkalinity			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppmas$CaCO_3$	$\vee$ ppmas$CaCO_3$	μ ppmas$CaCO_3$	σ ppmas$CaCO_3$
A	Sized	300	4	0	−2.40	−2.21	−2.31	0.09
B	Sized	300	4	0	−2.60	−2.55	−2.57	0.02
C	Sized	300	4	0	−2.16	−1.99	−2.08	0.08
A	Sized	300	4	200	−2.14	−2.08	−2.11	0.03
B	Sized	300	4	200	−2.34	−2.24	−2.29	0.05
C	Sized	300	4	200	−1.93	−1.87	−1.90	0.03
A	Sized	300	4	20000	−1.86	−1.69	−1.77	0.08
B	Sized	300	4	20000	−2.84	−1.83	−2.33	0.50
C	Sized	300	4	20000	−1.67	−1.52	−1.60	0.07
A	Sized	300	4	SeaWater	−1.30	−0.65	−0.97	0.33
B	Sized	300	4	SeaWater	−1.57	−0.96	−1.27	0.31
C	Sized	300	4	SeaWater	−1.17	−0.58	−0.88	0.29
A	Unsized	300	4	0	−2.07	−1.82	−1.95	0.13
B	Unsized	300	4	0	−2.20	−2.15	−2.17	0.02
A	Unsized	300	4	200	−2.03	−1.59	−1.81	0.22
B	Unsized	300	4	200	−2.14	−2.12	−2.13	0.01
A	Unsized	300	4	20000	−2.20	−1.98	−2.09	0.11
B	Unsized	300	4	20000	−2.13	−1.07	−1.60	0.53
A	Unsized	300	4	SeaWater	−1.60	−0.80	−1.20	0.40
B	Unsized	300	4	SeaWater	−1.50	−1.04	−1.27	0.23
A	Sized	300	7	0	4.69	4.89	4.79	0.10
B	Sized	300	7	0	3.78	5.33	4.55	0.77
C	Sized	300	7	0	4.93	5.14	5.03	0.10
A	Sized	300	7	200	6.75	7.13	6.94	0.19
B	Sized	300	7	200	5.43	6.61	6.02	0.59
C	Sized	300	7	200	7.08	7.49	7.29	0.20
A	Sized	300	7	20000	7.00	7.27	7.13	0.13

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Table 7.10: Alkalinity Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Alkalinity			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppmas$CaCO_3$	$\vee$ ppmas$CaCO_3$	μ ppmas$CaCO_3$	σ ppmas$CaCO_3$
B	Sized	300	7	20000	6.61	7.12	6.87	0.25
C	Sized	300	7	20000	7.35	7.63	7.49	0.14
A	Sized	300	7	SeaWater	78.84	80.07	79.46	0.62
B	Sized	300	7	SeaWater	77.11	77.57	77.34	0.23
C	Sized	300	7	SeaWater	82.78	84.08	83.43	0.65
A	Unsized	300	7	0	3.87	5.39	4.63	0.76
B	Unsized	300	7	0	3.71	5.27	4.49	0.78
A	Unsized	300	7	200	5.43	6.62	6.02	0.59
B	Unsized	300	7	200	5.27	6.43	5.85	0.58
A	Unsized	300	7	20000	6.30	6.81	6.55	0.26
B	Unsized	300	7	20000	6.19	6.70	6.44	0.26
A	Unsized	300	7	SeaWater	76.00	77.34	76.67	0.67
B	Unsized	300	7	SeaWater	73.81	75.16	74.48	0.68
A	Sized	300	10	0	15.48	15.79	15.63	0.16
B	Sized	300	10	0	13.98	14.04	14.01	0.03
C	Sized	300	10	0	16.25	16.58	16.42	0.16
A	Sized	300	10	200	18.78	19.06	18.92	0.14
B	Sized	300	10	200	14.86	17.99	16.43	1.56
C	Sized	300	10	200	19.72	20.01	19.87	0.15
A	Sized	300	10	20000	22.89	24.34	23.61	0.73
B	Sized	300	10	20000	18.85	20.57	19.71	0.86
C	Sized	300	10	20000	24.03	25.56	24.79	0.76
A	Sized	300	10	SeaWater	123.63	124.69	124.16	0.53
B	Sized	300	10	SeaWater	122.24	122.62	122.43	0.19
C	Sized	300	10	SeaWater	129.81	130.92	130.37	0.55
A	Unsized	300	10	0	14.74	15.03	14.89	0.14
B	Unsized	300	10	0	10.90	11.30	11.10	0.20

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Table 7.10: Alkalinity Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Alkalinity			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppmas$CaCO_3$	$\vee$ ppmas$CaCO_3$	μ ppmas$CaCO_3$	σ ppmas$CaCO_3$
A	Unsized	300	10	200	15.27	15.64	15.45	0.19
B	Unsized	300	10	200	12.95	13.26	13.11	0.16
A	Unsized	300	10	20000	16.64	17.38	17.01	0.37
B	Unsized	300	10	20000	14.67	14.77	14.72	0.05
A	Unsized	300	10	SeaWater	118.20	119.73	118.97	0.76
B	Unsized	300	10	SeaWater	116.84	117.93	117.38	0.54
A	Sized	300	13	0	1535.01	1568.32	1551.67	16.65
B	Sized	300	13	0	1445.56	1457.78	1451.67	6.11
C	Sized	300	13	0	1542.69	1576.16	1559.43	16.74
A	Sized	300	13	200	2115.68	2128.99	2122.33	6.66
B	Sized	300	13	200	2095.98	2107.35	2101.67	5.69
C	Sized	300	13	200	2128.37	2141.77	2135.07	6.70
A	Sized	300	13	20000	2187.69	2216.97	2202.33	14.64
B	Sized	300	13	20000	2118.00	2140.00	2129.00	11.00
C	Sized	300	13	20000	2203.01	2232.49	2217.75	14.74
A	Sized	300	13	SeaWater	4220.00	4260.00	4240.00	20.00
B	Sized	300	13	SeaWater	4165.56	4243.77	4204.67	39.11
C	Sized	300	13	SeaWater	4232.66	4272.78	4252.72	20.06
A	Unsized	300	13	0	1443.91	1478.09	1461.00	17.09
B	Unsized	300	13	0	1085.56	1097.78	1091.67	6.11
A	Unsized	300	13	200	1499.73	1522.27	1511.00	11.27
B	Unsized	300	13	200	1195.98	1207.35	1201.67	5.69
A	Unsized	300	13	20000	2079.72	2111.61	2095.67	15.95
B	Unsized	300	13	20000	2118.00	2140.00	2129.00	11.00
A	Unsized	300	13	SeaWater	4177.51	4231.82	4204.67	27.15
B	Unsized	300	13	SeaWater	4124.43	4164.90	4144.67	20.23

For a better understanding, change in the alkalinity content of the environments was plotted in graphs in Figure 7.10, 7.11, and 7.12. It can be seen from the figures that in general, the alkalinity content continues

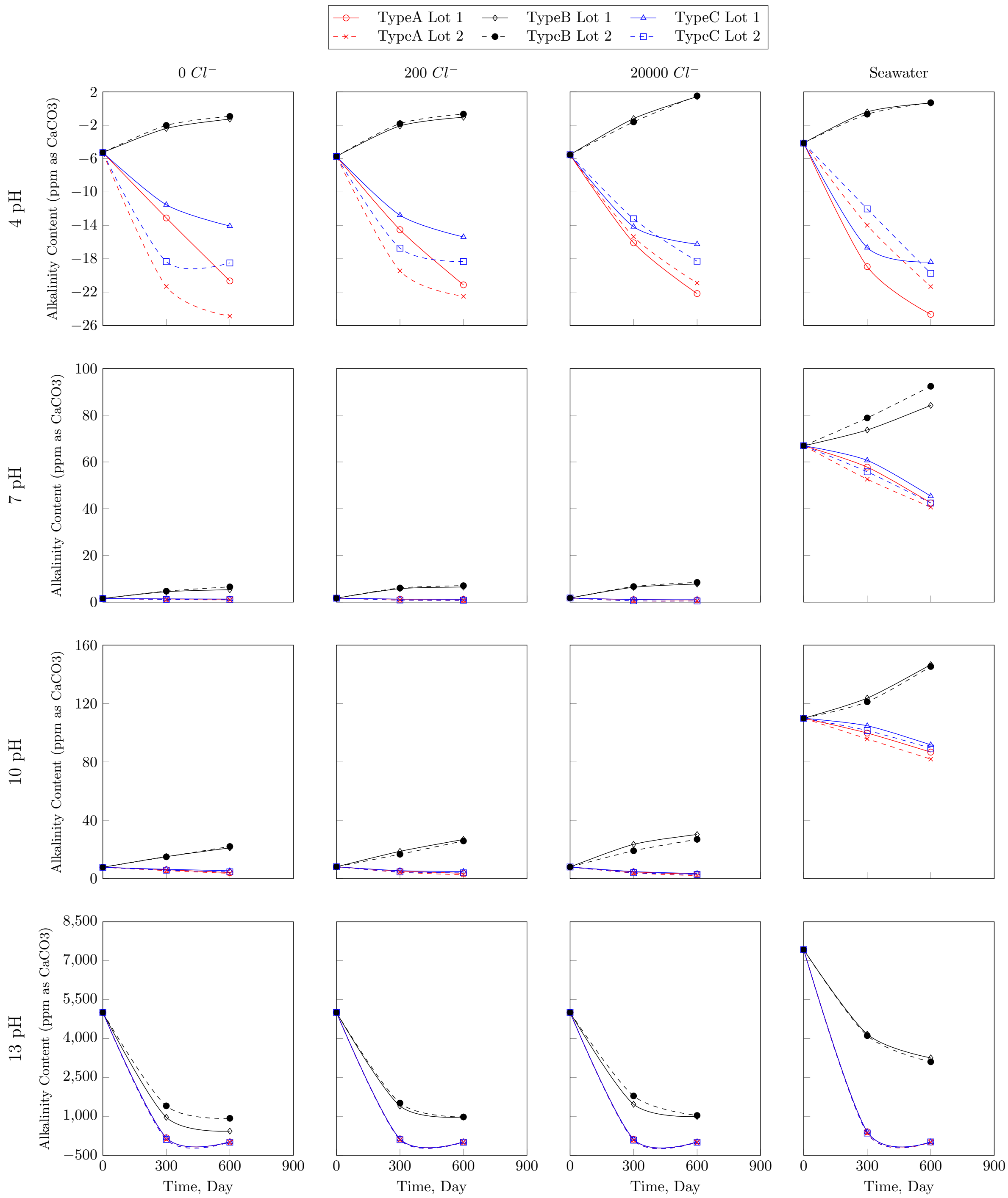

Figure 7.10: Alkalinity of environments after exposure of rebars

to decrease, with a few exceptions (vinyl-ester rebar sample combined in seawater with pH 10 or less, and all fiber only samples with pH 10 or less) but all trending to a slower rate of change, especially for the rebar in the pH 13 environment.

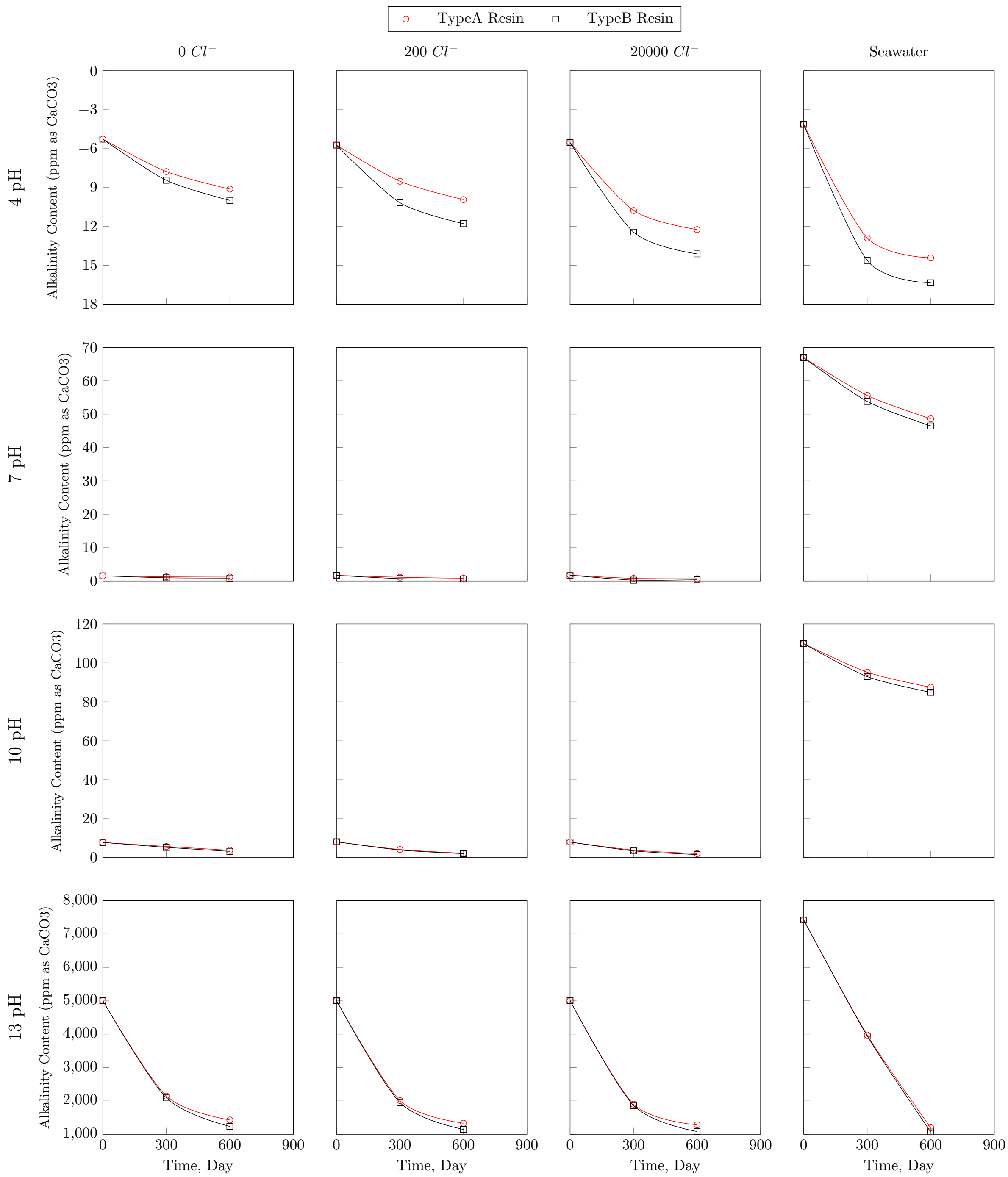

Figure 7.11: Alkalinity of environments after exposure of resins

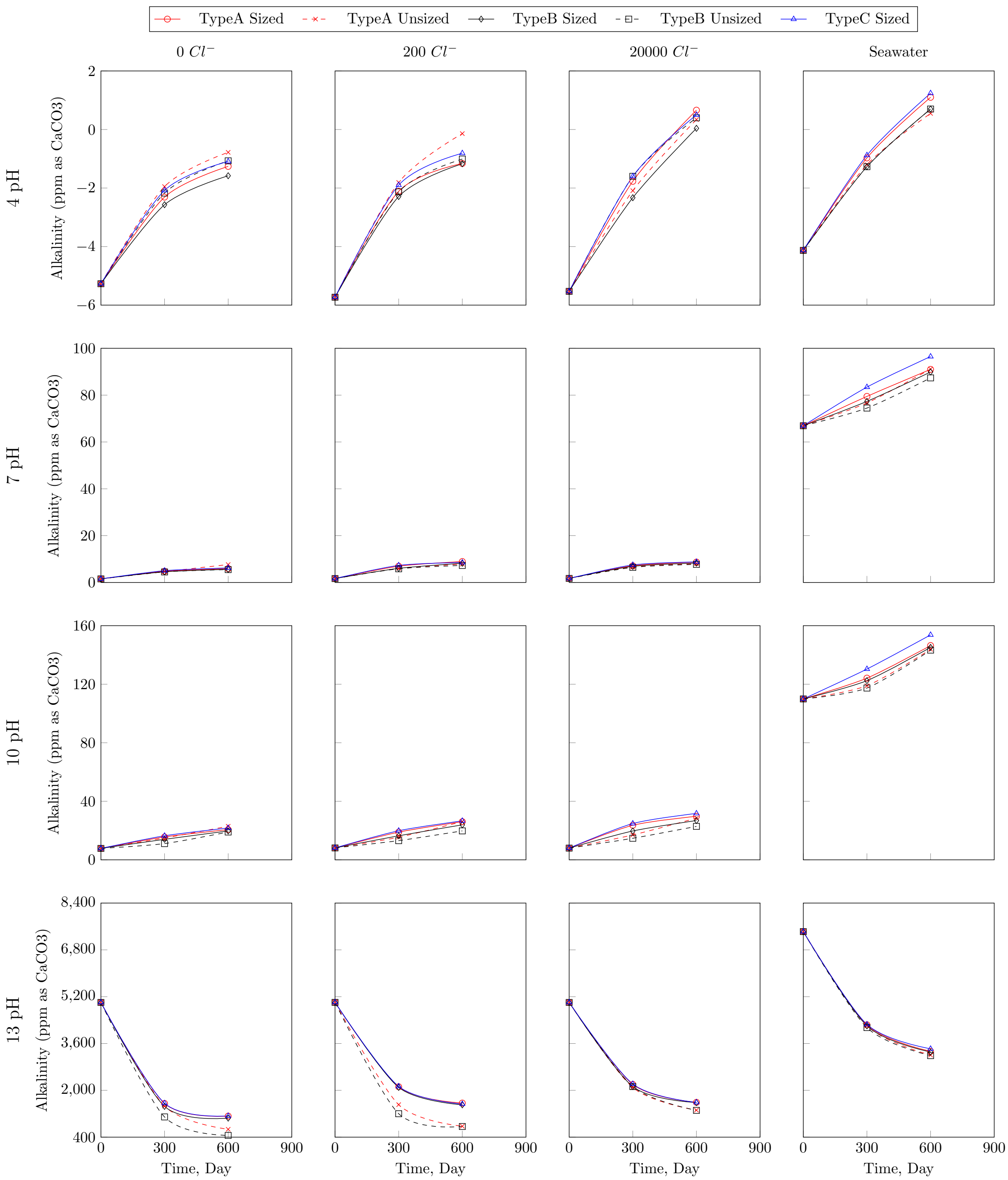

Figure 7.12: Alkalinity of environments after exposure of sized and unsized fibers

7.2.5 Anions

Chloride

Chloride content of the chemical environments was measured after 300 days of exposure. Tables 7.11, 7.12, and 7.13 below shows the Chloride data of environments in which rebars, resins, and fibers were exposed.

Table 7.11: Chloride Ion Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Chloride Ion			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	4	0	0.40	0.42	0.41	0.01
B	Vinyl Ester	1	300	4	0	0.48	0.54	0.51	0.03
C	Epoxy	1	300	4	0	0.52	0.55	0.53	0.01
A	Epoxy	1	300	4	200	214.52	214.60	214.56	0.04
B	Vinyl Ester	1	300	4	200	204.61	207.33	205.97	1.36
C	Epoxy	1	300	4	200	220.95	221.04	220.99	0.04
A	Epoxy	1	300	4	20000	19 965.12	19 988.21	19 976.67	11.55
B	Vinyl Ester	1	300	4	20000	19 911.19	19 975.48	19 943.33	32.15
C	Epoxy	1	300	4	20000	19 985.08	20 008.20	19 996.64	11.56
A	Epoxy	1	300	4	SeaWater	19 789.41	19 883.92	19 836.67	47.26
B	Vinyl Ester	1	300	4	SeaWater	19 861.79	19 884.88	19 873.33	11.55
C	Epoxy	1	300	4	SeaWater	19 809.20	19 903.81	19 856.50	47.31
A	Epoxy	2	300	4	0	0.36	0.39	0.37	0.02
B	Vinyl Ester	2	300	4	0	0.12	0.15	0.14	0.02
C	Epoxy	2	300	4	0	0.44	0.47	0.46	0.02
A	Epoxy	2	300	4	200	205.76	205.82	205.79	0.03
B	Vinyl Ester	2	300	4	200	203.59	204.47	204.03	0.44
C	Epoxy	2	300	4	200	211.52	211.58	211.55	0.03
A	Epoxy	2	300	4	20000	19 945.85	19 987.48	19 966.67	20.82
B	Vinyl Ester	2	300	4	20000	19 922.52	19 964.15	19 943.33	20.82
C	Epoxy	2	300	4	20000	19 975.77	20 017.46	19 996.62	20.85
A	Epoxy	2	300	4	SeaWater	19 796.41	19 883.59	19 840.00	43.59
B	Vinyl Ester	2	300	4	SeaWater	19 808.19	19 868.47	19 838.33	30.14
C	Epoxy	2	300	4	SeaWater	19 826.11	19 913.41	19 869.76	43.65
A	Epoxy	1	300	7	0	0.30	0.36	0.33	0.03
B	Vinyl Ester	1	300	7	0	0.35	0.42	0.39	0.04
C	Epoxy	1	300	7	0	0.39	0.47	0.43	0.04

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Table 7.11: Chloride Ion Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Chloride Ion			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	7	200	211.65	211.68	211.67	0.02
B	Vinyl Ester	1	300	7	200	206.53	207.03	206.78	0.25
C	Epoxy	1	300	7	200	218.00	218.03	218.02	0.02
A	Epoxy	1	300	7	20000	19 920.00	19 940.00	19 930.00	10.00
B	Vinyl Ester	1	300	7	20000	19 925.85	19 967.48	19 946.67	20.82
C	Epoxy	1	300	7	20000	19 939.92	19 959.94	19 949.93	10.01
A	Epoxy	1	300	7	SeaWater	19 803.94	19 876.06	19 840.00	36.06
B	Vinyl Ester	1	300	7	SeaWater	19 812.68	19 847.32	19 830.00	17.32
C	Epoxy	1	300	7	SeaWater	19 823.75	19 895.93	19 859.84	36.09
A	Epoxy	2	300	7	0	0.35	0.37	0.36	0.01
B	Vinyl Ester	2	300	7	0	0.27	0.29	0.28	0.01
C	Epoxy	2	300	7	0	0.42	0.45	0.44	0.01
A	Epoxy	2	300	7	200	204.61	204.71	204.66	0.05
B	Vinyl Ester	2	300	7	200	203.49	204.17	203.83	0.34
C	Epoxy	2	300	7	200	210.34	210.44	210.39	0.05
A	Epoxy	2	300	7	20000	19 912.92	19 993.75	19 953.33	40.41
B	Vinyl Ester	2	300	7	20000	19 914.11	19 949.23	19 931.67	17.56
C	Epoxy	2	300	7	20000	19 942.79	20 023.74	19 983.26	40.48
A	Epoxy	2	300	7	SeaWater	19 832.52	19 874.15	19 853.33	20.82
B	Vinyl Ester	2	300	7	SeaWater	19 801.55	19 871.79	19 836.67	35.12
C	Epoxy	2	300	7	SeaWater	19 862.27	19 903.96	19 883.11	20.85
A	Epoxy	1	300	10	0	0.61	0.65	0.63	0.02
B	Vinyl Ester	1	300	10	0	0.25	0.31	0.28	0.03
C	Epoxy	1	300	10	0	0.80	0.85	0.82	0.03
A	Epoxy	1	300	10	200	205.26	205.30	205.28	0.02
B	Vinyl Ester	1	300	10	200	206.07	207.53	206.80	0.73
C	Epoxy	1	300	10	200	211.41	211.46	211.43	0.02

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Table 7.11: Chloride Ion Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Chloride Ion			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	10	20000	19 894.17	19 985.83	19 940.00	45.83
B	Vinyl Ester	1	300	10	20000	19 913.94	19 986.06	19 950.00	36.06
C	Epoxy	1	300	10	20000	19 914.07	20 005.81	19 959.94	45.87
A	Epoxy	1	300	10	SeaWater	19 825.47	19 901.19	19 863.33	37.86
B	Vinyl Ester	1	300	10	SeaWater	19 821.50	19 871.83	19 846.67	25.17
C	Epoxy	1	300	10	SeaWater	19 845.30	19 921.09	19 883.20	37.90
A	Epoxy	2	300	10	0	0.83	0.87	0.85	0.02
B	Vinyl Ester	2	300	10	0	0.50	0.53	0.51	0.02
C	Epoxy	2	300	10	0	1.01	1.06	1.04	0.02
A	Epoxy	2	300	10	200	206.58	206.64	206.61	0.03
B	Vinyl Ester	2	300	10	200	201.61	202.42	202.02	0.40
C	Epoxy	2	300	10	200	212.37	212.42	212.40	0.03
A	Epoxy	2	300	10	20000	19 898.81	19 974.53	19 936.67	37.86
B	Vinyl Ester	2	300	10	20000	19 908.17	19 958.50	19 933.33	25.17
C	Epoxy	2	300	10	20000	19 928.66	20 004.49	19 966.57	37.92
A	Epoxy	2	300	10	SeaWater	19 840.00	19 880.00	19 860.00	20.00
B	Vinyl Ester	2	300	10	SeaWater	19 815.47	19 891.19	19 853.33	37.86
C	Epoxy	2	300	10	SeaWater	19 869.76	19 909.82	19 889.79	20.03
A	Epoxy	1	300	13	0	0.39	0.43	0.41	0.02
B	Vinyl Ester	1	300	13	0	0.45	0.51	0.48	0.03
C	Epoxy	1	300	13	0	0.51	0.56	0.54	0.03
A	Epoxy	1	300	13	200	212.15	212.19	212.17	0.02
B	Vinyl Ester	1	300	13	200	204.60	205.73	205.16	0.57
C	Epoxy	1	300	13	200	218.51	218.55	218.53	0.02
A	Epoxy	1	300	13	20000	19 917.15	20 009.52	19 963.33	46.19
B	Vinyl Ester	1	300	13	20000	19 912.78	19 973.88	19 943.33	30.55
C	Epoxy	1	300	13	20000	19 937.06	20 029.53	19 983.30	46.23

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Table 7.11: Chloride Ion Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Chloride Ion			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	13	SeaWater	19 821.53	19 881.81	19 851.67	30.14
B	Vinyl Ester	1	300	13	SeaWater	19 807.80	19 865.53	19 836.67	28.87
C	Epoxy	1	300	13	SeaWater	19 841.35	19 901.69	19 871.52	30.17
A	Epoxy	2	300	13	0	0.48	0.51	0.49	0.02
B	Vinyl Ester	2	300	13	0	0.60	0.67	0.63	0.03
C	Epoxy	2	300	13	0	0.58	0.62	0.60	0.02
A	Epoxy	2	300	13	200	207.87	207.91	207.89	0.02
B	Vinyl Ester	2	300	13	200	203.01	204.80	203.90	0.90
C	Epoxy	2	300	13	200	213.69	213.74	213.71	0.02
A	Epoxy	2	300	13	20000	19 911.19	19 975.48	19 943.33	32.15
B	Vinyl Ester	2	300	13	20000	19 901.70	19 984.97	19 943.33	41.63
C	Epoxy	2	300	13	20000	19 941.05	20 005.44	19 973.25	32.19
A	Epoxy	2	300	13	SeaWater	19 852.52	19 894.15	19 873.33	20.82
B	Vinyl Ester	2	300	13	SeaWater	19 800.81	19 875.86	19 838.33	37.53
C	Epoxy	2	300	13	SeaWater	19 882.30	19 923.99	19 903.14	20.85

Table 7.12: Chloride Ion Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Chloride Ion			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	300	4	0	0.57	0.62	0.60	0.03
B	Vinyl Ester	300	4	0	0.17	0.28	0.22	0.06
A	Epoxy	300	4	200	203.60	204.77	204.19	0.59
B	Vinyl Ester	300	4	200	205.06	206.04	205.55	0.49
A	Epoxy	300	4	20000	19 912.68	19 947.32	19 930.00	17.32
B	Vinyl Ester	300	4	20000	19 931.39	19 961.94	19 946.67	15.28
A	Epoxy	300	4	SeaWater	19 848.06	19 878.61	19 863.33	15.28
B	Vinyl Ester	300	4	SeaWater	19 815.47	19 891.19	19 853.33	37.86
A	Epoxy	300	7	0	0.61	0.65	0.63	0.02
B	Vinyl Ester	300	7	0	0.09	0.16	0.13	0.04
A	Epoxy	300	7	200	204.99	205.03	205.01	0.02
B	Vinyl Ester	300	7	200	202.47	204.82	203.65	1.17
A	Epoxy	300	7	20000	19 912.52	19 954.15	19 933.33	20.82
B	Vinyl Ester	300	7	20000	19 918.21	19 988.45	19 953.33	35.12
A	Epoxy	300	7	SeaWater	19 802.78	19 863.88	19 833.33	30.55
B	Vinyl Ester	300	7	SeaWater	19 821.50	19 871.83	19 846.67	25.17
A	Epoxy	300	10	0	0.73	0.77	0.75	0.02
B	Vinyl Ester	300	10	0	0.41	0.50	0.45	0.05
A	Epoxy	300	10	200	205.43	206.74	206.08	0.65
B	Vinyl Ester	300	10	200	205.40	206.39	205.90	0.49
A	Epoxy	300	10	20000	19 921.50	19 971.83	19 946.67	25.17
B	Vinyl Ester	300	10	20000	19 938.06	19 968.61	19 953.33	15.28
A	Epoxy	300	10	SeaWater	19 843.54	19 896.46	19 870.00	26.46
B	Vinyl Ester	300	10	SeaWater	19 807.34	19 906.00	19 856.67	49.33
A	Epoxy	300	13	0	0.37	0.41	0.39	0.02
B	Vinyl Ester	300	13	0	0.23	0.39	0.31	0.08
A	Epoxy	300	13	200	208.92	210.07	209.49	0.58

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Table 7.12: Chloride Ion Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Chloride Ion			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	300	13	200	200.99	207.16	204.07	3.08
A	Epoxy	300	13	20000	19 901.50	19 951.83	19 926.67	25.17
B	Vinyl Ester	300	13	20000	19 901.50	19 951.83	19 926.67	25.17
A	Epoxy	300	13	SeaWater	19 838.06	19 868.61	19 853.33	15.28
B	Vinyl Ester	300	13	SeaWater	19 830.24	19 876.43	19 853.33	23.09

Table 7.13: Chloride Ion Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Chloride Ion			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Sized	300	4	0	0.11	0.12	0.11	0.01
B	Sized	300	4	0	0.11	0.13	0.12	0.01
C	Sized	300	4	0	0.13	0.14	0.14	0.01
A	Sized	300	4	200	204.94	205.00	204.97	0.03
B	Sized	300	4	200	203.48	204.51	203.99	0.51
C	Sized	300	4	200	209.04	209.10	209.07	0.03
A	Sized	300	4	20000	19 888.81	19 964.53	19 926.67	37.86
B	Sized	300	4	20000	19 935.85	19 977.48	19 956.67	20.82
C	Sized	300	4	20000	19 928.58	20 004.46	19 966.52	37.94
A	Sized	300	4	SeaWater	19 803.94	19 876.06	19 840.00	36.06
B	Sized	300	4	SeaWater	19 791.19	19 855.48	19 823.33	32.15
C	Sized	300	4	SeaWater	19 843.55	19 915.81	19 879.68	36.13
A	Unsized	300	4	0	0.40	0.44	0.42	0.02
B	Unsized	300	4	0	0.16	0.19	0.17	0.02
A	Unsized	300	4	200	204.96	204.98	204.97	0.01
B	Unsized	300	4	200	202.00	203.02	202.51	0.51
A	Unsized	300	4	20000	19 931.39	19 961.94	19 946.67	15.28
B	Unsized	300	4	20000	19 929.11	19 964.23	19 946.67	17.56
A	Unsized	300	4	SeaWater	19 798.81	19 874.53	19 836.67	37.86
B	Unsized	300	4	SeaWater	19 798.23	19 878.44	19 838.33	40.10
A	Sized	300	7	0	0.14	0.18	0.16	0.02
B	Sized	300	7	0	0.11	0.15	0.13	0.02
C	Sized	300	7	0	0.17	0.21	0.19	0.02
A	Sized	300	7	200	207.77	207.82	207.79	0.02
B	Sized	300	7	200	202.86	204.14	203.50	0.64
C	Sized	300	7	200	211.93	211.97	211.95	0.02
A	Sized	300	7	20000	19 886.41	19 973.59	19 930.00	43.59
B	Sized	300	7	20000	19 950.89	19 962.44	19 956.67	5.77
C	Sized	300	7	20000	19 926.18	20 013.54	19 969.86	43.68
A	Sized	300	7	SeaWater	19 843.54	19 896.46	19 870.00	26.46
B	Sized	300	7	SeaWater	19 803.94	19 876.06	19 840.00	36.06
C	Sized	300	7	SeaWater	19 883.23	19 936.25	19 909.74	26.51
A	Unsized	300	7	0	0.24	0.27	0.26	0.02
B	Unsized	300	7	0	0.11	0.17	0.14	0.03
A	Unsized	300	7	200	207.39	207.43	207.41	0.02
B	Unsized	300	7	200	203.53	205.25	204.39	0.86
A	Unsized	300	7	20000	19 932.52	19 974.15	19 953.33	20.82
B	Unsized	300	7	20000	19 939.11	19 974.23	19 956.67	17.56
A	Unsized	300	7	SeaWater	19 796.41	19 883.59	19 840.00	43.59
B	Unsized	300	7	SeaWater	19 832.09	19 877.91	19 855.00	22.91
A	Sized	300	10	0	0.30	0.36	0.33	0.03

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Table 7.13: Chloride Ion Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Chloride Ion			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Sized	300	10	0	0.09	0.12	0.10	0.02
C	Sized	300	10	0	0.36	0.44	0.40	0.04
A	Sized	300	10	200	207.02	207.06	207.04	0.02
B	Sized	300	10	200	202.76	204.42	203.59	0.83
C	Sized	300	10	200	211.16	211.20	211.18	0.02
A	Sized	300	10	20000	19 935.85	19 977.48	19 956.67	20.82
B	Sized	300	10	20000	19 948.06	19 978.61	19 963.33	15.28
C	Sized	300	10	20000	19 975.72	20 017.44	19 996.58	20.86
A	Sized	300	10	SeaWater	19 789.41	19 883.92	19 836.67	47.26
B	Sized	300	10	SeaWater	19 861.39	19 891.94	19 876.67	15.28
C	Sized	300	10	SeaWater	19 828.99	19 923.69	19 876.34	47.35
A	Unsized	300	10	0	0.25	0.29	0.27	0.02
B	Unsized	300	10	0	0.14	0.18	0.16	0.02
A	Unsized	300	10	200	206.04	206.09	206.06	0.03
B	Unsized	300	10	200	203.62	205.72	204.67	1.05
A	Unsized	300	10	20000	19 910.00	19 950.00	19 930.00	20.00
B	Unsized	300	10	20000	19 952.68	19 987.32	19 970.00	17.32
A	Unsized	300	10	SeaWater	19 823.94	19 896.06	19 860.00	36.06
B	Unsized	300	10	SeaWater	19 820.24	19 866.43	19 843.33	23.09
A	Sized	300	13	0	0.52	0.59	0.56	0.03
B	Sized	300	13	0	0.14	0.15	0.15	0.01
C	Sized	300	13	0	0.63	0.71	0.67	0.04
A	Sized	300	13	200	207.02	207.43	207.23	0.21
B	Sized	300	13	200	202.62	204.29	203.45	0.84
C	Sized	300	13	200	211.16	211.58	211.37	0.21
A	Sized	300	13	20000	19 921.19	19 985.48	19 953.33	32.15
B	Sized	300	13	20000	19 931.39	19 961.94	19 946.67	15.28
C	Sized	300	13	20000	19 961.03	20 025.45	19 993.24	32.21
A	Sized	300	13	SeaWater	19 804.17	19 895.83	19 850.00	45.83
B	Sized	300	13	SeaWater	19 789.41	19 883.92	19 836.67	47.26
C	Sized	300	13	SeaWater	19 843.78	19 935.62	19 889.70	45.92
A	Unsized	300	13	0	0.28	0.32	0.30	0.02
B	Unsized	300	13	0	0.11	0.19	0.15	0.04
A	Unsized	300	13	200	208.95	209.03	208.99	0.04
B	Unsized	300	13	200	201.85	204.48	203.16	1.32
A	Unsized	300	13	20000	19 935.85	19 977.48	19 956.67	20.82
B	Unsized	300	13	20000	19 960.75	19 985.92	19 973.33	12.58
A	Unsized	300	13	SeaWater	19 805.47	19 881.19	19 843.33	37.86
B	Unsized	300	13	SeaWater	19 842.52	19 884.15	19 863.33	20.82

For a better understanding, change in the chloride content of the environments was plotted in graphs in

Figure 7.13, 7.14, and 7.15. It can be seen that the chloride content of all samples has increased except for

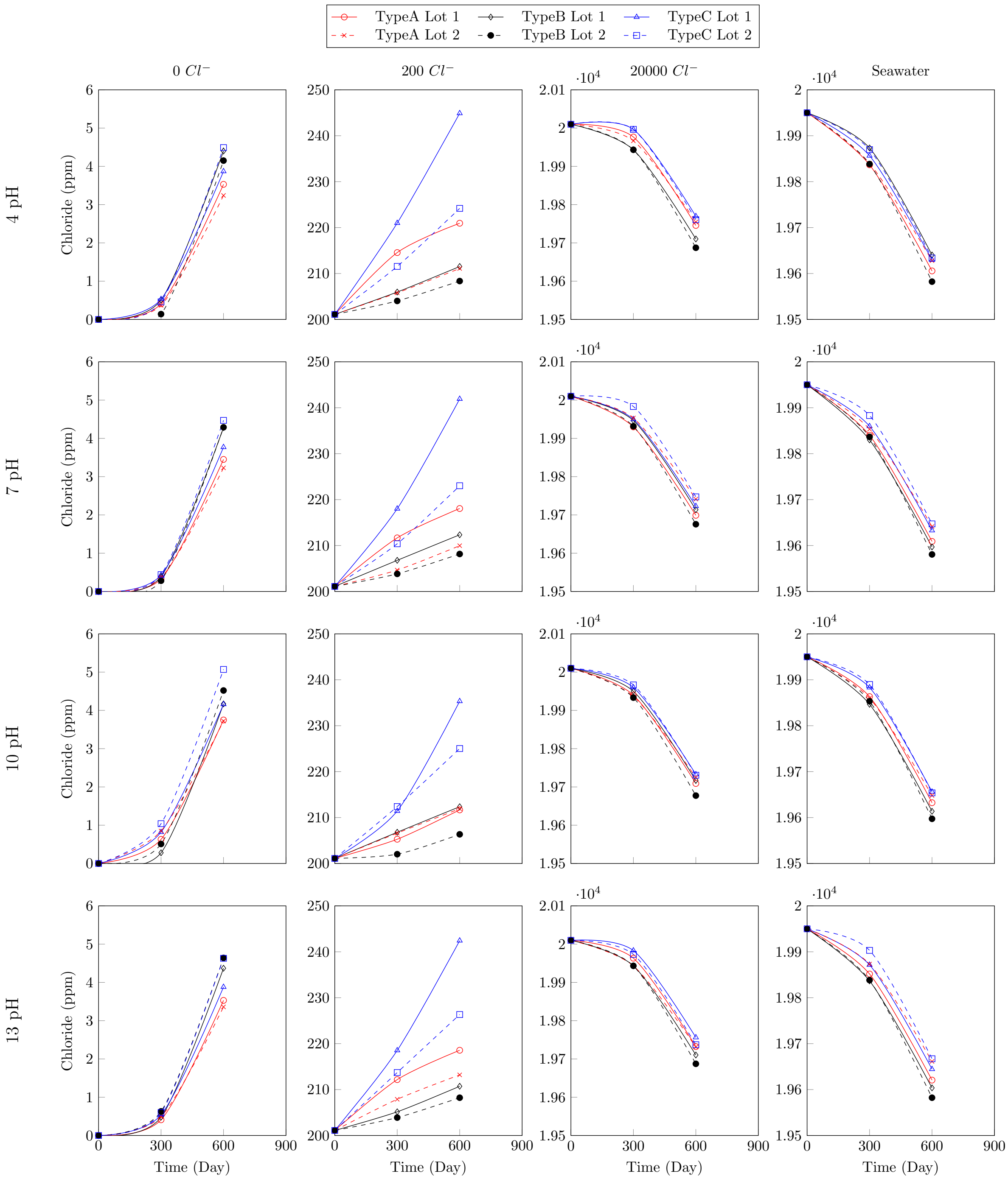

Figure 7.13: Chloride concentration of all environments after exposure of rebars

the 20000ppm synthetic solution and the seawater solution.

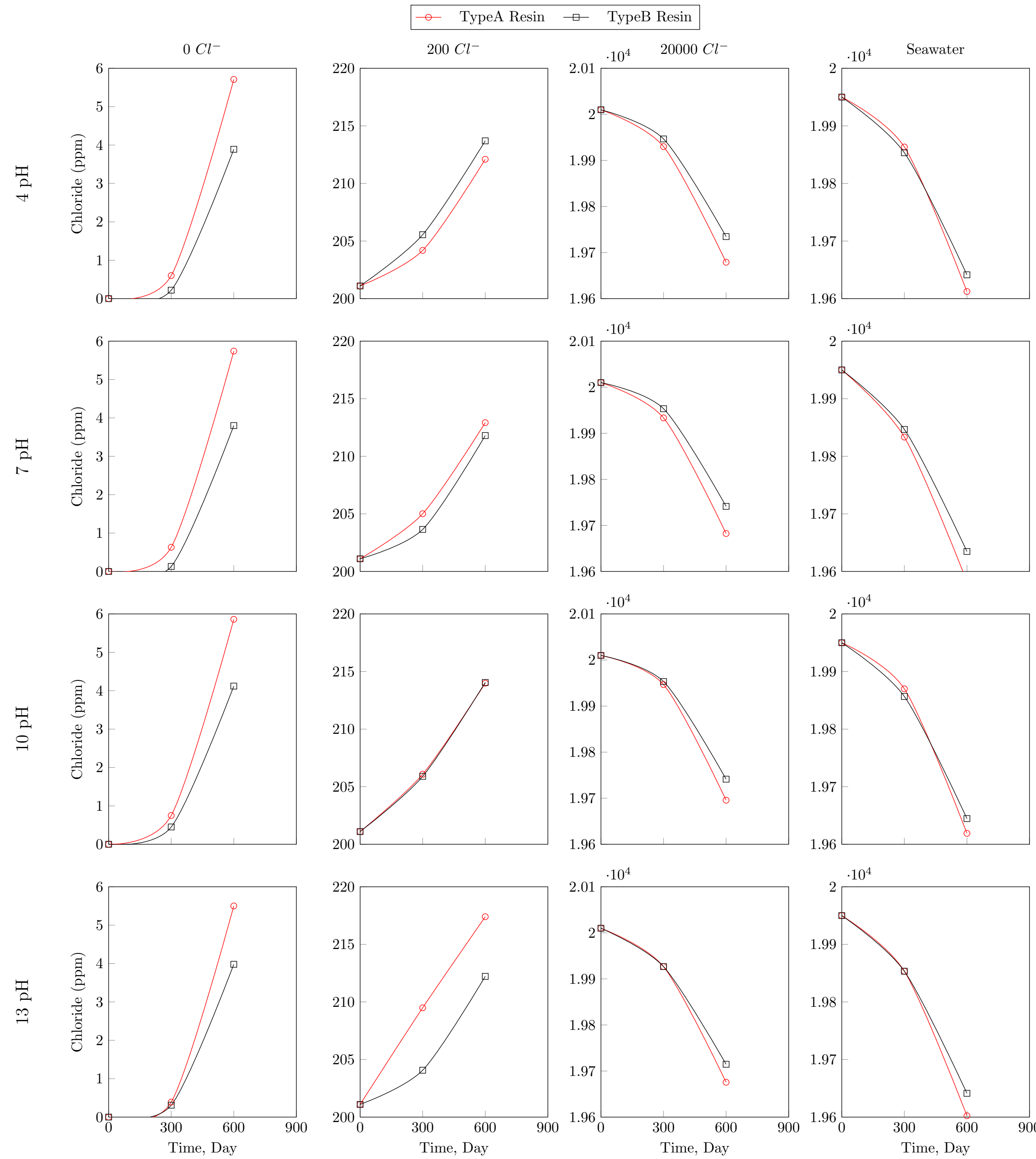

Figure 7.14: Chloride concentration of all environments after exposure of resins

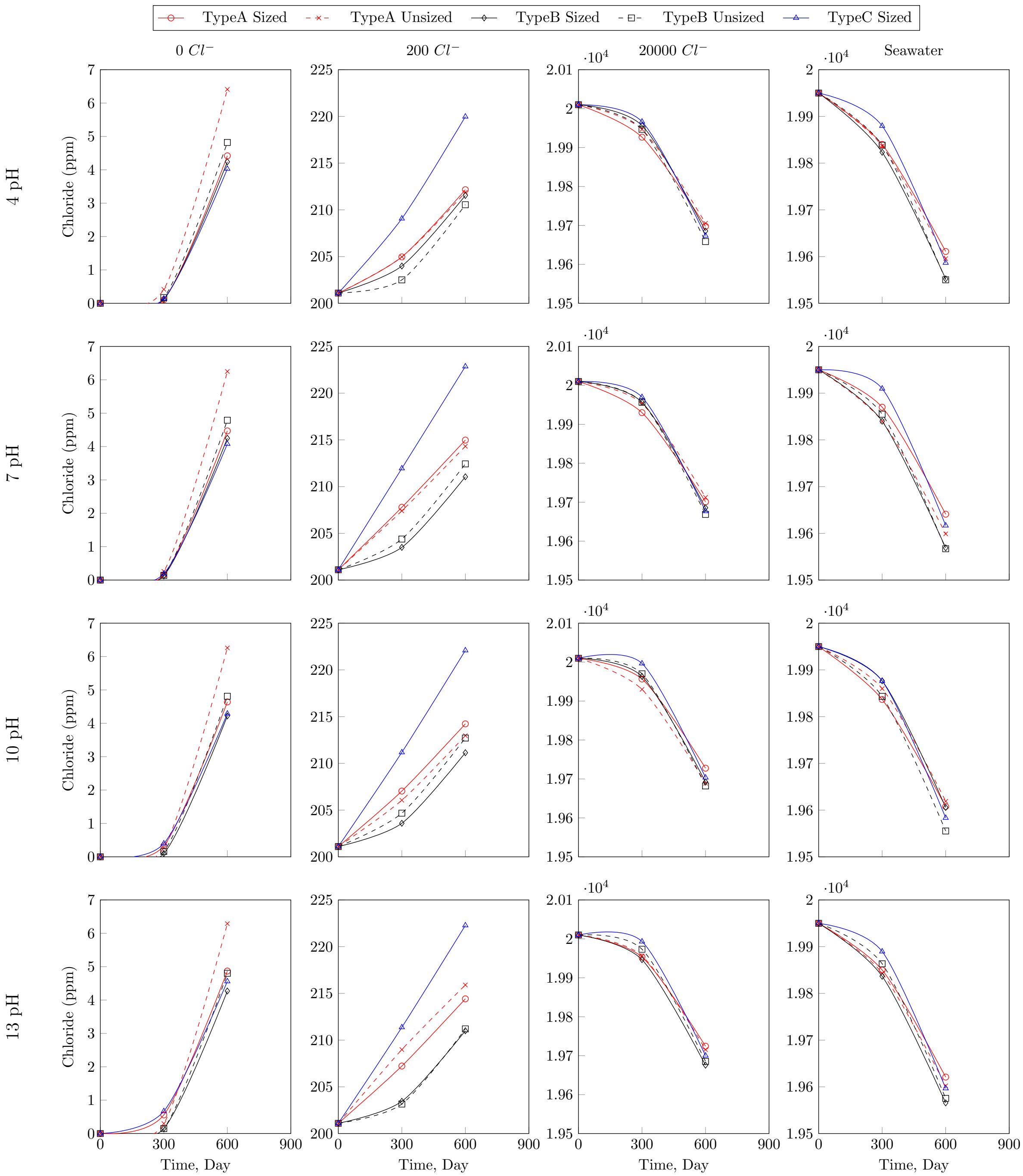

Figure 7.15: Chloride concentration of all environments after exposure of sized and unsized fibers

Sulfate

Sulfate content of the chemical environments was measured after 300 days of exposure. Tables 7.14, 7.15, and 7.16 below shows the sulfate data of environments in which rebars, resins, and fibers were exposed.

Table 7.14: Sulfate Ion Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Sulfate Ion			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	4	0	8.75	8.78	8.77	0.02
B	Vinyl Ester	1	300	4	0	7.24	7.46	7.35	0.11
C	Epoxy	1	300	4	0	11.11	11.15	11.13	0.02
A	Epoxy	1	300	4	200	8.37	8.42	8.40	0.03
B	Vinyl Ester	1	300	4	200	7.81	8.01	7.91	0.10
C	Epoxy	1	300	4	200	10.63	10.70	10.66	0.03
A	Epoxy	1	300	4	20000	8.16	8.21	8.19	0.03
B	Vinyl Ester	1	300	4	20000	7.67	8.20	7.94	0.27
C	Epoxy	1	300	4	20000	10.37	10.43	10.40	0.03
A	Epoxy	1	300	4	SeaWater	2493.81	2569.53	2531.67	37.86
B	Vinyl Ester	1	300	4	SeaWater	2540.12	2563.21	2551.67	11.55
C	Epoxy	1	300	4	SeaWater	2498.79	2574.67	2536.73	37.94
A	Epoxy	2	300	4	0	8.30	8.33	8.31	0.02
B	Vinyl Ester	2	300	4	0	7.35	7.97	7.66	0.31
C	Epoxy	2	300	4	0	10.79	10.83	10.81	0.02
A	Epoxy	2	300	4	200	7.96	8.00	7.98	0.02
B	Vinyl Ester	2	300	4	200	7.09	7.77	7.43	0.34
C	Epoxy	2	300	4	200	10.35	10.40	10.37	0.03
A	Epoxy	2	300	4	20000	8.16	8.20	8.18	0.02
B	Vinyl Ester	2	300	4	20000	7.33	8.03	7.68	0.35
C	Epoxy	2	300	4	20000	10.60	10.66	10.63	0.03
A	Epoxy	2	300	4	SeaWater	2535.00	2555.00	2545.00	10.00
B	Vinyl Ester	2	300	4	SeaWater	2554.16	2575.17	2564.67	10.50
C	Epoxy	2	300	4	SeaWater	2542.61	2562.67	2552.64	10.03
A	Epoxy	1	300	7	0	0.44	0.48	0.46	0.02
B	Vinyl Ester	1	300	7	0	0.20	0.28	0.24	0.04
C	Epoxy	1	300	7	0	0.55	0.61	0.58	0.03

Continued on next page ...

Table 7.14: Sulfate Ion Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Sulfate Ion			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	7	200	0.64	0.68	0.66	0.02
B	Vinyl Ester	1	300	7	200	0.57	0.63	0.60	0.03
C	Epoxy	1	300	7	200	0.81	0.86	0.83	0.03
A	Epoxy	1	300	7	20000	0.71	0.74	0.73	0.02
B	Vinyl Ester	1	300	7	20000	0.44	0.49	0.46	0.02
C	Epoxy	1	300	7	20000	0.90	0.94	0.92	0.02
A	Epoxy	1	300	7	SeaWater	2497.41	2591.92	2544.67	47.26
B	Vinyl Ester	1	300	7	SeaWater	2556.73	2579.27	2568.00	11.27
C	Epoxy	1	300	7	SeaWater	2502.40	2597.11	2549.76	47.35
A	Epoxy	2	300	7	0	0.75	0.79	0.77	0.02
B	Vinyl Ester	2	300	7	0	0.47	0.56	0.51	0.05
C	Epoxy	2	300	7	0	0.97	1.02	1.00	0.03
A	Epoxy	2	300	7	200	0.65	0.68	0.66	0.02
B	Vinyl Ester	2	300	7	200	0.67	0.71	0.69	0.02
C	Epoxy	2	300	7	200	0.84	0.88	0.86	0.02
A	Epoxy	2	300	7	20000	0.91	0.96	0.93	0.02
B	Vinyl Ester	2	300	7	20000	0.57	0.75	0.66	0.09
C	Epoxy	2	300	7	20000	1.18	1.24	1.21	0.03
A	Epoxy	2	300	7	SeaWater	2510.52	2552.15	2531.33	20.82
B	Vinyl Ester	2	300	7	SeaWater	2536.85	2578.48	2557.67	20.82
C	Epoxy	2	300	7	SeaWater	2518.05	2559.81	2538.93	20.88
A	Epoxy	1	300	10	0	0.18	0.21	0.19	0.02
B	Vinyl Ester	1	300	10	0	0.86	0.91	0.89	0.03
C	Epoxy	1	300	10	0	0.23	0.26	0.25	0.02
A	Epoxy	1	300	10	200	0.23	0.26	0.25	0.02
B	Vinyl Ester	1	300	10	200	0.71	0.79	0.75	0.04
C	Epoxy	1	300	10	200	0.29	0.33	0.31	0.02

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Table 7.14: Sulfate Ion Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Sulfate Ion			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	10	20000	0.33	0.36	0.35	0.02
B	Vinyl Ester	1	300	10	20000	0.25	0.31	0.28	0.03
C	Epoxy	1	300	10	20000	0.42	0.46	0.44	0.02
A	Epoxy	1	300	10	SeaWater	2500.00	2540.00	2520.00	20.00
B	Vinyl Ester	1	300	10	SeaWater	2556.16	2573.17	2564.67	8.50
C	Epoxy	1	300	10	SeaWater	2505.00	2545.08	2525.04	20.04
A	Epoxy	2	300	10	0	0.53	0.55	0.54	0.01
B	Vinyl Ester	2	300	10	0	0.79	0.87	0.83	0.04
C	Epoxy	2	300	10	0	0.69	0.72	0.70	0.01
A	Epoxy	2	300	10	200	0.48	0.50	0.49	0.01
B	Vinyl Ester	2	300	10	200	0.59	0.67	0.63	0.04
C	Epoxy	2	300	10	200	0.62	0.65	0.64	0.01
A	Epoxy	2	300	10	20000	0.58	0.61	0.59	0.02
B	Vinyl Ester	2	300	10	20000	0.35	0.37	0.36	0.01
C	Epoxy	2	300	10	20000	0.75	0.79	0.77	0.02
A	Epoxy	2	300	10	SeaWater	2511.79	2534.88	2523.33	11.55
B	Vinyl Ester	2	300	10	SeaWater	2568.83	2593.17	2581.00	12.17
C	Epoxy	2	300	10	SeaWater	2519.32	2542.48	2530.90	11.58
A	Epoxy	1	300	13	0	0.46	0.50	0.48	0.02
B	Vinyl Ester	1	300	13	0	0.51	0.58	0.55	0.04
C	Epoxy	1	300	13	0	0.58	0.64	0.61	0.03
A	Epoxy	1	300	13	200	0.45	0.48	0.46	0.02
B	Vinyl Ester	1	300	13	200	0.55	0.62	0.58	0.03
C	Epoxy	1	300	13	200	0.57	0.61	0.59	0.02
A	Epoxy	1	300	13	20000	0.45	0.48	0.46	0.02
B	Vinyl Ester	1	300	13	20000	0.43	0.47	0.45	0.02
C	Epoxy	1	300	13	20000	0.57	0.61	0.59	0.02

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Table 7.14: Sulfate Ion Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Sulfate Ion			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	13	SeaWater	2547.17	2597.50	2572.33	25.17
B	Vinyl Ester	1	300	13	SeaWater	2539.56	2551.11	2545.33	5.77
C	Epoxy	1	300	13	SeaWater	2552.26	2602.69	2577.48	25.22
A	Epoxy	2	300	13	0	0.44	0.46	0.45	0.01
B	Vinyl Ester	2	300	13	0	0.61	0.65	0.63	0.02
C	Epoxy	2	300	13	0	0.57	0.60	0.59	0.01
A	Epoxy	2	300	13	200	0.33	0.36	0.35	0.02
B	Vinyl Ester	2	300	13	200	0.34	0.42	0.38	0.04
C	Epoxy	2	300	13	200	0.43	0.47	0.45	0.02
A	Epoxy	2	300	13	20000	0.54	0.58	0.56	0.02
B	Vinyl Ester	2	300	13	20000	0.53	0.59	0.56	0.03
C	Epoxy	2	300	13	20000	0.71	0.76	0.73	0.03
A	Epoxy	2	300	13	SeaWater	2554.12	2577.21	2565.67	11.55
B	Vinyl Ester	2	300	13	SeaWater	2561.65	2581.68	2571.67	10.02
C	Epoxy	2	300	13	SeaWater	2561.78	2584.95	2573.36	11.58

Table 7.15: Sulfate Ion Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Sulfate Ion			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	300	4	0	7.67	7.76	7.71	0.05
B	Vinyl Ester	300	4	0	7.55	7.88	7.71	0.17
A	Epoxy	300	4	200	8.18	8.21	8.20	0.02
B	Vinyl Ester	300	4	200	7.07	7.91	7.49	0.42
A	Epoxy	300	4	20000	7.73	7.80	7.77	0.04
B	Vinyl Ester	300	4	20000	7.49	8.55	8.02	0.53
A	Epoxy	300	4	SeaWater	2554.16	2575.17	2564.67	10.50
B	Vinyl Ester	300	4	SeaWater	2582.56	2594.11	2588.33	5.77
A	Epoxy	300	7	0	0.66	0.71	0.68	0.02
B	Vinyl Ester	300	7	0	0.72	0.78	0.75	0.03
A	Epoxy	300	7	200	0.80	0.86	0.83	0.03
B	Vinyl Ester	300	7	200	0.59	0.65	0.62	0.03
A	Epoxy	300	7	20000	0.42	0.45	0.44	0.02
B	Vinyl Ester	300	7	20000	0.51	0.56	0.54	0.03
A	Epoxy	300	7	SeaWater	2571.14	2599.52	2585.33	14.19
B	Vinyl Ester	300	7	SeaWater	2571.70	2586.97	2579.33	7.64
A	Epoxy	300	10	0	0.85	0.92	0.89	0.04
B	Vinyl Ester	300	10	0	0.31	0.39	0.35	0.04
A	Epoxy	300	10	200	0.69	0.72	0.71	0.02
B	Vinyl Ester	300	10	200	0.33	0.41	0.37	0.04
A	Epoxy	300	10	20000	0.33	0.36	0.35	0.02
B	Vinyl Ester	300	10	20000	0.59	0.67	0.63	0.04
A	Epoxy	300	10	SeaWater	2565.12	2588.21	2576.67	11.55
B	Vinyl Ester	300	10	SeaWater	2566.39	2596.94	2581.67	15.28
A	Epoxy	300	13	0	0.70	0.75	0.72	0.02
B	Vinyl Ester	300	13	0	0.50	0.54	0.52	0.02
A	Epoxy	300	13	200	0.69	0.71	0.70	0.01
B	Vinyl Ester	300	13	200	0.75	0.77	0.76	0.01
A	Epoxy	300	13	20000	0.25	0.29	0.27	0.02
B	Vinyl Ester	300	13	20000	0.53	0.57	0.55	0.02
A	Epoxy	300	13	SeaWater	2549.89	2561.44	2555.67	5.77
B	Vinyl Ester	300	13	SeaWater	2556.32	2582.35	2569.33	13.01

Table 7.16: Sulfate Ion Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Sulfate Ion			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Sized	300	4	0	8.00	8.06	8.03	0.03
B	Sized	300	4	0	7.66	7.79	7.72	0.07
C	Sized	300	4	0	9.99	10.08	10.04	0.04
A	Sized	300	4	200	7.66	7.71	7.68	0.03
B	Sized	300	4	200	7.18	7.73	7.46	0.28
C	Sized	300	4	200	9.57	9.64	9.60	0.03
A	Sized	300	4	20000	7.34	7.38	7.36	0.02
B	Sized	300	4	20000	7.11	8.11	7.61	0.50
C	Sized	300	4	20000	9.17	9.22	9.20	0.03
A	Sized	300	4	SeaWater	2526.39	2556.94	2541.67	15.28
B	Sized	300	4	SeaWater	2570.93	2588.40	2579.67	8.74
C	Sized	300	4	SeaWater	2539.02	2569.73	2554.38	15.35
A	Unsized	300	4	0	7.68	7.80	7.74	0.06
B	Unsized	300	4	0	7.09	8.03	7.56	0.47
A	Unsized	300	4	200	7.41	7.49	7.45	0.04
B	Unsized	300	4	200	7.52	7.95	7.74	0.21
A	Unsized	300	4	20000	7.08	7.13	7.10	0.03
B	Unsized	300	4	20000	7.19	7.43	7.31	0.12
A	Unsized	300	4	SeaWater	2536.39	2566.94	2551.67	15.28
B	Unsized	300	4	SeaWater	2566.39	2596.94	2581.67	15.28
A	Sized	300	7	0	0.53	0.55	0.54	0.01
B	Sized	300	7	0	0.38	0.46	0.42	0.04
C	Sized	300	7	0	0.66	0.69	0.68	0.01
A	Sized	300	7	200	0.31	0.35	0.33	0.02
B	Sized	300	7	200	0.45	0.66	0.56	0.11
C	Sized	300	7	200	0.39	0.44	0.42	0.03
A	Sized	300	7	20000	0.57	0.60	0.58	0.02
B	Sized	300	7	20000	0.17	0.24	0.21	0.03
C	Sized	300	7	20000	0.71	0.75	0.73	0.02
A	Sized	300	7	SeaWater	2553.12	2576.21	2564.67	11.55
B	Sized	300	7	SeaWater	2579.55	2587.12	2583.33	3.79
C	Sized	300	7	SeaWater	2565.89	2589.09	2577.49	11.60
A	Unsized	300	7	0	0.67	0.71	0.69	0.02
B	Unsized	300	7	0	0.22	0.28	0.25	0.03
A	Unsized	300	7	200	0.61	0.66	0.64	0.03
B	Unsized	300	7	200	0.18	0.23	0.20	0.03
A	Unsized	300	7	20000	0.44	0.47	0.46	0.02
B	Unsized	300	7	20000	0.52	0.58	0.55	0.03
A	Unsized	300	7	SeaWater	2519.55	2589.79	2554.67	35.12
B	Unsized	300	7	SeaWater	2571.89	2583.44	2577.67	5.77
A	Sized	300	10	0	0.48	0.51	0.49	0.02

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Table 7.16: Sulfate Ion Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Sulfate Ion			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Sized	300	10	0	0.36	0.64	0.50	0.14
C	Sized	300	10	0	0.60	0.64	0.62	0.02
A	Sized	300	10	200	0.71	0.77	0.74	0.03
B	Sized	300	10	200	0.08	0.85	0.47	0.38
C	Sized	300	10	200	0.89	0.96	0.93	0.03
A	Sized	300	10	20000	0.21	0.27	0.24	0.03
B	Sized	300	10	20000	0.07	0.17	0.12	0.05
C	Sized	300	10	20000	0.27	0.33	0.30	0.03
A	Sized	300	10	SeaWater	2530.70	2545.97	2538.33	7.64
B	Sized	300	10	SeaWater	2577.17	2585.50	2581.33	4.16
C	Sized	300	10	SeaWater	2543.35	2558.70	2551.03	7.68
A	Unsized	300	10	0	0.54	0.58	0.56	0.02
B	Unsized	300	10	0	0.37	0.45	0.41	0.04
A	Unsized	300	10	200	0.25	0.31	0.28	0.03
B	Unsized	300	10	200	0.24	0.25	0.25	0.01
A	Unsized	300	10	20000	0.15	0.17	0.16	0.01
B	Unsized	300	10	20000	0.35	0.41	0.38	0.03
A	Unsized	300	10	SeaWater	2525.85	2567.48	2546.67	20.82
B	Unsized	300	10	SeaWater	2579.30	2594.04	2586.67	7.37
A	Sized	300	13	0	0.26	0.27	0.26	0.01
B	Sized	300	13	0	0.32	0.41	0.37	0.05
C	Sized	300	13	0	0.32	0.34	0.33	0.01
A	Sized	300	13	200	0.68	0.72	0.70	0.02
B	Sized	300	13	200	0.68	0.80	0.74	0.06
C	Sized	300	13	200	0.84	0.90	0.87	0.03
A	Sized	300	13	20000	0.23	0.29	0.26	0.03
B	Sized	300	13	20000	0.10	0.11	0.11	0.01
C	Sized	300	13	20000	0.29	0.36	0.33	0.03
A	Sized	300	13	SeaWater	2560.79	2583.88	2572.33	11.55
B	Sized	300	13	SeaWater	2577.35	2582.65	2580.00	2.65
C	Sized	300	13	SeaWater	2573.59	2596.80	2585.20	11.60
A	Unsized	300	13	0	0.49	0.53	0.51	0.02
B	Unsized	300	13	0	0.32	0.34	0.33	0.01
A	Unsized	300	13	200	0.36	0.40	0.38	0.02
B	Unsized	300	13	200	0.64	0.69	0.67	0.02
A	Unsized	300	13	20000	0.14	0.16	0.15	0.01
B	Unsized	300	13	20000	0.45	0.54	0.50	0.05
A	Unsized	300	13	SeaWater	2541.68	2576.32	2559.00	17.32
B	Unsized	300	13	SeaWater	2572.58	2588.75	2580.67	8.08

For a better understanding, change in the sulfate content of the environments was plotted in graphs in

Figure 7.16, 7.17, and 7.18. It can be seen that sulfate concentration of all samples has increased except the

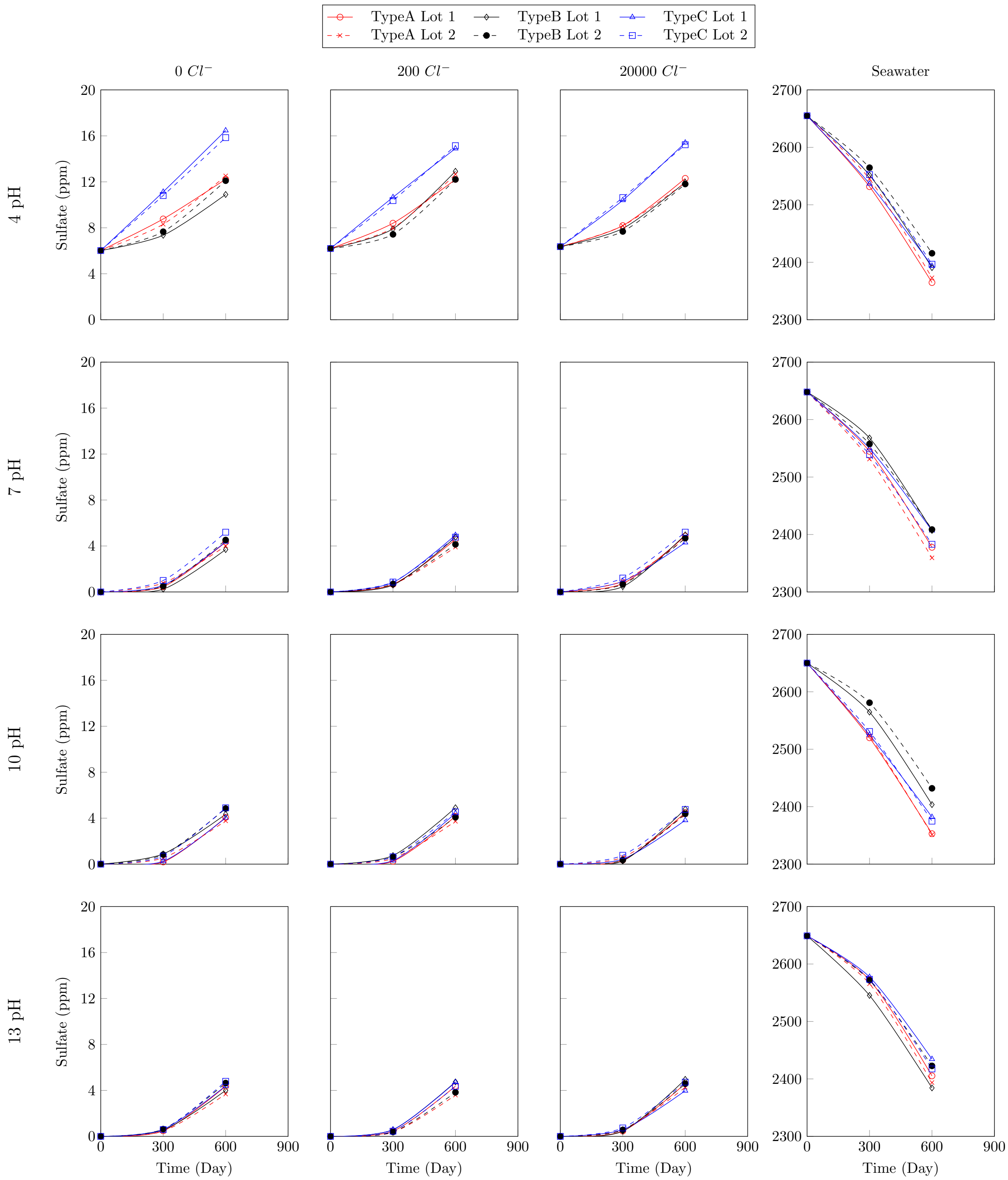

Figure 7.16: Sulfate concentration of all environments after exposure of rebars

seawater samples.

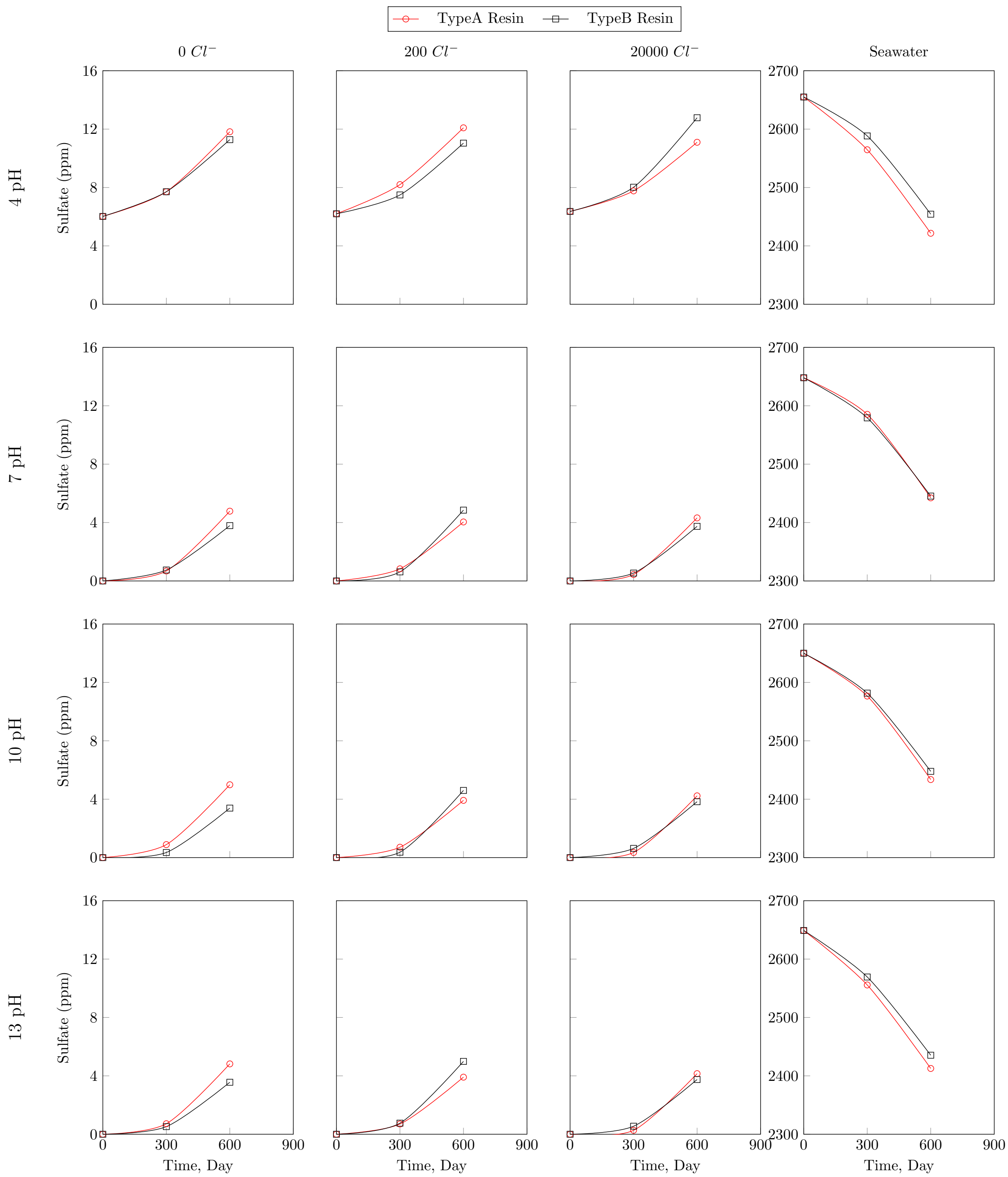

Figure 7.17: Sulfate concentration of all environments after exposure of resins

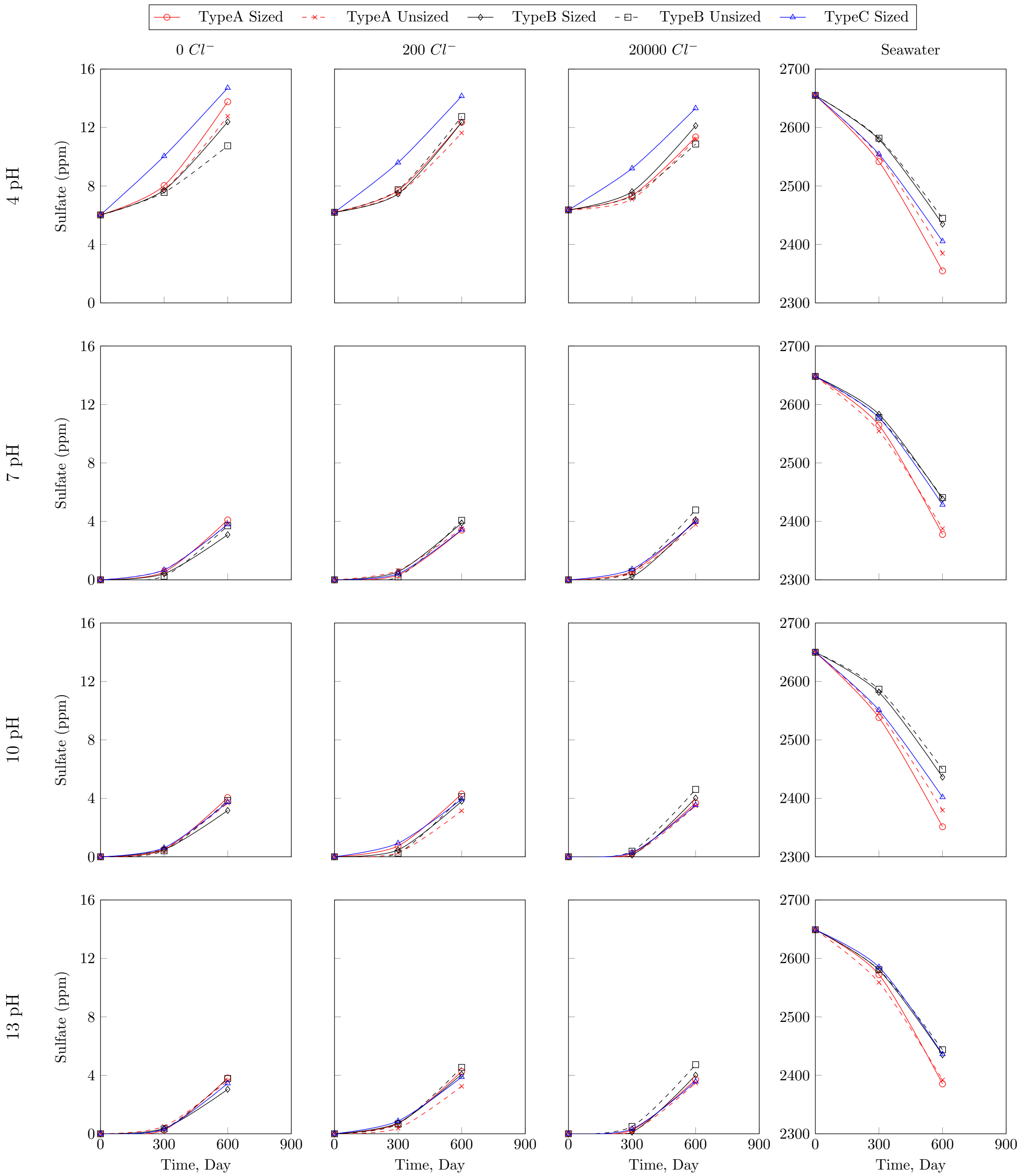

Figure 7.18: Sulfate concentration of all environments after exposure of sized and unsized fibers

7.2.6 Metals

Metals such as Aluminum, Calcium, Chromium, Iron, Magnesium, Potassium, Silicon, and Sodium were measured after 300 days of exposure and the results are tabulated in this subsection.

Aluminum

Aluminum content of the chemical environments was measured after 300 days of exposure. Tables 7.17, 7.18, and 7.19 below shows the pH data of environments in which rebars, resins, and fibers were exposed.

Table 7.17: Aluminum Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Aluminum			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	4	0	12.30	13.11	12.71	0.41
B	Vinyl Ester	1	300	4	0	8.75	9.15	8.95	0.20
C	Epoxy	1	300	4	0	16.65	17.66	17.15	0.51
A	Epoxy	1	300	4	200	15.30	18.95	17.13	1.83
B	Vinyl Ester	1	300	4	200	10.51	12.32	11.42	0.90
C	Epoxy	1	300	4	200	20.84	25.40	23.12	2.28
A	Epoxy	1	300	4	20000	20.26	22.38	21.32	1.06
B	Vinyl Ester	1	300	4	20000	12.97	14.02	13.49	0.52
C	Epoxy	1	300	4	20000	27.46	30.10	28.78	1.32
A	Epoxy	1	300	4	SeaWater	29.20	30.99	30.09	0.89
B	Vinyl Ester	1	300	4	SeaWater	17.69	18.57	18.13	0.44
C	Epoxy	1	300	4	SeaWater	39.51	41.74	40.62	1.12
A	Epoxy	2	300	4	0	17.63	18.45	18.04	0.41
B	Vinyl Ester	2	300	4	0	10.12	10.59	10.36	0.23
C	Epoxy	2	300	4	0	21.08	22.23	21.65	0.57
A	Epoxy	2	300	4	200	23.84	27.53	25.69	1.85
B	Vinyl Ester	2	300	4	200	12.17	14.25	13.21	1.04
C	Epoxy	2	300	4	200	28.24	33.41	30.83	2.58
A	Epoxy	2	300	4	20000	32.62	34.75	33.68	1.07
B	Vinyl Ester	2	300	4	20000	15.00	16.21	15.61	0.60
C	Epoxy	2	300	4	20000	38.93	41.91	40.42	1.49
A	Epoxy	2	300	4	SeaWater	49.05	50.86	49.95	0.90
B	Vinyl Ester	2	300	4	SeaWater	20.45	21.47	20.96	0.51
C	Epoxy	2	300	4	SeaWater	58.68	61.21	59.94	1.26
A	Epoxy	1	300	7	0	15.74	18.51	17.12	1.38
B	Vinyl Ester	1	300	7	0	11.21	12.58	11.89	0.68
C	Epoxy	1	300	7	0	21.39	24.84	23.12	1.73
A	Epoxy	1	300	7	200	16.99	25.19	21.09	4.10
B	Vinyl Ester	1	300	7	200	11.85	15.91	13.88	2.03
C	Epoxy	1	300	7	200	23.35	33.60	28.48	5.13
A	Epoxy	1	300	7	20000	26.48	29.16	27.82	1.34
B	Vinyl Ester	1	300	7	20000	16.73	18.05	17.39	0.66

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Table 7.17: Aluminum Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Aluminum			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
C	Epoxy	1	300	7	20000	35.88	39.23	37.56	1.67
A	Epoxy	1	300	7	SeaWater	35.00	38.57	36.79	1.79
B	Vinyl Ester	1	300	7	SeaWater	21.01	22.78	21.90	0.88
C	Epoxy	1	300	7	SeaWater	47.43	51.90	49.66	2.23
A	Epoxy	2	300	7	0	23.27	26.05	24.66	1.39
B	Vinyl Ester	2	300	7	0	12.97	14.55	13.76	0.79
C	Epoxy	2	300	7	0	27.64	31.54	29.59	1.95
A	Epoxy	2	300	7	200	27.92	36.20	32.06	4.14
B	Vinyl Ester	2	300	7	200	13.71	18.40	16.05	2.34
C	Epoxy	2	300	7	200	32.67	44.27	38.47	5.80
A	Epoxy	2	300	7	20000	43.16	45.87	44.51	1.35
B	Vinyl Ester	2	300	7	20000	19.35	20.88	20.11	0.77
C	Epoxy	2	300	7	20000	51.52	55.31	53.42	1.89
A	Epoxy	2	300	7	SeaWater	60.00	63.61	61.80	1.80
B	Vinyl Ester	2	300	7	SeaWater	24.30	26.34	25.32	1.02
C	Epoxy	2	300	7	SeaWater	71.64	76.69	74.16	2.53
A	Epoxy	1	300	10	0	18.77	21.04	19.91	1.14
B	Vinyl Ester	1	300	10	0	13.07	14.20	13.64	0.56
C	Epoxy	1	300	10	0	25.45	28.30	26.88	1.42
A	Epoxy	1	300	10	200	25.05	26.92	25.99	0.93
B	Vinyl Ester	1	300	10	200	16.41	17.34	16.87	0.46
C	Epoxy	1	300	10	200	33.91	36.25	35.08	1.17
A	Epoxy	1	300	10	20000	30.22	37.45	33.83	3.61
B	Vinyl Ester	1	300	10	20000	19.10	22.67	20.88	1.79
C	Epoxy	1	300	10	20000	41.16	50.19	45.67	4.52
A	Epoxy	1	300	10	SeaWater	40.93	47.11	44.02	3.09
B	Vinyl Ester	1	300	10	SeaWater	24.37	27.42	25.89	1.53
C	Epoxy	1	300	10	SeaWater	55.57	63.28	59.43	3.86
A	Epoxy	2	300	10	0	27.92	30.21	29.07	1.15
B	Vinyl Ester	2	300	10	0	15.13	16.43	15.78	0.65
C	Epoxy	2	300	10	0	33.27	36.49	34.88	1.61
A	Epoxy	2	300	10	200	39.08	40.96	40.02	0.94
B	Vinyl Ester	2	300	10	200	18.99	20.05	19.52	0.53
C	Epoxy	2	300	10	200	46.70	49.34	48.02	1.32
A	Epoxy	2	300	10	20000	51.16	58.46	54.81	3.65
B	Vinyl Ester	2	300	10	20000	22.09	26.22	24.15	2.06
C	Epoxy	2	300	10	20000	60.66	70.88	65.77	5.11
A	Epoxy	2	300	10	SeaWater	71.72	77.95	74.83	3.12
B	Vinyl Ester	2	300	10	SeaWater	28.18	31.70	29.94	1.76
C	Epoxy	2	300	10	SeaWater	85.44	94.17	89.80	4.36
A	Epoxy	1	300	13	0	23.24	29.41	26.33	3.09
B	Vinyl Ester	1	300	13	0	16.26	19.32	17.79	1.53

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Table 7.17: Aluminum Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Aluminum			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
C	Epoxy	1	300	13	0	31.68	39.40	35.54	3.86
A	Epoxy	1	300	13	200	31.47	35.13	33.30	1.83
B	Vinyl Ester	1	300	13	200	20.44	22.25	21.35	0.90
C	Epoxy	1	300	13	200	42.67	47.24	44.96	2.28
A	Epoxy	1	300	13	20000	36.19	43.50	39.84	3.65
B	Vinyl Ester	1	300	13	20000	22.48	26.10	24.29	1.81
C	Epoxy	1	300	13	20000	49.22	58.35	53.79	4.57
A	Epoxy	1	300	13	SeaWater	49.23	51.91	50.57	1.34
B	Vinyl Ester	1	300	13	SeaWater	28.74	30.07	29.40	0.66
C	Epoxy	1	300	13	SeaWater	66.60	69.95	68.27	1.67
A	Epoxy	2	300	13	0	35.84	42.08	38.96	3.12
B	Vinyl Ester	2	300	13	0	18.82	22.34	20.58	1.76
C	Epoxy	2	300	13	0	42.39	51.12	46.75	4.36
A	Epoxy	2	300	13	200	50.11	53.80	51.95	1.85
B	Vinyl Ester	2	300	13	200	23.65	25.74	24.69	1.04
C	Epoxy	2	300	13	200	59.76	64.92	62.34	2.58
A	Epoxy	2	300	13	20000	61.65	69.03	65.34	3.69
B	Vinyl Ester	2	300	13	20000	26.01	30.18	28.09	2.09
C	Epoxy	2	300	13	20000	73.24	83.58	78.41	5.17
A	Epoxy	2	300	13	SeaWater	85.63	88.34	86.98	1.35
B	Vinyl Ester	2	300	13	SeaWater	33.23	34.76	33.99	0.77
C	Epoxy	2	300	13	SeaWater	102.48	106.27	104.38	1.89

Table 7.18: Aluminum Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Aluminum			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	300	4	SeaWater	1.55	1.95	1.75	0.20
B	Vinyl Ester	300	4	SeaWater	1.62	1.82	1.72	0.10
A	Epoxy	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	300	7	SeaWater	1.49	2.09	1.79	0.30
B	Vinyl Ester	300	7	SeaWater	1.54	1.94	1.74	0.20
A	Epoxy	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	300	10	SeaWater	1.72	1.92	1.82	0.10
B	Vinyl Ester	300	10	SeaWater	1.57	1.97	1.77	0.20
A	Epoxy	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.00

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Table 7.18: Aluminum Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Aluminum			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	300	13	SeaWater	1.75	1.95	1.85	0.10
B	Vinyl Ester	300	13	SeaWater	1.65	1.95	1.8	0.15

Table 7.19: Aluminum Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Aluminum			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Sized	300	4	0	2.62	2.84	2.73	0.11
B	Sized	300	4	0	1.91	2.11	2.01	0.10
C	Sized	300	4	0	2.96	3.21	3.08	0.13
A	Sized	300	4	200	2.73	3.75	3.24	0.51
B	Sized	300	4	200	2.11	3.01	2.56	0.45
C	Sized	300	4	200	3.08	4.24	3.66	0.58
A	Sized	300	4	20000	3.69	4.29	3.99	0.30
B	Sized	300	4	20000	2.76	3.28	3.02	0.26
C	Sized	300	4	20000	4.17	4.84	4.51	0.33
A	Sized	300	4	SeaWater	6.65	7.15	6.90	0.25
B	Sized	300	4	SeaWater	3.83	4.27	4.05	0.22
C	Sized	300	4	SeaWater	7.51	8.08	7.80	0.28
A	Unsized	300	4	0	2.26	2.55	2.41	0.14
B	Unsized	300	4	0	1.81	2.02	1.91	0.11
A	Unsized	300	4	200	2.23	3.51	2.87	0.64
B	Unsized	300	4	200	2.01	2.95	2.48	0.47
A	Unsized	300	4	20000	3.18	3.92	3.55	0.37
B	Unsized	300	4	20000	2.62	3.17	2.89	0.27
A	Unsized	300	4	SeaWater	3.62	4.08	3.85	0.23
B	Unsized	300	4	SeaWater	5.87	6.50	6.18	0.31
A	Sized	300	7	0	3.06	3.84	3.45	0.39
B	Sized	300	7	0	2.33	3.01	2.67	0.34
C	Sized	300	7	0	3.46	4.34	3.90	0.44
A	Sized	300	7	200	2.96	5.26	4.11	1.15
B	Sized	300	7	200	2.10	4.12	3.11	1.01
C	Sized	300	7	200	3.34	5.95	4.64	1.30
A	Sized	300	7	20000	4.40	5.16	4.78	0.38
B	Sized	300	7	20000	3.56	4.22	3.89	0.33
C	Sized	300	7	20000	4.98	5.83	5.40	0.43
A	Sized	300	7	SeaWater	7.17	8.17	7.67	0.50
B	Sized	300	7	SeaWater	4.45	5.33	4.89	0.44
C	Sized	300	7	SeaWater	8.10	9.23	8.67	0.57
A	Unsized	300	7	0	2.56	3.53	3.04	0.48
B	Unsized	300	7	0	2.19	2.90	2.55	0.36
A	Unsized	300	7	200	2.20	5.08	3.64	1.44
B	Unsized	300	7	200	1.96	4.08	3.02	1.06
A	Unsized	300	7	20000	3.78	4.72	4.25	0.47
B	Unsized	300	7	20000	3.37	4.06	3.71	0.35
A	Unsized	300	7	SeaWater	6.26	7.51	6.89	0.63
B	Unsized	300	7	SeaWater	4.19	5.12	4.66	0.46
A	Sized	300	10	0	3.58	4.22	3.90	0.32

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Table 7.19: Aluminum Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Aluminum			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Sized	300	10	0	2.78	3.34	3.06	0.28
C	Sized	300	10	0	4.05	4.77	4.41	0.36
A	Sized	300	10	200	4.96	5.48	5.22	0.26
B	Sized	300	10	200	3.55	4.01	3.78	0.23
C	Sized	300	10	200	5.60	6.19	5.90	0.30
A	Sized	300	10	20000	4.97	6.99	5.98	1.01
B	Sized	300	10	20000	3.78	5.56	4.67	0.89
C	Sized	300	10	20000	5.61	7.90	6.76	1.15
A	Sized	300	10	SeaWater	7.45	9.19	8.32	0.87
B	Sized	300	10	SeaWater	5.02	6.54	5.78	0.76
C	Sized	300	10	SeaWater	8.42	10.38	9.40	0.98
A	Unsized	300	10	0	3.04	3.84	3.44	0.40
B	Unsized	300	10	0	2.63	3.22	2.93	0.29
A	Unsized	300	10	200	4.30	4.96	4.63	0.33
B	Unsized	300	10	200	3.44	3.93	3.69	0.24
A	Unsized	300	10	20000	4.07	6.60	5.33	1.27
B	Unsized	300	10	20000	3.53	5.40	4.47	0.93
A	Unsized	300	10	SeaWater	6.41	8.57	7.49	1.08
B	Unsized	300	10	SeaWater	4.72	6.31	5.51	0.80
A	Sized	300	13	0	4.14	5.88	5.01	0.87
B	Sized	300	13	0	3.23	4.75	3.99	0.76
C	Sized	300	13	0	4.68	6.64	5.66	0.98
A	Sized	300	13	200	5.64	6.66	6.15	0.51
B	Sized	300	13	200	4.33	5.23	4.78	0.45
C	Sized	300	13	200	6.37	7.53	6.95	0.58
A	Sized	300	13	20000	5.98	8.04	7.01	1.03
B	Sized	300	13	20000	4.53	6.33	5.43	0.90
C	Sized	300	13	20000	6.76	9.08	7.92	1.16
A	Sized	300	13	SeaWater	9.56	10.32	9.94	0.38
B	Sized	300	13	SeaWater	6.23	6.89	6.56	0.33
C	Sized	300	13	SeaWater	10.81	11.66	11.23	0.43
A	Unsized	300	13	0	3.35	5.51	4.43	1.08
B	Unsized	300	13	0	3.04	4.64	3.84	0.80
A	Unsized	300	13	200	4.82	6.10	5.46	0.64
B	Unsized	300	13	200	4.21	5.16	4.68	0.47
A	Unsized	300	13	20000	4.98	7.55	6.27	1.28
B	Unsized	300	13	20000	4.23	6.12	5.18	0.95
A	Unsized	300	13	SeaWater	8.67	9.62	9.14	0.47
B	Unsized	300	13	SeaWater	5.91	6.61	6.26	0.35

For a better understanding, change in the Aluminum content of the environments was plotted in graphs in Figure 7.19, 7.20, and 7.21. It can be seen that the Aluminum concentration has decreased in all

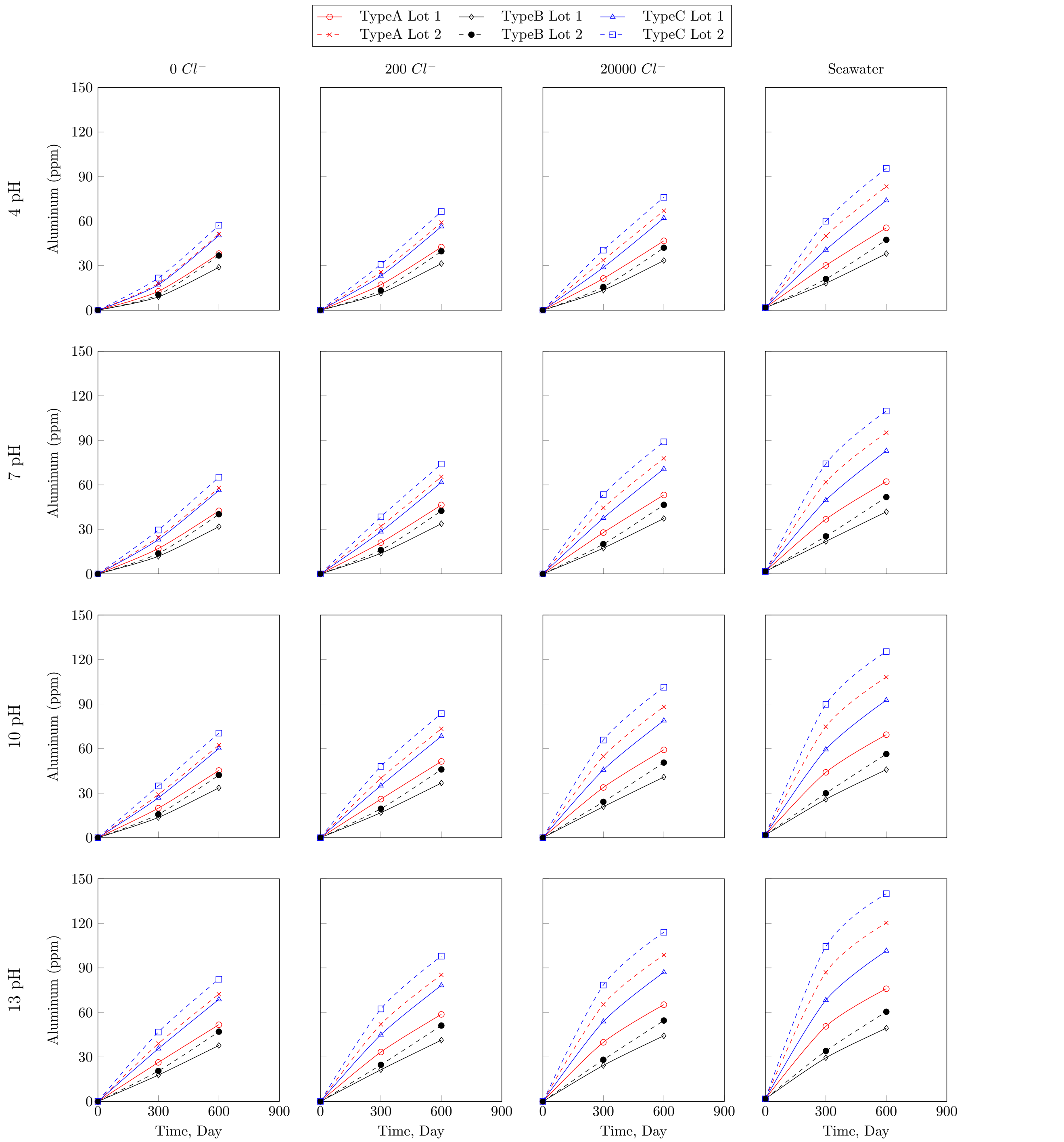

Figure 7.19: Aluminum concentration of all environments after exposure of rebars

environments except the environments that had resin samples.

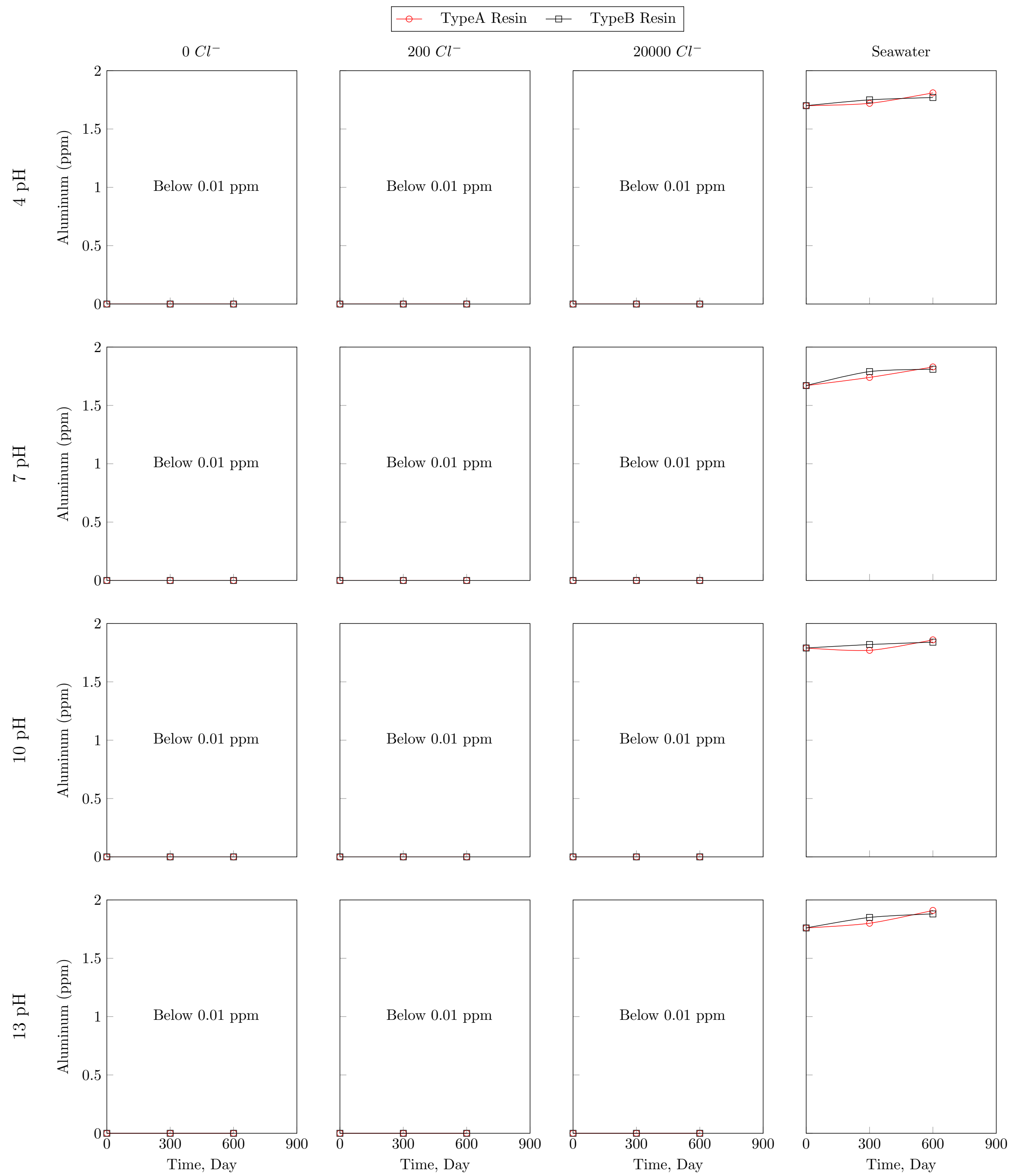

Figure 7.20: Aluminum concentration of all environments after exposure of resins

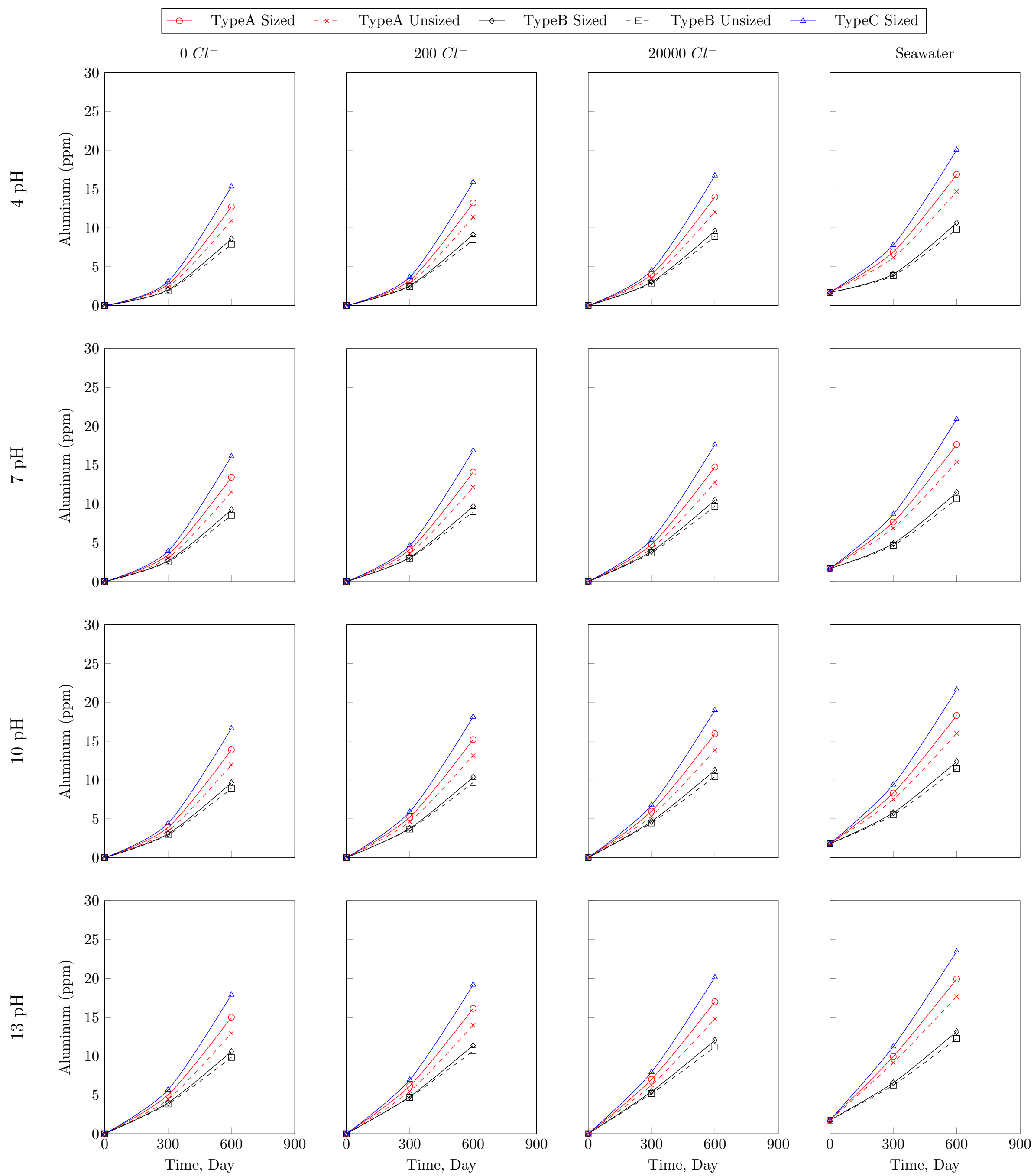

Figure 7.21: Aluminum concentration of all environments after exposure of sized and unsized fibers

Calcium

Calcium content of the chemical environments was measured after 300 days of exposure. Tables 7.20, 7.21, and 7.22 below shows the pH data of environments in which rebars, resins, and fibers were exposed.

Table 7.20: Calcium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Calcium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	4	0	2.92	3.05	2.99	0.07
B	Vinyl Ester	1	300	4	0	2.09	2.12	2.10	0.01
C	Epoxy	1	300	4	0	3.45	3.63	3.54	0.09
A	Epoxy	1	300	4	200	3.04	3.97	3.51	0.46
B	Vinyl Ester	1	300	4	200	2.38	2.55	2.47	0.09
C	Epoxy	1	300	4	200	3.54	4.78	4.16	0.62
A	Epoxy	1	300	4	20000	7.42	9.40	8.41	0.99
B	Vinyl Ester	1	300	4	20000	5.73	6.10	5.92	0.19
C	Epoxy	1	300	4	20000	8.63	11.29	9.96	1.33
A	Epoxy	1	300	4	SeaWater	509.82	516.68	513.25	3.43
B	Vinyl Ester	1	300	4	SeaWater	501.73	507.45	504.59	2.86
C	Epoxy	1	300	4	SeaWater	522.76	534.11	528.44	5.67
A	Epoxy	2	300	4	0	7.56	8.28	7.92	0.36
B	Vinyl Ester	2	300	4	0	5.35	5.38	5.36	0.01
C	Epoxy	2	300	4	0	9.70	10.62	10.16	0.46
A	Epoxy	2	300	4	200	6.75	11.83	9.29	2.54
B	Vinyl Ester	2	300	4	200	6.19	6.39	6.29	0.10
C	Epoxy	2	300	4	200	8.70	15.15	11.92	3.22
A	Epoxy	2	300	4	20000	16.84	27.73	22.28	5.45
B	Vinyl Ester	2	300	4	20000	14.87	15.29	15.08	0.21
C	Epoxy	2	300	4	20000	26.13	31.05	28.59	2.46
A	Epoxy	2	300	4	SeaWater	533.51	541.23	537.37	3.86
B	Vinyl Ester	2	300	4	SeaWater	534.14	540.63	537.39	3.24
C	Epoxy	2	300	4	SeaWater	550.55	564.45	557.50	6.95
A	Epoxy	1	300	7	0	2.80	3.33	3.07	0.26
B	Vinyl Ester	1	300	7	0	2.11	2.21	2.16	0.05
C	Epoxy	1	300	7	0	3.28	3.99	3.64	0.35
A	Epoxy	1	300	7	200	3.97	5.57	4.77	0.80
B	Vinyl Ester	1	300	7	200	2.72	2.94	2.83	0.11
C	Epoxy	1	300	7	200	3.43	4.62	4.02	0.59
A	Epoxy	1	300	7	20000	8.65	13.67	11.16	2.51
B	Vinyl Ester	1	300	7	20000	7.38	8.32	7.85	0.47
C	Epoxy	1	300	7	20000	9.85	16.59	13.22	3.37
A	Epoxy	1	300	7	SeaWater	520.07	524.70	522.38	2.32
B	Vinyl Ester	1	300	7	SeaWater	511.64	515.50	513.57	1.93
C	Epoxy	1	300	7	SeaWater	535.01	540.67	537.84	2.83
A	Epoxy	2	300	7	0	6.68	9.58	8.13	1.45

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Table 7.20: Calcium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Calcium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	2	300	7	0	5.45	5.56	5.50	0.06
C	Epoxy	2	300	7	0	8.59	12.28	10.43	1.84
A	Epoxy	2	300	7	200	7.40	13.93	10.67	3.27
B	Vinyl Ester	2	300	7	200	7.09	7.35	7.22	0.13
C	Epoxy	2	300	7	200	9.54	17.83	13.69	4.15
A	Epoxy	2	300	7	20000	25.77	33.36	29.57	3.79
B	Vinyl Ester	2	300	7	20000	19.48	20.55	20.02	0.53
C	Epoxy	2	300	7	20000	31.72	44.17	37.94	6.23
A	Epoxy	2	300	7	SeaWater	544.33	549.54	546.93	2.61
B	Vinyl Ester	2	300	7	SeaWater	544.76	549.14	546.95	2.19
C	Epoxy	2	300	7	SeaWater	563.96	570.88	567.42	3.46
A	Epoxy	1	300	10	0	3.18	3.44	3.31	0.13
B	Vinyl Ester	1	300	10	0	2.30	2.35	2.33	0.02
C	Epoxy	1	300	10	0	3.74	4.10	3.92	0.18
A	Epoxy	1	300	10	200	4.28	5.60	4.94	0.66
B	Vinyl Ester	1	300	10	200	3.35	3.60	3.48	0.12
C	Epoxy	1	300	10	200	4.97	6.74	5.85	0.89
A	Epoxy	1	300	10	20000	9.06	15.00	12.03	2.97
B	Vinyl Ester	1	300	10	20000	7.91	9.02	8.47	0.56
C	Epoxy	1	300	10	20000	10.27	18.25	14.26	3.99
A	Epoxy	1	300	10	SeaWater	519.18	532.69	525.93	6.76
B	Vinyl Ester	1	300	10	SeaWater	511.43	522.69	517.06	5.63
C	Epoxy	1	300	10	SeaWater	533.25	549.74	541.50	8.24
A	Epoxy	2	300	10	0	8.04	9.49	8.76	0.73
B	Vinyl Ester	2	300	10	0	5.91	5.96	5.93	0.03
C	Epoxy	2	300	10	0	10.33	12.17	11.25	0.92
A	Epoxy	2	300	10	200	9.46	16.72	13.09	3.63
B	Vinyl Ester	2	300	10	200	8.72	9.01	8.86	0.14
C	Epoxy	2	300	10	200	12.20	21.41	16.80	4.61
A	Epoxy	2	300	10	20000	25.55	38.22	31.89	6.34
B	Vinyl Ester	2	300	10	20000	20.96	22.22	21.59	0.63
C	Epoxy	2	300	10	20000	33.55	48.30	40.92	7.37
A	Epoxy	2	300	10	SeaWater	543.05	558.25	550.65	7.60
B	Vinyl Ester	2	300	10	SeaWater	544.28	557.06	550.67	6.39
C	Epoxy	2	300	10	SeaWater	561.18	581.38	571.28	10.10
A	Epoxy	1	300	13	0	2.90	5.54	4.22	1.32
B	Vinyl Ester	1	300	13	0	2.72	3.22	2.97	0.25
C	Epoxy	1	300	13	0	3.23	6.78	5.00	1.77
A	Epoxy	1	300	13	200	4.89	10.17	7.53	2.64
B	Vinyl Ester	1	300	13	200	4.80	5.79	5.30	0.50
C	Epoxy	1	300	13	200	6.44	11.40	8.92	2.48
A	Epoxy	1	300	13	20000	14.93	17.83	16.38	1.45

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Table 7.20: Calcium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Calcium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	1	300	13	20000	11.25	11.79	11.52	0.27
C	Epoxy	1	300	13	20000	17.46	21.35	19.41	1.95
A	Epoxy	1	300	13	SeaWater	521.23	536.11	528.67	7.44
B	Vinyl Ester	1	300	13	SeaWater	513.55	525.95	519.75	6.20
C	Epoxy	1	300	13	SeaWater	535.24	553.39	544.31	9.08
A	Epoxy	2	300	13	0	3.93	18.45	11.19	7.26
B	Vinyl Ester	2	300	13	0	7.30	7.86	7.58	0.28
C	Epoxy	2	300	13	0	5.15	23.58	14.36	9.21
A	Epoxy	2	300	13	200	12.43	27.48	19.96	7.52
B	Vinyl Ester	2	300	13	200	12.95	14.07	13.51	0.56
C	Epoxy	2	300	13	200	21.02	30.20	25.61	4.59
A	Epoxy	2	300	13	20000	35.41	51.39	43.40	7.99
B	Vinyl Ester	2	300	13	20000	29.07	29.69	29.38	0.31
C	Epoxy	2	300	13	20000	52.09	59.30	55.70	3.60
A	Epoxy	2	300	13	SeaWater	545.15	561.89	553.52	8.37
B	Vinyl Ester	2	300	13	SeaWater	546.49	560.57	553.53	7.04
C	Epoxy	2	300	13	SeaWater	563.13	585.37	574.25	11.12

Table 7.21: Calcium Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Calcium			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	300	4	0	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	300	4	0	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	300	4	200	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	300	4	200	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	300	4	20000	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	300	4	20000	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	300	4	SeaWater	458.38	460.46	459.42	1.04
B	Vinyl Ester	300	4	SeaWater	456.94	461.46	459.2	2.26
A	Epoxy	300	7	0	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	300	7	0	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	300	7	200	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	300	7	200	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	300	7	20000	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	300	7	20000	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	300	7	SeaWater	465.93	469.27	467.6	1.67
B	Vinyl Ester	300	7	SeaWater	465.62	469.12	467.37	1.75
A	Epoxy	300	10	0	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	300	10	0	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	300	10	200	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	300	10	200	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	300	10	20000	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	300	10	20000	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	300	10	SeaWater	468.74	472.82	470.78	2.04
B	Vinyl Ester	300	10	SeaWater	468.45	472.63	470.54	2.09
A	Epoxy	300	13	0	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	300	13	0	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	300	13	200	Below 0.05	Below 0.05	Below 0.05	0.00

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Table 7.21: Calcium Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Calcium			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	300	13	200	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	300	13	20000	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	300	13	20000	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	300	13	SeaWater	471.73	474.73	473.23	1.50
B	Vinyl Ester	300	13	SeaWater	471.88	474.1	472.99	1.11

Table 7.22: Calcium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Calcium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Sized	300	4	0	0.85	0.88	0.87	0.01
B	Sized	300	4	0	0.78	0.80	0.79	0.01
C	Sized	300	4	0	0.95	0.99	0.97	0.02
A	Sized	300	4	200	0.92	1.11	1.02	0.09
B	Sized	300	4	200	0.85	1.00	0.92	0.08
C	Sized	300	4	200	1.03	1.25	1.14	0.11
A	Sized	300	4	20000	2.24	2.64	2.44	0.20
B	Sized	300	4	20000	2.05	2.38	2.22	0.17
C	Sized	300	4	20000	2.49	2.97	2.73	0.24
A	Sized	300	4	SeaWater	473.51	479.60	476.56	3.05
B	Sized	300	4	SeaWater	464.67	469.75	467.21	2.54
C	Sized	300	4	SeaWater	483.32	490.76	487.04	3.72
A	Unsized	300	4	0	0.75	0.77	0.76	0.01
B	Unsized	300	4	0	0.70	0.72	0.71	0.01
A	Unsized	300	4	200	0.81	0.98	0.89	0.08
B	Unsized	300	4	200	0.76	0.91	0.83	0.08
A	Unsized	300	4	20000	1.97	2.32	2.14	0.17
B	Unsized	300	4	20000	1.83	2.16	1.99	0.16
A	Unsized	300	4	SeaWater	466.72	472.09	469.41	2.68
B	Unsized	300	4	SeaWater	460.02	465.05	462.54	2.52
A	Sized	300	7	0	0.84	0.94	0.89	0.05
B	Sized	300	7	0	0.76	0.85	0.81	0.04
C	Sized	300	7	0	0.93	1.06	1.00	0.06
A	Sized	300	7	200	1.05	1.29	1.17	0.12
B	Sized	300	7	200	0.96	1.16	1.06	0.10
C	Sized	300	7	200	1.16	1.45	1.31	0.14
A	Sized	300	7	20000	2.73	3.74	3.23	0.50
B	Sized	300	7	20000	2.52	3.36	2.94	0.42
C	Sized	300	7	20000	3.01	4.23	3.62	0.61
A	Sized	300	7	SeaWater	482.98	487.09	485.03	2.06
B	Sized	300	7	SeaWater	473.81	477.24	475.52	1.72
C	Sized	300	7	SeaWater	493.19	498.22	495.71	2.51
A	Unsized	300	7	0	0.74	0.83	0.78	0.05
B	Unsized	300	7	0	0.68	0.77	0.73	0.04
A	Unsized	300	7	200	0.92	1.13	1.03	0.10
B	Unsized	300	7	200	0.86	1.05	0.95	0.10
A	Unsized	300	7	20000	2.40	3.29	2.85	0.44
B	Unsized	300	7	20000	2.23	3.06	2.65	0.41
A	Unsized	300	7	SeaWater	475.95	479.57	477.76	1.81
B	Unsized	300	7	SeaWater	469.07	472.47	470.77	1.70
A	Sized	300	10	0	0.93	0.99	0.96	0.03

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Table 7.22: Calcium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Calcium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Sized	300	10	0	0.85	0.89	0.87	0.02
C	Sized	300	10	0	1.04	1.11	1.07	0.03
A	Sized	300	10	200	1.30	1.56	1.43	0.13
B	Sized	300	10	200	1.19	1.41	1.30	0.11
C	Sized	300	10	200	1.44	1.77	1.60	0.16
A	Sized	300	10	20000	2.89	4.08	3.49	0.59
B	Sized	300	10	20000	2.68	3.67	3.17	0.50
C	Sized	300	10	20000	3.18	4.63	3.91	0.72
A	Sized	300	10	SeaWater	482.33	494.34	488.33	6.01
B	Sized	300	10	SeaWater	473.75	483.76	478.76	5.01
C	Sized	300	10	SeaWater	491.75	506.40	499.08	7.33
A	Unsized	300	10	0	0.82	0.87	0.84	0.02
B	Unsized	300	10	0	0.76	0.81	0.78	0.02
A	Unsized	300	10	200	1.14	1.38	1.26	0.12
B	Unsized	300	10	200	1.06	1.28	1.17	0.11
A	Unsized	300	10	20000	2.55	3.59	3.07	0.52
B	Unsized	300	10	20000	2.36	3.34	2.85	0.49
A	Unsized	300	10	SeaWater	475.72	486.29	481.01	5.29
B	Unsized	300	10	SeaWater	469.01	478.92	473.97	4.95
A	Sized	300	13	0	0.96	1.49	1.22	0.26
B	Sized	300	13	0	0.89	1.33	1.11	0.22
C	Sized	300	13	0	1.05	1.69	1.37	0.32
A	Sized	300	13	200	1.65	2.71	2.18	0.53
B	Sized	300	13	200	1.54	2.42	1.98	0.44
C	Sized	300	13	200	1.80	3.09	2.44	0.64
A	Sized	300	13	20000	4.46	5.04	4.75	0.29
B	Sized	300	13	20000	4.07	4.56	4.32	0.24
C	Sized	300	13	20000	4.96	5.67	5.32	0.35
A	Sized	300	13	SeaWater	484.26	497.48	490.87	6.61
B	Sized	300	13	SeaWater	475.74	486.76	481.25	5.51
C	Sized	300	13	SeaWater	493.60	509.74	501.67	8.07
A	Unsized	300	13	0	0.85	1.31	1.08	0.23
B	Unsized	300	13	0	0.78	1.22	1.00	0.22
A	Unsized	300	13	200	1.46	2.39	1.92	0.46
B	Unsized	300	13	200	1.35	2.22	1.79	0.44
A	Unsized	300	13	20000	3.92	4.43	4.18	0.26
B	Unsized	300	13	20000	3.64	4.12	3.88	0.24
A	Unsized	300	13	SeaWater	477.69	489.33	483.51	5.82
B	Unsized	300	13	SeaWater	470.98	481.89	476.43	5.46

For a better understanding, change in the Calcium content of the environments was plotted in graphs in

Figure 7.22, 7.23, and 7.24. It can be seen that the Calcium content has increased in all environments

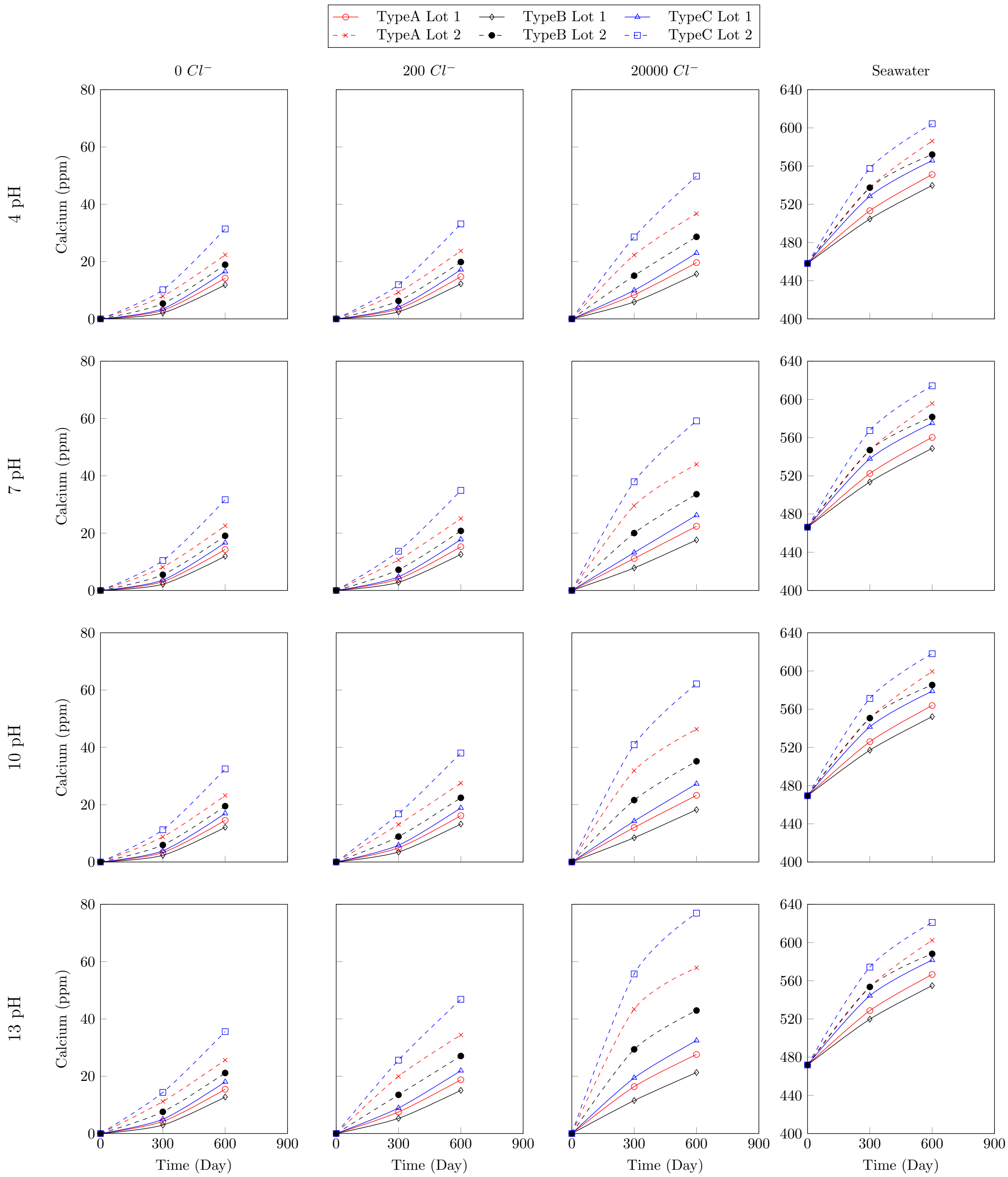

Figure 7.22: Calcium concentration of all environments after exposure of rebars

except the environments that had resin samples.

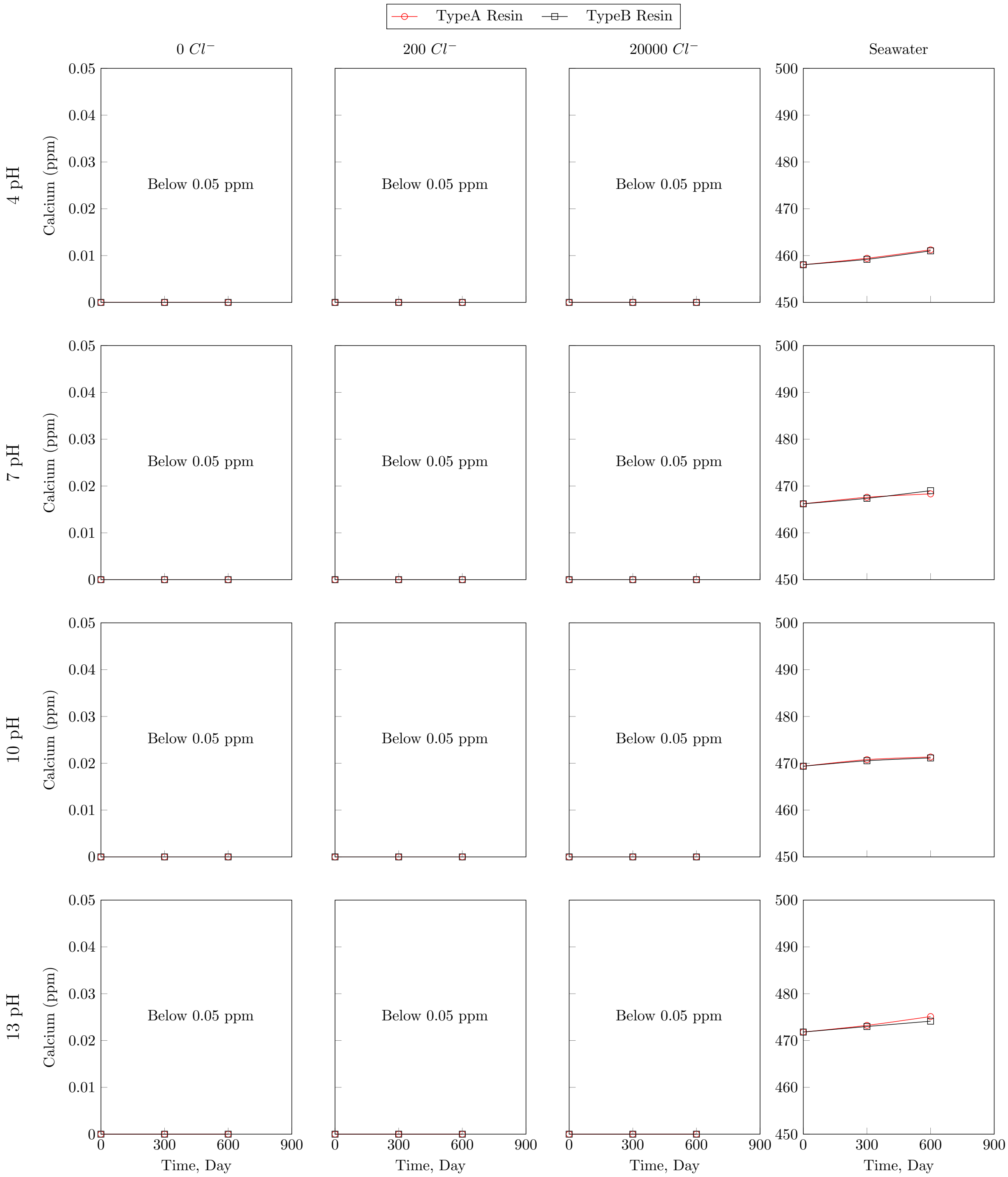

Figure 7.23: Calcium concentration of all environments after exposure of resins

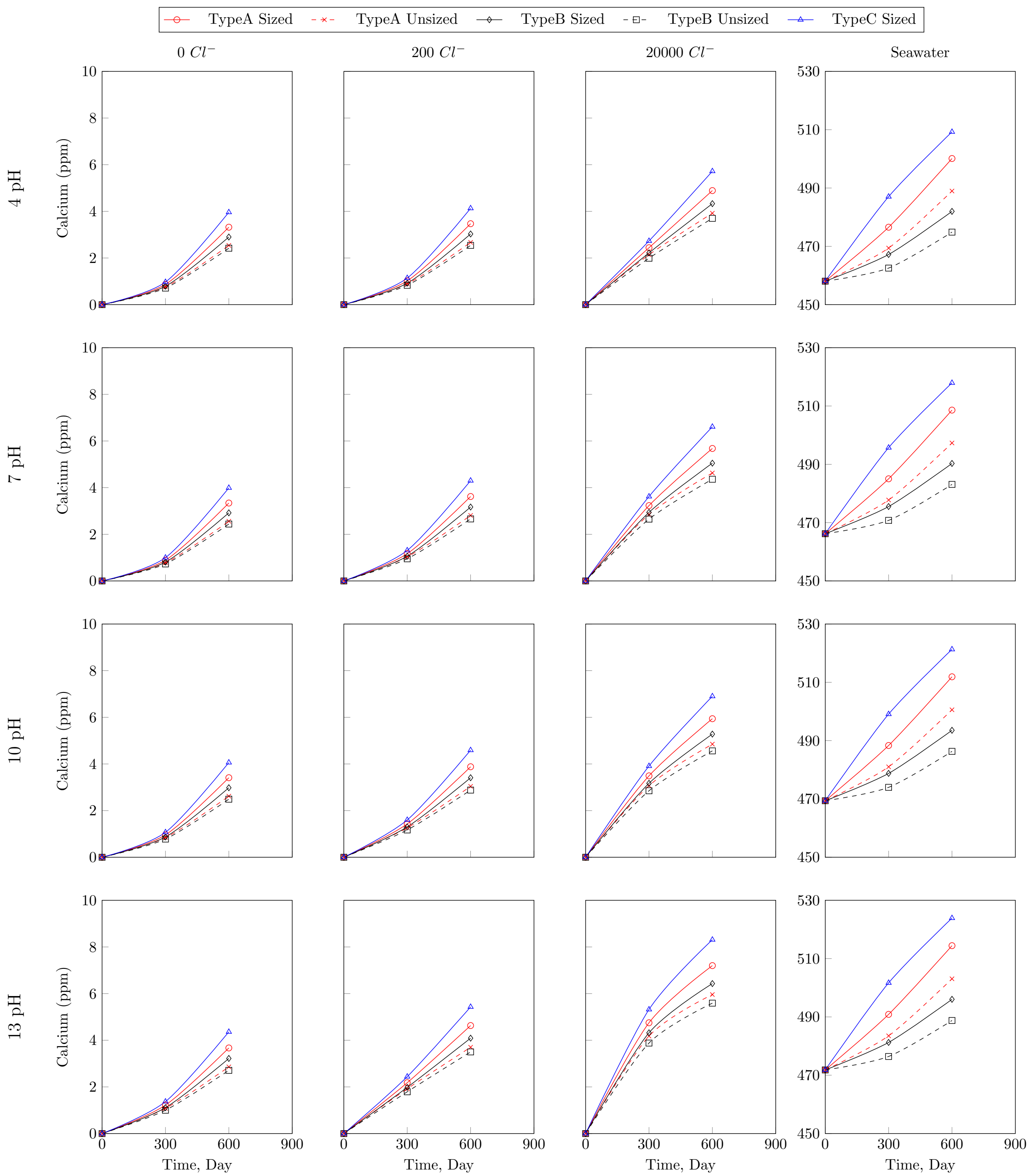

Figure 7.24: Calcium concentration of all environments after exposure of sized and unsized fibers

Chromium

Chromium content of the chemical environments was measured after 300 days of exposure. Tables 7.23, 7.24, and 7.25 below shows the pH data of environments in which rebars, resins, and fibers were exposed.

Table 7.23: Chromium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Chromium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	1	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	1	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	1	300	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	300	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	300	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	300	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	300	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	300	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	1	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.0

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Table 7.23: Chromium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Chromium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	1	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	1	300	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	300	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	300	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	300	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	300	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	300	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	1	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	1	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.0

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Table 7.23: Chromium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Chromium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	1	300	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	300	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	300	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	300	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	300	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	300	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	1	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	1	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	1	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0

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Table 7.23: Chromium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Chromium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	300	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	300	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	300	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	300	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	300	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0

Table 7.24: Chromium Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Chromium			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	300	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	300	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	300	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	300	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	300	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	300	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.0

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Table 7.24: Chromium Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Chromium			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	300	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	300	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0

Table 7.25: Chromium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Chromium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Sized	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	300	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	300	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	300	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	300	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	300	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0

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Table 7.25: Chromium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Chromium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Sized	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	300	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	300	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	300	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	300	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	300	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	300	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	300	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	300	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.0

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Table 7.25: Chromium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Chromium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Unsized	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	300	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	300	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	300	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	300	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	300	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	300	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	300	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0

For a better understanding, change in the Chromium content of the environments was plotted in graphs in Figure 7.25, 7.26, and 7.27. It can be seen that the Chromium concentration has not changed over time

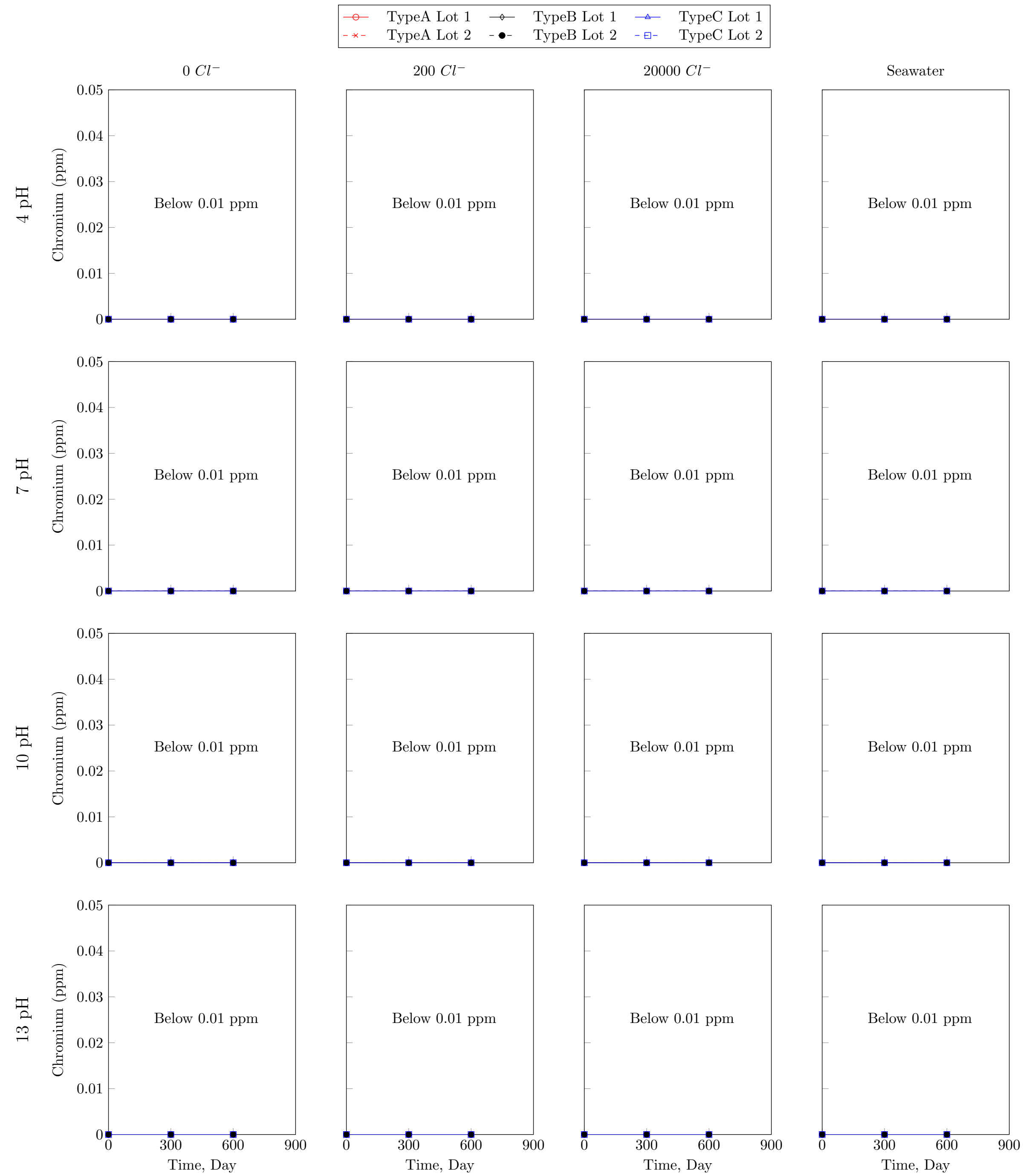

Figure 7.25: Chromium concentration of all environments after exposure of rebars

in all exposure environments.

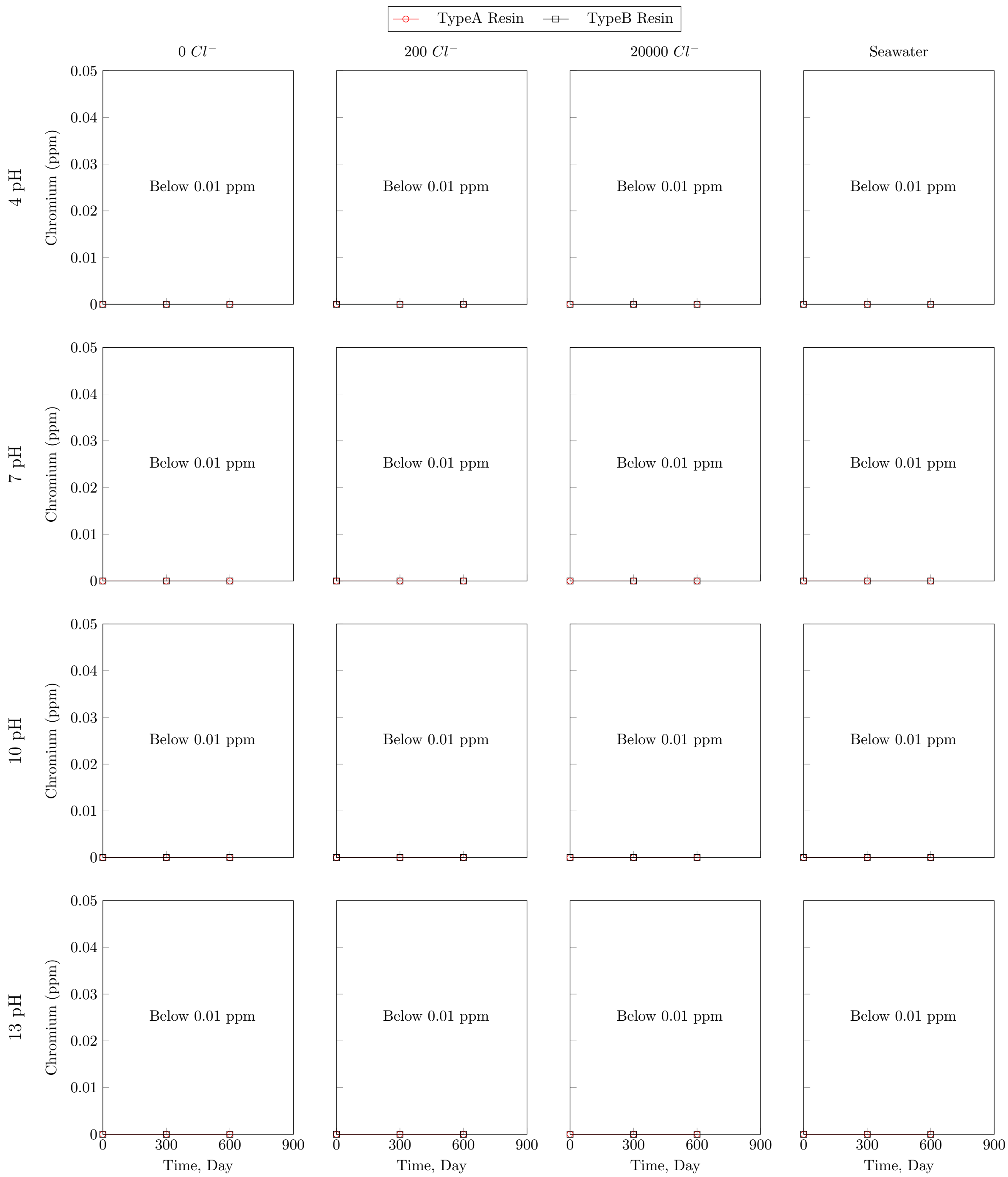

Figure 7.26: Chromium concentration of all environments after exposure of resins

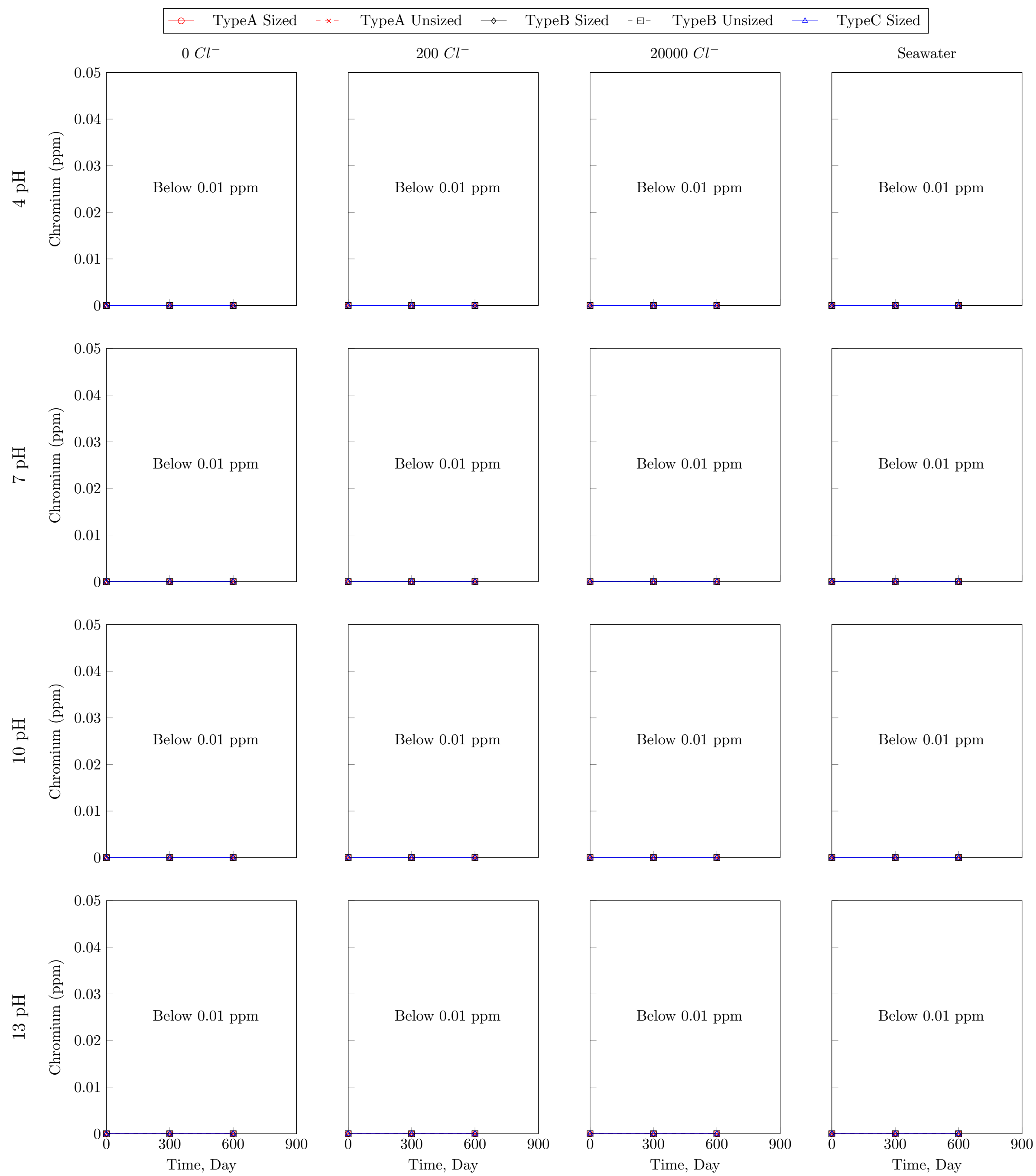

Figure 7.27: Chromium concentration of all environments after exposure of sized and unsized fibers

Iron

Iron content of the chemical environments was measured after 300 days of exposure. Tables 7.26, 7.27, and 7.28 below shows the pH data of environments in which rebars, resins, and fibers were exposed.

Table 7.26: Iron Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Iron			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	4	0	4.71	4.78	4.74	0.04
B	Vinyl Ester	1	300	4	0	3.32	3.35	3.34	0.01
C	Epoxy	1	300	4	0	6.12	6.21	6.16	0.04
A	Epoxy	1	300	4	200	5.64	6.13	5.89	0.25
B	Vinyl Ester	1	300	4	200	3.82	4.03	3.92	0.10
C	Epoxy	1	300	4	200	7.36	7.95	7.65	0.30
A	Epoxy	1	300	4	20000	14.37	15.42	14.90	0.53
B	Vinyl Ester	1	300	4	20000	9.21	9.64	9.43	0.22
C	Epoxy	1	300	4	20000	18.73	20.00	19.36	0.64
A	Epoxy	1	300	4	SeaWater	16.58	21.31	18.95	2.36
B	Vinyl Ester	1	300	4	SeaWater	10.45	12.38	11.41	0.96
C	Epoxy	1	300	4	SeaWater	21.79	27.47	24.63	2.84
A	Epoxy	2	300	4	0	6.68	6.78	6.73	0.05
B	Vinyl Ester	2	300	4	0	5.05	5.10	5.07	0.02
C	Epoxy	2	300	4	0	7.67	7.81	7.74	0.07
A	Epoxy	2	300	4	200	9.68	10.64	10.16	0.48
B	Vinyl Ester	2	300	4	200	5.79	6.13	5.96	0.17
C	Epoxy	2	300	4	200	8.47	9.19	8.83	0.36
A	Epoxy	2	300	4	20000	22.77	24.30	23.53	0.77
B	Vinyl Ester	2	300	4	20000	13.95	14.69	14.32	0.37
C	Epoxy	2	300	4	20000	26.04	28.09	27.06	1.03
A	Epoxy	2	300	4	SeaWater	28.02	34.88	31.45	3.43
B	Vinyl Ester	2	300	4	SeaWater	15.70	18.97	17.34	1.63
C	Epoxy	2	300	4	SeaWater	31.58	40.76	36.17	4.59
A	Epoxy	1	300	7	0	4.80	5.08	4.94	0.14
B	Vinyl Ester	1	300	7	0	3.37	3.49	3.43	0.06
C	Epoxy	1	300	7	0	6.25	6.59	6.42	0.17
A	Epoxy	1	300	7	200	6.53	7.17	6.85	0.32
B	Vinyl Ester	1	300	7	200	4.38	4.64	4.51	0.13
C	Epoxy	1	300	7	200	8.52	9.29	8.91	0.38
A	Epoxy	1	300	7	20000	18.68	21.37	20.03	1.34
B	Vinyl Ester	1	300	7	20000	11.97	13.06	12.52	0.55
C	Epoxy	1	300	7	20000	24.42	27.64	26.03	1.61
A	Epoxy	1	300	7	SeaWater	23.93	26.33	25.13	1.20
B	Vinyl Ester	1	300	7	SeaWater	14.47	15.45	14.96	0.49
C	Epoxy	1	300	7	SeaWater	31.23	34.10	32.67	1.44
A	Epoxy	2	300	7	0	6.91	7.32	7.11	0.20

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Table 7.26: Iron Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Iron			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	2	300	7	0	5.11	5.31	5.21	0.10
C	Epoxy	2	300	7	0	7.90	8.45	8.18	0.27
A	Epoxy	2	300	7	200	9.95	10.87	10.41	0.46
B	Vinyl Ester	2	300	7	200	6.63	7.07	6.85	0.22
C	Epoxy	2	300	7	200	11.36	12.59	11.97	0.62
A	Epoxy	2	300	7	20000	30.10	33.98	32.04	1.94
B	Vinyl Ester	2	300	7	20000	18.08	19.94	19.01	0.93
C	Epoxy	2	300	7	20000	34.24	39.45	36.85	2.60
A	Epoxy	2	300	7	SeaWater	40.47	43.95	42.21	1.74
B	Vinyl Ester	2	300	7	SeaWater	21.89	23.55	22.72	0.83
C	Epoxy	2	300	7	SeaWater	46.21	50.88	48.55	2.33
A	Epoxy	1	300	10	0	5.33	5.47	5.40	0.07
B	Vinyl Ester	1	300	10	0	3.67	3.73	3.70	0.03
C	Epoxy	1	300	10	0	6.94	7.10	7.02	0.08
A	Epoxy	1	300	10	200	8.17	8.88	8.52	0.35
B	Vinyl Ester	1	300	10	200	5.39	5.68	5.54	0.14
C	Epoxy	1	300	10	200	10.66	11.51	11.08	0.42
A	Epoxy	1	300	10	20000	20.29	23.47	21.88	1.59
B	Vinyl Ester	1	300	10	20000	12.86	14.15	13.51	0.65
C	Epoxy	1	300	10	20000	26.54	30.35	28.44	1.91
A	Epoxy	1	300	10	SeaWater	28.65	35.78	32.22	3.56
B	Vinyl Ester	1	300	10	SeaWater	17.50	20.40	18.95	1.45
C	Epoxy	1	300	10	SeaWater	37.60	46.16	41.88	4.28
A	Epoxy	2	300	10	0	7.78	7.99	7.88	0.10
B	Vinyl Ester	2	300	10	0	5.57	5.67	5.62	0.05
C	Epoxy	2	300	10	0	8.93	9.20	9.07	0.14
A	Epoxy	2	300	10	200	12.62	13.64	13.13	0.51
B	Vinyl Ester	2	300	10	200	8.17	8.65	8.41	0.24
C	Epoxy	2	300	10	200	14.41	15.78	15.10	0.69
A	Epoxy	2	300	10	20000	33.14	37.75	35.44	2.30
B	Vinyl Ester	2	300	10	20000	19.42	21.61	20.51	1.10
C	Epoxy	2	300	10	20000	37.68	43.84	40.76	3.08
A	Epoxy	2	300	10	SeaWater	49.60	59.93	54.77	5.17
B	Vinyl Ester	2	300	10	SeaWater	26.32	31.25	28.78	2.46
C	Epoxy	2	300	10	SeaWater	56.06	69.91	62.98	6.92
A	Epoxy	1	300	13	0	6.29	7.70	6.99	0.71
B	Vinyl Ester	1	300	13	0	4.44	5.01	4.73	0.29
C	Epoxy	1	300	13	0	8.25	9.94	9.09	0.85
A	Epoxy	1	300	13	200	11.76	14.58	13.17	1.41
B	Vinyl Ester	1	300	13	200	7.86	9.02	8.44	0.58
C	Epoxy	1	300	13	200	15.42	18.81	17.12	1.69
A	Epoxy	1	300	13	20000	29.38	30.93	30.16	0.78

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Table 7.26: Iron Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Iron			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	1	300	13	20000	18.07	18.70	18.39	0.32
C	Epoxy	1	300	13	20000	38.27	40.13	39.20	0.93
A	Epoxy	1	300	13	SeaWater	40.54	46.89	43.71	3.18
B	Vinyl Ester	1	300	13	SeaWater	24.12	26.71	25.41	1.30
C	Epoxy	1	300	13	SeaWater	53.01	60.63	56.82	3.81
A	Epoxy	2	300	13	0	9.33	11.37	10.35	1.02
B	Vinyl Ester	2	300	13	0	6.69	7.67	7.18	0.49
C	Epoxy	2	300	13	0	10.53	13.27	11.90	1.37
A	Epoxy	2	300	13	200	18.50	22.59	20.54	2.05
B	Vinyl Ester	2	300	13	200	11.85	13.80	12.82	0.98
C	Epoxy	2	300	13	200	20.88	26.36	23.62	2.74
A	Epoxy	2	300	13	20000	48.33	50.58	49.46	1.13
B	Vinyl Ester	2	300	13	20000	27.39	28.47	27.93	0.54
C	Epoxy	2	300	13	20000	55.37	58.38	56.88	1.51
A	Epoxy	2	300	13	SeaWater	60.58	69.79	65.18	4.60
B	Vinyl Ester	2	300	13	SeaWater	36.40	40.79	38.59	2.20
C	Epoxy	2	300	13	SeaWater	68.79	81.13	74.96	6.17

Table 7.27: Iron Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Iron			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	300	4	0	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	300	4	0	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	300	4	200	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	300	4	200	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	300	4	20000	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	300	4	20000	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	300	4	SeaWater	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	300	4	SeaWater	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	300	7	0	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	300	7	0	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	300	7	200	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	300	7	200	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	300	7	20000	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	300	7	20000	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	300	7	SeaWater	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	300	7	SeaWater	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	300	10	0	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	300	10	0	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	300	10	200	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	300	10	200	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	300	10	20000	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	300	10	20000	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	300	10	SeaWater	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	300	10	SeaWater	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	300	13	0	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	300	13	0	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	300	13	200	Below 0.05	Below 0.05	Below 0.05	0.0

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Table 7.27: Iron Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Iron			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	300	13	200	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	300	13	20000	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	300	13	20000	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	300	13	SeaWater	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	300	13	SeaWater	Below 0.05	Below 0.05	Below 0.05	0.0

Table 7.28: Iron Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Iron			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Sized	300	4	0	0.94	0.96	0.95	0.01
B	Sized	300	4	0	0.74	0.76	0.75	0.01
C	Sized	300	4	0	1.05	1.08	1.06	0.01
A	Sized	300	4	200	1.40	1.56	1.48	0.08
B	Sized	300	4	200	0.81	0.95	0.88	0.07
C	Sized	300	4	200	1.56	1.75	1.66	0.09
A	Sized	300	4	20000	2.83	3.19	3.01	0.18
B	Sized	300	4	20000	1.96	2.26	2.11	0.15
C	Sized	300	4	20000	3.17	3.57	3.37	0.20
A	Sized	300	4	SeaWater	5.53	7.15	6.34	0.81
B	Sized	300	4	SeaWater	1.88	3.22	2.55	0.67
C	Sized	300	4	SeaWater	6.19	8.01	7.10	0.91
A	Unsized	300	4	0	0.88	0.91	0.89	0.01
B	Unsized	300	4	0	0.69	0.71	0.70	0.01
A	Unsized	300	4	200	1.31	1.51	1.41	0.10
B	Unsized	300	4	200	0.76	0.91	0.84	0.08
A	Unsized	300	4	20000	2.67	3.10	2.88	0.21
B	Unsized	300	4	20000	1.89	2.22	2.06	0.17
A	Unsized	300	4	SeaWater	5.17	7.08	6.12	0.96
B	Unsized	300	4	SeaWater	1.80	3.27	2.53	0.74
A	Sized	300	7	0	0.93	1.03	0.98	0.05
B	Sized	300	7	0	0.73	0.81	0.77	0.04
C	Sized	300	7	0	1.04	1.15	1.10	0.05
A	Sized	300	7	200	1.45	1.67	1.56	0.11
B	Sized	300	7	200	0.92	1.10	1.01	0.09
C	Sized	300	7	200	1.63	1.87	1.75	0.12
A	Sized	300	7	20000	3.32	4.24	3.78	0.46
B	Sized	300	7	20000	2.42	3.18	2.80	0.38
C	Sized	300	7	20000	3.72	4.75	4.23	0.51
A	Sized	300	7	SeaWater	6.60	7.42	7.01	0.41
B	Sized	300	7	SeaWater	3.00	3.68	3.34	0.34
C	Sized	300	7	SeaWater	7.39	8.31	7.85	0.46
A	Unsized	300	7	0	0.87	0.98	0.93	0.06
B	Unsized	300	7	0	0.68	0.76	0.72	0.04
A	Unsized	300	7	200	1.36	1.61	1.49	0.13
B	Unsized	300	7	200	0.87	1.06	0.96	0.10
A	Unsized	300	7	20000	3.09	4.17	3.63	0.54
B	Unsized	300	7	20000	2.35	3.19	2.77	0.42
A	Unsized	300	7	SeaWater	6.30	7.27	6.79	0.49
B	Unsized	300	7	SeaWater	2.95	3.70	3.33	0.37
A	Sized	300	10	0	1.09	1.13	1.11	0.02

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Table 7.28: Iron Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Iron			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Sized	300	10	0	0.81	0.85	0.83	0.02
C	Sized	300	10	0	1.22	1.27	1.24	0.03
A	Sized	300	10	200	1.77	2.01	1.89	0.12
B	Sized	300	10	200	1.14	1.34	1.24	0.10
C	Sized	300	10	200	1.98	2.25	2.12	0.14
A	Sized	300	10	20000	3.69	4.77	4.23	0.54
B	Sized	300	10	20000	2.57	3.47	3.02	0.45
C	Sized	300	10	20000	4.13	5.35	4.74	0.61
A	Sized	300	10	SeaWater	6.45	8.89	7.67	1.22
B	Sized	300	10	SeaWater	3.22	5.24	4.23	1.01
C	Sized	300	10	SeaWater	7.22	9.96	8.59	1.37
A	Unsized	300	10	0	1.02	1.08	1.05	0.03
B	Unsized	300	10	0	0.76	0.80	0.78	0.02
A	Unsized	300	10	200	1.08	1.30	1.19	0.11
B	Unsized	300	10	200	1.66	1.95	1.80	0.14
A	Unsized	300	10	20000	3.43	4.71	4.07	0.64
B	Unsized	300	10	20000	2.49	3.48	2.99	0.50
A	Unsized	300	10	SeaWater	5.97	8.86	7.42	1.44
B	Unsized	300	10	SeaWater	3.11	5.33	4.22	1.11
A	Sized	300	13	0	1.12	1.60	1.36	0.24
B	Sized	300	13	0	0.86	1.26	1.06	0.20
C	Sized	300	13	0	1.25	1.79	1.52	0.27
A	Sized	300	13	200	2.19	3.15	2.67	0.48
B	Sized	300	13	200	1.49	2.29	1.89	0.40
C	Sized	300	13	200	2.45	3.53	2.99	0.54
A	Sized	300	13	20000	5.62	6.16	5.89	0.27
B	Sized	300	13	20000	3.89	4.33	4.11	0.22
C	Sized	300	13	20000	6.30	6.89	6.60	0.30
A	Sized	300	13	SeaWater	7.66	9.84	8.75	1.09
B	Sized	300	13	SeaWater	4.77	6.57	5.67	0.90
C	Sized	300	13	SeaWater	8.58	11.02	9.80	1.22
A	Unsized	300	13	0	1.00	1.57	1.29	0.29
B	Unsized	300	13	0	0.78	1.22	1.00	0.22
A	Unsized	300	13	200	1.98	3.12	2.55	0.57
B	Unsized	300	13	200	1.39	2.27	1.83	0.44
A	Unsized	300	13	20000	5.36	5.99	5.68	0.31
B	Unsized	300	13	20000	3.83	4.32	4.07	0.24
A	Unsized	300	13	SeaWater	7.19	9.76	8.48	1.29
B	Unsized	300	13	SeaWater	4.62	6.60	5.61	0.99

For a better understanding, change in the Iron content of the environments was plotted in graphs in Figure 7.28, 7.29, and 7.30. It can be seen that the Iron content of all environments has increased except for

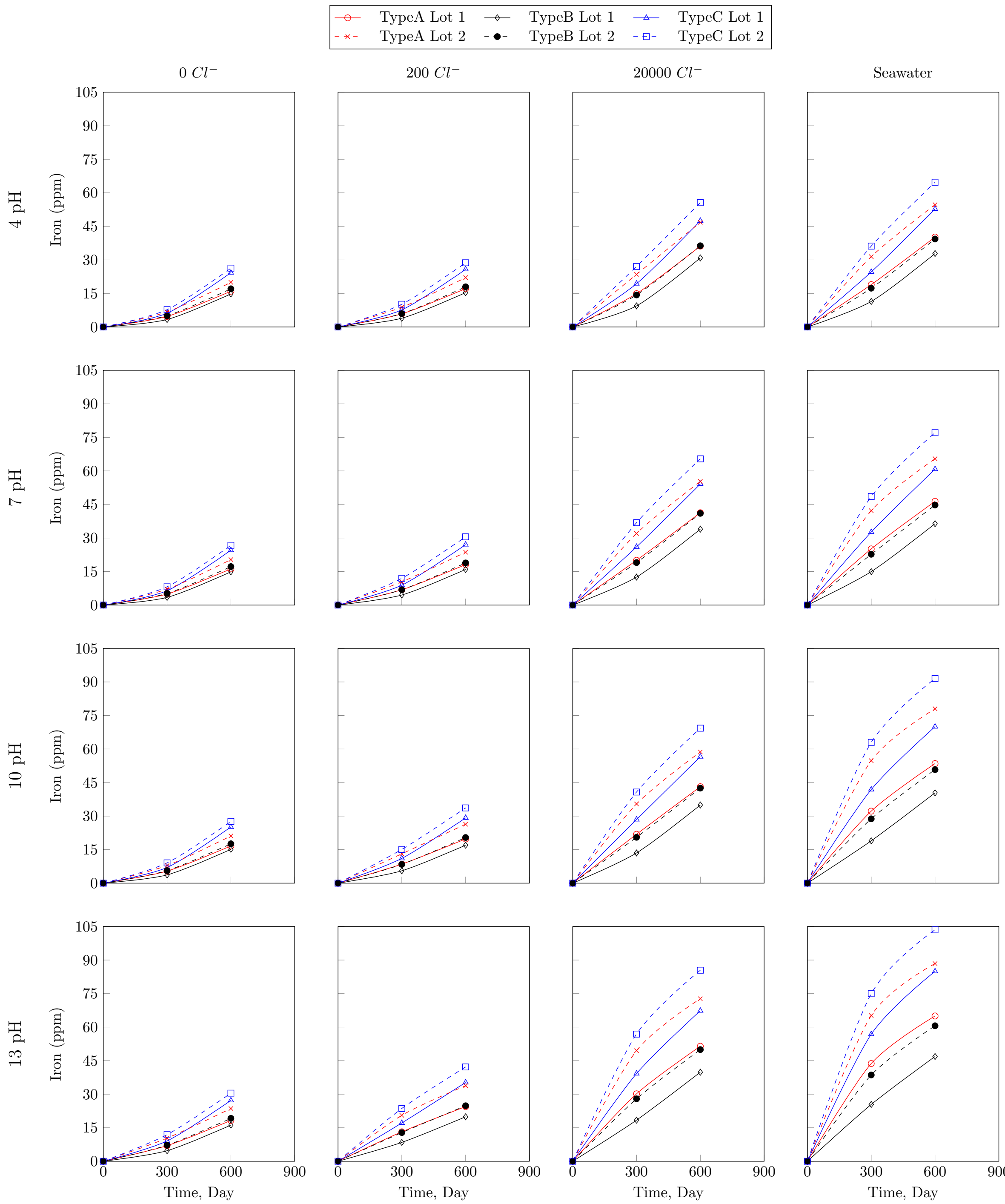

Figure 7.28: Iron concentration of all environments after exposure of rebars

the environments in which resin samples were exposed.

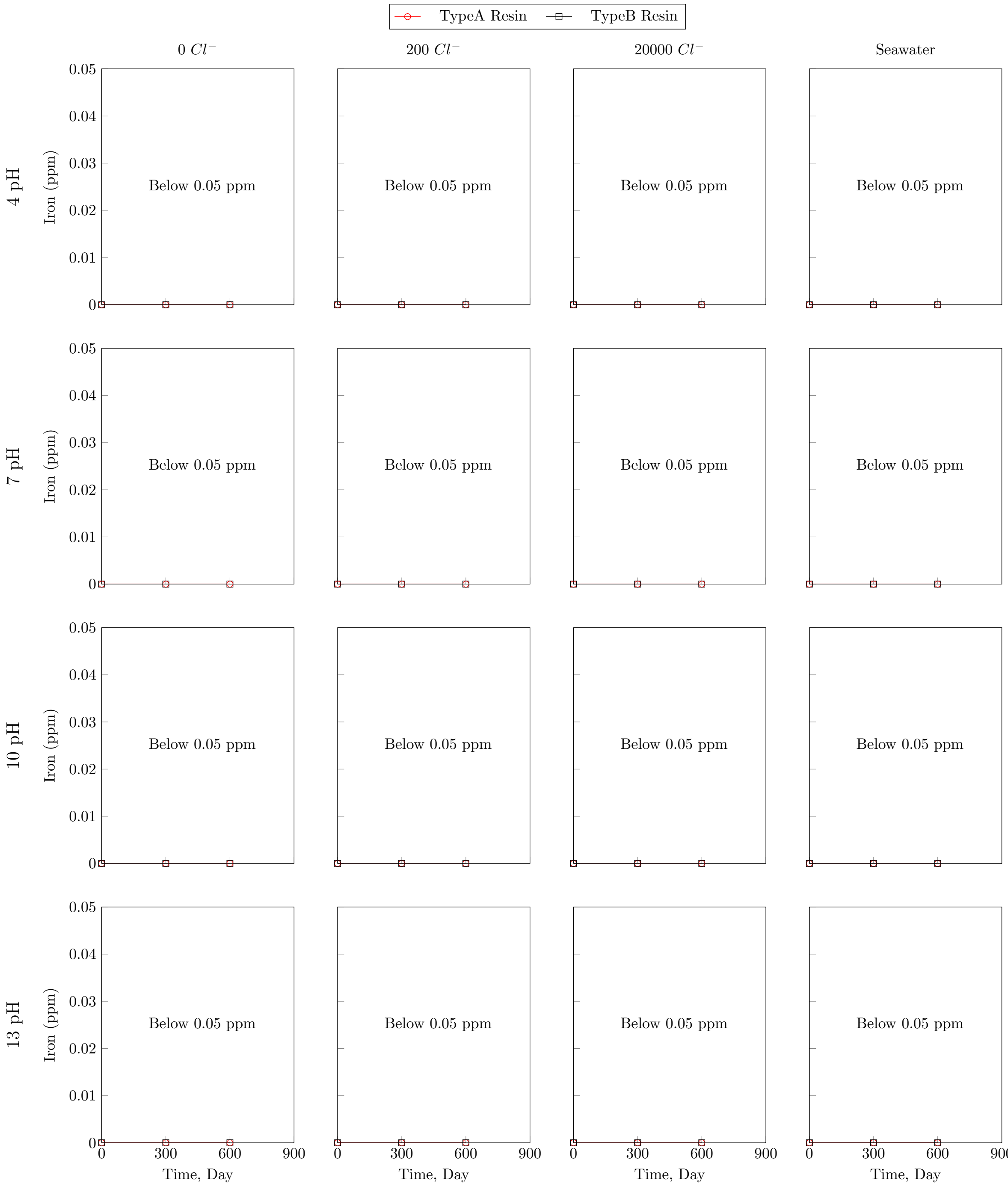

Figure 7.29: Iron concentration of all environments after exposure of resins

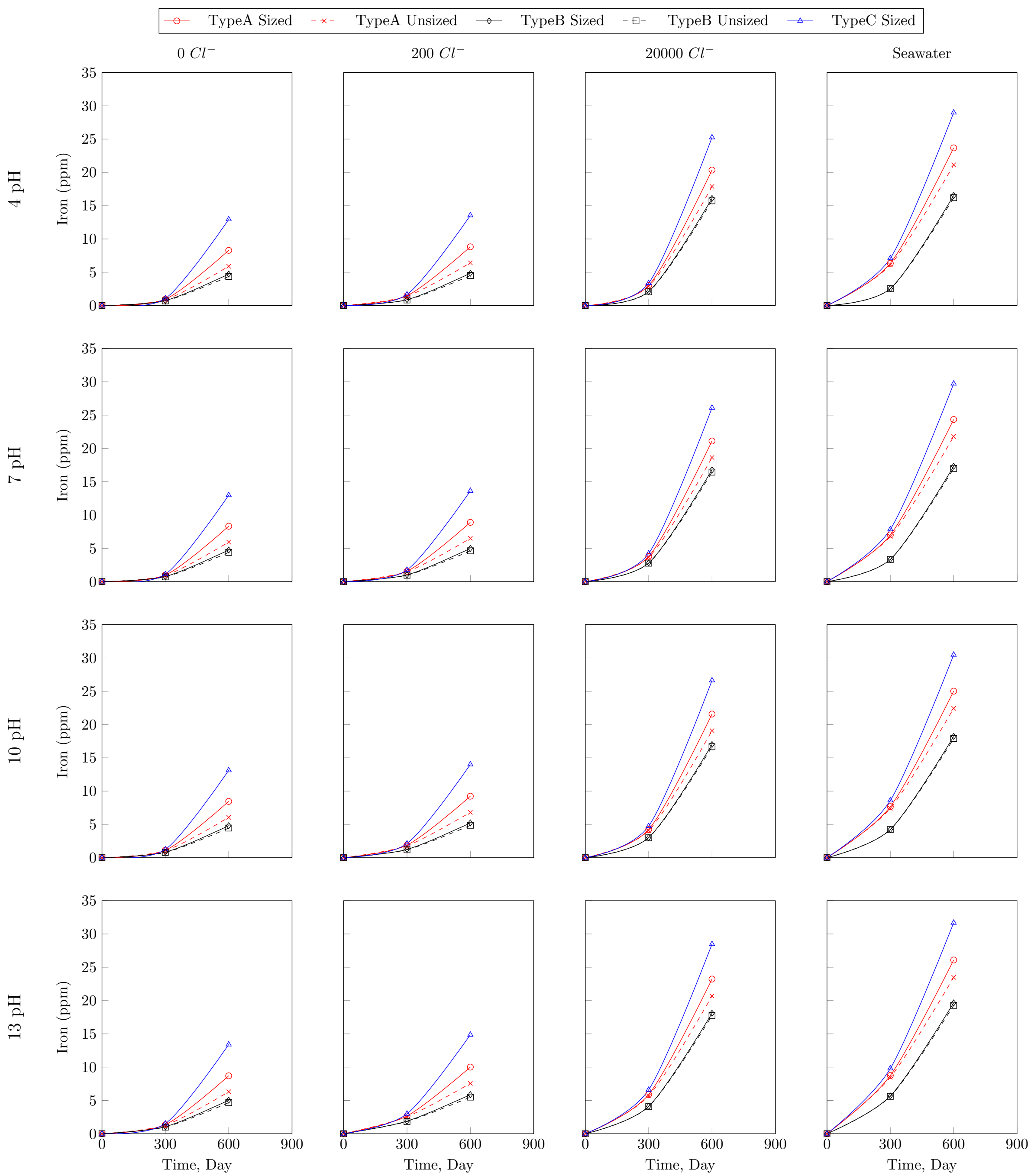

Figure 7.30: Iron concentration of all environments after exposure of sized and unsized fibers

Magnesium

Magnesium content of the chemical environments was measured after 300 days of exposure. Tables 7.29, 7.30, and 7.31 below shows the pH data of environments in which rebars, resins, and fibers were exposed.

Table 7.29: Magnesium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Magnesium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	1	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	1	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	1	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	1	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	1	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	1	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	1	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	1	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	1	300	4	SeaWater	1382.45	1392.89	1387.67	5.22
B	Vinyl Ester	1	300	4	SeaWater	1405.04	1414.14	1409.59	4.55
C	Epoxy	1	300	4	SeaWater	1395.75	1407.34	1401.55	5.79
A	Epoxy	2	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	2	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	2	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	2	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	2	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	2	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	2	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	2	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	2	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	2	300	4	SeaWater	1376.21	1386.45	1381.33	5.12
B	Vinyl Ester	2	300	4	SeaWater	1393.92	1405.72	1399.82	5.90
C	Epoxy	2	300	4	SeaWater	1383.81	1397.64	1390.73	6.91
A	Epoxy	1	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	1	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	1	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.00

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Table 7.29: Magnesium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Magnesium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	1	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	1	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	1	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	1	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	1	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	1	300	7	SeaWater	1370.89	1380.01	1375.45	4.56
B	Vinyl Ester	1	300	7	SeaWater	1389.33	1407.17	1398.25	8.92
C	Epoxy	1	300	7	SeaWater	1384.14	1394.26	1389.20	5.06
A	Epoxy	2	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	2	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	2	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	2	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	2	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	2	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	2	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	2	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	2	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	2	300	7	SeaWater	1364.54	1374.50	1369.52	4.98
B	Vinyl Ester	2	300	7	SeaWater	1386.70	1396.26	1391.48	4.78
C	Epoxy	2	300	7	SeaWater	1372.11	1385.55	1378.83	6.72
A	Epoxy	1	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	1	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	1	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	1	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	1	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	1	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.00

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Table 7.29: Magnesium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Magnesium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	1	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	1	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	1	300	10	SeaWater	1359.14	1373.34	1366.24	7.10
B	Vinyl Ester	1	300	10	SeaWater	1382.01	1393.35	1387.68	5.67
C	Epoxy	1	300	10	SeaWater	1372.02	1387.78	1379.90	7.88
A	Epoxy	2	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	2	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	2	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	2	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	2	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	2	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	2	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	2	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	2	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	2	300	10	SeaWater	1357.11	1368.69	1362.90	5.79
B	Vinyl Ester	2	300	10	SeaWater	1371.03	1386.79	1378.91	7.88
C	Epoxy	2	300	10	SeaWater	1364.35	1379.98	1372.17	7.82
A	Epoxy	1	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	1	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	1	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	1	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	1	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	1	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	1	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	1	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	1	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00

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Table 7.29: Magnesium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Magnesium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	13	SeaWater	1358.00	1365.12	1361.56	3.56
B	Vinyl Ester	1	300	13	SeaWater	1373.06	1386.90	1379.98	6.92
C	Epoxy	1	300	13	SeaWater	1371.23	1379.13	1375.18	3.95
A	Epoxy	2	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	2	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	2	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	2	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	2	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	2	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	2	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	2	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	2	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	2	300	13	SeaWater	1346.33	1359.89	1353.11	6.78
B	Vinyl Ester	2	300	13	SeaWater	1363.09	1381.33	1372.21	9.12
C	Epoxy	2	300	13	SeaWater	1353.16	1371.47	1362.32	9.15

Table 7.30: Magnesium Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Magnesium			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	300	4	0	0.0212	0.0218	0.0215	0.00
B	Vinyl Ester	300	4	0	0.0210	0.0214	0.0212	0.00
A	Epoxy	300	4	200	0.0203	0.0211	0.0207	0.00
B	Vinyl Ester	300	4	200	0.0202	0.0206	0.0204	0.00
A	Epoxy	300	4	20000	0.0215	0.0217	0.0216	0.00
B	Vinyl Ester	300	4	20000	0.0210	0.0216	0.0213	0.00
A	Epoxy	300	4	SeaWater	1452.47	1467.59	1460.03	7.56
B	Vinyl Ester	300	4	SeaWater	1453.54	1463.50	1458.52	4.98
A	Epoxy	300	7	0	0.0217	0.0223	0.0220	0.00
B	Vinyl Ester	300	7	0	0.0216	0.0218	0.0217	0.00
A	Epoxy	300	7	200	0.0202	0.0212	0.0207	0.00
B	Vinyl Ester	300	7	200	0.0201	0.0207	0.0204	0.00
A	Epoxy	300	7	20000	0.0211	0.0215	0.0213	0.00
B	Vinyl Ester	300	7	20000	0.0206	0.0214	0.0210	0.00
A	Epoxy	300	7	SeaWater	1473.97	1486.43	1480.20	6.23
B	Vinyl Ester	300	7	SeaWater	1468.81	1488.57	1478.69	9.88
A	Epoxy	300	10	0	0.0206	0.0214	0.0210	0.00
B	Vinyl Ester	300	10	0	0.0206	0.0208	0.0207	0.00
A	Epoxy	300	10	200	0.0197	0.0209	0.0203	0.00
B	Vinyl Ester	300	10	200	0.0199	0.0201	0.0200	0.00
A	Epoxy	300	10	20000	0.0203	0.0207	0.0205	0.00
B	Vinyl Ester	300	10	20000	0.0197	0.0207	0.0202	0.00
A	Epoxy	300	10	SeaWater	1468.61	1486.63	1477.62	9.01
B	Vinyl Ester	300	10	SeaWater	1469.22	1483.00	1476.11	6.89
A	Epoxy	300	13	0	0.0211	0.0215	0.0213	0.00
B	Vinyl Ester	300	13	0	0.0206	0.0214	0.0210	0.00
A	Epoxy	300	13	200	0.0210	0.0212	0.0211	0.00
B	Vinyl Ester	300	13	200	0.0207	0.0209	0.0208	0.00
A	Epoxy	300	13	20000	0.0205	0.0209	0.0207	0.00
B	Vinyl Ester	300	13	20000	0.0201	0.0207	0.0204	0.00
A	Epoxy	300	13	SeaWater	1493.83	1504.71	1499.27	5.44
B	Vinyl Ester	300	13	SeaWater	1488.88	1506.64	1497.76	8.88

Table 7.31: Magnesium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Magnesium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Sized	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Sized	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
C	Sized	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Sized	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Sized	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
C	Sized	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Sized	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Sized	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
C	Sized	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Sized	300	4	SeaWater	1402.74	1416.52	1409.63	6.89
B	Sized	300	4	SeaWater	1416.15	1434.83	1425.49	9.34
C	Sized	300	4	SeaWater	1419.52	1433.58	1426.55	7.03
A	Unsized	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Unsized	300	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Unsized	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Unsized	300	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Unsized	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Unsized	300	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Unsized	300	4	SeaWater	1415.10	1429.56	1422.33	7.23
B	Unsized	300	4	SeaWater	1425.49	1447.97	1436.73	11.24
A	Sized	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Sized	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.00
C	Sized	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Sized	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Sized	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
C	Sized	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Sized	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00

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Table 7.31: Magnesium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Magnesium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Sized	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00
C	Sized	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Sized	300	7	SeaWater	1394.23	1412.69	1403.46	9.23
B	Sized	300	7	SeaWater	1409.55	1425.15	1417.35	7.80
C	Sized	300	7	SeaWater	1410.89	1429.72	1420.30	9.41
A	Unsized	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Unsized	300	7	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Unsized	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Unsized	300	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Unsized	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Unsized	300	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Unsized	300	7	SeaWater	1405.51	1427.53	1416.52	11.01
B	Unsized	300	7	SeaWater	1422.44	1436.00	1429.22	6.78
A	Sized	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Sized	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.00
C	Sized	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Sized	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Sized	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.00
C	Sized	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Sized	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Sized	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
C	Sized	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Sized	300	10	SeaWater	1388.34	1402.56	1395.45	7.11
B	Sized	300	10	SeaWater	1395.13	1417.23	1406.18	11.05
C	Sized	300	10	SeaWater	1404.94	1419.45	1412.19	7.25
A	Unsized	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Unsized	300	10	0	Below 0.01	Below 0.01	Below 0.01	0.00

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Table 7.31: Magnesium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Magnesium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Unsized	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Unsized	300	10	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Unsized	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Unsized	300	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Unsized	300	10	SeaWater	1393.88	1417.92	1405.90	12.02
B	Unsized	300	10	SeaWater	1406.36	1424.24	1415.30	8.94
A	Sized	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Sized	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
C	Sized	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Sized	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Sized	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.00
C	Sized	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Sized	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Sized	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00
C	Sized	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Sized	300	13	SeaWater	1377.49	1389.75	1383.62	6.13
B	Sized	300	13	SeaWater	1385.46	1406.10	1395.78	10.32
C	Sized	300	13	SeaWater	1393.97	1406.47	1400.22	6.25
A	Unsized	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Unsized	300	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Unsized	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Unsized	300	13	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Unsized	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Unsized	300	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Unsized	300	13	SeaWater	1388.55	1407.01	1397.78	9.23
B	Unsized	300	13	SeaWater	1396.95	1415.17	1406.06	9.11

For a better understanding, change in the Magnesium content of the environments was plotted in graphs in Figure 7.31, 7.32, and 7.33. It can be seen that the Magnesium concentration in all environments has

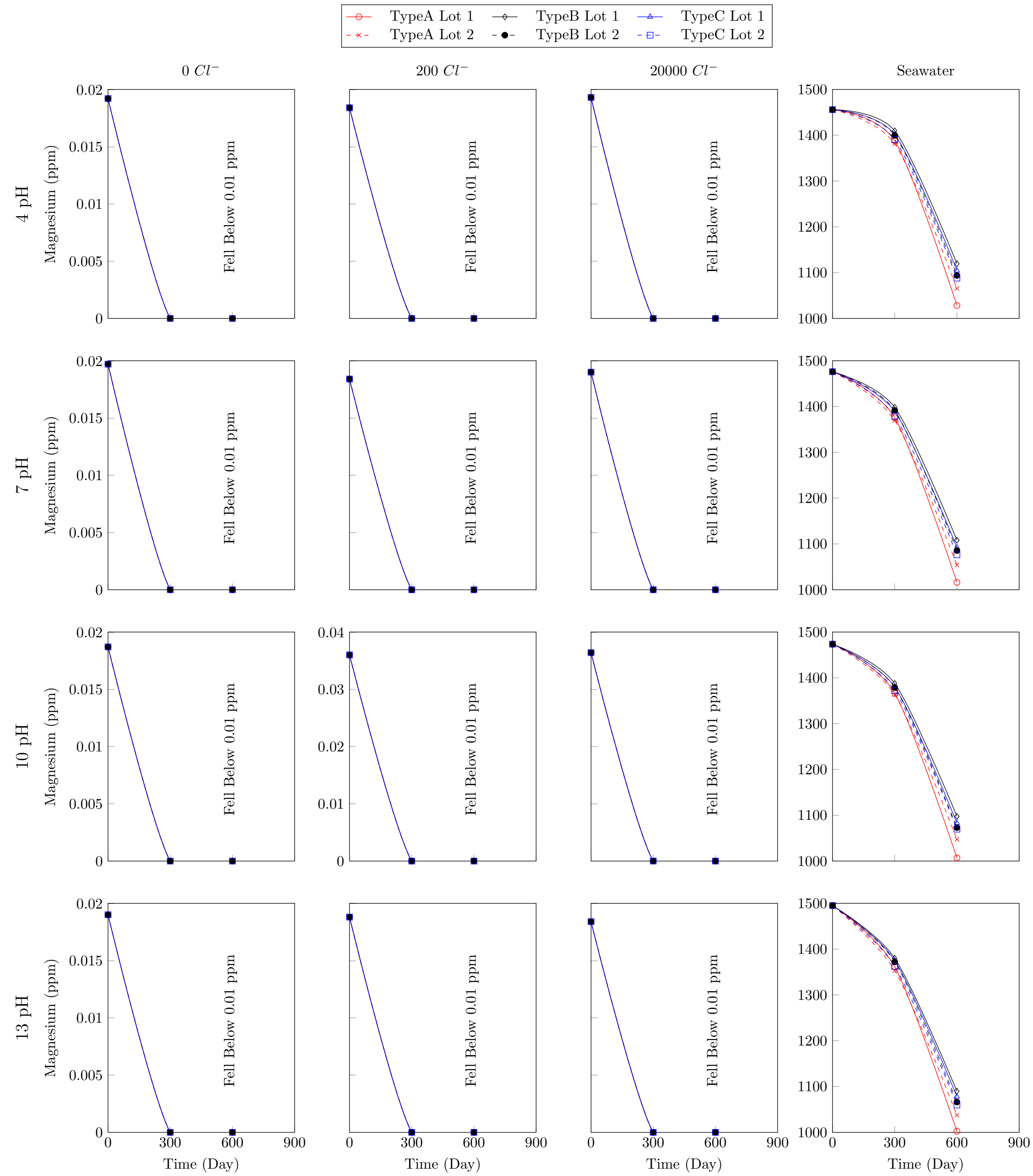

Figure 7.31: Magnesium concentration of all environments after exposure of rebars

decreased except for the environments in which resin samples were exposed.

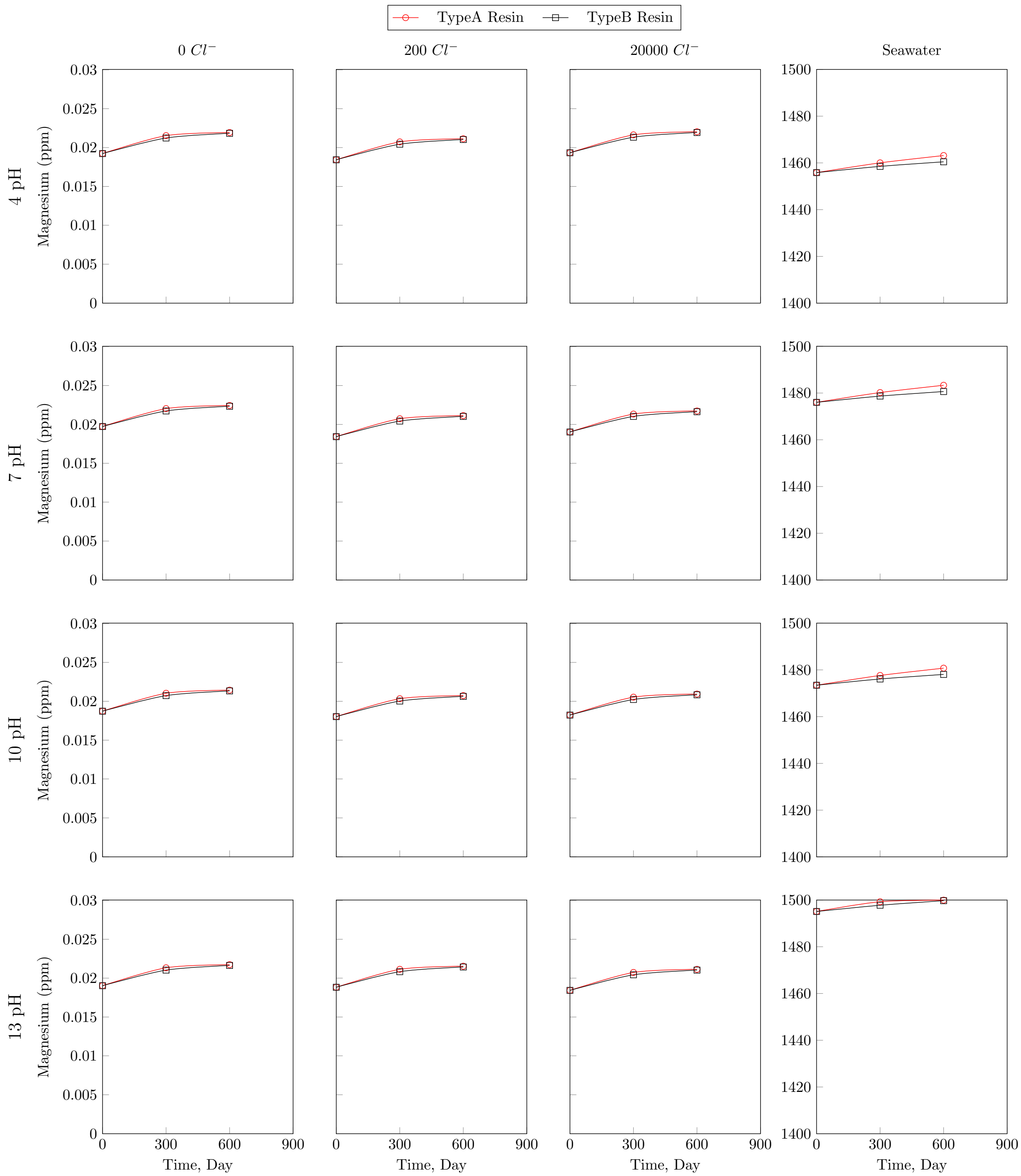

Figure 7.32: Magnesium concentration of all environments after exposure of resins

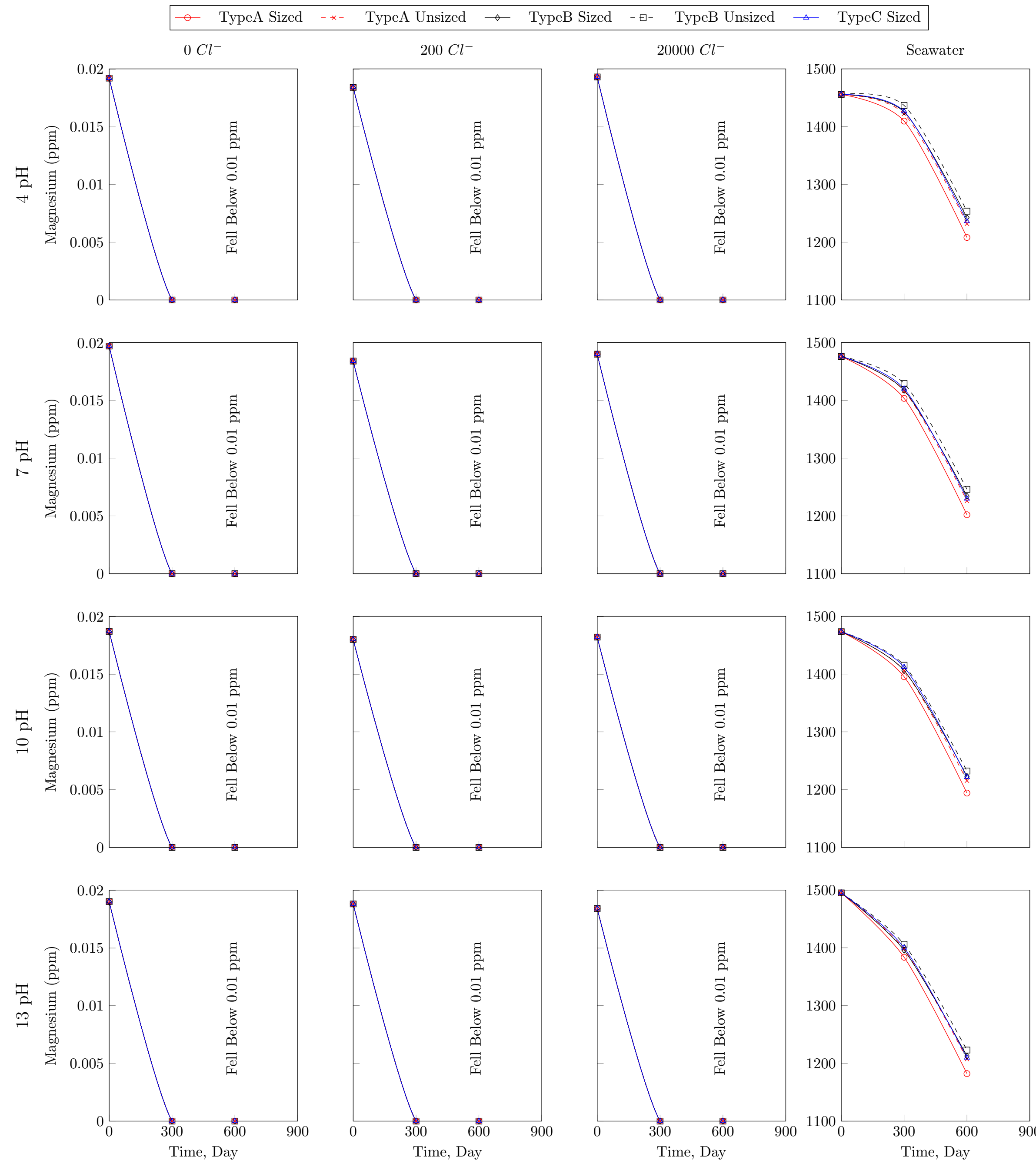

Figure 7.33: Magnesium concentration of all environments after exposure of sized and unsized fibers

Potassium

Potassium content of the chemical environments was measured after 300 days of exposure. Tables 7.32, 7.33, and 7.34 below shows the pH data of environments in which rebars, resins, and fibers were exposed.

Table 7.32: Potassium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Potassium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	4	0	0.08	0.08	0.08	0.00
B	Vinyl Ester	1	300	4	0	0.05	0.06	0.05	0.00
C	Epoxy	1	300	4	0	0.09	0.09	0.09	0.00
A	Epoxy	1	300	4	200	0.09	0.09	0.09	0.00
B	Vinyl Ester	1	300	4	200	0.06	0.07	0.06	0.00
C	Epoxy	1	300	4	200	0.10	0.10	0.10	0.00
A	Epoxy	1	300	4	20000	0.10	0.10	0.10	0.00
B	Vinyl Ester	1	300	4	20000	0.07	0.08	0.07	0.00
C	Epoxy	1	300	4	20000	0.11	0.12	0.12	0.00
A	Epoxy	1	300	4	SeaWater	408.56	420.80	414.68	6.12
B	Vinyl Ester	1	300	4	SeaWater	399.81	411.15	405.48	5.67
C	Epoxy	1	300	4	SeaWater	428.31	442.51	435.41	7.10
A	Epoxy	2	300	4	0	0.10	0.10	0.10	0.00
B	Vinyl Ester	2	300	4	0	0.06	0.06	0.06	0.00
C	Epoxy	2	300	4	0	0.14	0.14	0.14	0.00
A	Epoxy	2	300	4	200	0.11	0.12	0.12	0.00
B	Vinyl Ester	2	300	4	200	0.07	0.07	0.07	0.00
C	Epoxy	2	300	4	200	0.16	0.16	0.16	0.00
A	Epoxy	2	300	4	20000	0.13	0.13	0.13	0.00
B	Vinyl Ester	2	300	4	20000	0.08	0.08	0.08	0.00
C	Epoxy	2	300	4	20000	0.18	0.18	0.18	0.00
A	Epoxy	2	300	4	SeaWater	419.58	435.12	427.35	7.77
B	Vinyl Ester	2	300	4	SeaWater	402.26	420.30	411.28	9.02
C	Epoxy	2	300	4	SeaWater	431.66	452.95	442.30	10.64
A	Epoxy	1	300	7	0	0.08	0.08	0.08	0.00
B	Vinyl Ester	1	300	7	0	0.06	0.06	0.06	0.00
C	Epoxy	1	300	7	0	0.09	0.09	0.09	0.00
A	Epoxy	1	300	7	200	0.09	0.09	0.09	0.00
B	Vinyl Ester	1	300	7	200	0.07	0.07	0.07	0.00
C	Epoxy	1	300	7	200	0.10	0.11	0.11	0.00
A	Epoxy	1	300	7	20000	0.10	0.10	0.10	0.00
B	Vinyl Ester	1	300	7	20000	0.07	0.08	0.08	0.00
C	Epoxy	1	300	7	20000	0.12	0.12	0.12	0.00
A	Epoxy	1	300	7	SeaWater	416.35	429.91	423.13	6.78
B	Vinyl Ester	1	300	7	SeaWater	406.64	420.06	413.35	6.71
C	Epoxy	1	300	7	SeaWater	436.42	452.15	444.28	7.86
A	Epoxy	2	300	7	0	0.10	0.11	0.11	0.00

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Table 7.32: Potassium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Potassium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	2	300	7	0	0.06	0.06	0.06	0.00
C	Epoxy	2	300	7	0	0.15	0.15	0.15	0.00
A	Epoxy	2	300	7	200	0.12	0.12	0.12	0.00
B	Vinyl Ester	2	300	7	200	0.07	0.07	0.07	0.00
C	Epoxy	2	300	7	200	0.17	0.17	0.17	0.00
A	Epoxy	2	300	7	20000	0.13	0.13	0.13	0.00
B	Vinyl Ester	2	300	7	20000	0.08	0.08	0.08	0.00
C	Epoxy	2	300	7	20000	0.18	0.19	0.19	0.00
A	Epoxy	2	300	7	SeaWater	433.89	445.91	439.90	6.01
B	Vinyl Ester	2	300	7	SeaWater	407.65	429.67	418.66	11.01
C	Epoxy	2	300	7	SeaWater	447.06	463.53	455.29	8.23
A	Epoxy	1	300	10	0	0.08	0.08	0.08	0.00
B	Vinyl Ester	1	300	10	0	0.06	0.06	0.06	0.00
C	Epoxy	1	300	10	0	0.09	0.10	0.09	0.00
A	Epoxy	1	300	10	200	0.09	0.10	0.09	0.00
B	Vinyl Ester	1	300	10	200	0.07	0.07	0.07	0.00
C	Epoxy	1	300	10	200	0.11	0.11	0.11	0.00
A	Epoxy	1	300	10	20000	0.10	0.11	0.10	0.00
B	Vinyl Ester	1	300	10	20000	0.08	0.08	0.08	0.00
C	Epoxy	1	300	10	20000	0.12	0.12	0.12	0.00
A	Epoxy	1	300	10	SeaWater	423.11	441.53	432.32	9.21
B	Vinyl Ester	1	300	10	SeaWater	410.71	422.93	416.82	6.11
C	Epoxy	1	300	10	SeaWater	443.26	464.62	453.94	10.68
A	Epoxy	2	300	10	0	0.11	0.11	0.11	0.00
B	Vinyl Ester	2	300	10	0	0.06	0.07	0.06	0.00
C	Epoxy	2	300	10	0	0.15	0.15	0.15	0.00
A	Epoxy	2	300	10	200	0.12	0.12	0.12	0.00
B	Vinyl Ester	2	300	10	200	0.07	0.08	0.07	0.00
C	Epoxy	2	300	10	200	0.17	0.17	0.17	0.00
A	Epoxy	2	300	10	20000	0.13	0.14	0.14	0.00
B	Vinyl Ester	2	300	10	20000	0.08	0.08	0.08	0.00
C	Epoxy	2	300	10	20000	0.19	0.19	0.19	0.00
A	Epoxy	2	300	10	SeaWater	437.29	449.27	443.28	5.99
B	Vinyl Ester	2	300	10	SeaWater	414.75	435.21	424.98	10.23
C	Epoxy	2	300	10	SeaWater	450.59	467.01	458.80	8.21
A	Epoxy	1	300	13	0	0.08	0.09	0.09	0.00
B	Vinyl Ester	1	300	13	0	0.06	0.07	0.06	0.00
C	Epoxy	1	300	13	0	0.10	0.10	0.10	0.00
A	Epoxy	1	300	13	200	0.09	0.10	0.10	0.00
B	Vinyl Ester	1	300	13	200	0.07	0.07	0.07	0.00
C	Epoxy	1	300	13	200	0.11	0.11	0.11	0.00
A	Epoxy	1	300	13	20000	0.10	0.11	0.11	0.00

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Table 7.32: Potassium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Potassium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	∧ ppm	∨ ppm	μ ppm	σ ppm
B	Vinyl Ester	1	300	13	20000	0.08	0.08	0.08	0.00
C	Epoxy	1	300	13	20000	0.12	0.13	0.12	0.00
A	Epoxy	1	300	13	SeaWater	429.29	445.59	437.44	8.15
B	Vinyl Ester	1	300	13	SeaWater	413.26	431.28	422.27	9.01
C	Epoxy	1	300	13	SeaWater	449.86	468.77	459.31	9.45
A	Epoxy	2	300	13	0	0.11	0.12	0.11	0.00
B	Vinyl Ester	2	300	13	0	0.07	0.07	0.07	0.00
C	Epoxy	2	300	13	0	0.15	0.16	0.16	0.00
A	Epoxy	2	300	13	200	0.12	0.13	0.13	0.00
B	Vinyl Ester	2	300	13	200	0.07	0.08	0.08	0.00
C	Epoxy	2	300	13	200	0.17	0.18	0.18	0.00
A	Epoxy	2	300	13	20000	0.13	0.14	0.14	0.00
B	Vinyl Ester	2	300	13	20000	0.08	0.09	0.08	0.00
C	Epoxy	2	300	13	20000	0.19	0.20	0.19	0.00
A	Epoxy	2	300	13	SeaWater	442.33	462.11	452.22	9.89
B	Vinyl Ester	2	300	13	SeaWater	424.29	438.53	431.41	7.12
C	Epoxy	2	300	13	SeaWater	454.50	481.60	468.05	13.55

Table 7.33: Potassium Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Potassium			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	∧ ppm	∨ ppm	μ ppm	σ ppm
A	Epoxy	300	4	0	0.0069	0.0073	0.0071	0.00
B	Vinyl Ester	300	4	0	0.0069	0.0071	0.0070	0.00
A	Epoxy	300	4	200	0.0068	0.0074	0.0071	0.00
B	Vinyl Ester	300	4	200	0.0069	0.0071	0.0070	0.00
A	Epoxy	300	4	20000	0.0070	0.0072	0.0071	0.00
B	Vinyl Ester	300	4	20000	0.0068	0.0072	0.0070	0.00
A	Epoxy	300	4	SeaWater	375.86	388.32	382.09	6.23
B	Vinyl Ester	300	4	SeaWater	378.53	384.97	381.75	3.22
A	Epoxy	300	7	0	0.0066	0.0076	0.0071	0.00
B	Vinyl Ester	300	7	0	0.0067	0.0073	0.0070	0.00
A	Epoxy	300	7	200	0.0069	0.0073	0.0071	0.00
B	Vinyl Ester	300	7	200	0.0069	0.0071	0.0070	0.00
A	Epoxy	300	7	20000	0.0070	0.0072	0.0071	0.00
B	Vinyl Ester	300	7	20000	0.0068	0.0072	0.0070	0.00

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Table 7.33: Potassium Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Potassium			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	300	7	SeaWater	387.58	399.14	393.36	5.78
B	Vinyl Ester	300	7	SeaWater	387.35	398.69	393.02	5.67
A	Epoxy	300	10	0	0.0069	0.0071	0.0070	0.00
B	Vinyl Ester	300	10	0	0.0067	0.0071	0.0069	0.00
A	Epoxy	300	10	200	0.0069	0.0073	0.0071	0.00
B	Vinyl Ester	300	10	200	0.0066	0.0074	0.0070	0.00
A	Epoxy	300	10	20000	0.0068	0.0074	0.0071	0.00
B	Vinyl Ester	300	10	20000	0.0069	0.0071	0.0070	0.00
A	Epoxy	300	10	SeaWater	384.14	392.80	388.47	4.33
B	Vinyl Ester	300	10	SeaWater	381.35	394.91	388.13	6.78
A	Epoxy	300	13	0	0.0071	0.0073	0.0072	0.00
B	Vinyl Ester	300	13	0	0.0070	0.0072	0.0071	0.00
A	Epoxy	300	13	200	0.0068	0.0074	0.0071	0.00
B	Vinyl Ester	300	13	200	0.0067	0.0073	0.0070	0.00
A	Epoxy	300	13	20000	0.0066	0.0074	0.0070	0.00
B	Vinyl Ester	300	13	20000	0.0064	0.0074	0.0069	0.00
A	Epoxy	300	13	SeaWater	391.25	400.59	395.92	4.67
B	Vinyl Ester	300	13	SeaWater	391.03	400.13	395.58	4.55

Table 7.34: Potassium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Potassium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Sized	300	4	0	0.03	0.03	0.03	0.00
B	Sized	300	4	0	0.01	0.02	0.01	0.00
C	Sized	300	4	0	0.03	0.03	0.03	0.00
A	Sized	300	4	200	0.04	0.04	0.04	0.00
B	Sized	300	4	200	0.02	0.02	0.02	0.00
C	Sized	300	4	200	0.04	0.04	0.04	0.00
A	Sized	300	4	20000	0.04	0.05	0.05	0.00
B	Sized	300	4	20000	0.02	0.03	0.03	0.00
C	Sized	300	4	20000	0.05	0.05	0.05	0.00
A	Sized	300	4	SeaWater	391.33	411.35	401.34	10.01
B	Sized	300	4	SeaWater	388.20	398.00	393.10	4.90
C	Sized	300	4	SeaWater	402.37	424.39	413.38	11.01
A	Unsized	300	4	0	0.02	0.02	0.02	0.00

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Table 7.34: Potassium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Potassium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Unsized	300	4	0	0.01	0.01	0.01	0.00
A	Unsized	300	4	200	0.02	0.02	0.02	0.00
B	Unsized	300	4	200	0.01	0.01	0.01	0.00
A	Unsized	300	4	20000	0.02	0.03	0.03	0.00
B	Unsized	300	4	20000	0.01	0.01	0.01	0.00
A	Unsized	300	4	SeaWater	379.43	395.45	387.44	8.01
B	Unsized	300	4	SeaWater	379.43	384.09	381.76	2.33
A	Sized	300	7	0	0.03	0.03	0.03	0.00
B	Sized	300	7	0	0.02	0.02	0.02	0.00
C	Sized	300	7	0	0.03	0.03	0.03	0.00
A	Sized	300	7	200	0.04	0.04	0.04	0.00
B	Sized	300	7	200	0.02	0.02	0.02	0.00
C	Sized	300	7	200	0.04	0.04	0.04	0.00
A	Sized	300	7	20000	0.05	0.05	0.05	0.00
B	Sized	300	7	20000	0.03	0.03	0.03	0.00
C	Sized	300	7	20000	0.05	0.05	0.05	0.00
A	Sized	300	7	SeaWater	402.46	421.36	411.91	9.45
B	Sized	300	7	SeaWater	393.83	409.59	401.71	7.88
C	Sized	300	7	SeaWater	413.87	434.66	424.26	10.40
A	Unsized	300	7	0	0.02	0.02	0.02	0.00
B	Unsized	300	7	0	0.01	0.01	0.01	0.00
A	Unsized	300	7	200	0.02	0.02	0.02	0.00
B	Unsized	300	7	200	0.01	0.01	0.01	0.00
A	Unsized	300	7	20000	0.03	0.03	0.03	0.00
B	Unsized	300	7	20000	0.01	0.01	0.01	0.00
A	Unsized	300	7	SeaWater	387.67	405.11	396.39	8.72
B	Unsized	300	7	SeaWater	383.15	393.13	388.14	4.99
A	Sized	300	10	0	0.03	0.03	0.03	0.00
B	Sized	300	10	0	0.02	0.02	0.02	0.00
C	Sized	300	10	0	0.04	0.04	0.04	0.00
A	Sized	300	10	200	0.04	0.04	0.04	0.00
B	Sized	300	10	200	0.02	0.02	0.02	0.00
C	Sized	300	10	200	0.04	0.05	0.05	0.00
A	Sized	300	10	20000	0.05	0.05	0.05	0.00
B	Sized	300	10	20000	0.03	0.03	0.03	0.00
C	Sized	300	10	20000	0.05	0.06	0.05	0.00
A	Sized	300	10	SeaWater	408.10	426.56	417.33	9.23
B	Sized	300	10	SeaWater	398.41	416.43	407.42	9.01
C	Sized	300	10	SeaWater	419.69	440.00	429.85	10.15
A	Unsized	300	10	0	0.02	0.02	0.02	0.00
B	Unsized	300	10	0	0.01	0.01	0.01	0.00
A	Unsized	300	10	200	0.02	0.03	0.02	0.00

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Table 7.34: Potassium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Potassium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Unsized	300	10	200	0.01	0.01	0.01	0.00
A	Unsized	300	10	20000	0.03	0.03	0.03	0.00
B	Unsized	300	10	20000	0.01	0.02	0.01	0.00
A	Unsized	300	10	SeaWater	396.18	409.72	402.95	6.77
B	Unsized	300	10	SeaWater	387.14	397.26	392.20	5.06
A	Sized	300	13	0	0.03	0.04	0.04	0.00
B	Sized	300	13	0	0.02	0.02	0.02	0.00
C	Sized	300	13	0	0.04	0.04	0.04	0.00
A	Sized	300	13	200	0.04	0.05	0.04	0.00
B	Sized	300	13	200	0.02	0.03	0.02	0.00
C	Sized	300	13	200	0.05	0.05	0.05	0.00
A	Sized	300	13	20000	0.05	0.05	0.05	0.00
B	Sized	300	13	20000	0.03	0.03	0.03	0.00
C	Sized	300	13	20000	0.05	0.06	0.06	0.00
A	Sized	300	13	SeaWater	412.60	434.80	423.70	11.10
B	Sized	300	13	SeaWater	401.92	420.56	411.24	9.32
C	Sized	300	13	SeaWater	424.21	448.63	436.42	12.21
A	Unsized	300	13	0	0.02	0.03	0.02	0.00
B	Unsized	300	13	0	0.01	0.01	0.01	0.00
A	Unsized	300	13	200	0.02	0.03	0.03	0.00
B	Unsized	300	13	200	0.01	0.01	0.01	0.00
A	Unsized	300	13	20000	0.03	0.03	0.03	0.00
B	Unsized	300	13	20000	0.01	0.02	0.01	0.00
A	Unsized	300	13	SeaWater	400.32	415.66	407.99	7.67
B	Unsized	300	13	SeaWater	390.64	404.82	397.73	7.09

For a better understanding, change in the Potassium content of the environments was plotted in graphs in Figure 7.34, 7.35, and 7.36. It can be seen that the Potassium concentration in all environments has increased except for the environments in which resin samples were exposed.

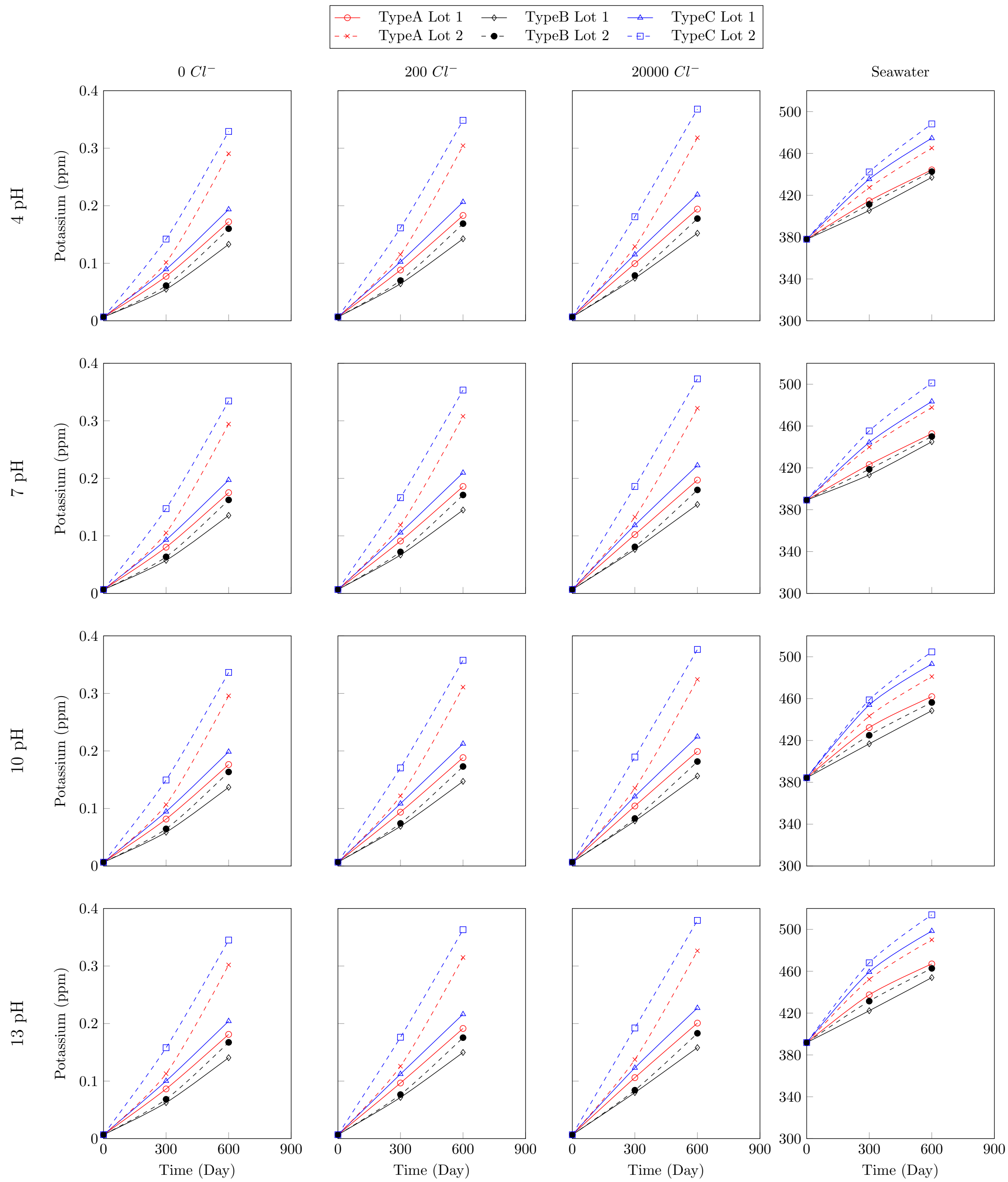

Figure 7.34: Potassium concentration of all environments after exposure of rebars

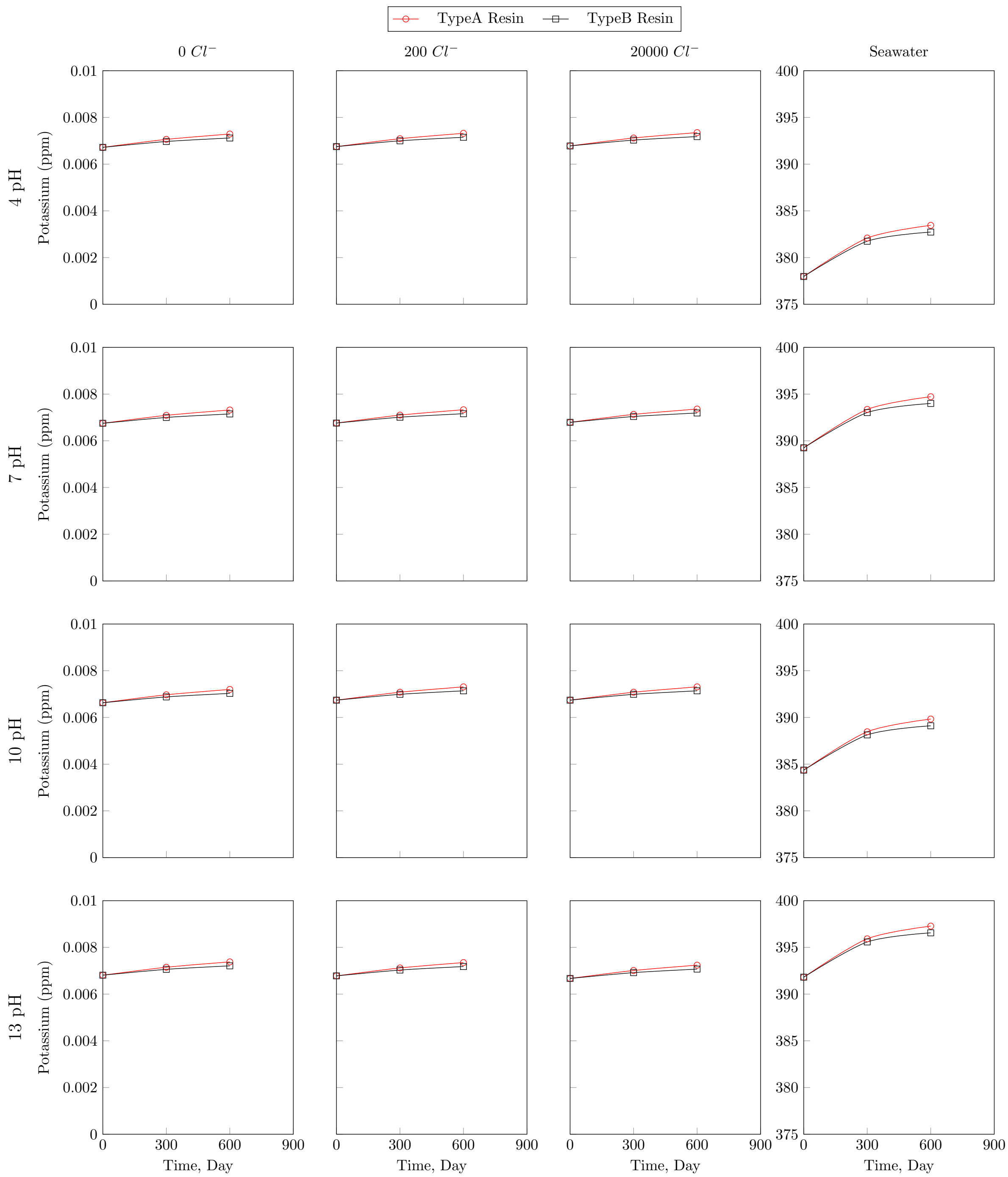

Figure 7.35: Potassium concentration of all environments after exposure of resins

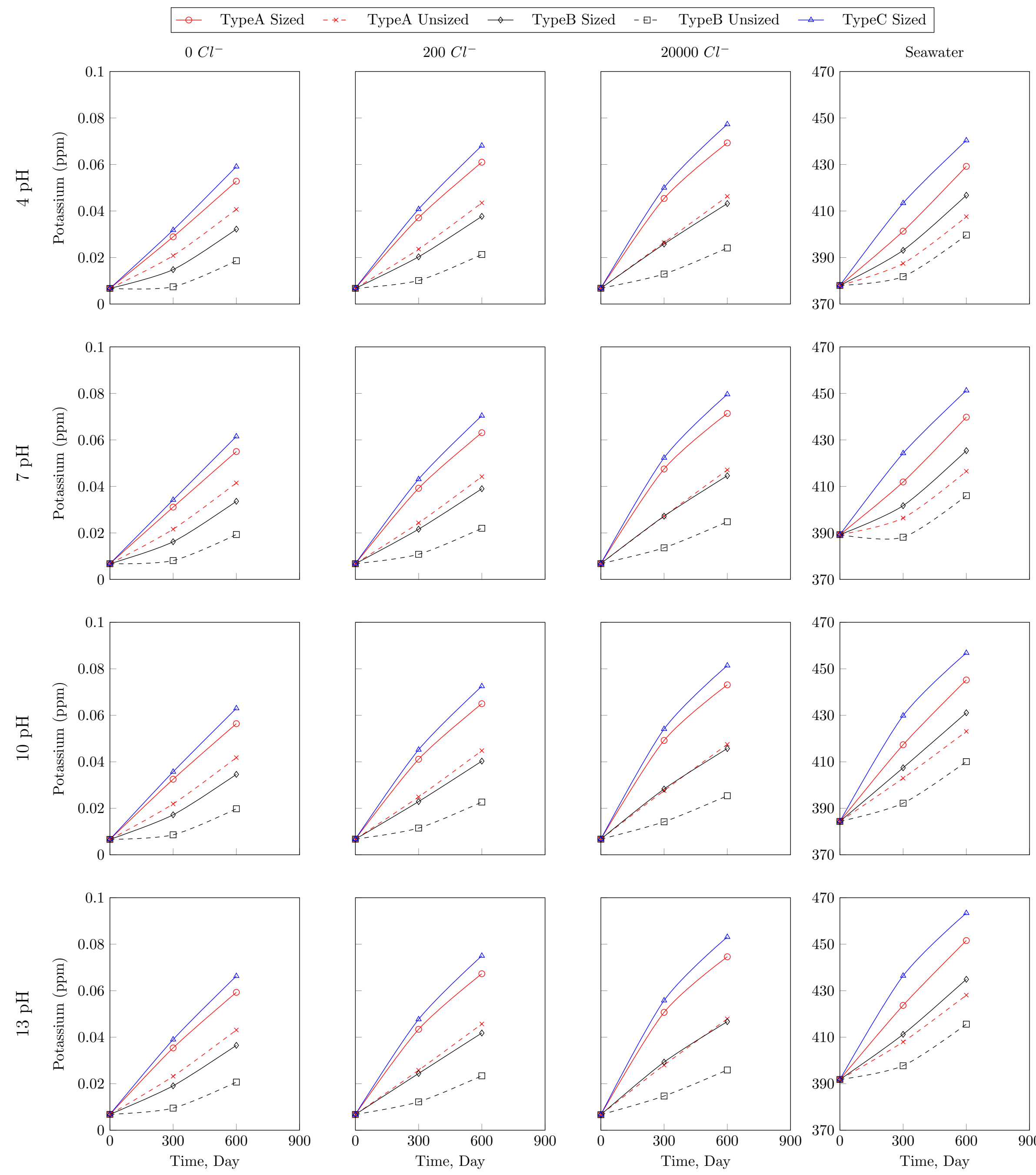

Figure 7.36: Potassium concentration of all environments after exposure of sized and unsized fibers

Silicon

Silicon content of the chemical environments was measured after 300 days of exposure. Tables 7.35, 7.36, and 7.37 below shows the pH data of environments in which rebars, resins, and fibers were exposed.

Table 7.35: Silicon Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Silicon			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	4	0	20.52	23.45	21.99	1.46
B	Vinyl Ester	1	300	4	0	14.76	16.21	15.48	0.72
C	Epoxy	1	300	4	0	27.85	31.51	29.68	1.83
A	Epoxy	1	300	4	200	25.80	30.53	28.17	2.37
B	Vinyl Ester	1	300	4	200	17.61	19.95	18.78	1.17
C	Epoxy	1	300	4	200	35.07	40.99	38.03	2.96
A	Epoxy	1	300	4	20000	33.04	34.07	33.56	0.52
B	Vinyl Ester	1	300	4	20000	20.98	21.49	21.24	0.26
C	Epoxy	1	300	4	20000	44.65	45.95	45.30	0.65
A	Epoxy	1	300	4	SeaWater	2.93	3.96	3.44	0.52
B	Vinyl Ester	1	300	4	SeaWater	3.29	3.80	3.54	0.26
C	Epoxy	1	300	4	SeaWater	2.84	4.18	3.51	0.67
A	Epoxy	2	300	4	0	29.74	32.70	31.22	1.48
B	Vinyl Ester	2	300	4	0	21.21	22.76	21.99	0.78
C	Epoxy	2	300	4	0	38.66	42.51	40.58	1.92
A	Epoxy	2	300	4	200	39.86	44.64	42.25	2.39
B	Vinyl Ester	2	300	4	200	26.91	29.43	28.17	1.26
C	Epoxy	2	300	4	200	51.82	58.04	54.93	3.11
A	Epoxy	2	300	4	20000	52.50	53.54	53.02	0.52
B	Vinyl Ester	2	300	4	20000	33.28	33.83	33.56	0.27
C	Epoxy	2	300	4	20000	68.25	69.60	68.92	0.68
A	Epoxy	2	300	4	SeaWater	2.95	3.99	3.47	0.52
B	Vinyl Ester	2	300	4	SeaWater	3.31	3.85	3.58	0.27
C	Epoxy	2	300	4	SeaWater	2.86	4.22	3.54	0.68
A	Epoxy	1	300	7	0	24.88	30.64	27.76	2.88
B	Vinyl Ester	1	300	7	0	17.85	20.71	19.28	1.43
C	Epoxy	1	300	7	0	33.87	41.08	37.48	3.60
A	Epoxy	1	300	7	200	30.62	32.60	31.61	0.99
B	Vinyl Ester	1	300	7	200	20.31	21.29	20.80	0.49
C	Epoxy	1	300	7	200	41.44	43.92	42.68	1.24
A	Epoxy	1	300	7	20000	37.51	41.21	39.36	1.85
B	Vinyl Ester	1	300	7	20000	23.69	25.52	24.60	0.92
C	Epoxy	1	300	7	20000	50.83	55.45	53.14	2.31
A	Epoxy	1	300	7	SeaWater	2.73	4.79	3.76	1.03
B	Vinyl Ester	1	300	7	SeaWater	3.37	4.39	3.88	0.51
C	Epoxy	1	300	7	SeaWater	2.49	5.18	3.84	1.34
A	Epoxy	2	300	7	0	37.06	42.89	39.98	2.91

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Table 7.35: Silicon Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Silicon			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	2	300	7	0	26.23	29.30	27.76	1.53
C	Epoxy	2	300	7	0	48.18	55.75	51.97	3.79
A	Epoxy	2	300	7	200	47.05	49.05	48.05	1.00
B	Vinyl Ester	2	300	7	200	31.09	32.14	31.61	0.53
C	Epoxy	2	300	7	200	61.17	63.77	62.47	1.30
A	Epoxy	2	300	7	20000	61.11	64.85	62.98	1.87
B	Vinyl Ester	2	300	7	20000	38.38	40.35	39.36	0.98
C	Epoxy	2	300	7	20000	79.45	84.31	81.88	2.43
A	Epoxy	2	300	7	SeaWater	2.77	4.85	3.81	1.04
B	Vinyl Ester	2	300	7	SeaWater	3.39	4.49	3.94	0.55
C	Epoxy	2	300	7	SeaWater	2.53	5.24	3.89	1.36
A	Epoxy	1	300	10	0	28.08	35.40	31.74	3.66
B	Vinyl Ester	1	300	10	0	19.93	23.55	21.74	1.81
C	Epoxy	1	300	10	0	38.28	47.42	42.85	4.57
A	Epoxy	1	300	10	200	34.52	40.03	37.27	2.75
B	Vinyl Ester	1	300	10	200	22.84	25.57	24.20	1.36
C	Epoxy	1	300	10	200	46.88	53.76	50.32	3.44
A	Epoxy	1	300	10	20000	42.63	47.27	44.95	2.32
B	Vinyl Ester	1	300	10	20000	26.60	28.90	27.75	1.15
C	Epoxy	1	300	10	20000	57.78	63.59	60.68	2.90
A	Epoxy	1	300	10	SeaWater	2.66	5.32	3.99	1.33
B	Vinyl Ester	1	300	10	SeaWater	3.36	4.68	4.02	0.66
C	Epoxy	1	300	10	SeaWater	2.34	5.80	4.07	1.73
A	Epoxy	2	300	10	0	42.65	50.04	46.34	3.69
B	Vinyl Ester	2	300	10	0	29.80	33.69	31.74	1.95
C	Epoxy	2	300	10	0	55.44	65.05	60.25	4.80
A	Epoxy	2	300	10	200	54.62	60.18	57.40	2.78
B	Vinyl Ester	2	300	10	200	35.81	38.74	37.27	1.47
C	Epoxy	2	300	10	200	71.01	78.24	74.62	3.62
A	Epoxy	2	300	10	20000	70.47	75.17	72.82	2.35
B	Vinyl Ester	2	300	10	20000	43.71	46.19	44.95	1.24
C	Epoxy	2	300	10	20000	91.62	97.72	94.67	3.05
A	Epoxy	2	300	10	SeaWater	2.60	5.30	3.95	1.35
B	Vinyl Ester	2	300	10	SeaWater	3.38	4.80	4.09	0.71
C	Epoxy	2	300	10	SeaWater	2.28	5.78	4.03	1.75
A	Epoxy	1	300	13	0	35.63	37.61	36.62	0.99
B	Vinyl Ester	1	300	13	0	24.25	25.23	24.74	0.49
C	Epoxy	1	300	13	0	48.20	50.67	49.43	1.24
A	Epoxy	1	300	13	200	41.10	43.94	42.52	1.42
B	Vinyl Ester	1	300	13	200	26.55	27.96	27.25	0.70
C	Epoxy	1	300	13	200	55.62	59.17	57.40	1.77
A	Epoxy	1	300	13	20000	44.83	52.83	48.83	4.00

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Table 7.35: Silicon Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Silicon			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	1	300	13	20000	27.80	31.76	29.78	1.98
C	Epoxy	1	300	13	20000	60.92	70.93	65.92	5.00
A	Epoxy	1	300	13	SeaWater	2.62	5.46	4.04	1.42
B	Vinyl Ester	1	300	13	SeaWater	3.41	4.81	4.11	0.70
C	Epoxy	1	300	13	SeaWater	2.27	5.97	4.12	1.85
A	Epoxy	2	300	13	0	53.19	55.19	54.19	1.00
B	Vinyl Ester	2	300	13	0	36.09	37.14	36.62	0.53
C	Epoxy	2	300	13	0	69.15	71.75	70.45	1.30
A	Epoxy	2	300	13	200	64.89	67.76	66.33	1.43
B	Vinyl Ester	2	300	13	200	41.76	43.27	42.52	0.76
C	Epoxy	2	300	13	200	84.36	88.09	86.22	1.86
A	Epoxy	2	300	13	20000	76.04	84.13	80.09	4.04
B	Vinyl Ester	2	300	13	20000	46.70	50.96	48.83	2.13
C	Epoxy	2	300	13	20000	98.86	109.37	104.11	5.25
A	Epoxy	2	300	13	SeaWater	2.64	5.50	4.07	1.43
B	Vinyl Ester	2	300	13	SeaWater	3.37	4.89	4.13	0.76
C	Epoxy	2	300	13	SeaWater	2.29	6.02	4.15	1.86

Table 7.36: Silicon Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Silicon			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	300	4	0	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	300	4	0	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	300	4	200	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	300	4	200	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	300	4	20000	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	300	4	20000	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	300	4	SeaWater	2.97	4.99	3.98	1.01
B	Vinyl Ester	300	4	SeaWater	2.77	4.99	3.88	1.11
A	Epoxy	300	7	0	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	300	7	0	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	300	7	200	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	300	7	200	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	300	7	20000	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	300	7	20000	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	300	7	SeaWater	2.83	5.47	4.15	1.32
B	Vinyl Ester	300	7	SeaWater	3.03	5.07	4.05	1.02
A	Epoxy	300	10	0	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	300	10	0	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	300	10	200	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	300	10	200	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	300	10	20000	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	300	10	20000	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	300	10	SeaWater	3.30	5.46	4.38	1.08
B	Vinyl Ester	300	10	SeaWater	3.11	5.45	4.28	1.17
A	Epoxy	300	13	0	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	300	13	0	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	300	13	200	Below 0.05	Below 0.05	Below 0.05	0.00

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Table 7.36: Silicon Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Silicon			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	300	13	200	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	300	13	20000	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	300	13	20000	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	300	13	SeaWater	3.26	5.60	4.43	1.17
B	Vinyl Ester	300	13	SeaWater	3.12	5.54	4.33	1.21

Table 7.37: Silicon Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Silicon			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Sized	300	4	0	6.33	7.03	6.68	0.35
B	Sized	300	4	0	4.71	5.39	5.05	0.34
C	Sized	300	4	0	7.21	8.01	7.61	0.40
A	Sized	300	4	200	7.11	8.24	7.68	0.57
B	Sized	300	4	200	5.23	6.33	5.78	0.55
C	Sized	300	4	200	8.10	9.40	8.75	0.65
A	Sized	300	4	20000	8.32	8.57	8.44	0.12
B	Sized	300	4	20000	6.20	6.44	6.32	0.12
C	Sized	300	4	20000	9.48	9.77	9.63	0.14
A	Sized	300	4	SeaWater	3.14	3.38	3.26	0.12
B	Sized	300	4	SeaWater	3.10	3.34	3.22	0.12
C	Sized	300	4	SeaWater	3.18	3.46	3.32	0.14
A	Unsized	300	4	0	5.18	5.97	5.57	0.39
B	Unsized	300	4	0	3.89	4.72	4.30	0.41
A	Unsized	300	4	200	5.84	7.11	6.47	0.63
B	Unsized	300	4	200	4.30	5.64	4.97	0.67
A	Unsized	300	4	20000	7.05	7.32	7.19	0.14
B	Unsized	300	4	20000	5.34	5.63	5.49	0.15
A	Unsized	300	4	SeaWater	2.83	3.11	2.97	0.14
B	Unsized	300	4	SeaWater	2.60	2.89	2.74	0.15
A	Sized	300	7	0	7.12	8.50	7.81	0.69
B	Sized	300	7	0	5.23	6.57	5.90	0.67
C	Sized	300	7	0	8.12	9.69	8.91	0.79
A	Sized	300	7	200	8.05	8.52	8.29	0.24
B	Sized	300	7	200	6.00	6.46	6.23	0.23
C	Sized	300	7	200	9.18	9.72	9.45	0.27
A	Sized	300	7	20000	9.02	9.90	9.46	0.44
B	Sized	300	7	20000	6.64	7.50	7.07	0.43
C	Sized	300	7	20000	10.28	11.29	10.78	0.50
A	Sized	300	7	SeaWater	3.59	4.08	3.83	0.25
B	Sized	300	7	SeaWater	3.54	4.02	3.78	0.24
C	Sized	300	7	SeaWater	3.63	4.19	3.91	0.28
A	Unsized	300	7	0	5.77	7.31	6.54	0.77
B	Unsized	300	7	0	4.22	5.86	5.04	0.82
A	Unsized	300	7	200	6.74	7.27	7.00	0.27
B	Unsized	300	7	200	5.09	5.65	5.37	0.28
A	Unsized	300	7	20000	7.57	8.57	8.07	0.50
B	Unsized	300	7	20000	5.63	6.68	6.15	0.52
A	Unsized	300	7	SeaWater	3.23	3.78	3.50	0.28
B	Unsized	300	7	SeaWater	2.94	3.52	3.23	0.29
A	Sized	300	10	0	7.66	9.42	8.54	0.88

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Table 7.37: Silicon Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Silicon			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Sized	300	10	0	5.60	7.30	6.45	0.85
C	Sized	300	10	0	8.74	10.73	9.74	1.00
A	Sized	300	10	200	8.65	9.97	9.31	0.66
B	Sized	300	10	200	6.35	7.63	6.99	0.64
C	Sized	300	10	200	9.86	11.37	10.61	0.75
A	Sized	300	10	20000	9.86	10.97	10.41	0.56
B	Sized	300	10	20000	7.23	8.31	7.77	0.54
C	Sized	300	10	20000	11.24	12.50	11.87	0.63
A	Sized	300	10	SeaWater	3.78	4.41	4.09	0.32
B	Sized	300	10	SeaWater	3.72	4.34	4.03	0.31
C	Sized	300	10	SeaWater	3.82	4.54	4.18	0.36
A	Unsized	300	10	0	6.18	8.15	7.16	0.98
B	Unsized	300	10	0	4.48	6.56	5.52	1.04
A	Unsized	300	10	200	7.15	8.62	7.89	0.74
B	Unsized	300	10	200	5.26	6.82	6.04	0.78
A	Unsized	300	10	20000	8.28	9.53	8.90	0.62
B	Unsized	300	10	20000	6.12	7.43	6.78	0.66
A	Unsized	300	10	SeaWater	3.39	4.11	3.75	0.36
B	Unsized	300	10	SeaWater	3.07	3.83	3.45	0.38
A	Sized	300	13	0	9.20	9.68	9.44	0.24
B	Sized	300	13	0	6.89	7.35	7.12	0.23
C	Sized	300	13	0	10.49	11.03	10.76	0.27
A	Sized	300	13	200	9.89	10.57	10.23	0.34
B	Sized	300	13	200	7.34	8.00	7.67	0.33
C	Sized	300	13	200	11.28	12.05	11.66	0.39
A	Sized	300	13	20000	10.07	11.99	11.03	0.96
B	Sized	300	13	20000	7.29	9.15	8.22	0.93
C	Sized	300	13	20000	11.48	13.67	12.58	1.09
A	Sized	300	13	SeaWater	3.84	4.52	4.18	0.34
B	Sized	300	13	SeaWater	3.78	4.44	4.11	0.33
C	Sized	300	13	SeaWater	3.88	4.65	4.27	0.38
A	Unsized	300	13	0	7.67	8.21	7.94	0.27
B	Unsized	300	13	0	5.83	6.39	6.11	0.28
A	Unsized	300	13	200	8.31	9.07	8.69	0.38
B	Unsized	300	13	200	6.24	7.04	6.64	0.40
A	Unsized	300	13	20000	8.38	10.53	9.45	1.07
B	Unsized	300	13	20000	6.05	8.32	7.18	1.13
A	Unsized	300	13	SeaWater	3.72	4.48	4.10	0.38
B	Unsized	300	13	SeaWater	3.12	3.93	3.53	0.40

For a better understanding, change in the Silicon content of the environments was plotted in graphs in

Figure 7.37, 7.38, and 7.39. It can be seen that the silicon concentration has increased in al exposure

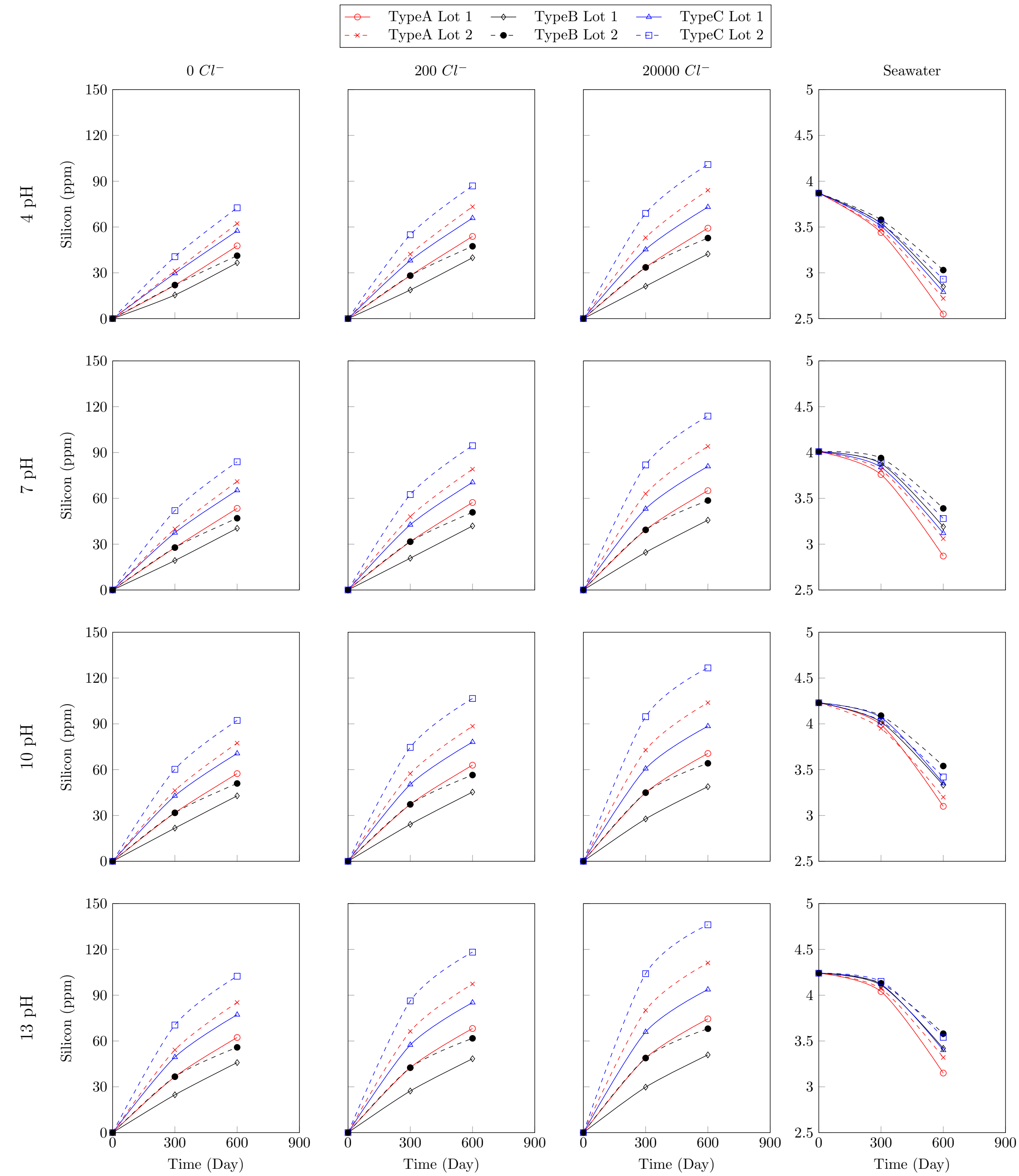

Figure 7.37: Silicon concentration of all environments after exposure of rebars

environments except the sea water environments and the exposure environments with resin samples.

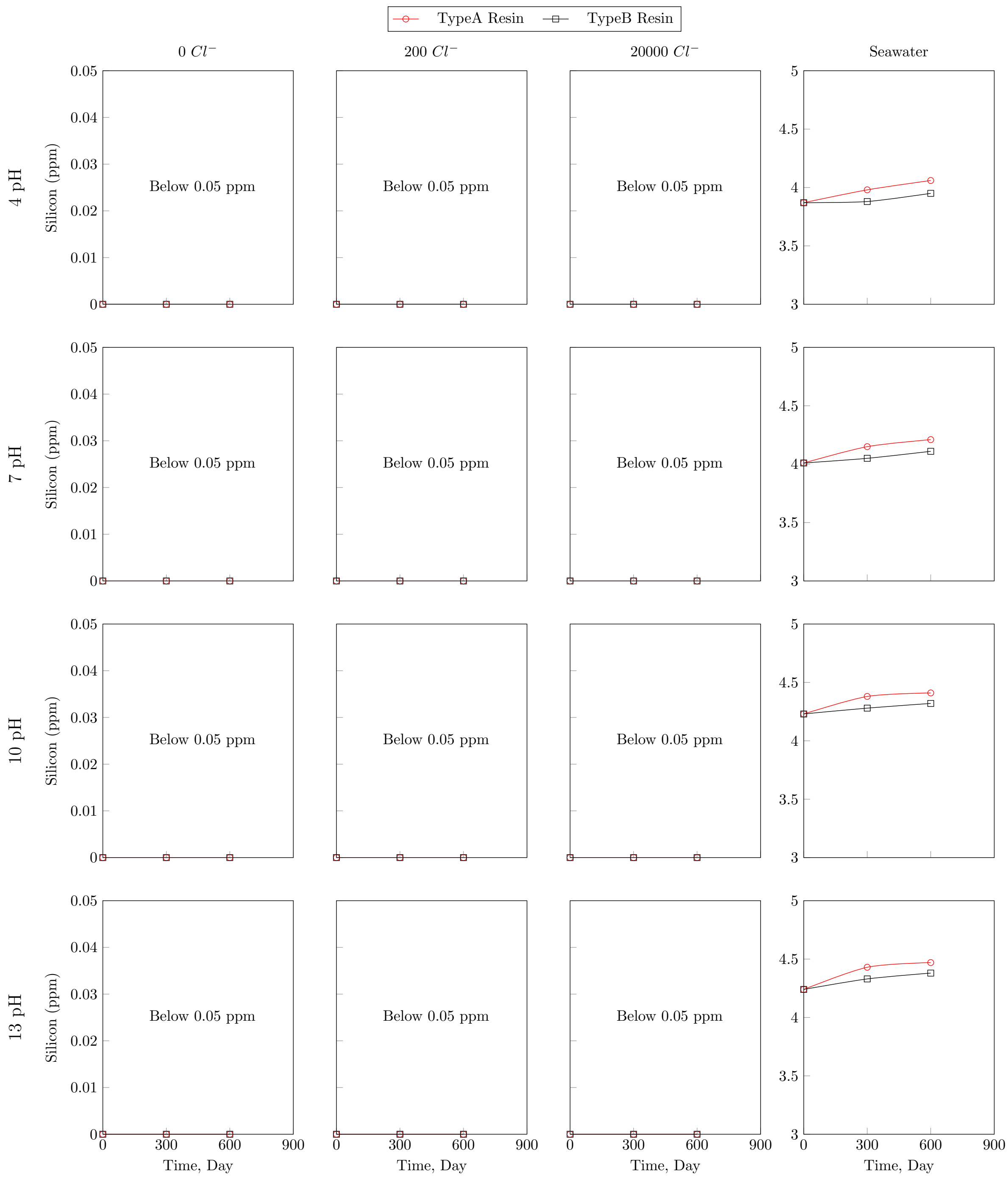

Figure 7.38: Silicon concentration of all environments after exposure of resins

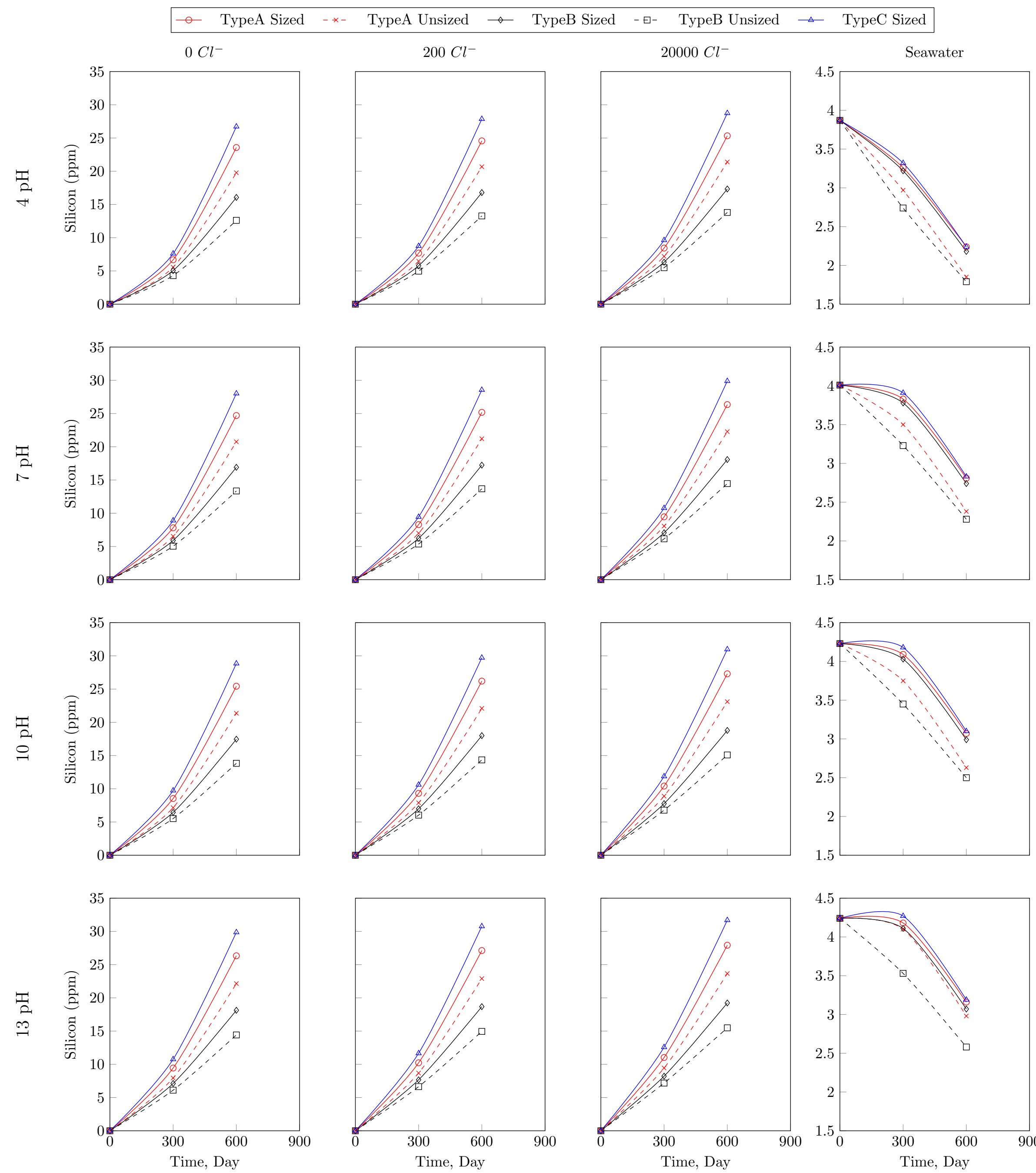

Figure 7.39: Silicon concentration of all environments after exposure of sized and unsized fibers

Sodium

Sodium content of the chemical environments was measured after 300 days of exposure. Tables 7.38, 7.39, and 7.40 below shows the pH data of environments in which rebars, resins, and fibers were exposed.

Table 7.38: Sodium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Sodium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	4	0	0.04	0.12	0.08	0.04
B	Vinyl Ester	1	300	4	0	0.04	0.12	0.08	0.04
C	Epoxy	1	300	4	0	0.05	0.09	0.07	0.02
A	Epoxy	1	300	4	200	113.27	122.23	117.75	4.48
B	Vinyl Ester	1	300	4	200	120.37	127.53	123.95	3.58
C	Epoxy	1	300	4	200	107.40	113.66	110.53	3.13
A	Epoxy	1	300	4	20000	13 158.61	13 206.70	13 182.66	24.04
B	Vinyl Ester	1	300	4	20000	13 166.35	13 212.15	13 189.25	22.90
C	Epoxy	1	300	4	20000	13 132.82	13 211.41	13 172.11	39.29
A	Epoxy	1	300	4	SeaWater	11 419.96	11 515.70	11 467.83	47.87
B	Vinyl Ester	1	300	4	SeaWater	11 440.83	11 506.31	11 473.57	32.74
C	Epoxy	1	300	4	SeaWater	11 420.26	11 497.06	11 458.66	38.40
A	Epoxy	2	300	4	0	0.06	0.08	0.07	0.01
B	Vinyl Ester	2	300	4	0	0.07	0.08	0.08	0.01
C	Epoxy	2	300	4	0	0.06	0.08	0.07	0.01
A	Epoxy	2	300	4	200	100.68	111.27	105.98	5.29
B	Vinyl Ester	2	300	4	200	109.53	113.58	111.55	2.02
C	Epoxy	2	300	4	200	94.59	104.36	99.48	4.88
A	Epoxy	2	300	4	20000	13 137.88	13 201.07	13 169.47	31.59
B	Vinyl Ester	2	300	4	20000	13 148.36	13 203.76	13 176.06	27.70
C	Epoxy	2	300	4	20000	13 119.92	13 197.96	13 158.94	39.02
A	Epoxy	2	300	4	SeaWater	11 415.74	11 496.99	11 456.36	40.63
B	Vinyl Ester	2	300	4	SeaWater	11 439.59	11 484.60	11 462.09	22.50
C	Epoxy	2	300	4	SeaWater	11 420.43	11 473.96	11 447.20	26.77
A	Epoxy	1	300	7	0	0.07	0.09	0.08	0.01
B	Vinyl Ester	1	300	7	0	0.07	0.09	0.08	0.01
C	Epoxy	1	300	7	0	0.06	0.09	0.08	0.01

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Table 7.38: Sodium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Sodium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	7	200	115.41	123.48	119.44	4.03
B	Vinyl Ester	1	300	7	200	120.33	131.13	125.73	5.40
C	Epoxy	1	300	7	200	109.78	114.46	112.12	2.34
A	Epoxy	1	300	7	20000	13 226.76	13 281.74	13 254.25	27.49
B	Vinyl Ester	1	300	7	20000	13 224.37	13 297.39	13 260.88	36.51
C	Epoxy	1	300	7	20000	13 222.77	13 264.52	13 243.64	20.88
A	Epoxy	1	300	7	SeaWater	11 448.45	11 502.93	11 475.69	27.24
B	Vinyl Ester	1	300	7	SeaWater	11 461.40	11 501.47	11 481.43	20.04
C	Epoxy	1	300	7	SeaWater	11 434.48	11 498.55	11 466.51	32.03
A	Epoxy	2	300	7	0	0.07	0.08	0.08	0.01
B	Vinyl Ester	2	300	7	0	0.07	0.09	0.08	0.01
C	Epoxy	2	300	7	0	0.06	0.08	0.07	0.01
A	Epoxy	2	300	7	200	101.34	113.66	107.50	6.16
B	Vinyl Ester	2	300	7	200	109.54	116.77	113.16	3.61
C	Epoxy	2	300	7	200	95.01	106.80	100.91	5.90
A	Epoxy	2	300	7	20000	13 211.72	13 270.27	13 240.99	29.27
B	Vinyl Ester	2	300	7	20000	13 215.62	13 279.62	13 247.62	32.00
C	Epoxy	2	300	7	20000	13 207.79	13 253.01	13 230.40	22.61
A	Epoxy	2	300	7	SeaWater	11 425.57	11 502.86	11 464.22	38.65
B	Vinyl Ester	2	300	7	SeaWater	11 439.46	11 500.44	11 469.95	30.49
C	Epoxy	2	300	7	SeaWater	11 414.32	11 495.77	11 455.04	40.73
A	Epoxy	1	300	10	0	0.78	3.35	2.07	1.29
B	Vinyl Ester	1	300	10	0	1.01	3.31	2.16	1.15
C	Epoxy	1	300	10	0	0.40	3.54	1.97	1.57
A	Epoxy	1	300	10	200	119.10	131.02	125.06	5.96
B	Vinyl Ester	1	300	10	200	124.90	138.38	131.64	6.74
C	Epoxy	1	300	10	200	111.58	123.20	117.39	5.81

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Table 7.38: Sodium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Sodium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	10	20000	13 231.22	13 305.90	13 268.56	37.34
B	Vinyl Ester	1	300	10	20000	13 235.79	13 314.61	13 275.20	39.41
C	Epoxy	1	300	10	20000	13 232.51	13 283.38	13 257.95	25.43
A	Epoxy	1	300	10	SeaWater	11 452.66	11 533.82	11 493.24	40.58
B	Vinyl Ester	1	300	10	SeaWater	11 465.97	11 532.01	11 498.99	33.02
C	Epoxy	1	300	10	SeaWater	11 437.93	11 530.15	11 484.04	46.11
A	Epoxy	2	300	10	0	1.72	2.21	1.96	0.24
B	Vinyl Ester	2	300	10	0	1.73	2.38	2.06	0.32
C	Epoxy	2	300	10	0	1.75	2.00	1.87	0.12
A	Epoxy	2	300	10	200	106.53	118.57	112.55	6.02
B	Vinyl Ester	2	300	10	200	111.49	125.46	118.48	6.99
C	Epoxy	2	300	10	200	101.01	110.29	105.65	4.64
A	Epoxy	2	300	10	20000	13 231.20	13 279.39	13 255.29	24.09
B	Vinyl Ester	2	300	10	20000	13 232.61	13 291.24	13 261.92	29.31
C	Epoxy	2	300	10	20000	13 210.60	13 278.78	13 244.69	34.09
A	Epoxy	2	300	10	SeaWater	11 449.48	11 514.01	11 481.74	32.27
B	Vinyl Ester	2	300	10	SeaWater	11 454.28	11 520.70	11 487.49	33.21
C	Epoxy	2	300	10	SeaWater	11 446.36	11 498.76	11 472.56	26.20
A	Epoxy	1	300	13	0	2258.68	2283.44	2271.06	12.38
B	Vinyl Ester	1	300	13	0	2275.85	2298.29	2287.07	11.22
C	Epoxy	1	300	13	0	2250.21	2262.38	2256.30	6.09
A	Epoxy	1	300	13	200	2443.93	2462.04	2452.99	9.05
B	Vinyl Ester	1	300	13	200	2457.84	2482.72	2470.28	12.44
C	Epoxy	1	300	13	200	2426.72	2447.37	2437.04	10.33
A	Epoxy	1	300	13	20000	15 212.09	15 281.59	15 246.84	34.75
B	Vinyl Ester	1	300	13	20000	15 213.08	15 295.85	15 254.47	41.38
C	Epoxy	1	300	13	20000	15 200.33	15 268.96	15 234.64	34.32

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Table 7.38: Sodium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Sodium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	300	13	SeaWater	13 810.73	13 877.87	13 844.30	33.57
B	Vinyl Ester	1	300	13	SeaWater	13 808.75	13 893.70	13 851.23	42.47
C	Epoxy	1	300	13	SeaWater	13 804.67	13 861.78	13 833.22	28.56
A	Epoxy	2	300	13	0	2233.15	2263.55	2248.35	15.20
B	Vinyl Ester	2	300	13	0	2258.92	2269.48	2264.20	5.28
C	Epoxy	2	300	13	0	2218.40	2249.07	2233.74	15.34
A	Epoxy	2	300	13	200	2415.64	2441.27	2428.46	12.82
B	Vinyl Ester	2	300	13	200	2414.22	2476.93	2445.58	31.35
C	Epoxy	2	300	13	200	2400.65	2424.70	2412.67	12.02
A	Epoxy	2	300	13	20000	15 194.02	15 269.16	15 231.59	37.57
B	Vinyl Ester	2	300	13	20000	15 204.92	15 273.50	15 239.21	34.29
C	Epoxy	2	300	13	20000	15 182.93	15 255.88	15 219.41	36.47
A	Epoxy	2	300	13	SeaWater	13 785.86	13 875.05	13 830.46	44.60
B	Vinyl Ester	2	300	13	SeaWater	13 790.34	13 884.41	13 837.37	47.03
C	Epoxy	2	300	13	SeaWater	13 787.43	13 851.35	13 819.39	31.96

Table 7.39: Sodium Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Sodium			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	300	4	0	0.07	0.10	0.09	0.01
B	Vinyl Ester	300	4	0	0.07	0.10	0.09	0.02
A	Epoxy	300	4	200	135.50	151.51	143.50	8.01
B	Vinyl Ester	300	4	200	134.47	152.48	143.47	9.01
A	Epoxy	300	4	20000	13 182.77	13 256.50	13 219.63	36.86
B	Vinyl Ester	300	4	20000	13 175.52	13 258.46	13 216.99	41.47
A	Epoxy	300	4	SeaWater	11 483.04	11 516.96	11 500.00	16.96
B	Vinyl Ester	300	4	SeaWater	11 478.62	11 516.78	11 497.70	19.08
A	Epoxy	300	7	0	0.06	0.13	0.09	0.04
B	Vinyl Ester	300	7	0	0.05	0.13	0.09	0.04
A	Epoxy	300	7	200	138.45	152.68	145.56	7.11
B	Vinyl Ester	300	7	200	137.53	153.54	145.53	8.00
A	Epoxy	300	7	20000	13 265.03	13 317.82	13 291.43	26.39
B	Vinyl Ester	300	7	20000	13 259.08	13 318.46	13 288.77	29.69
A	Epoxy	300	7	SeaWater	11 484.06	11 531.71	11 507.88	23.82
B	Vinyl Ester	300	7	SeaWater	11 478.78	11 532.38	11 505.58	26.80
A	Epoxy	300	10	0	1.94	2.85	2.40	0.46
B	Vinyl Ester	300	10	0	1.88	2.91	2.40	0.51
A	Epoxy	300	10	200	143.35	161.46	152.41	9.06
B	Vinyl Ester	300	10	200	142.19	162.56	152.38	10.19
A	Epoxy	300	10	20000	13 266.33	13 345.23	13 305.78	39.45
B	Vinyl Ester	300	10	20000	13 258.74	13 347.50	13 303.12	44.38
A	Epoxy	300	10	SeaWater	11 500.47	11 550.48	11 525.48	25.01
B	Vinyl Ester	300	10	SeaWater	11 495.04	11 551.31	11 523.17	28.13
A	Epoxy	300	13	0	2310.44	2334.52	2322.48	12.04
B	Vinyl Ester	300	13	0	2308.47	2335.56	2322.01	13.55
A	Epoxy	300	13	200	2496.44	2520.60	2508.52	12.08
B	Vinyl Ester	300	13	200	2494.43	2521.61	2508.02	13.59
A	Epoxy	300	13	20000	15 245.41	15 333.81	15 289.61	44.20
B	Vinyl Ester	300	13	20000	15 236.82	15 336.27	15 286.55	49.73
A	Epoxy	300	13	SeaWater	13 846.44	13 919.83	13 883.13	36.70
B	Vinyl Ester	300	13	SeaWater	13 839.07	13 921.64	13 880.36	41.28

Table 7.40: Sodium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Sodium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	∧ ppm	∨ ppm	μ ppm	σ ppm
A	Sized	300	4	0	0.06	0.10	0.08	0.02
B	Sized	300	4	0	0.07	0.10	0.08	0.01
C	Sized	300	4	0	0.06	0.10	0.08	0.02
A	Sized	300	4	200	127.87	133.80	130.84	2.97
B	Sized	300	4	200	134.71	140.73	137.72	3.01
C	Sized	300	4	200	121.98	129.22	125.60	3.62
A	Sized	300	4	20000	13 154.57	13 237.14	13 195.85	41.29
B	Sized	300	4	20000	13 165.59	13 239.32	13 202.45	36.86
C	Sized	300	4	20000	13 141.93	13 228.67	13 185.30	43.37
A	Sized	300	4	SeaWater	11 460.32	11 498.31	11 479.31	19.00
B	Sized	300	4	SeaWater	11 468.09	11 502.01	11 485.05	16.96
C	Sized	300	4	SeaWater	11 446.95	11 493.30	11 470.13	23.17
A	Unsized	300	4	0	0.05	0.11	0.08	0.03
B	Unsized	300	4	0	0.06	0.10	0.08	0.02
A	Unsized	300	4	200	125.65	138.64	132.14	6.49
B	Unsized	300	4	200	134.83	143.37	139.10	4.27
A	Unsized	300	4	20000	13 167.80	13 234.46	13 201.13	33.33
B	Unsized	300	4	20000	13 167.39	13 248.08	13 207.74	40.35
A	Unsized	300	4	SeaWater	11 447.30	11 520.51	11 483.90	36.61
B	Unsized	300	4	SeaWater	11 465.56	11 513.73	11 489.65	24.08
A	Sized	300	7	0	0.04	0.12	0.08	0.04
B	Sized	300	7	0	0.05	0.12	0.09	0.04
C	Sized	300	7	0	0.03	0.13	0.08	0.05
A	Sized	300	7	200	126.75	138.68	132.71	5.97
B	Sized	300	7	200	133.59	145.81	139.70	6.11
C	Sized	300	7	200	120.13	134.68	127.41	7.28
A	Sized	300	7	20000	13 237.96	13 297.07	13 267.52	29.56
B	Sized	300	7	20000	13 247.76	13 300.54	13 274.15	26.39
C	Sized	300	7	20000	13 220.84	13 292.96	13 256.90	36.06
A	Sized	300	7	SeaWater	11 460.50	11 513.86	11 487.18	26.68
B	Sized	300	7	SeaWater	11 469.10	11 516.75	11 492.93	23.82
C	Sized	300	7	SeaWater	11 445.44	11 510.54	11 477.99	32.55
A	Unsized	300	7	0	0.01	0.16	0.08	0.08
B	Unsized	300	7	0	0.04	0.14	0.09	0.05
A	Unsized	300	7	200	126.85	141.23	134.04	7.19
B	Unsized	300	7	200	132.42	149.78	141.10	8.68
A	Unsized	300	7	20000	13 227.86	13 317.79	13 272.82	44.96
B	Unsized	300	7	20000	13 241.99	13 316.94	13 279.46	37.48
A	Unsized	300	7	SeaWater	11 460.35	11 523.20	11 491.77	31.42
B	Unsized	300	7	SeaWater	11 463.69	11 531.35	11 497.52	33.83
A	Sized	300	10	0	1.66	2.69	2.17	0.51

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Table 7.40: Sodium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Sodium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Sized	300	10	0	1.82	2.73	2.28	0.46
C	Sized	300	10	0	1.45	2.70	2.08	0.62
A	Sized	300	10	200	133.81	144.10	138.95	5.14
B	Sized	300	10	200	141.21	151.32	146.27	5.06
C	Sized	300	10	200	127.12	139.67	133.39	6.27
A	Sized	300	10	20000	13 237.66	13 326.03	13 281.84	44.18
B	Sized	300	10	20000	13 249.04	13 327.94	13 288.49	39.45
C	Sized	300	10	20000	13 237.32	13 305.12	13 271.22	33.90
A	Sized	300	10	SeaWater	11 476.73	11 532.75	11 504.74	28.01
B	Sized	300	10	SeaWater	11 485.49	11 535.51	11 510.50	25.01
C	Sized	300	10	SeaWater	11 461.37	11 529.71	11 495.54	34.17
A	Unsized	300	10	0	1.21	3.18	2.20	0.98
B	Unsized	300	10	0	1.65	2.95	2.30	0.65
A	Unsized	300	10	200	131.43	149.25	140.34	8.91
B	Unsized	300	10	200	140.55	154.91	147.73	7.18
A	Unsized	300	10	20000	13 251.77	13 322.54	13 287.16	35.38
B	Unsized	300	10	20000	13 250.79	13 336.82	13 293.80	43.02
A	Unsized	300	10	SeaWater	11 485.37	11 533.32	11 509.34	23.98
B	Unsized	300	10	SeaWater	11 479.59	11 550.61	11 515.10	35.51
A	Sized	300	13	0	2285.52	2302.48	2294.00	8.48
B	Sized	300	13	0	2304.13	2316.21	2310.17	6.04
C	Sized	300	13	0	2268.74	2289.44	2279.09	10.35
A	Sized	300	13	200	2466.23	2489.29	2477.76	11.53
B	Sized	300	13	200	2483.15	2507.31	2495.23	12.08
C	Sized	300	13	200	2453.59	2469.73	2461.66	8.07
A	Sized	300	13	20000	15 212.60	15 311.60	15 262.10	49.50
B	Sized	300	13	20000	15 225.53	15 313.93	15 269.73	44.20
C	Sized	300	13	20000	15 208.50	15 291.29	15 249.89	41.39
A	Sized	300	13	SeaWater	13 817.06	13 899.26	13 858.16	41.10
B	Sized	300	13	SeaWater	13 828.40	13 901.79	13 865.09	36.70
C	Sized	300	13	SeaWater	13 811.93	13 882.21	13 847.07	35.14
A	Unsized	300	13	0	2296.43	2314.51	2305.47	9.04
B	Unsized	300	13	0	2306.21	2323.37	2314.79	8.58
A	Unsized	300	13	200	2480.08	2500.23	2490.15	10.07
B	Unsized	300	13	200	2483.07	2517.38	2500.22	17.15
A	Unsized	300	13	20000	15 238.40	15 298.01	15 268.20	29.80
B	Unsized	300	13	20000	15 243.08	15 308.61	15 275.84	32.76
A	Unsized	300	13	SeaWater	13 818.82	13 908.59	13 863.70	44.88
B	Unsized	300	13	SeaWater	13 834.53	13 906.75	13 870.64	36.11

For a better understanding, change in the Sodium content of the environments was plotted in graphs in

Figure 7.40, 7.41, and 7.42. It can be seen that the Sodium concentration of exposure environments has

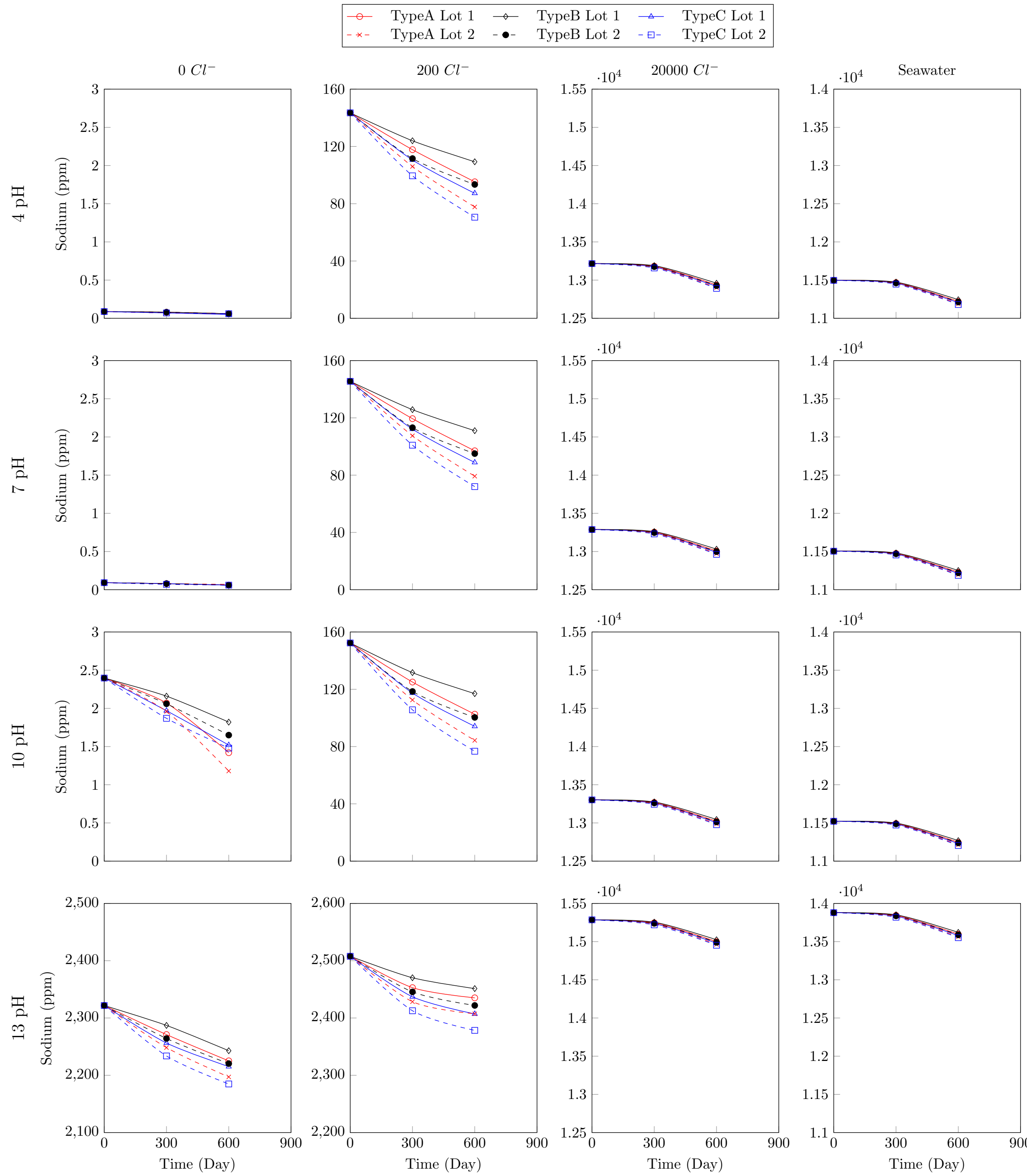

Figure 7.40: Sodium concentration of all environments after exposure of rebars

decreased except in the environments with resin samples.

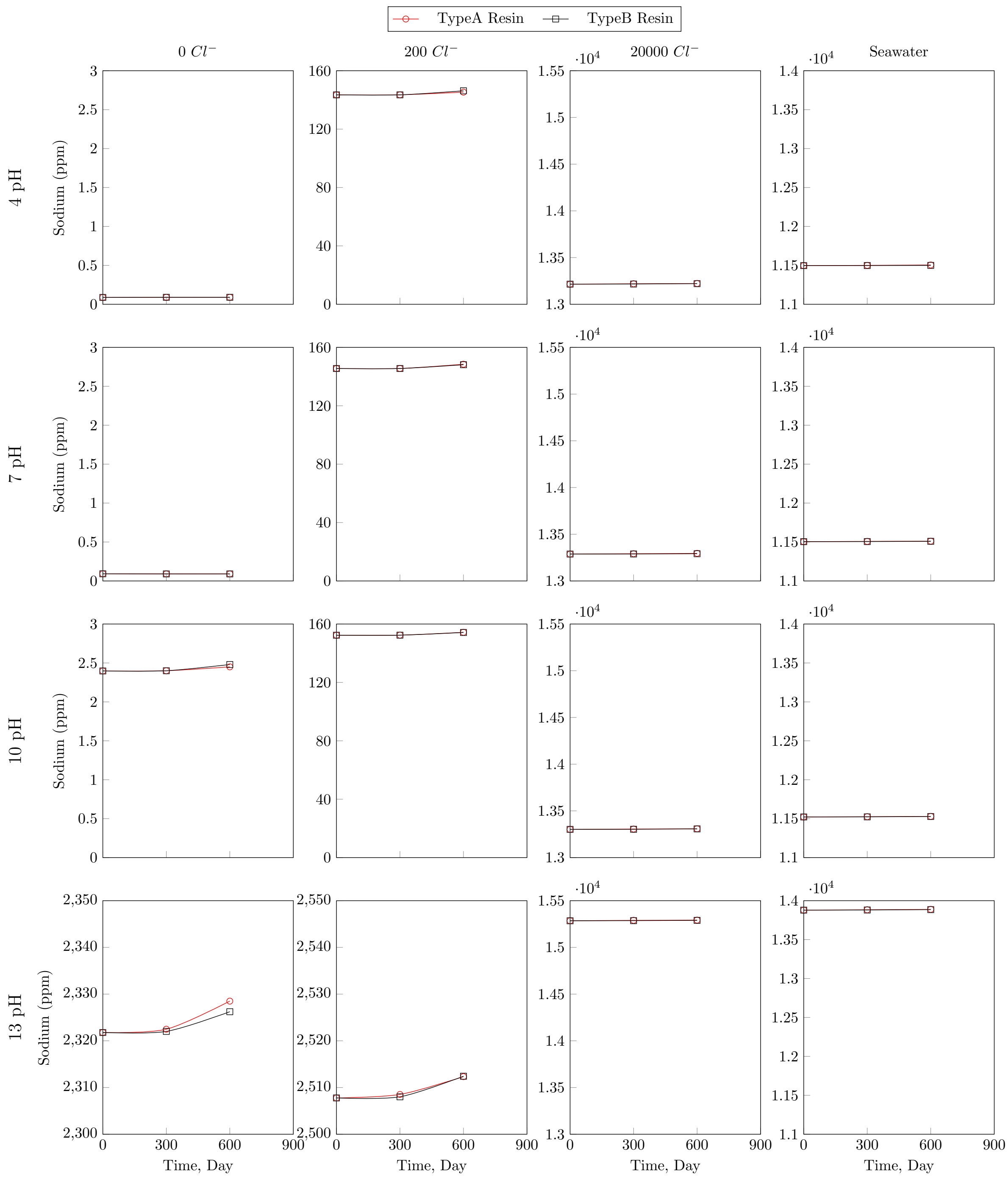

Figure 7.41: Sodium concentration of all environments after exposure of resins

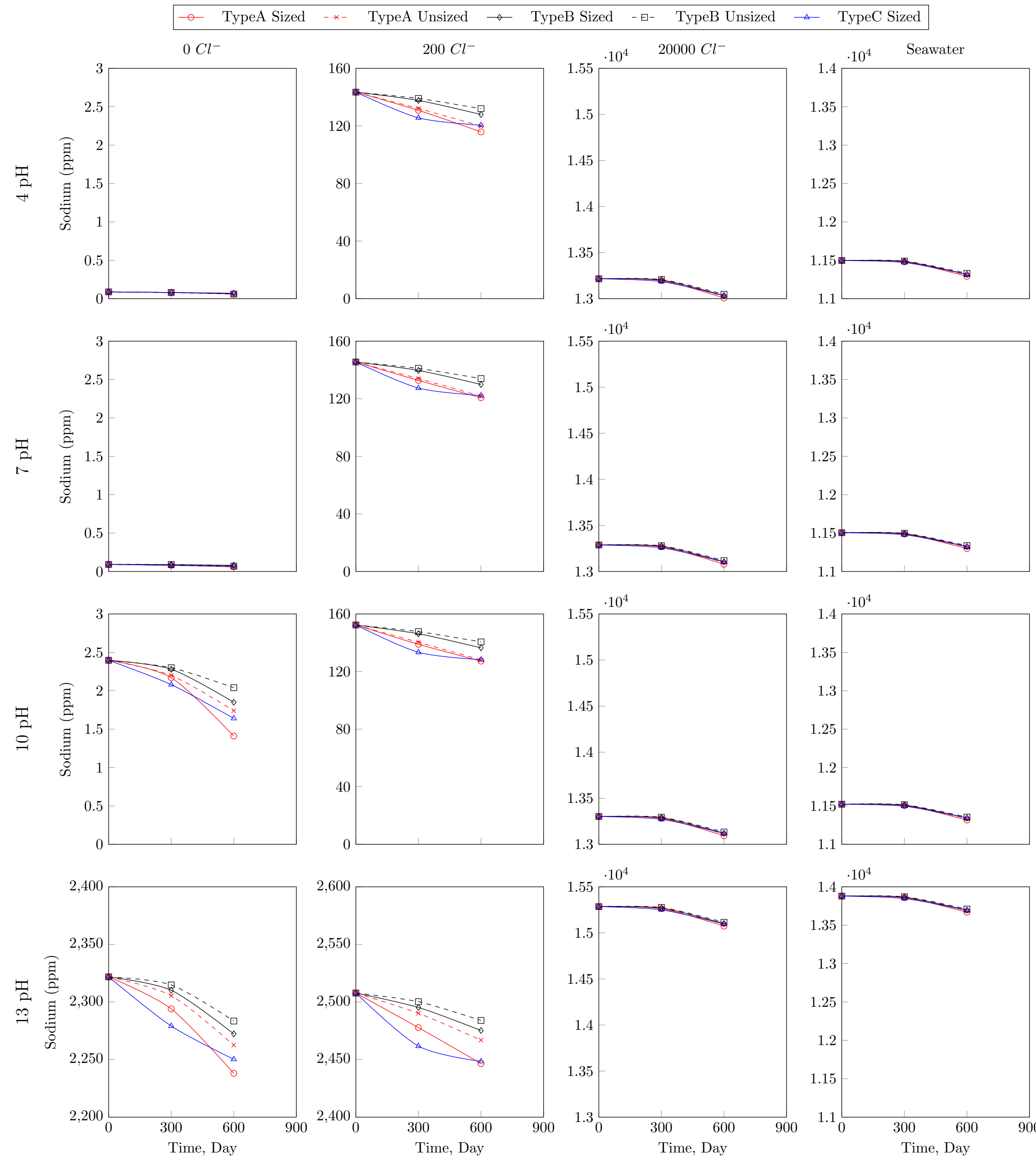

Figure 7.42: Sodium concentration of all environments after exposure of sized and unsized fibers

7.3 Corrosion Behavior of Solid Samples after 300 Days of Exposure under SEM

In this section, the scanning electron microscopic (SEM) images has been analyzed for each type of rebar, fiber and resin samples.

7.3.1 Type A Lot 1 Rebars at day 300

The SEM image analysis of the Type A Lot 1 rebars under 16 different environments for day 300 at 200x, 1000x, 2000x and 5000x magnifications were as the following Figures 7.43, 7.44, 7.45, and 7.46.

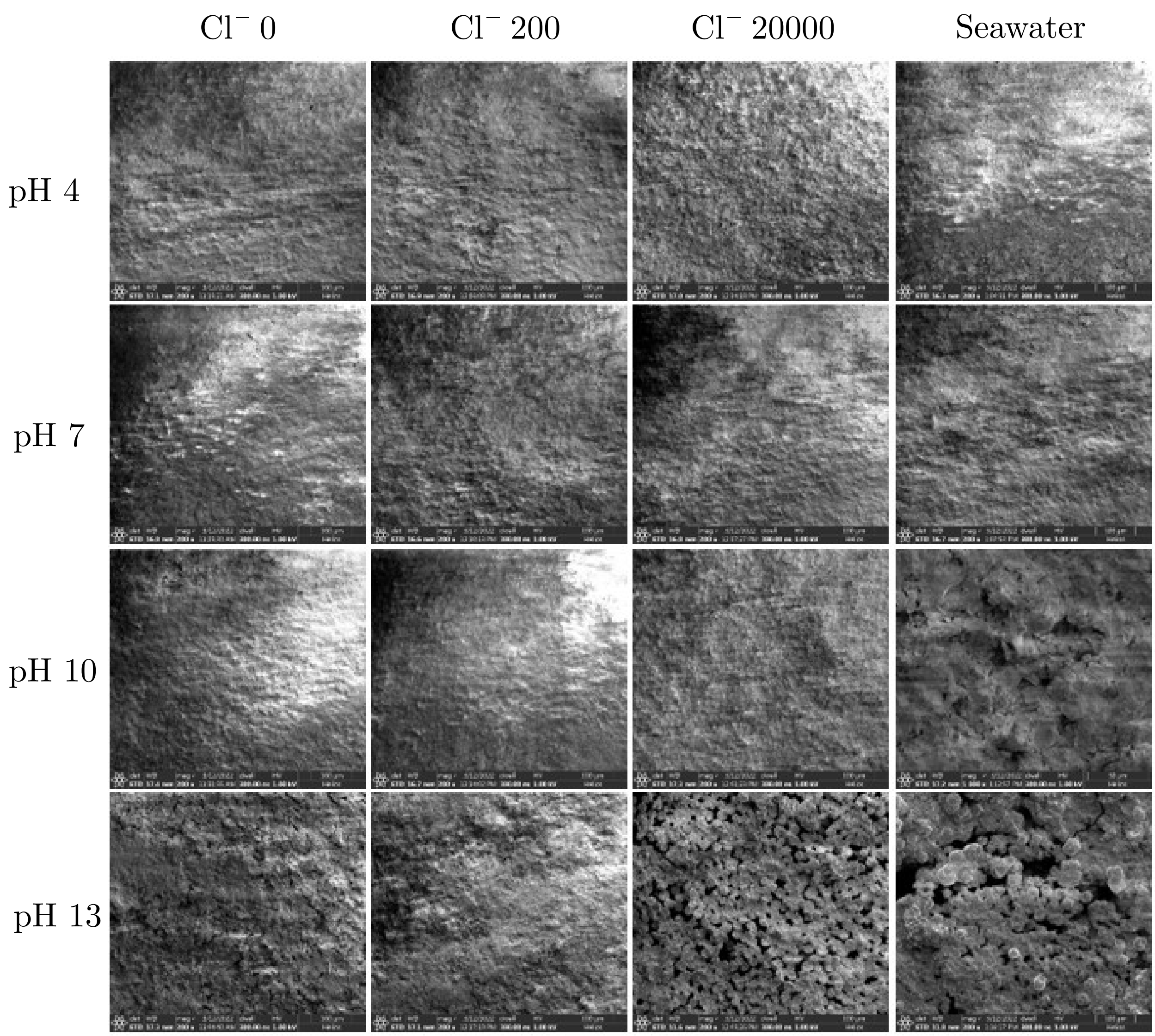

Figure 7.43: Type A Lot 1 rebars at day 300 under 200x magnification

From the figures above it can be assessed that the more the Type A rebars approached higher pH and higher salinity environments, the corrosive layers became more prominent and dense. 13 pH, seawater environment comparatively had more degrading effect.

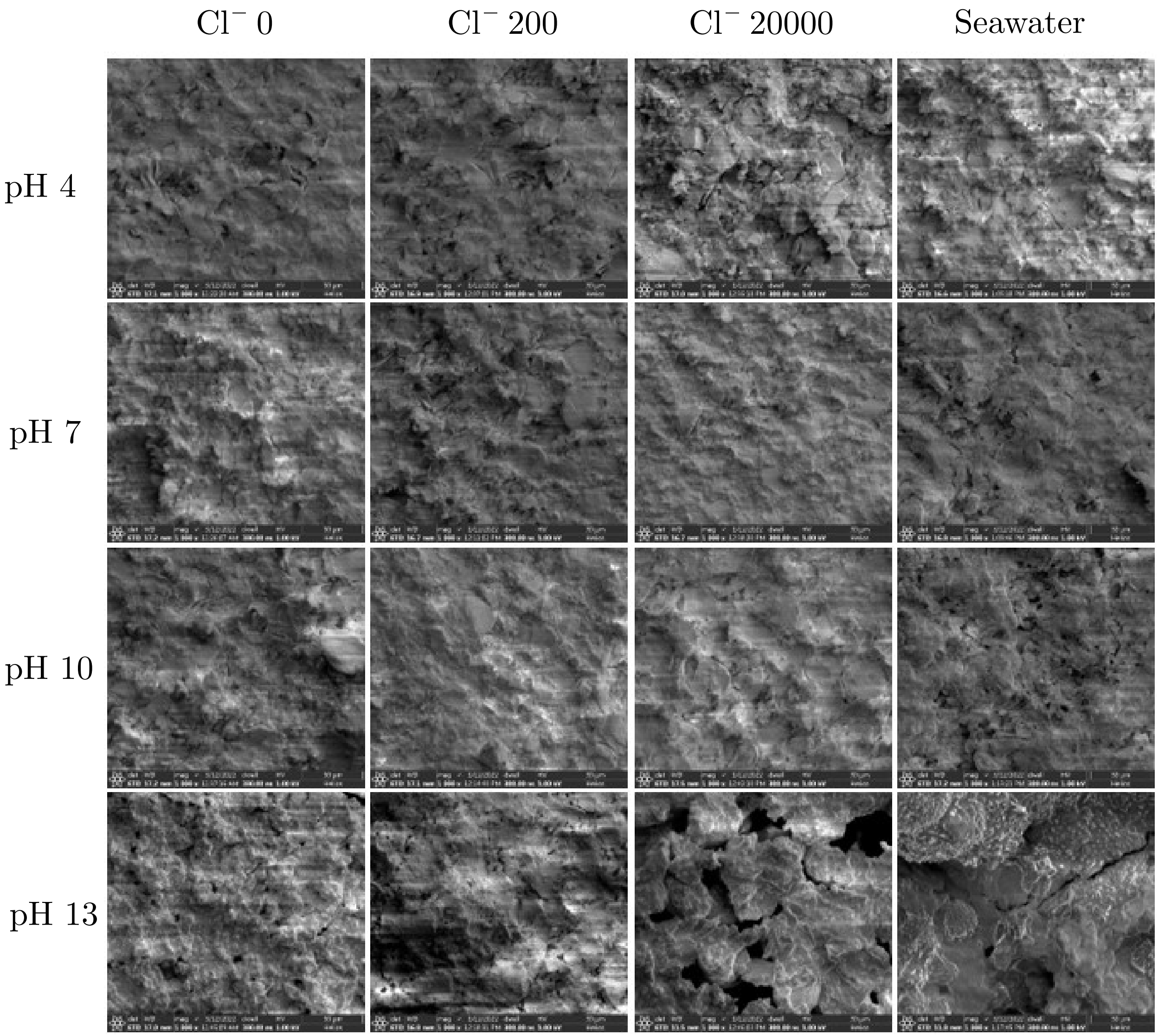

Figure 7.44: Type A Lot 1 rebars at day 300 under 1000x magnification

7.3.2 Type B Lot 1 Rebars at day 300

The SEM image analysis of the Type B Lot 1 rebars under 16 different environments for day 300 at 200x, 1000x, 2000x and 5000x magnifications were as the following Figures 7.47, 7.48, 7.49, and 7.50.

From the figures above it can be assessed that the more the Type B rebars approached higher pH and higher salinity environments, the corrosive layers became more prominent and dense. 13 pH, seawater environment comparatively had more degrading effect.

7.3.3 Type C Lot 1 Rebars at day 300

The SEM image analysis of the Type C Lot 1 rebars under 16 different environments for day 300 at 200x, 1000x, 2000x and 5000x magnifications were as the following Figures 7.51, 7.52, 7.53, and 7.54.

From the figures above it can be assessed that the more the Type C rebars approached higher pH and higher salinity environments, the corrosive layers became more prominent and dense. 13 pH, seawater environment comparatively had more degrading effect.

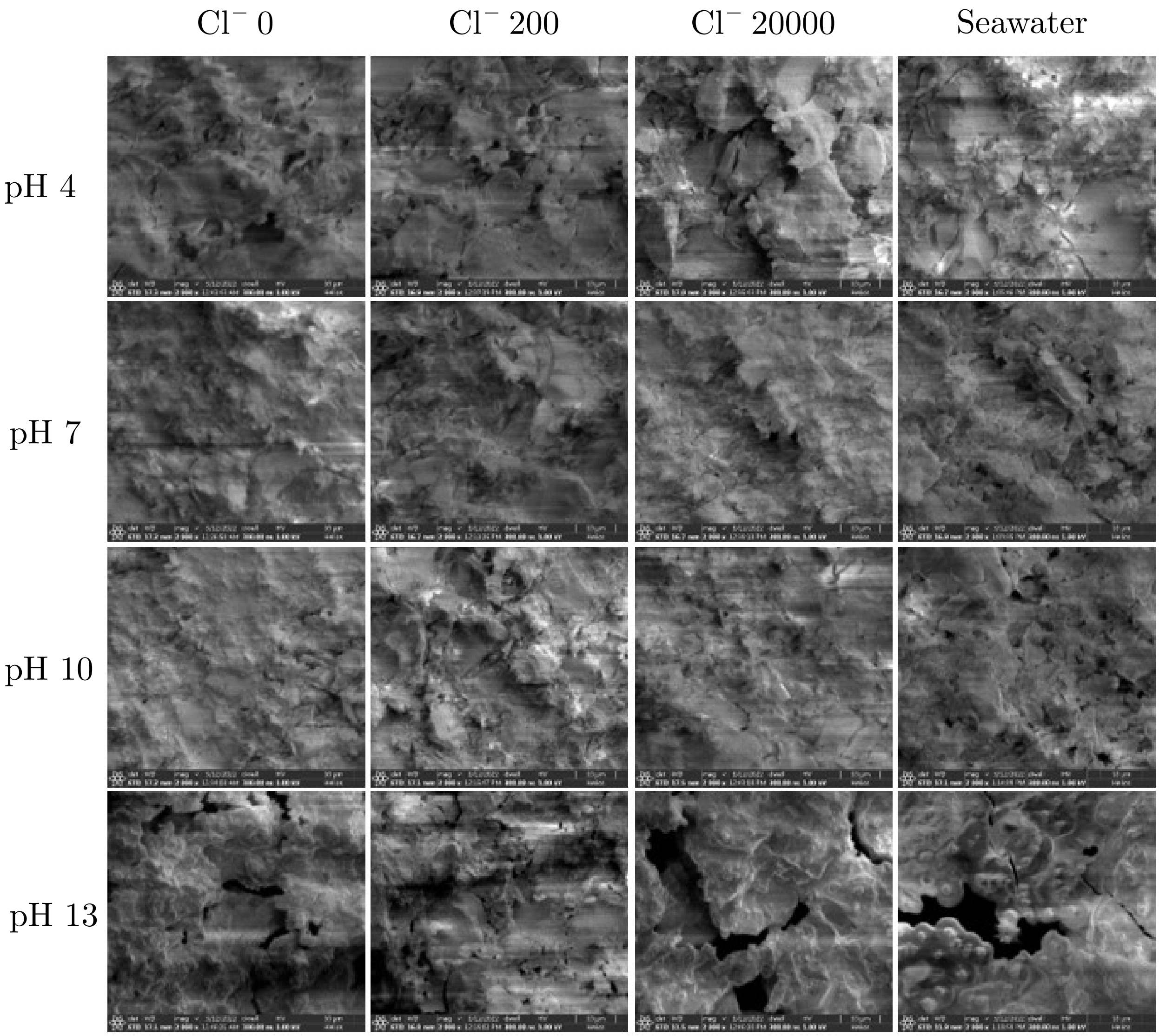

Figure 7.45: Type A Lot 1 rebars at day 300 under 2000x magnification

7.3.4 Type A Sized Fibers at day 300

The SEM image analysis of the Type A sized fibers under 16 different environments for day 300 at 200x and 2000x magnifications were as the following Figures 7.55, and 7.56.

7.3.5 Type A Unsized Fibers at day 300

The SEM image analysis of the Type A unsized fibers under 16 different environments for day 300 at 200x and 2000x magnifications were as the following Figures 7.57, and 7.58.

From the figures above it can be assessed that the more the Type A fibers approached higher pH and higher salinity environments, the corrosive layers became more prominent and dense. After day 300, the sizing material completely came off of the sized fibers. Also, the more corrosion layers could be seen to be formed over the unsized fibers than the sized ones, which meant the sizing protected the fiber to some extent from degradation. 13 pH, seawater environment comparatively had more degrading effect for both the sized and unsized fibers.

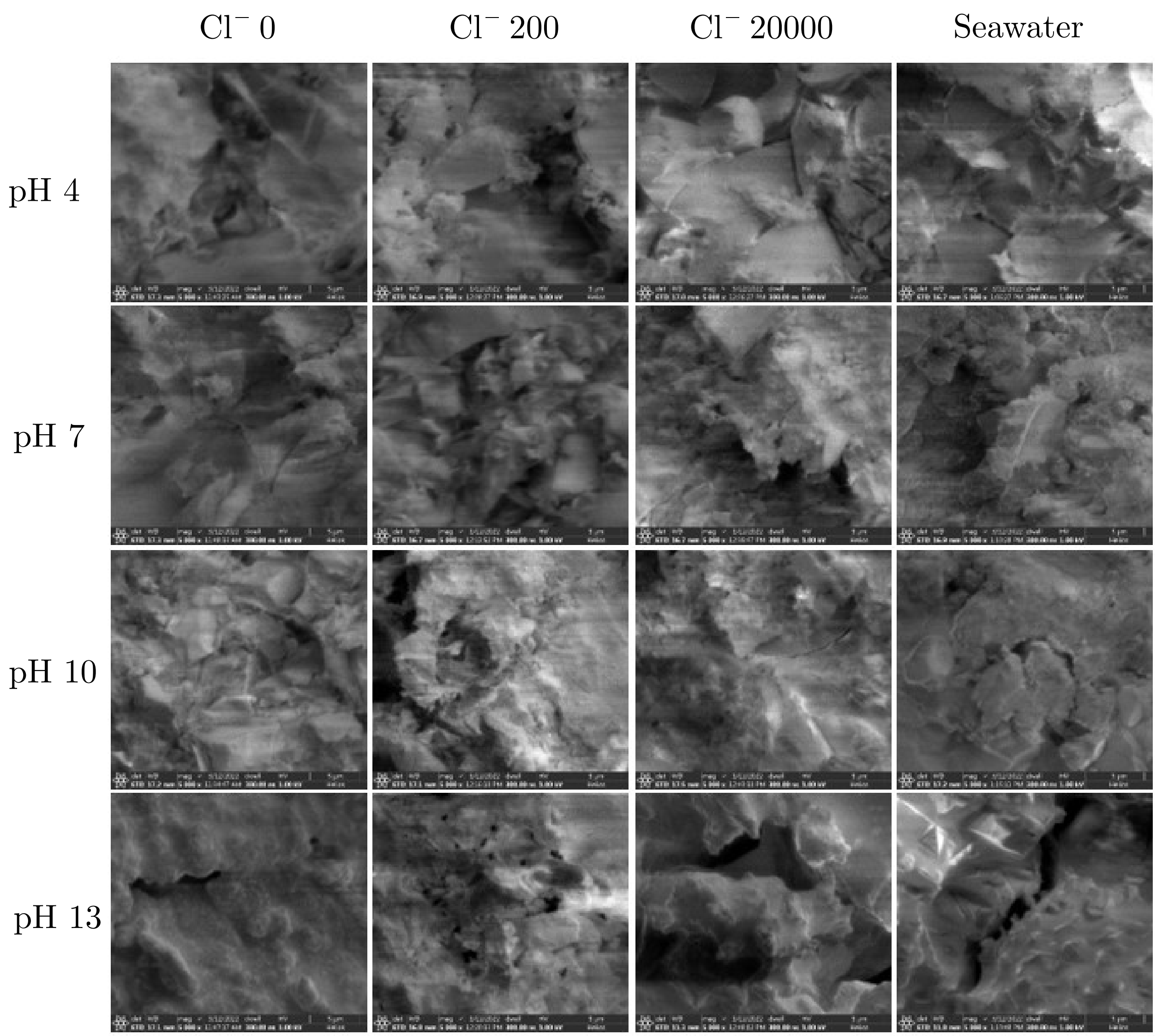

Figure 7.46: Type A Lot 1 rebars at day 300 under 5000x magnification

7.3.6 Type B Sized Fibers at day 300

The SEM image analysis of the Type B sized fibers under 16 different environments for day 300 at 200x, 2000x and 5000x magnifications were as the following Figures 7.59, 7.60, and 7.61.

7.3.7 Type B Unsized Fibers at day 300

The SEM image analysis of the Type B unsized fibers under 16 different environments for day 300 at 200x, 2000x and 5000x magnifications were as the following Figures 7.62, 7.63, and 7.64.

From the figures above it can be assessed that the more the Type B fibers approached higher pH and higher salinity environments, the corrosive layers became more prominent and dense. After day 300, the sizing material completely came off of the sized fibers. Also, the more corrosion layers could be seen to be formed over the unsized fibers than the sized ones, which meant the sizing protected the fiber to some extent from degradation. 13 pH, seawater environment comparatively had more degrading effect for both the sized and unsized fibers.

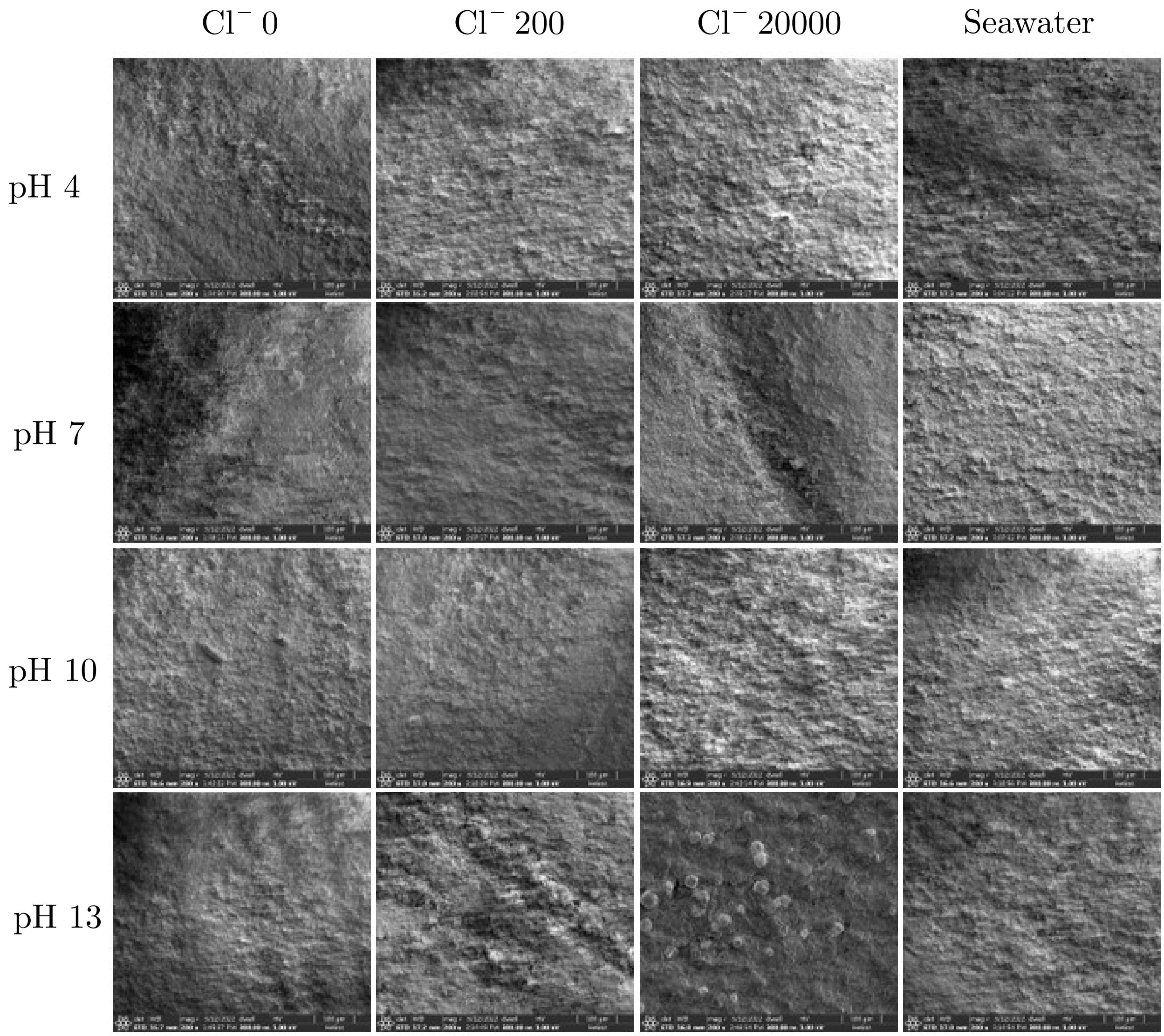

Figure 7.47: Type B Lot 1 rebars at day 300 under 200x magnification

7.3.8 Type C Sized Fibers at day 300

The SEM image analysis of the Type C sized fibers under 16 different environments for day 300 at 200x, 2000x and 5000x magnifications were as the following Figures 7.65, 7.66, and 7.67.

From the figures above it can be assessed that the more the Type C fibers approached higher pH and higher salinity environments, the corrosive layers became more prominent and dense. After day 300, the sizing material completely came off of the sized fibers. 13 pH, seawater environment comparatively had more degrading effect.

7.3.9 Type A Resins at day 300

The SEM image analysis of the Type A resins under 16 different environments for day 300 at 150x, 500x and 1500x magnifications were as the following Figures 7.68, 7.69, and 7.70.

From the figures above it can be assessed that the more the Type A resins approached higher pH and higher salinity environments, the corrosive layers became more prominent and dense. 13 pH, seawater environment

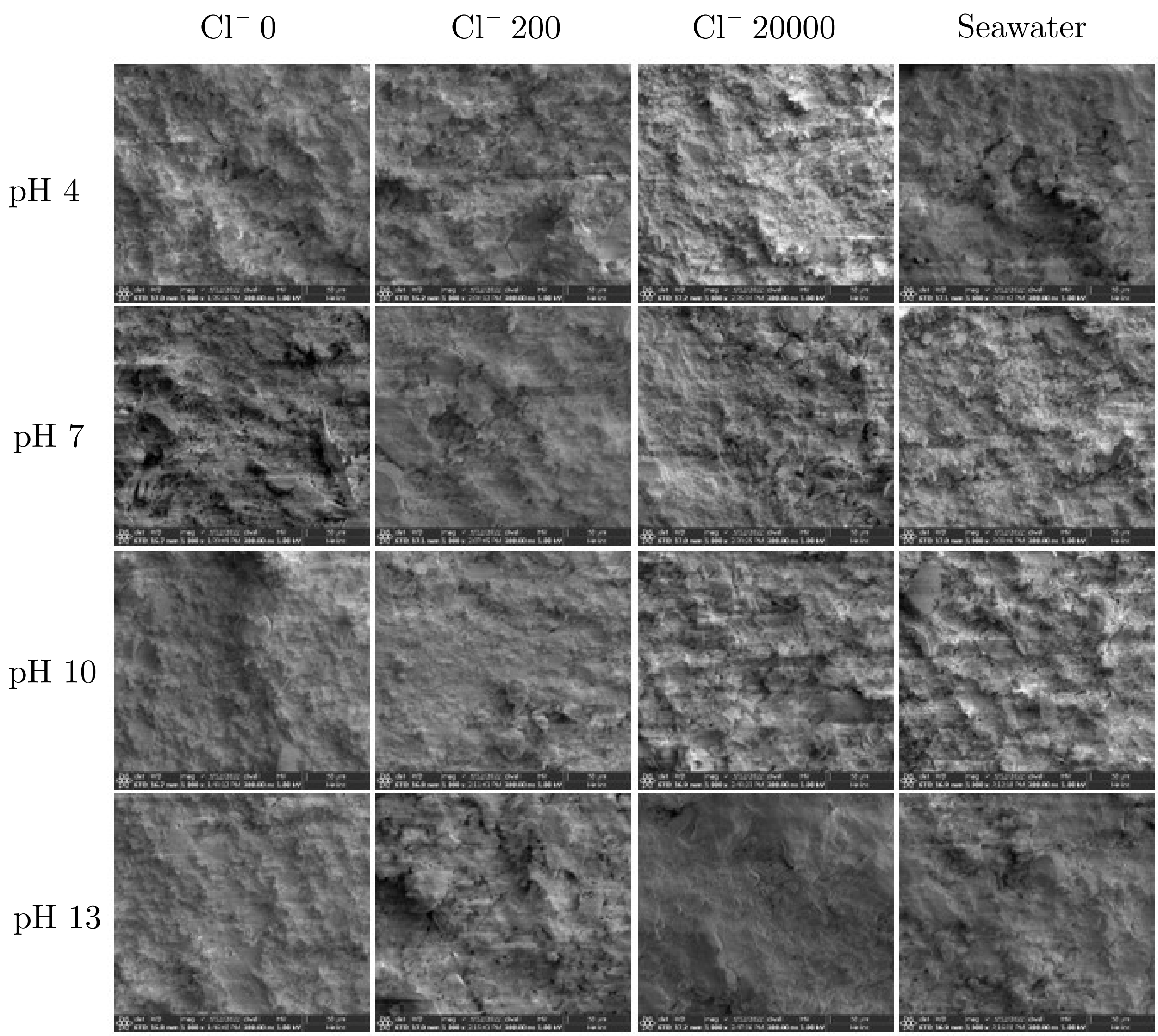

Figure 7.48: Type B Lot 1 rebars at day 300 under 1000x magnification

comparatively had more degrading effect.

7.3.10 Type B Resins at day 300

The SEM image analysis of the Type B resins under 16 different environments for day 300 at 150x, 500x and 1500x magnifications were as the following Figures 7.71, 7.72, and 7.73.

From the figures above it can be assessed that the more the Type B resins approached higher pH and higher salinity environments, the corrosive layers became more prominent and dense. 13 pH, seawater environment comparatively had more degrading effect.

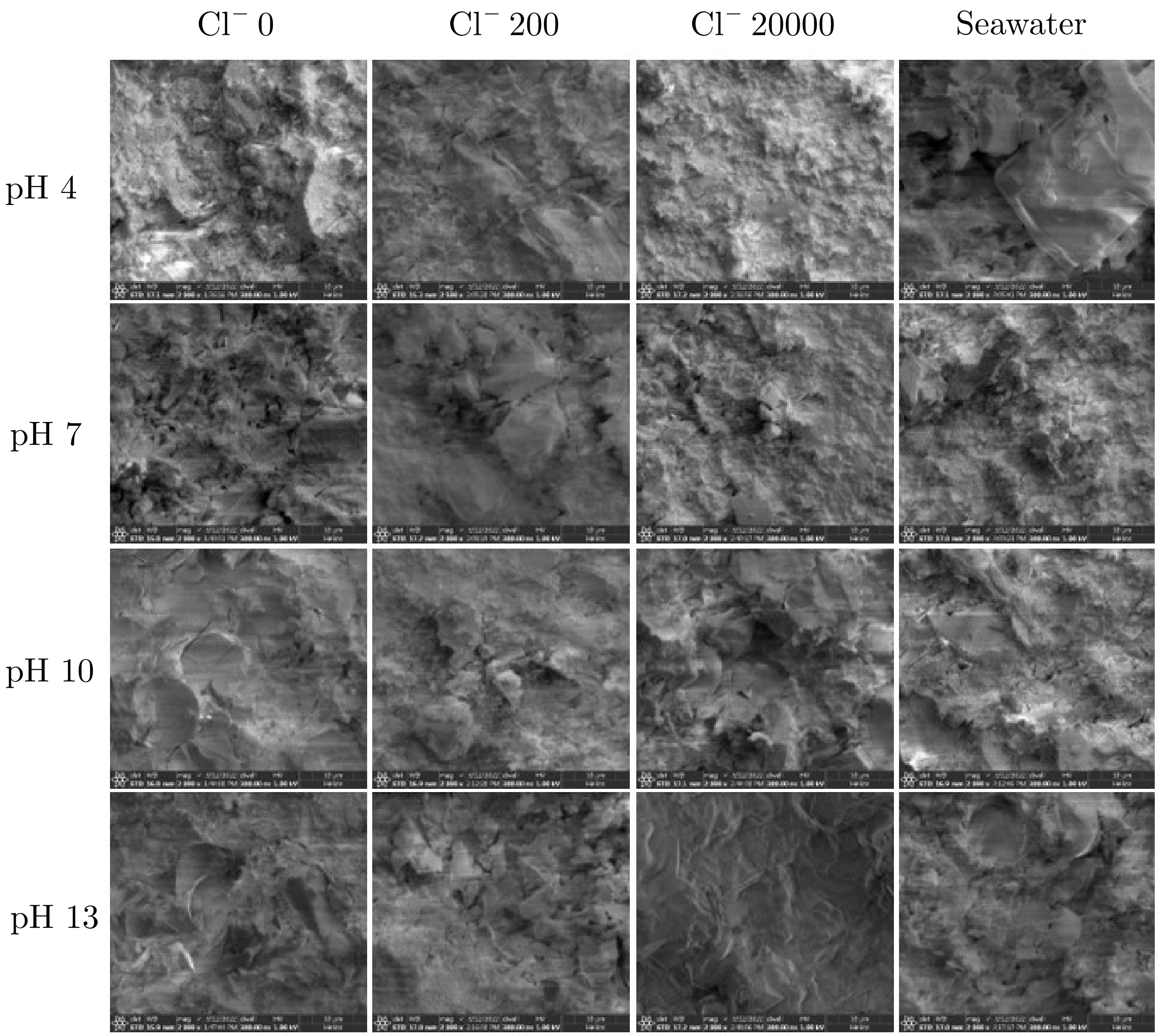

Figure 7.49: Type B Lot 1 rebars at day 300 under 2000x magnification

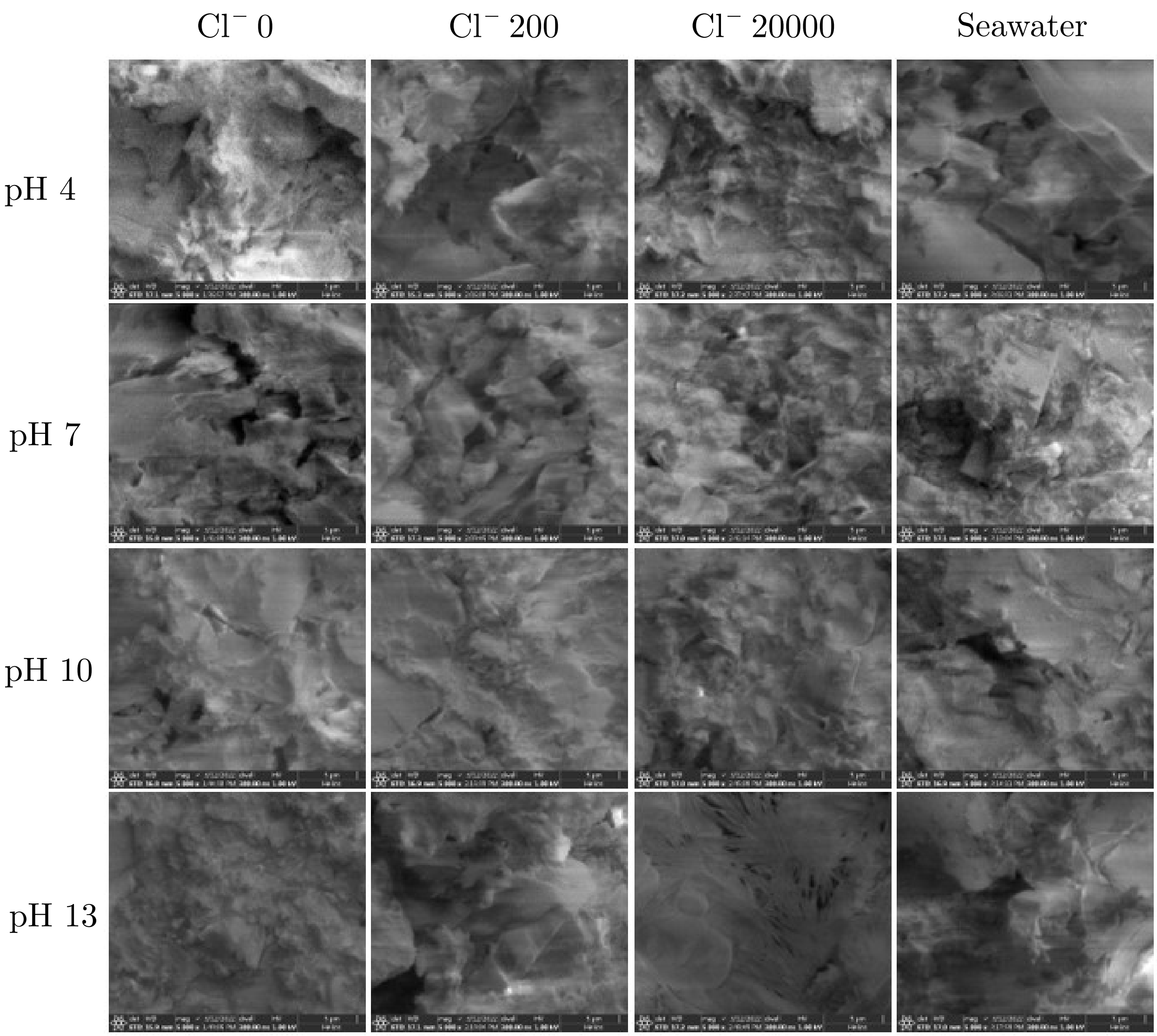

Figure 7.50: Type B Lot 1 rebars at day 300 under 5000x magnification

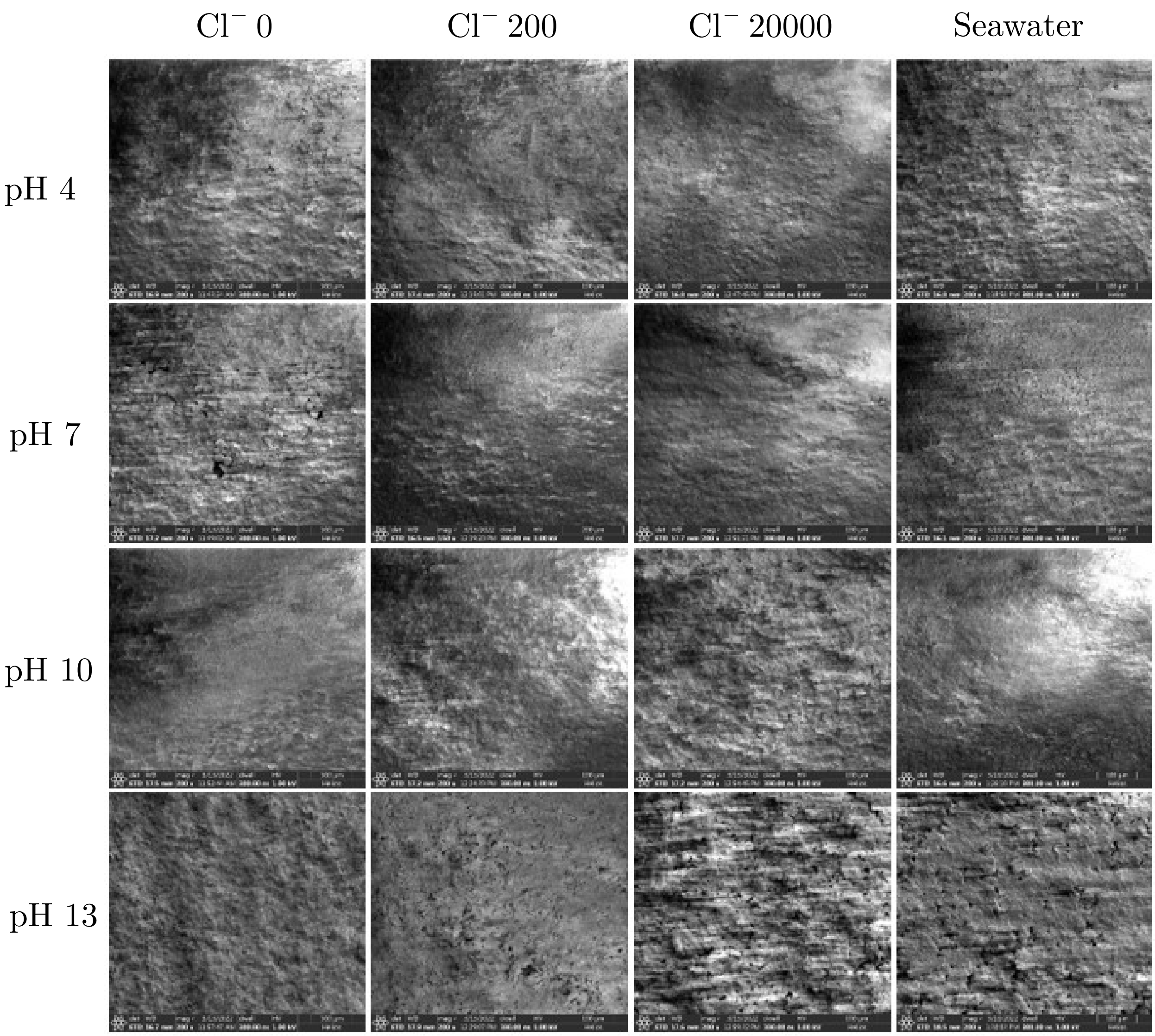

Figure 7.51: Type C Lot 1 rebars at day 300 under 200x magnification

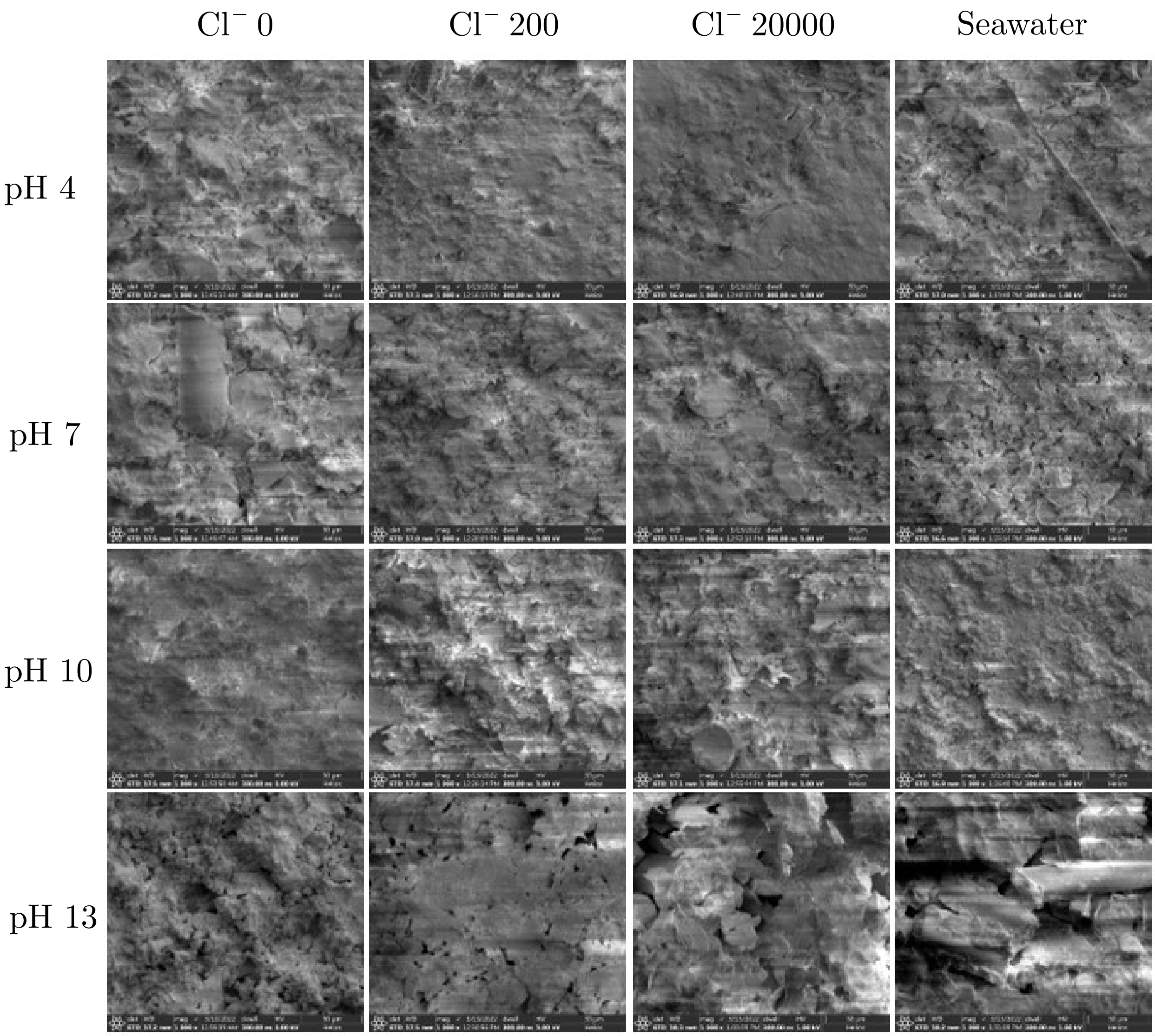

Figure 7.52: Type C Lot 1 rebars at day 300 under 1000x magnification

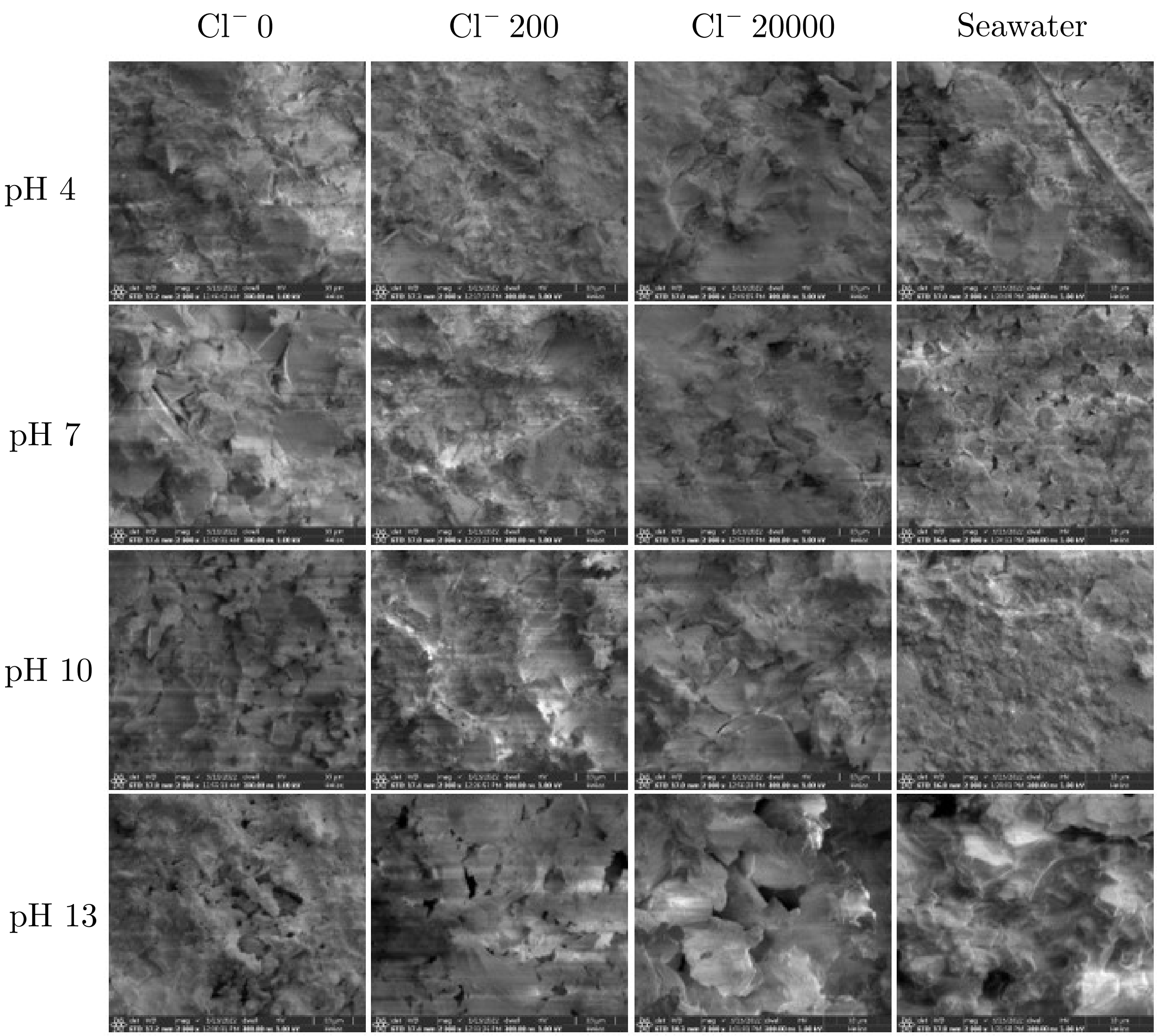

Figure 7.53: Type C Lot 1 rebars at day 300 under 2000x magnification

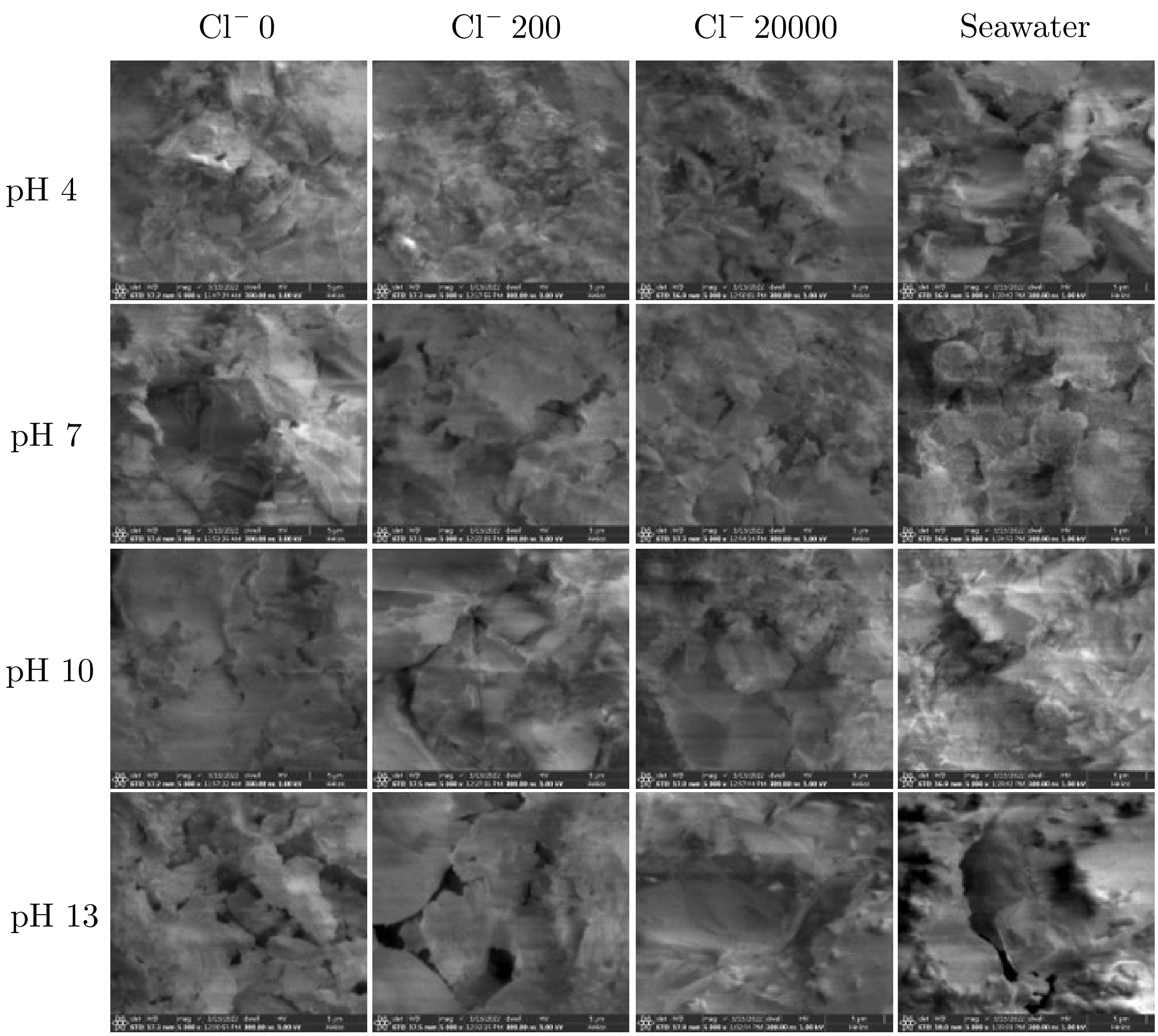

Figure 7.54: Type C Lot 1 rebars at day 300 under 5000x magnification

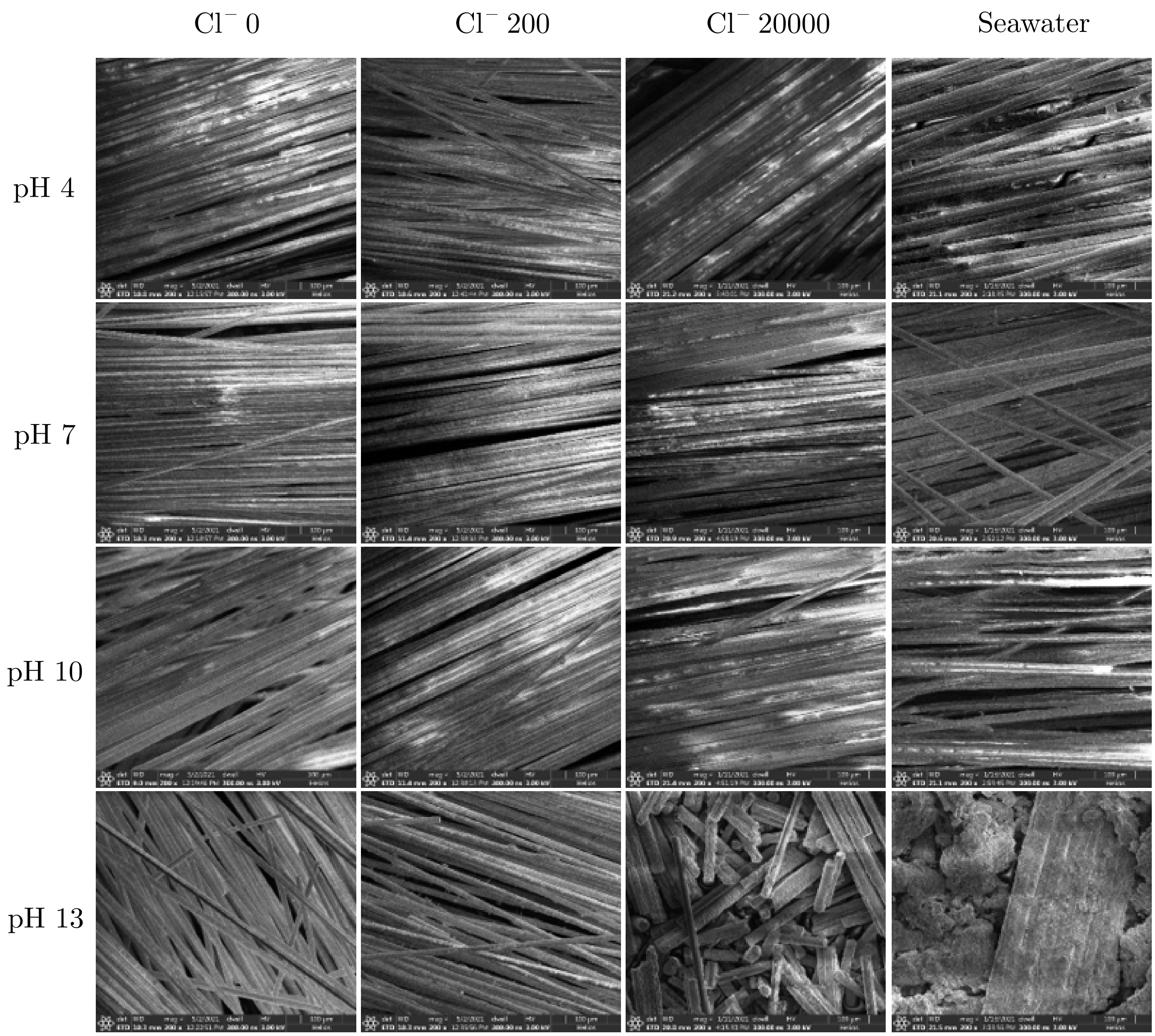

Figure 7.55: Type A sized fibers at day 300 under 200x magnification

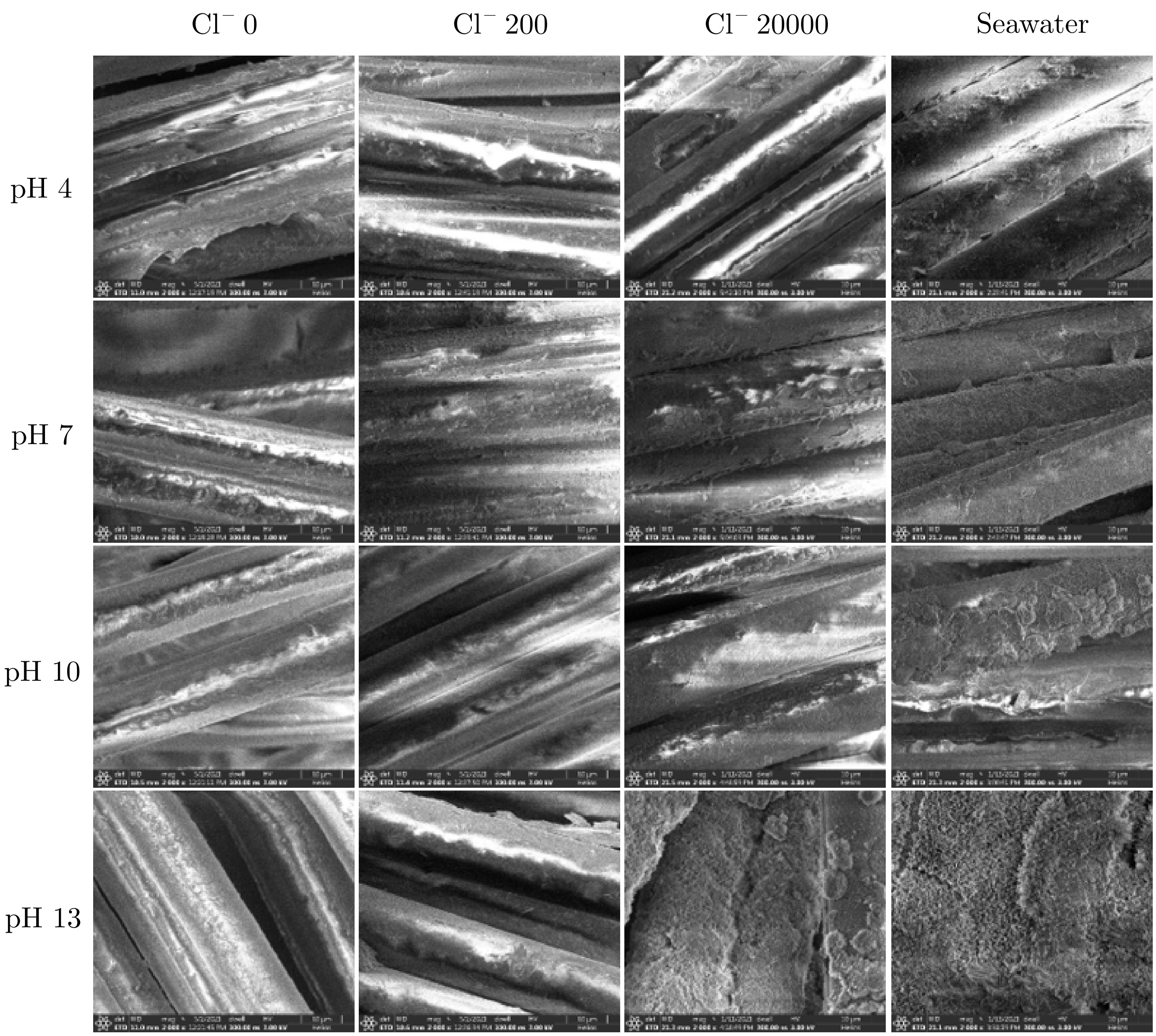

Figure 7.56: Type A sized fibers at day 300 under 2000x magnification

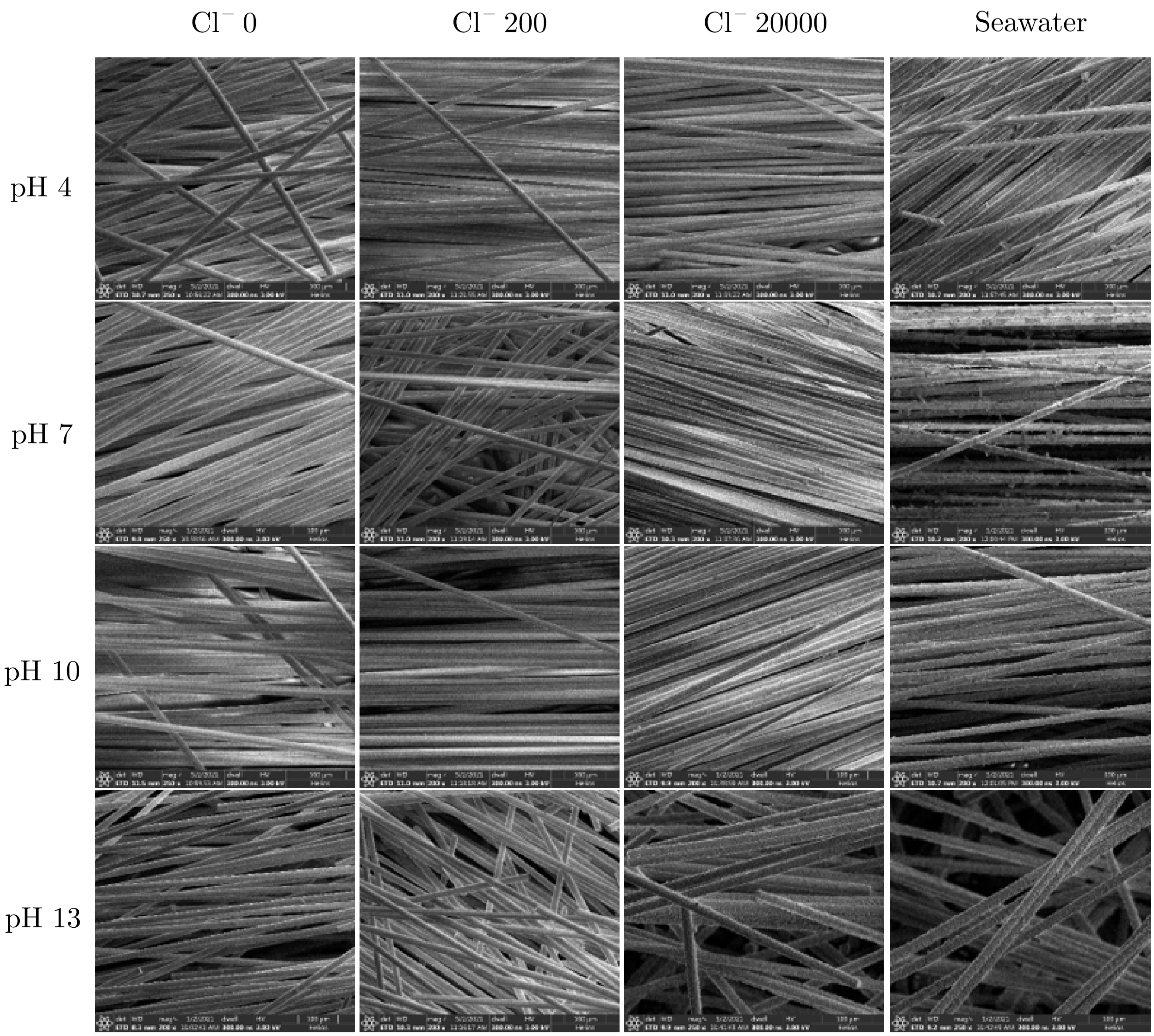

Figure 7.57: Type A unsized fibers at day 300 under 200x magnification

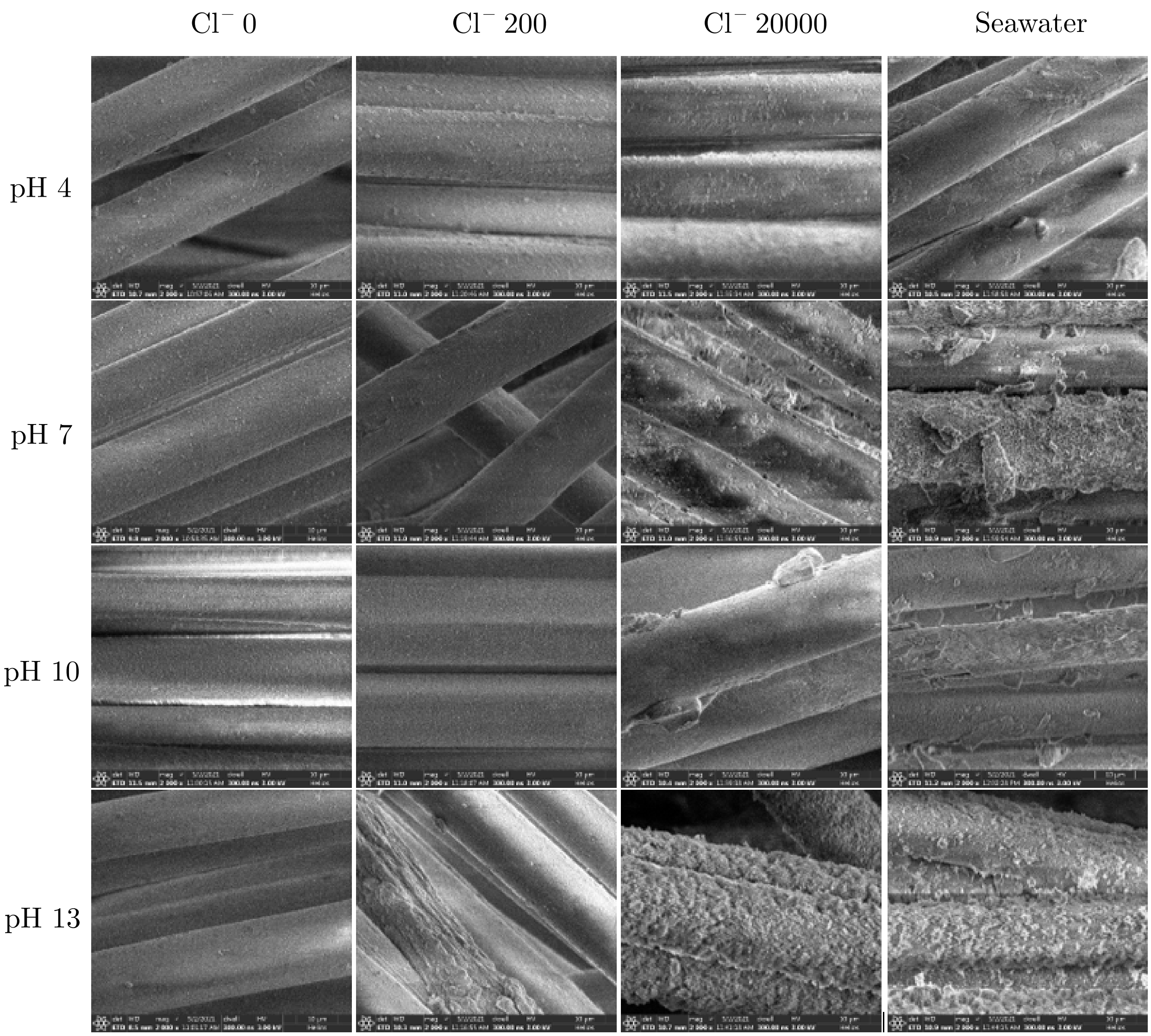

Figure 7.58: Type A unsized fibers at day 300 under 2000x magnification

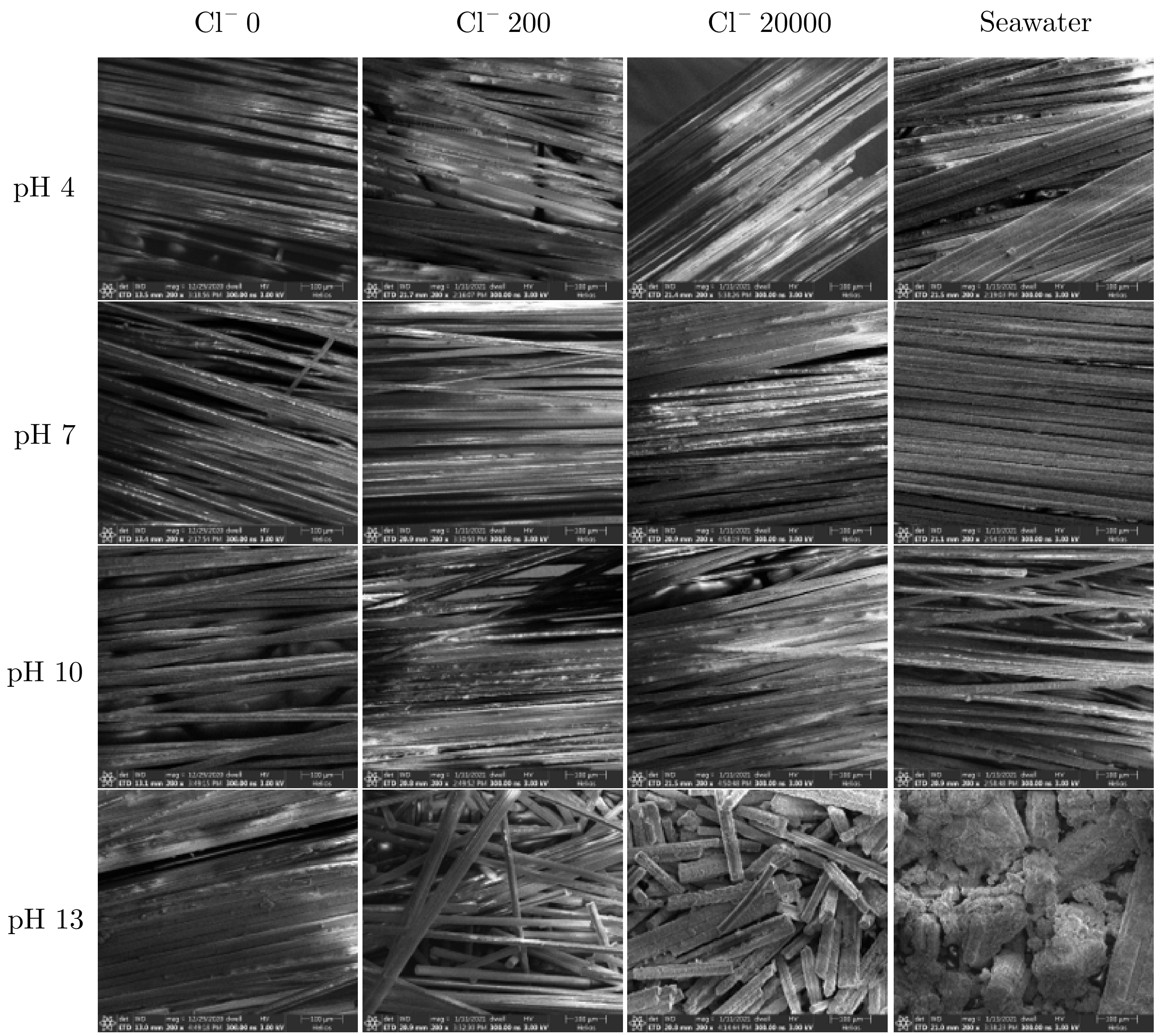

Figure 7.59: Type B sized fibers at day 300 under 200x magnification

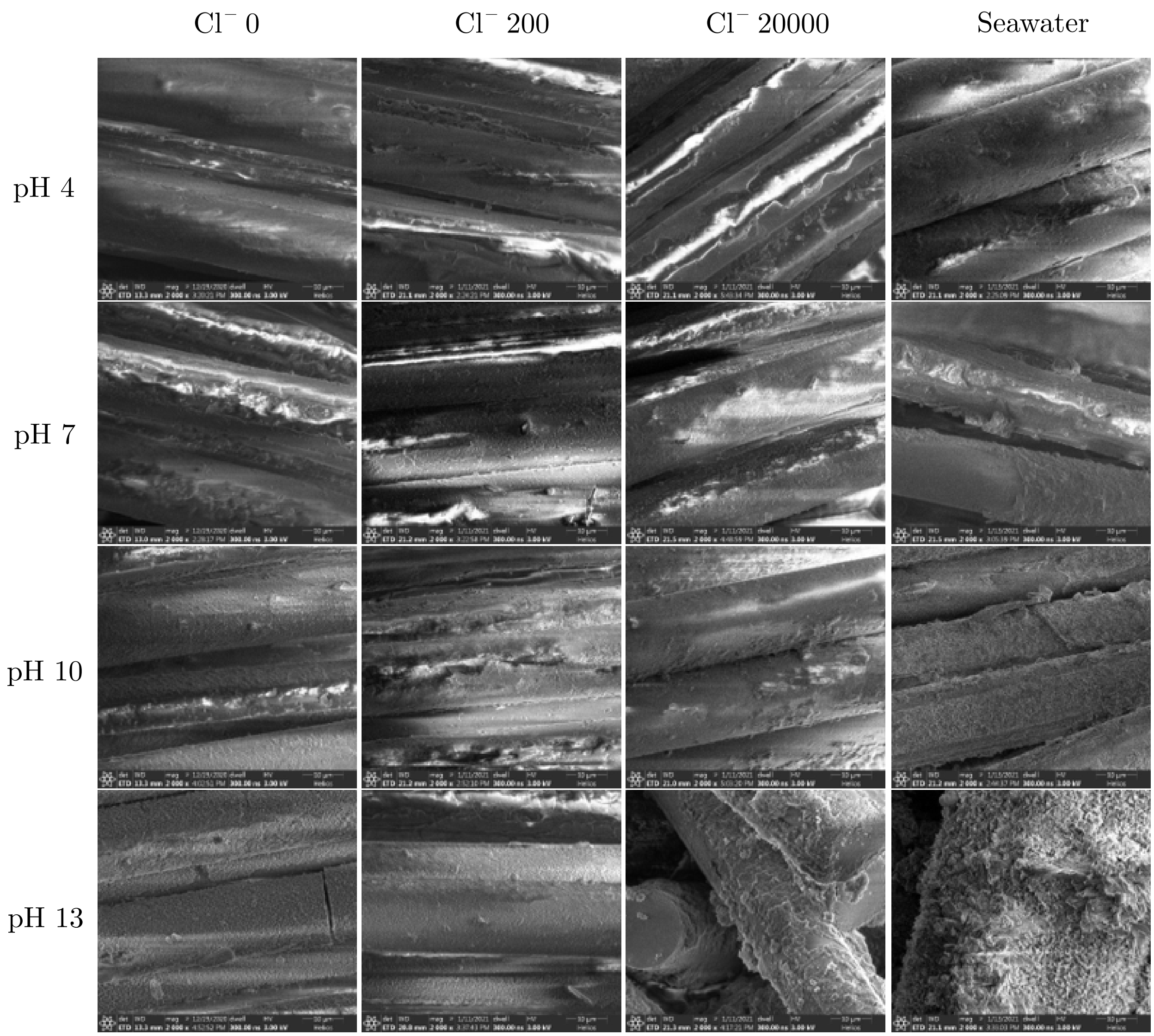

Figure 7.60: Type B sized fibers at day 300 under 2000x magnification

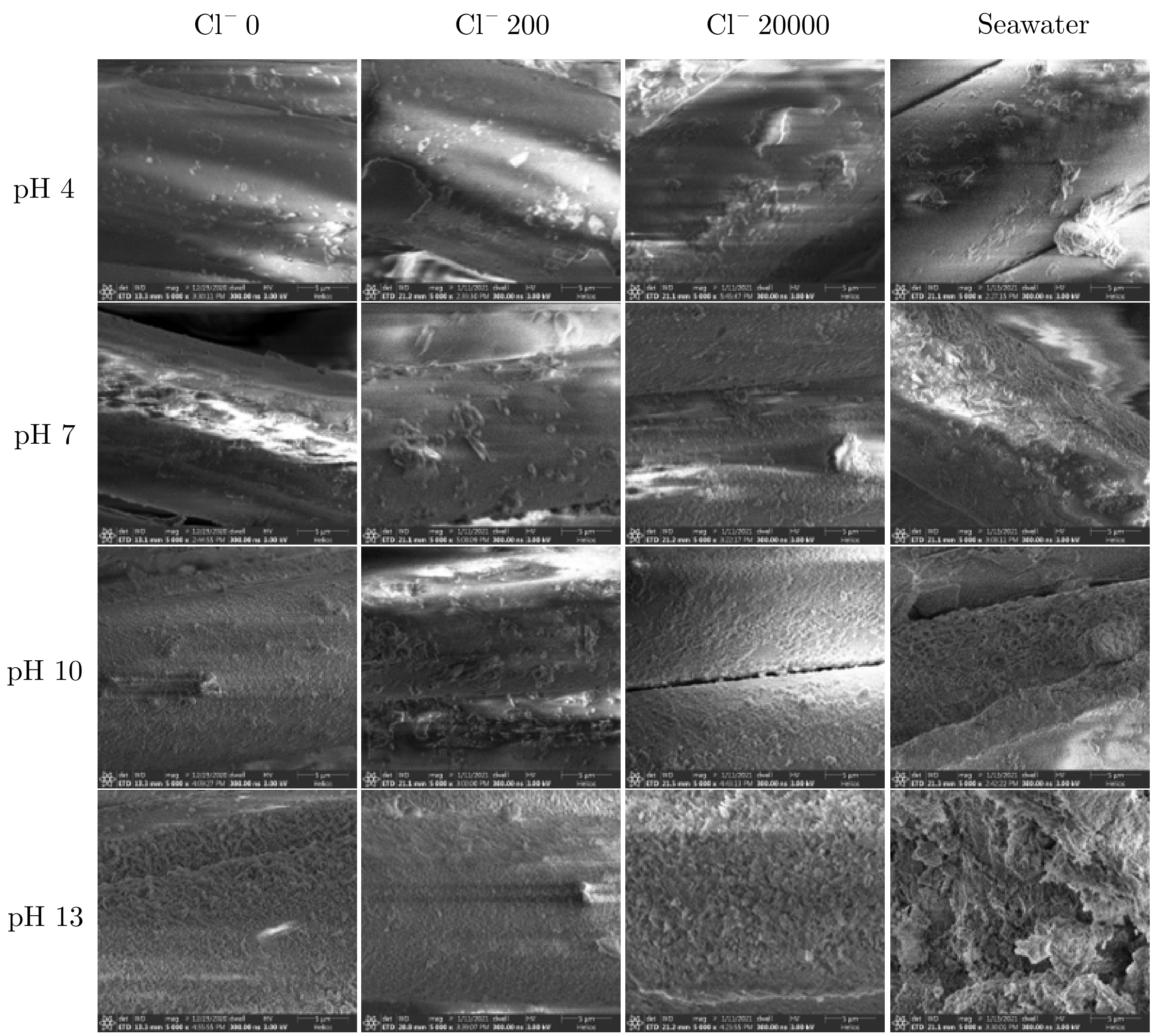

Figure 7.61: Type B sized fibers at day 300 under 5000x magnification

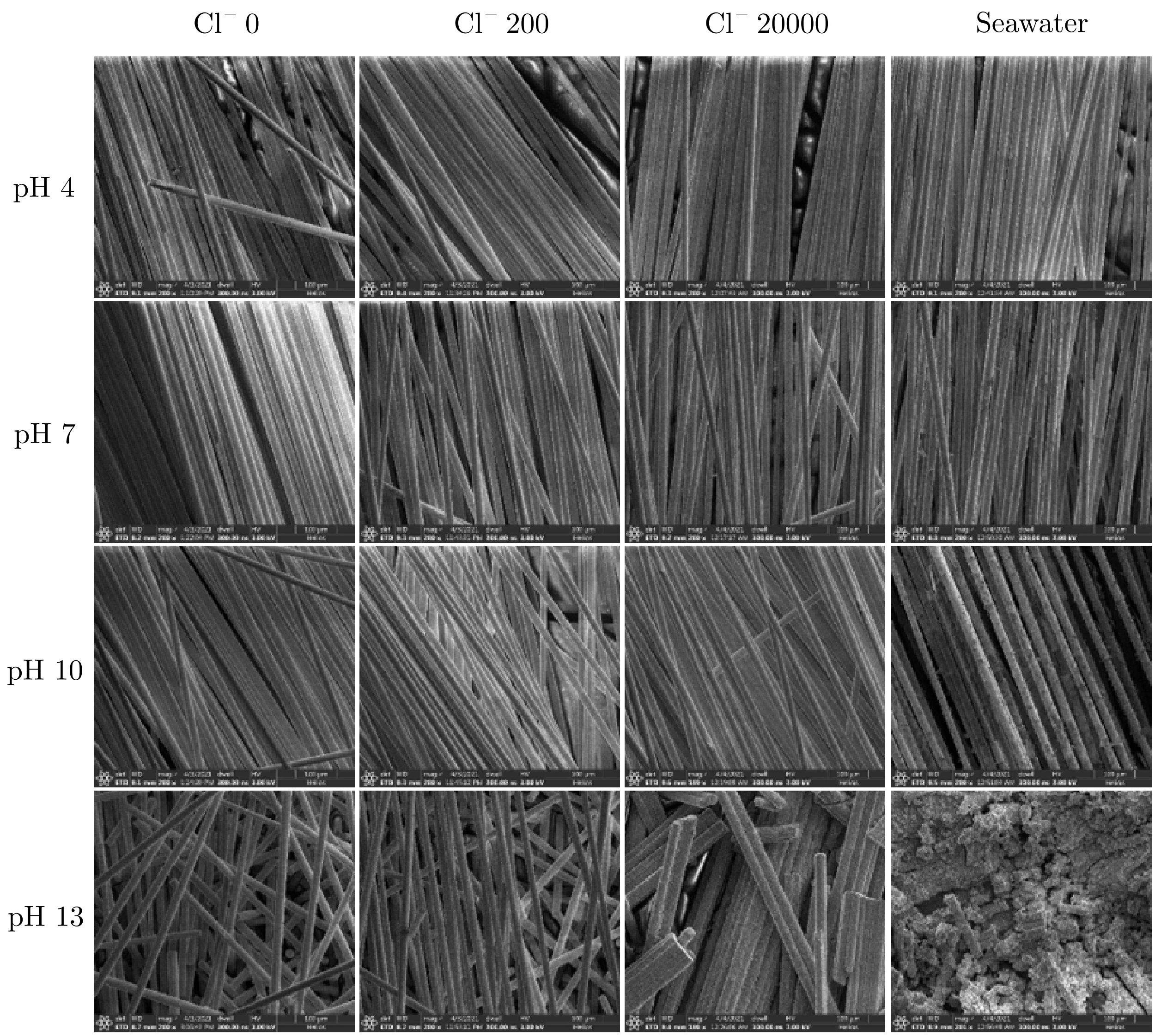

Figure 7.62: Type B unsized fibers at day 300 under 200x magnification

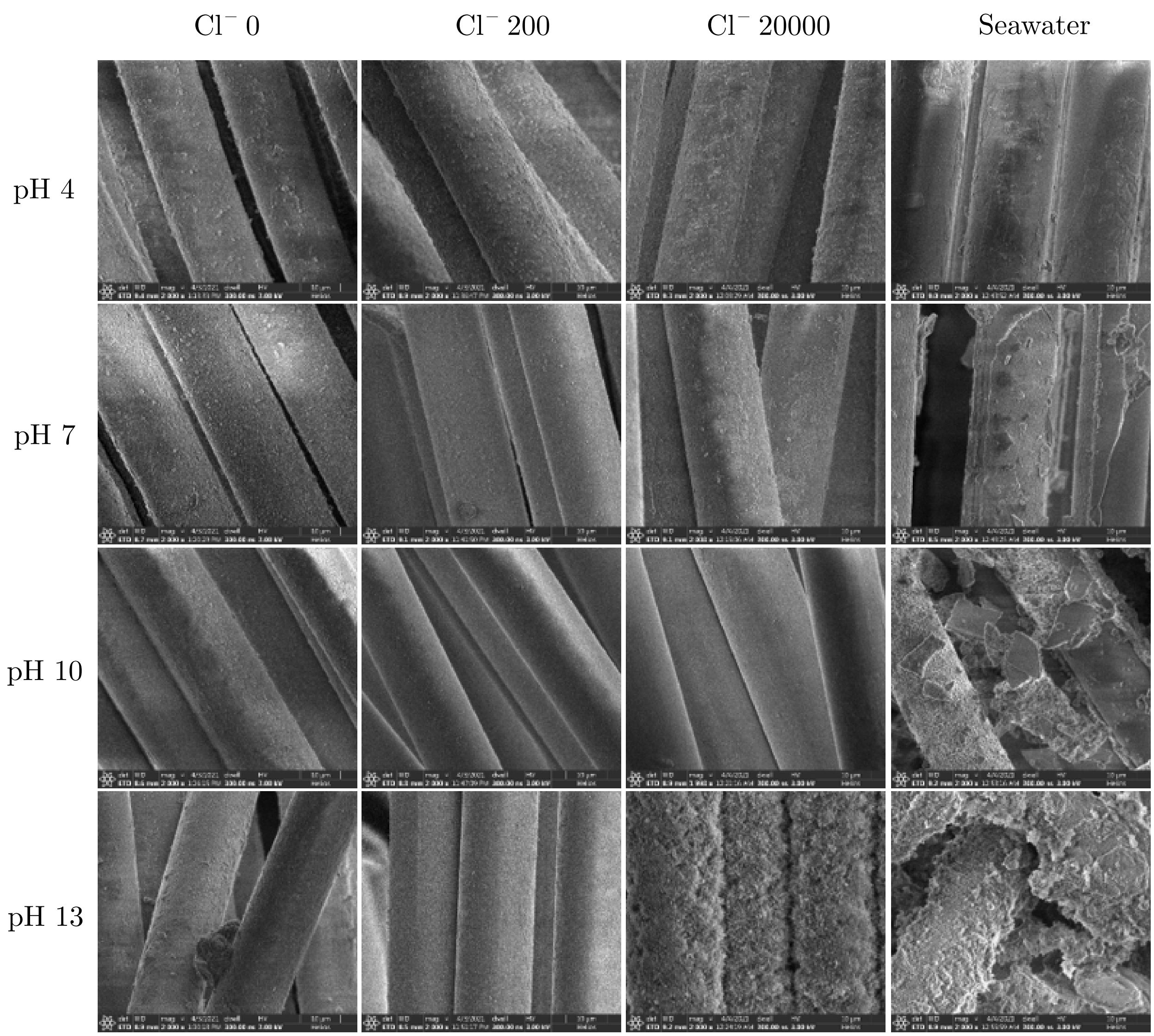

Figure 7.63: Type B unsized fibers at day 300 under 2000x magnification

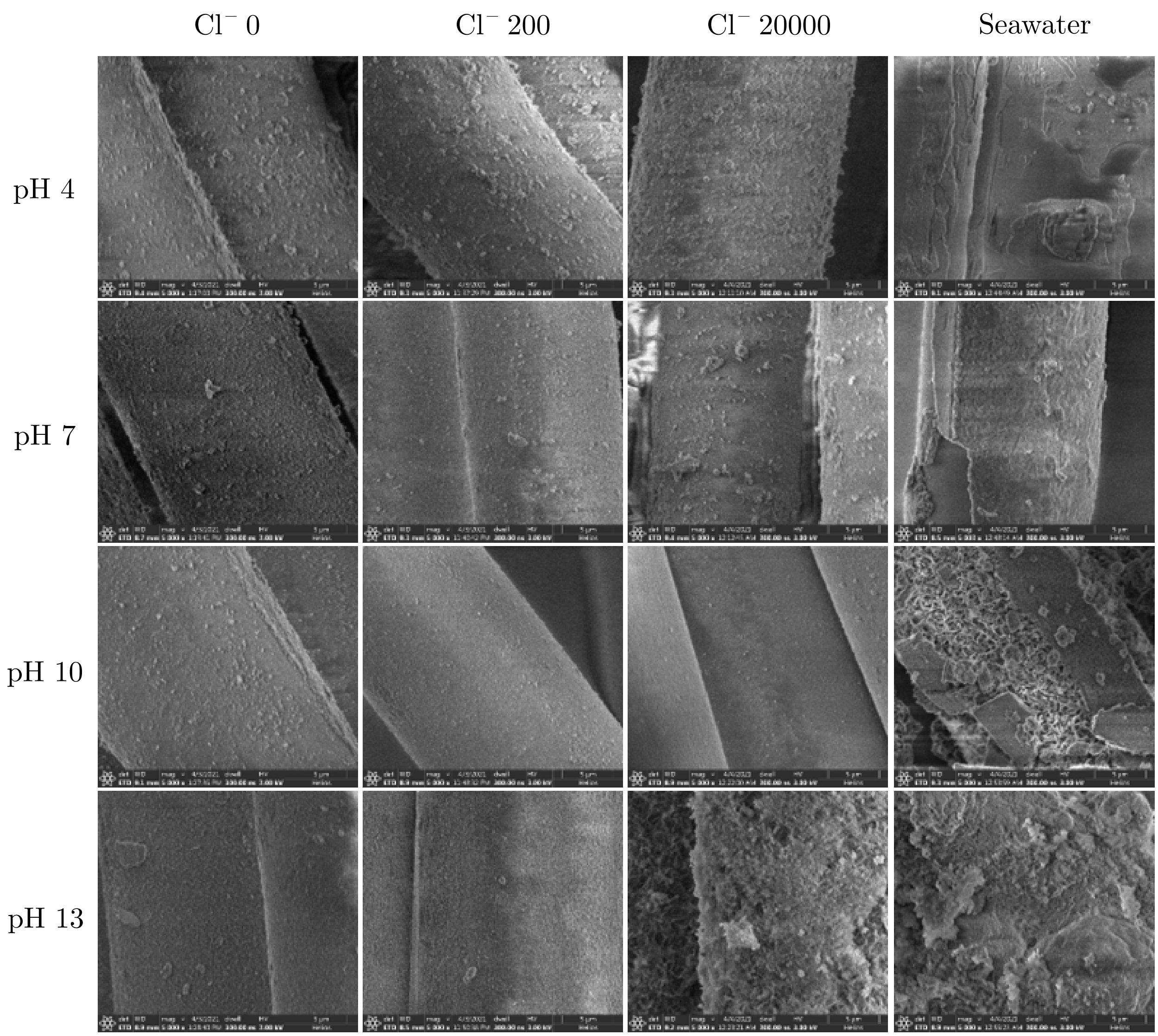

Figure 7.64: Type B unsized fibers at day 300 under 5000x magnification

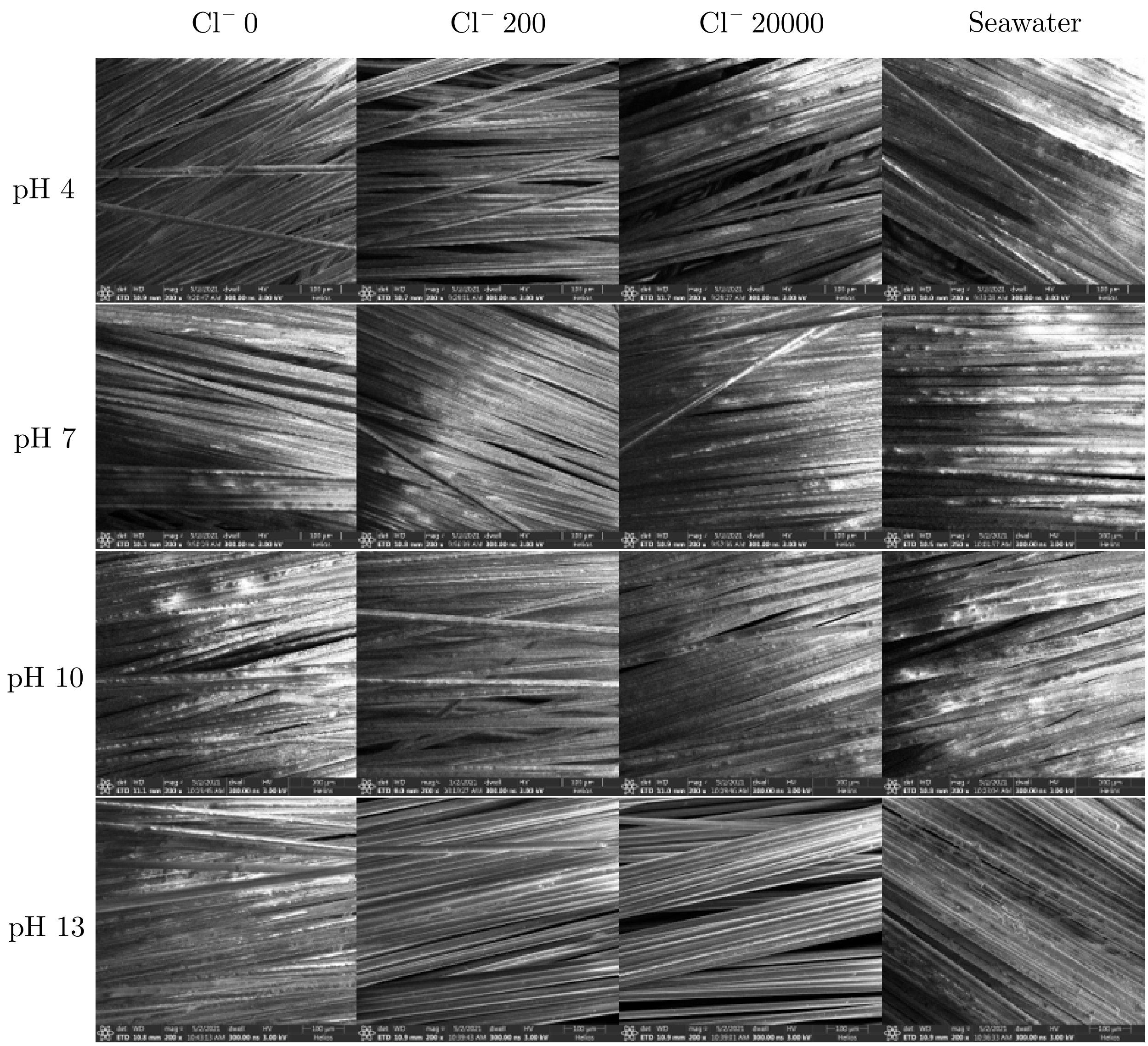

Figure 7.65: Type C sized fibers at day 300 under 200x magnification

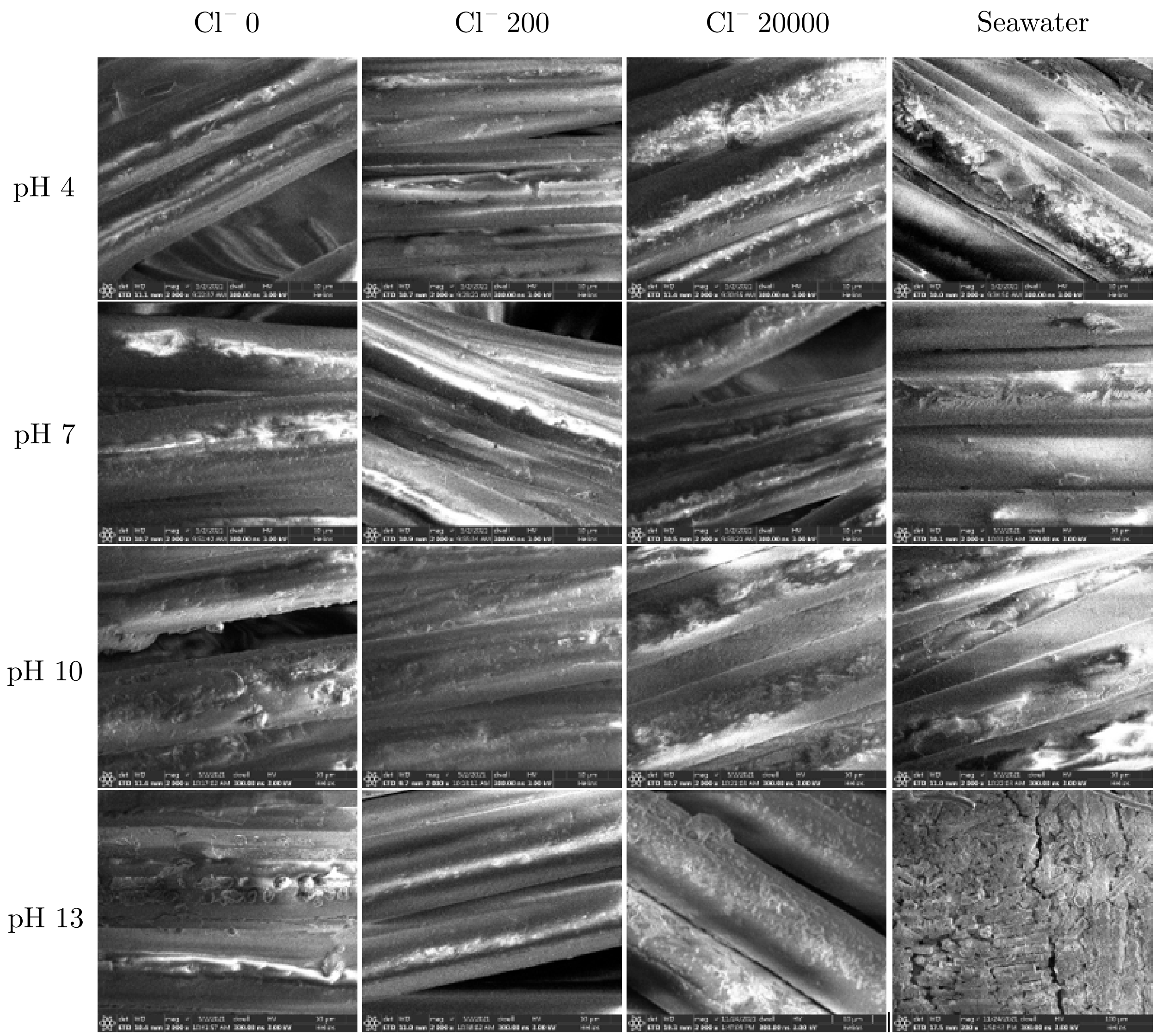

Figure 7.66: Type C sized fibers at day 300 under 2000x magnification

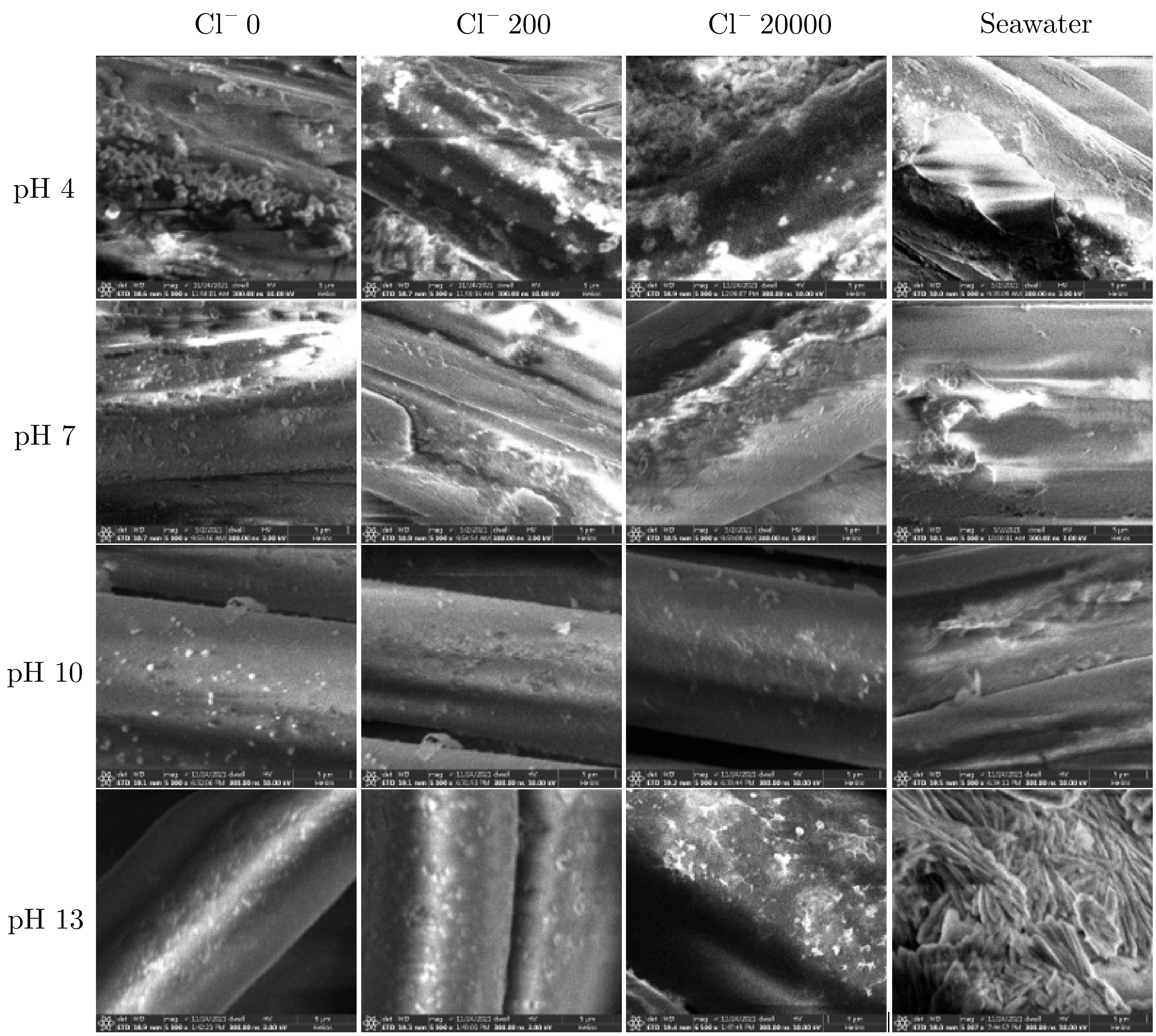

Figure 7.67: Type C sized fibers at day 300 under 5000x magnification

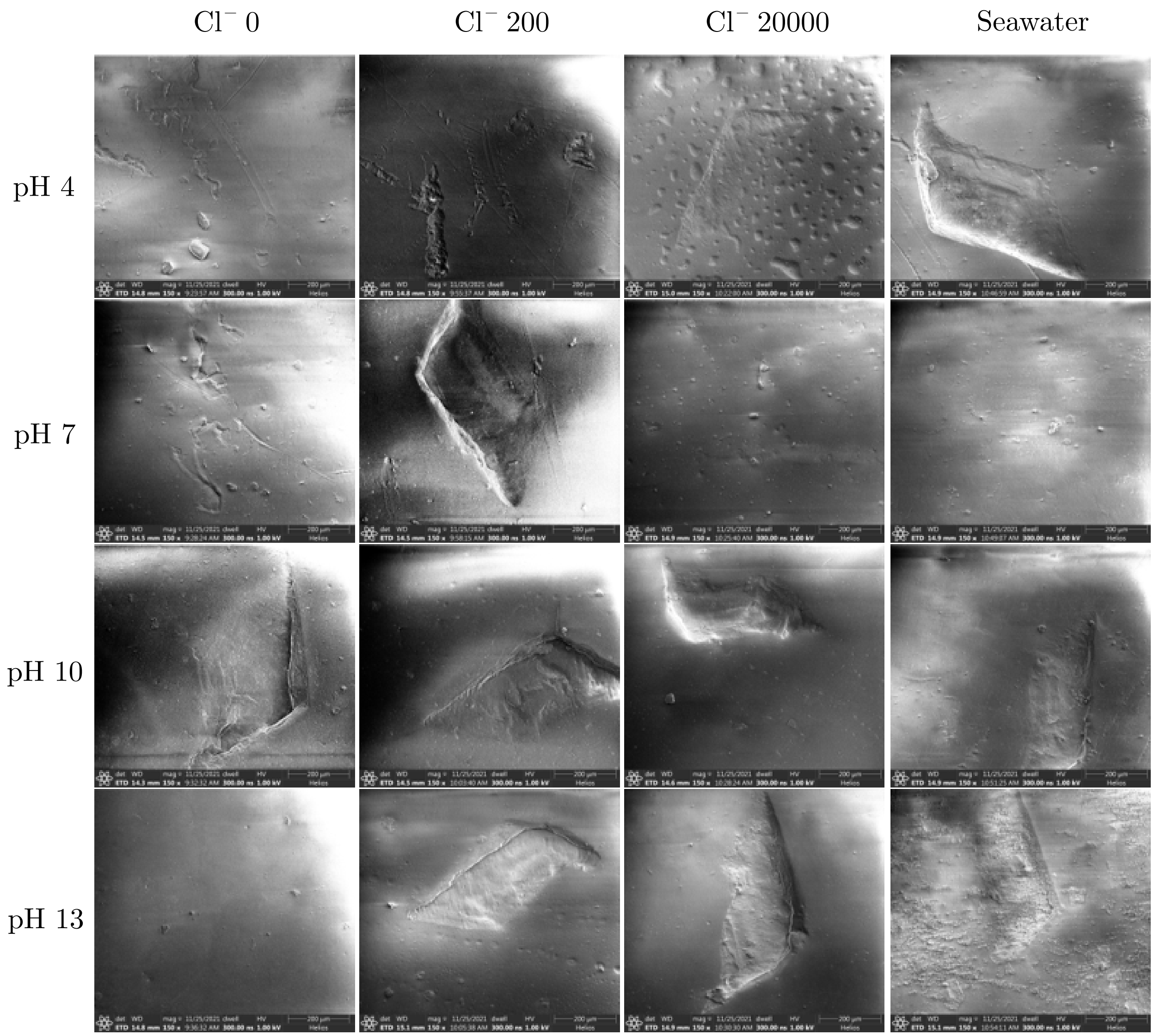

Figure 7.68: Type A resins at day 300 under 150x magnification

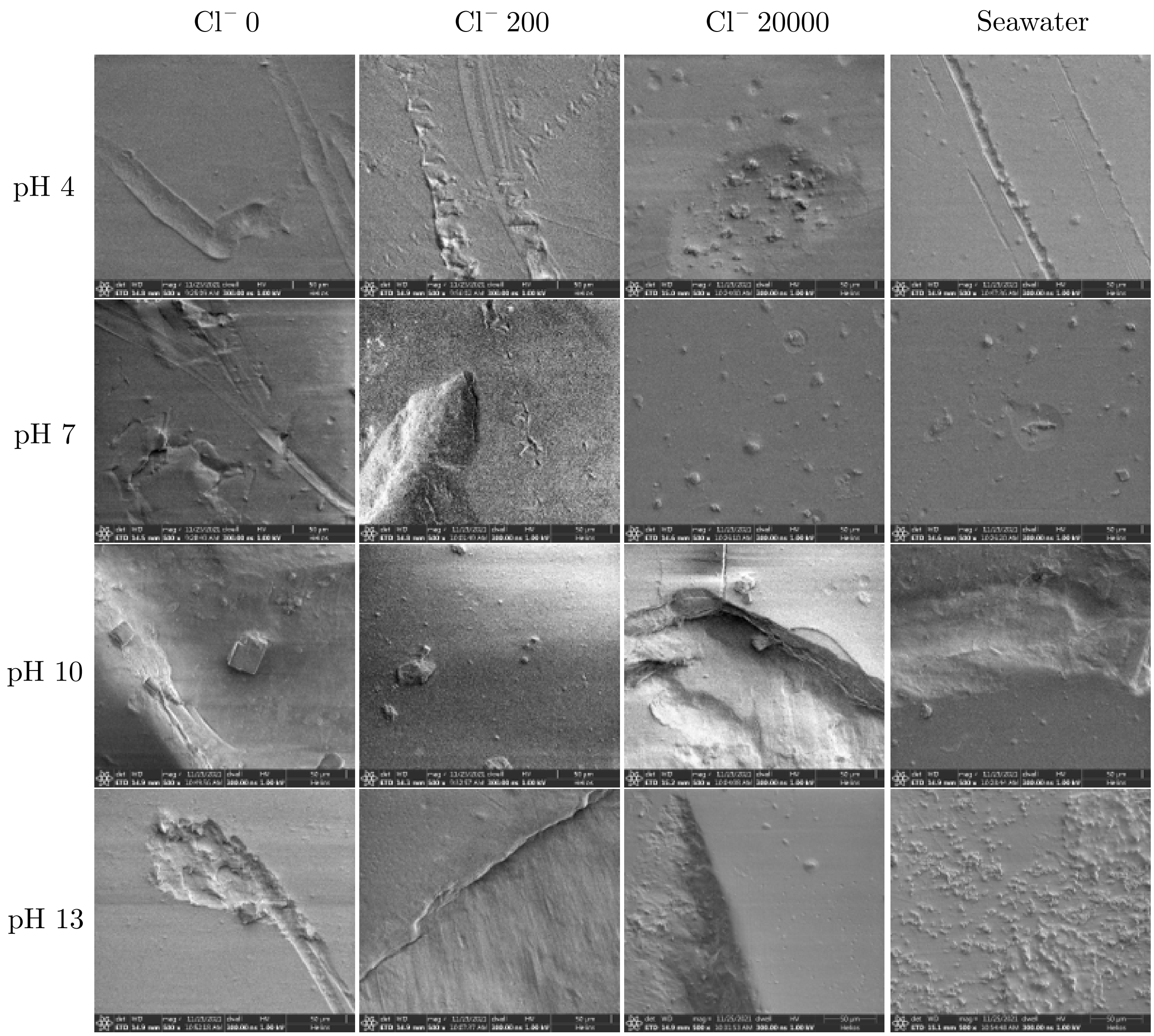

Figure 7.69: Type A resins at day 300 under 500x magnification

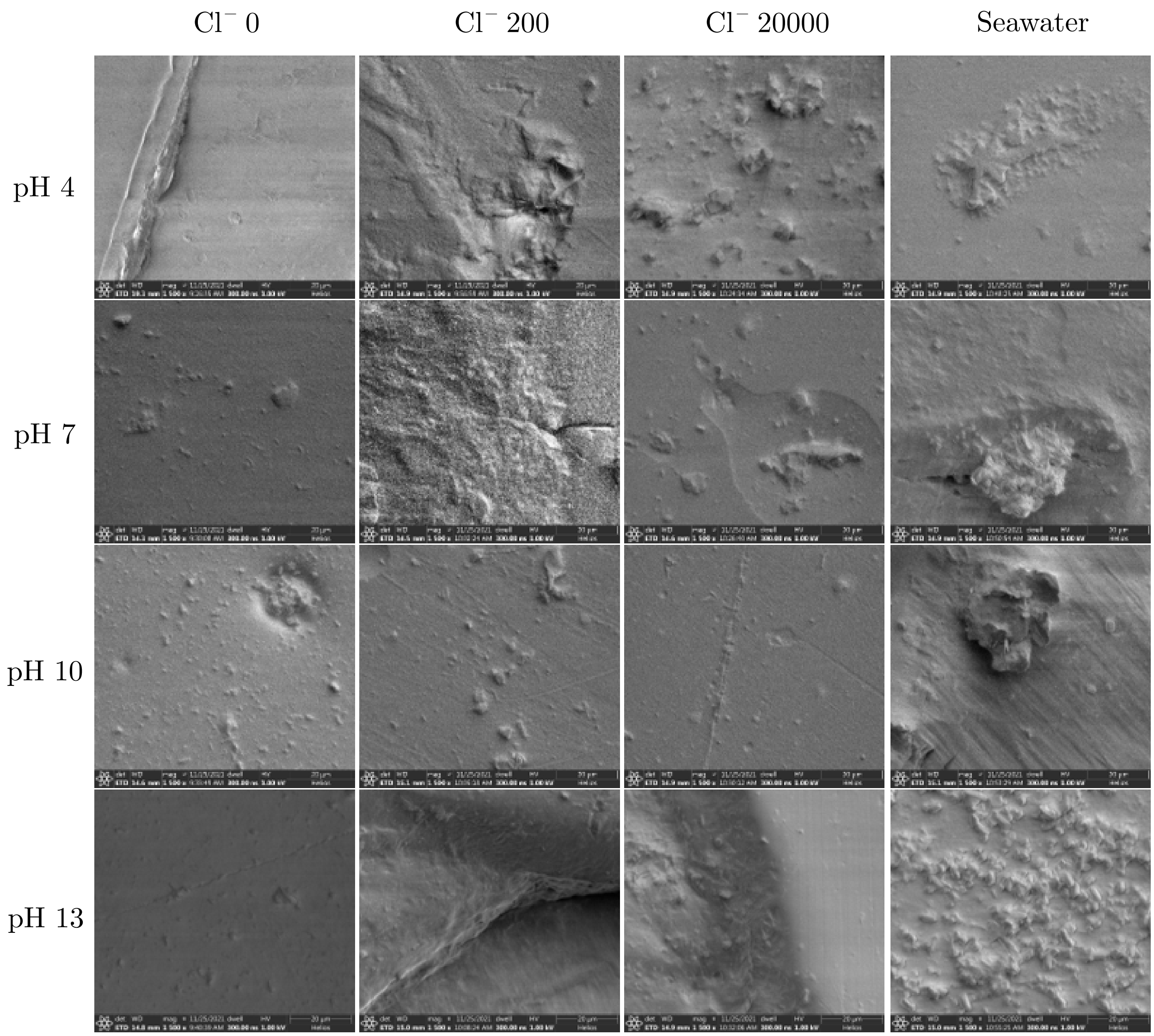

Figure 7.70: Type A resins at day 300 under 1500x magnification

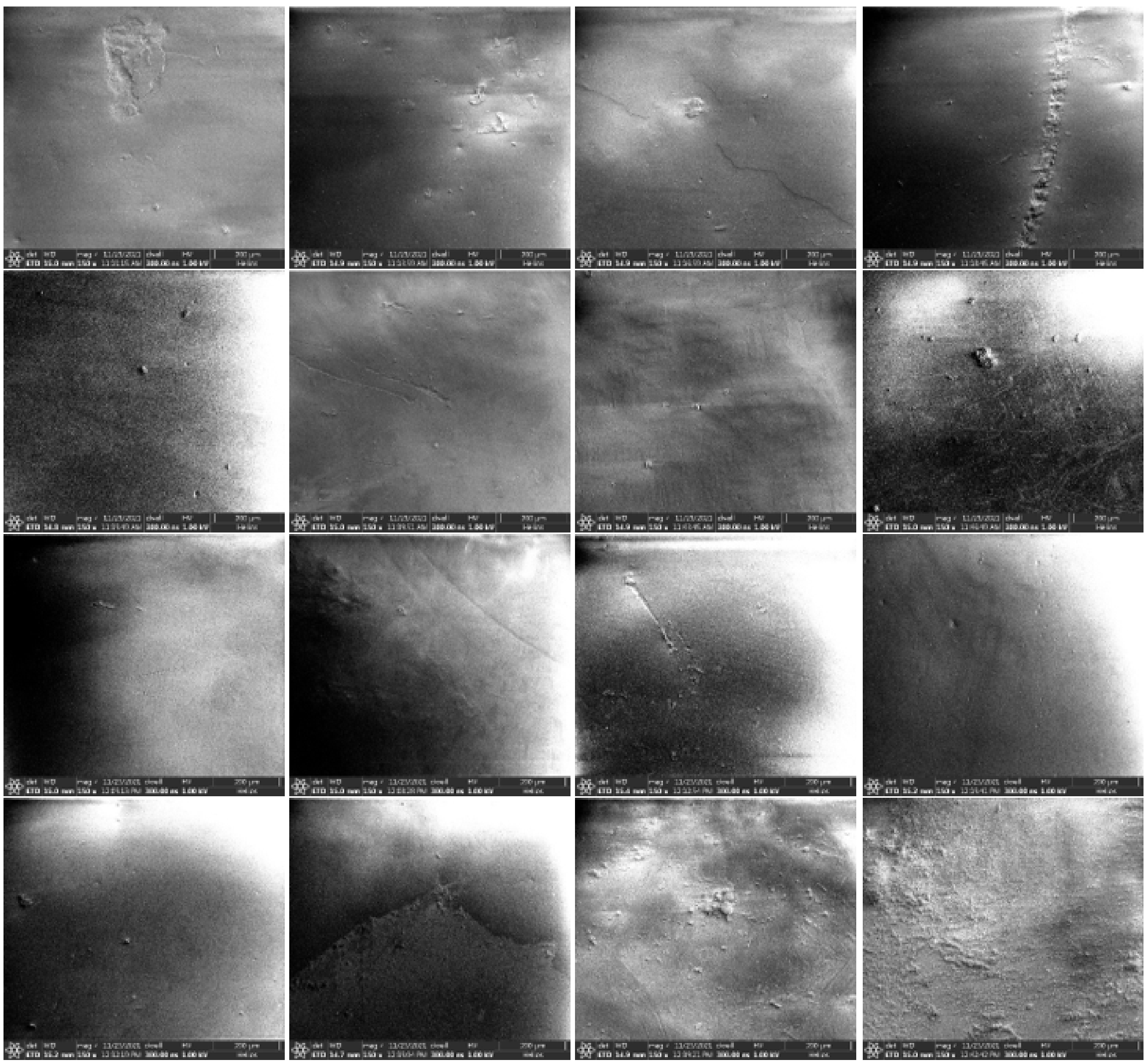

Figure 7.71: Type B resins at day 300 under 150x magnification

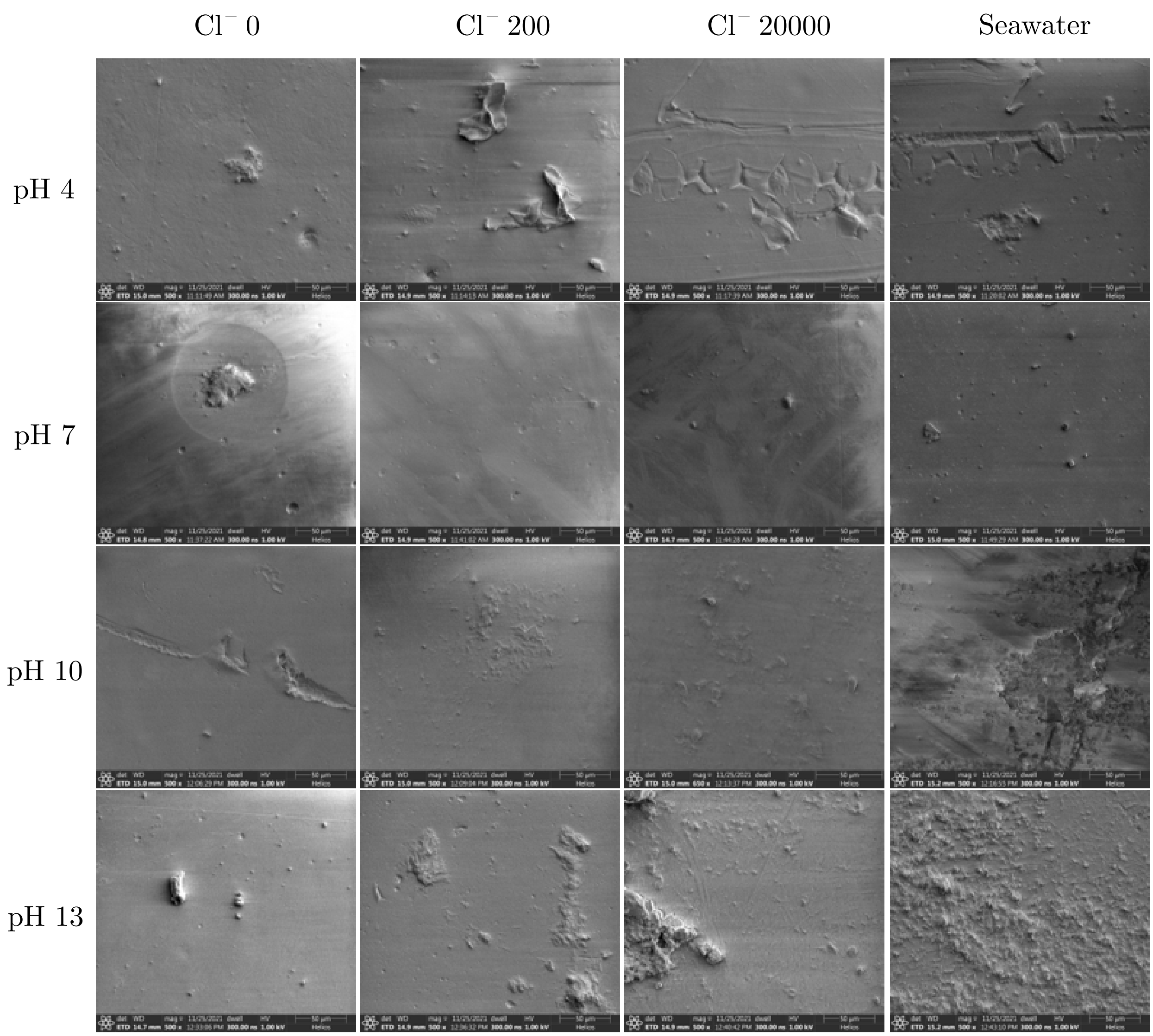

Figure 7.72: Type B resins at day 300 under 500x magnification

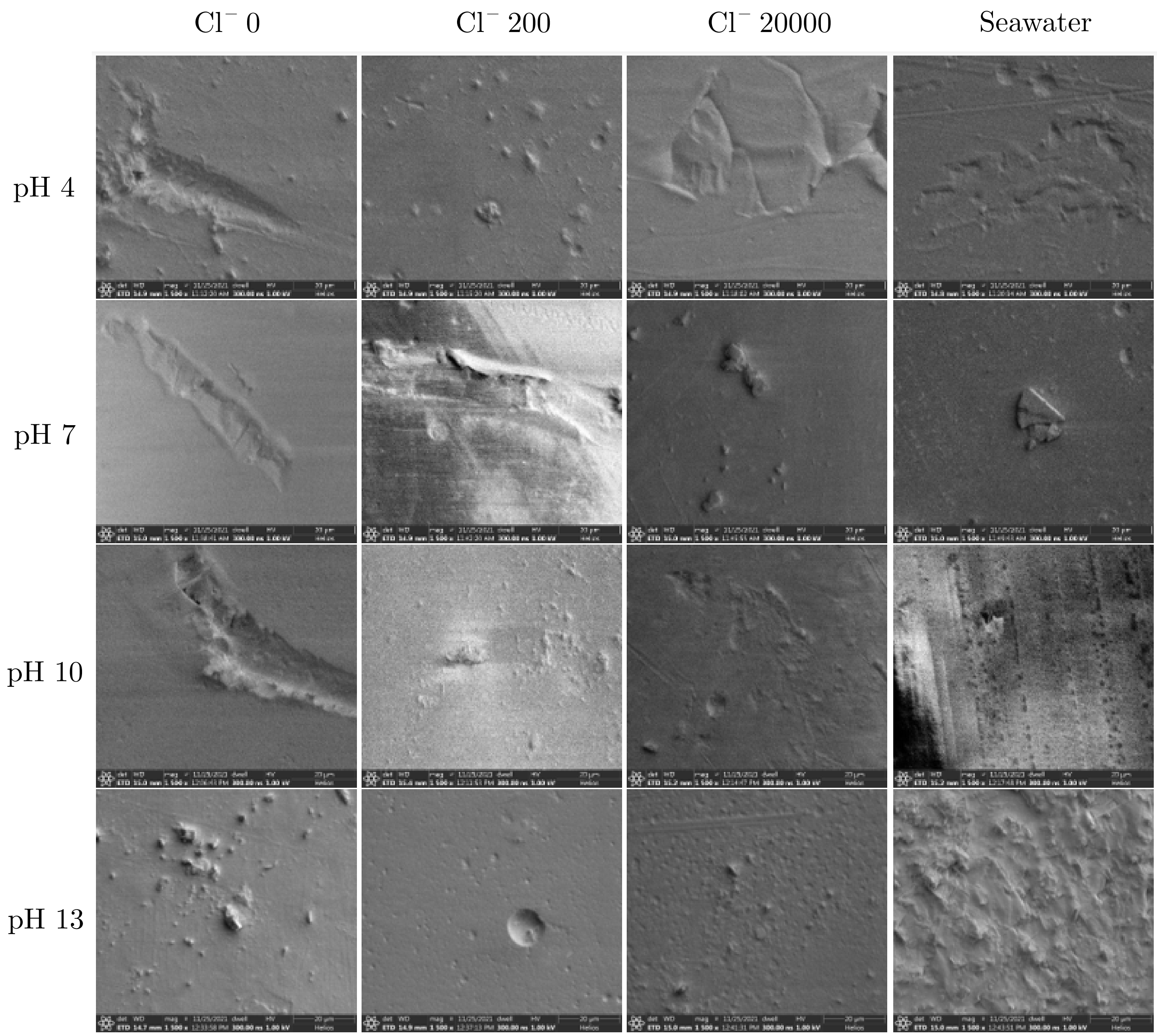

Figure 7.73: Type B resins at day 300 under 1500x magnification

7.4 Mechanical Properties of Components After Exposure to Aggressive Environments

In this section, the mechanical properties such as tensile strength of rebar components is detailed.

7.4.1 Resin Tensile Test

The resins were tested according to the ASTM D 638 (ASTM-International, 2014) to evaluate the tensile properties. The recorded and processed data of the tensile strength test are shown in this section via graphs and table.

Load-Displacement Behavior

To compare the load-displacement behavior of the different resin samples and specimens, the graphs in Figures 7.74 and 7.75 plot the recorded test data. As shown, the x-axis of the graph represents the cross-head extension—which has to be interpreted with care because it includes the elastic deformation of the load frame and the test fixtures—and the y-axis indicates the applied and measured load. Figure 7.74, and 7.75 shows that, although the extension of both resins during the test was similar regardless of the conditioned environments, the peak load was much higher for Type A resin in comparison with Type B resin. All the tested resin specimens failed in similar fashion.

Stress-Strain Behavior

The stress-strain behavior of the failed resins of all types was plotted to quantify and compare the elastic moduli of the tested resins. The data in Figures 7.76 and 7.77 were plotted to compare the stress-strain behavior of the different resin types. Accordingly, the x-axis shows the applied stress while the y-axis represents the outermost surface strain that was measured with an external extensometer. It can be seen in Figure 7.76 and 7.77 that stress-strain behavior of both resins are identical and linear until failure.

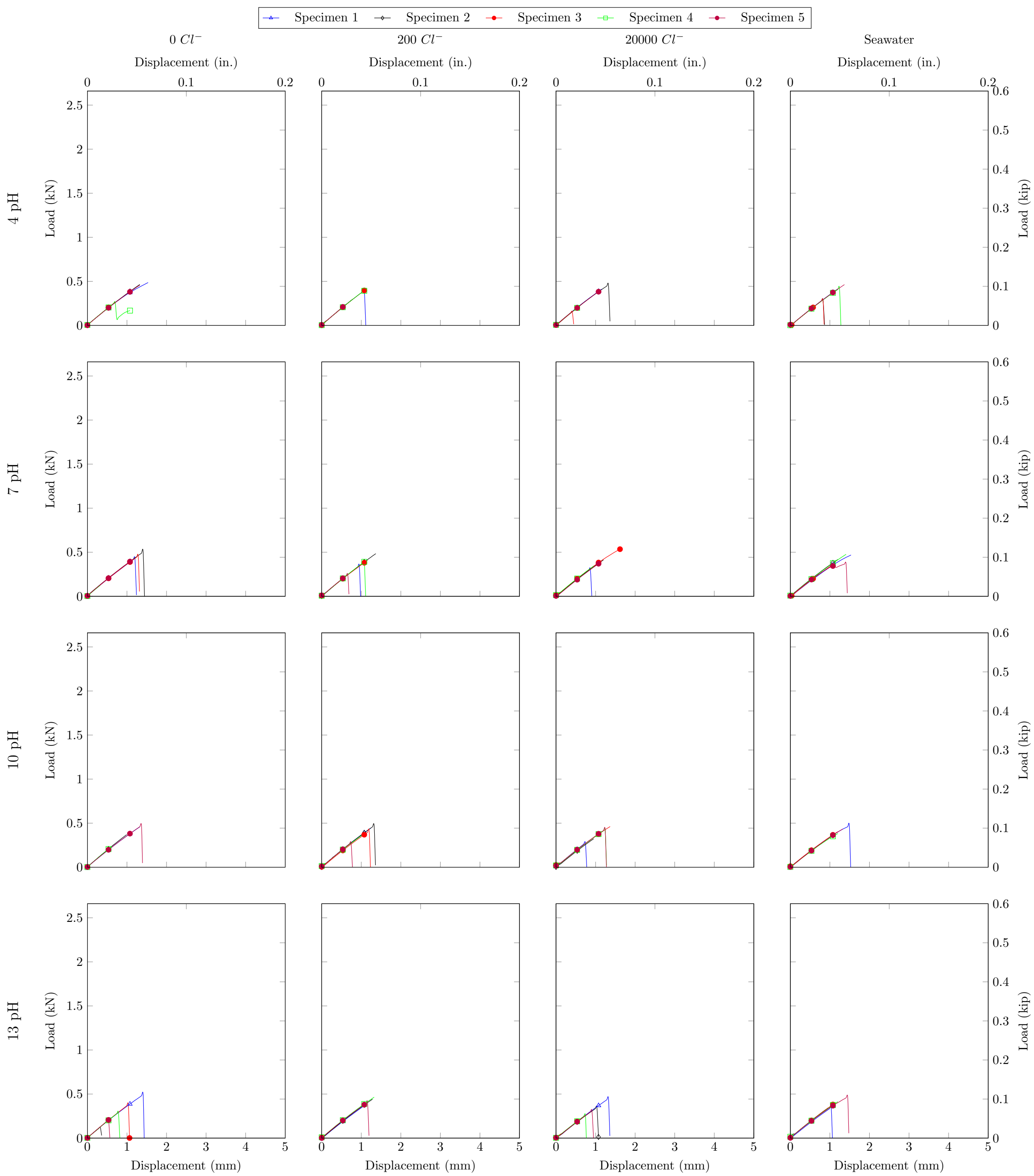

Figure 7.74: 300Day Tensile strength-displacement behavior of Type A Resin

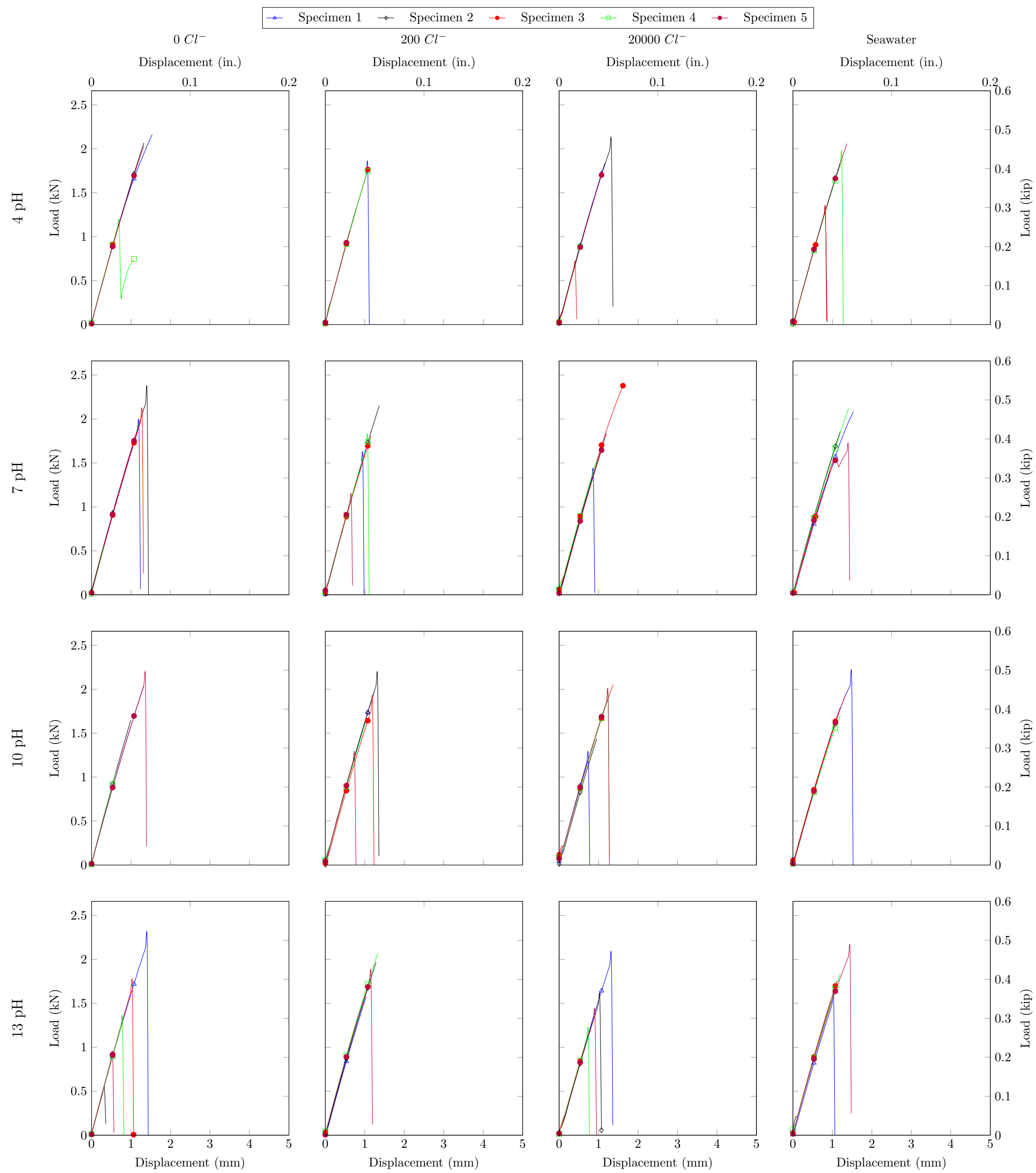

Figure 7.75: 300Day Tensile strength-displacement behavior of Type B Resin

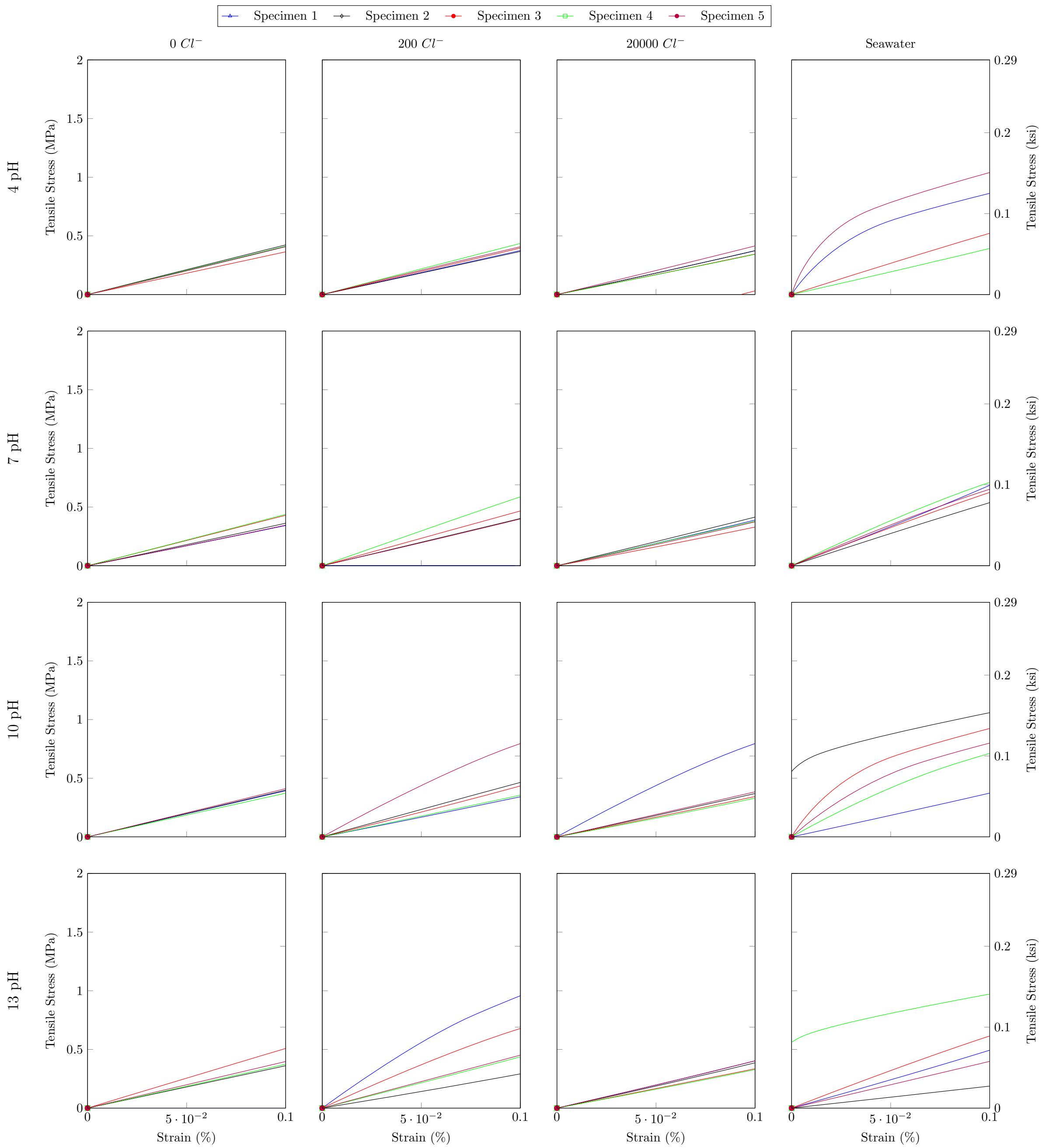

Figure 7.76: 300Day Tensile stress - Strain behavior of rebar Type A Resin

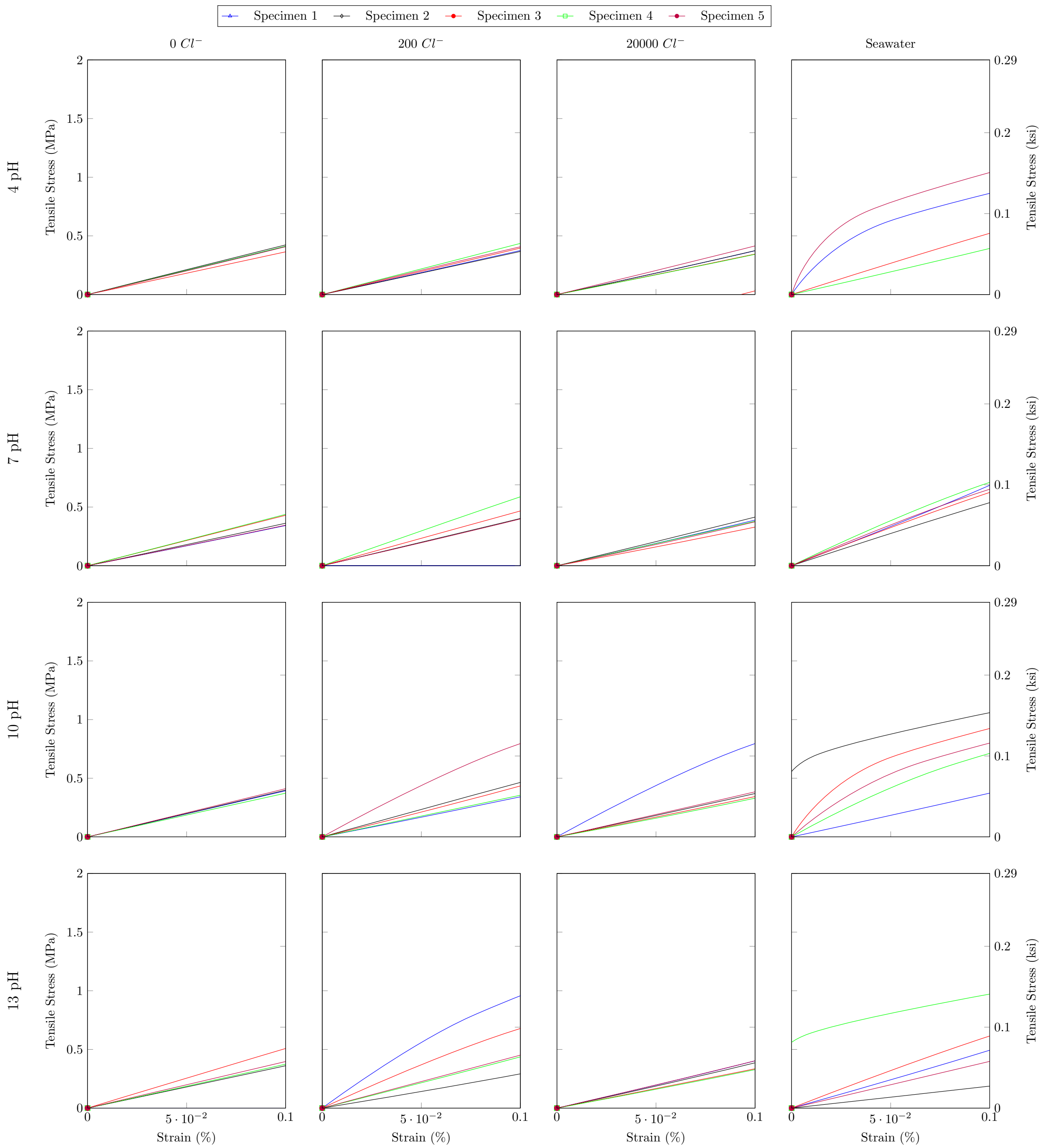

Figure 7.77: 300Day Tensile stress - Strain behavior of rebar Type B Resin

7.5 Rebar Mechanical Properties

7.5.1 Transverse Shear Test

ASTM D 7617 (ASTM-International, 2012b) was used in the process of testing and analyzing the transverse shear strength of the rebars. Tested and processed data are plotted in the following subsections.

Load-Displacement

The graphs plotted in Figures 7.78, 7.79, 7.80, 7.81, 7.82, and 7.83 show the load-displacement behavior recorded during the transverse shear tests of # 3 and # 5 rebars from all rebar types and exposure environments tested in this study. The x-axis of the graph represents the cross-head extension or the relative displacement between the edges of the directly sheared specimen, while the y-axis shows the measured force throughout the load application period.

The Graph in figure 7.78 shows a linear behavior until it reaches the ultimate failure load. It can be seen that # 5 sized rebar sustained higher load in comparison with # 3 rebars. It can be seen that rebars exposed to 4pH and 7pH sustained a consistent load while the displacement of the rebars varied. The graph in Figure 7.79 shows a comparison between the load and the displacement for transverse shear strength of # 3 and # 5 rebars Lot 1 from Type B rebar. It can be seen that the graph had a linear behavior until it reached the ultimate failure load. All the rebars sizes sustained a consistent load with similar displacement. The Graph in Figure 7.80 shows the load - displacement behavior of Type C rebars. Linearity can be seen until it reaches the ultimate failure load. It can be seen that # 5 sized rebar sustained higher load in comparison with # 3 rebars. The graph in Figure 7.81 presents a comparison between the load and the displacement for transverse shear strength of # 3 and # 5 rebars from Type A from Lot 2. The graph shows a linear behavior until it reached approximately 90% of the ultimate failure load. The visualized data in Figure 7.82 show the load-displacement behavior for transverse shear strength of # 3 and # 5 rebars Lot 2 from Type B rebar. It can be seen that the material behaved linearly until approximately 90 % of the ultimate failure load was reached. All the # 3 rebars sustained a consistent load while # 5 rebars sustained same peak load but the displacement of the rebars varied. The graph in Figure 7.83 shows a comparison between the load and the displacement for transverse shear strength of # 3 and # 5 rebars from Lot 2. The graph shows a linear behavior until it reached approximately 90% of the ultimate failure load.

Transverse Stress-Displacement

The results obtained from the transverse test was properly reduced and analyzed. These results are shown via graphs and table. The graphs in Figures 7.84, 7.85, 7.86, 7.87, 7.88, and 7.89 compare the stress-displacement behavior of transverse shear test of # 3 and # 5 rebars from all rebar types that were tested for this research project. The data along the x-axis represents the cross-head extension or the direct shear displacement, while the y-axis signifies the measured shear stress.

The data in Figure 7.84 show that the material behaved nearly linearly until the ultimate failure load was reached. It can be seen in Figure 7.84 that the stress-strain behavior of all rebars was close but not identical—specifically, it varied significantly for rebar number # 5.

The graph in Figure 7.85 presents the stress-displacement behavior of transverse shear test of rebar Type B Lot 1. From the stress-strain behavior of rebar Type B as shown in Figure 7.85, it can be seen that the rebars underwent similar failure behavior. The graph in Figure 7.86 compares the stress - strain behavior of Type C rebar from Lot 1. It shows the linearity of tested rebar until the ultimate failure load was reached. It can be seen in Figure 7.86 that the stress-strain behavior of all rebars was close but not identical—specifically, it varied significantly for rebar number # 5. The graph in Figure 7.87 presents the stress-displacement behavior

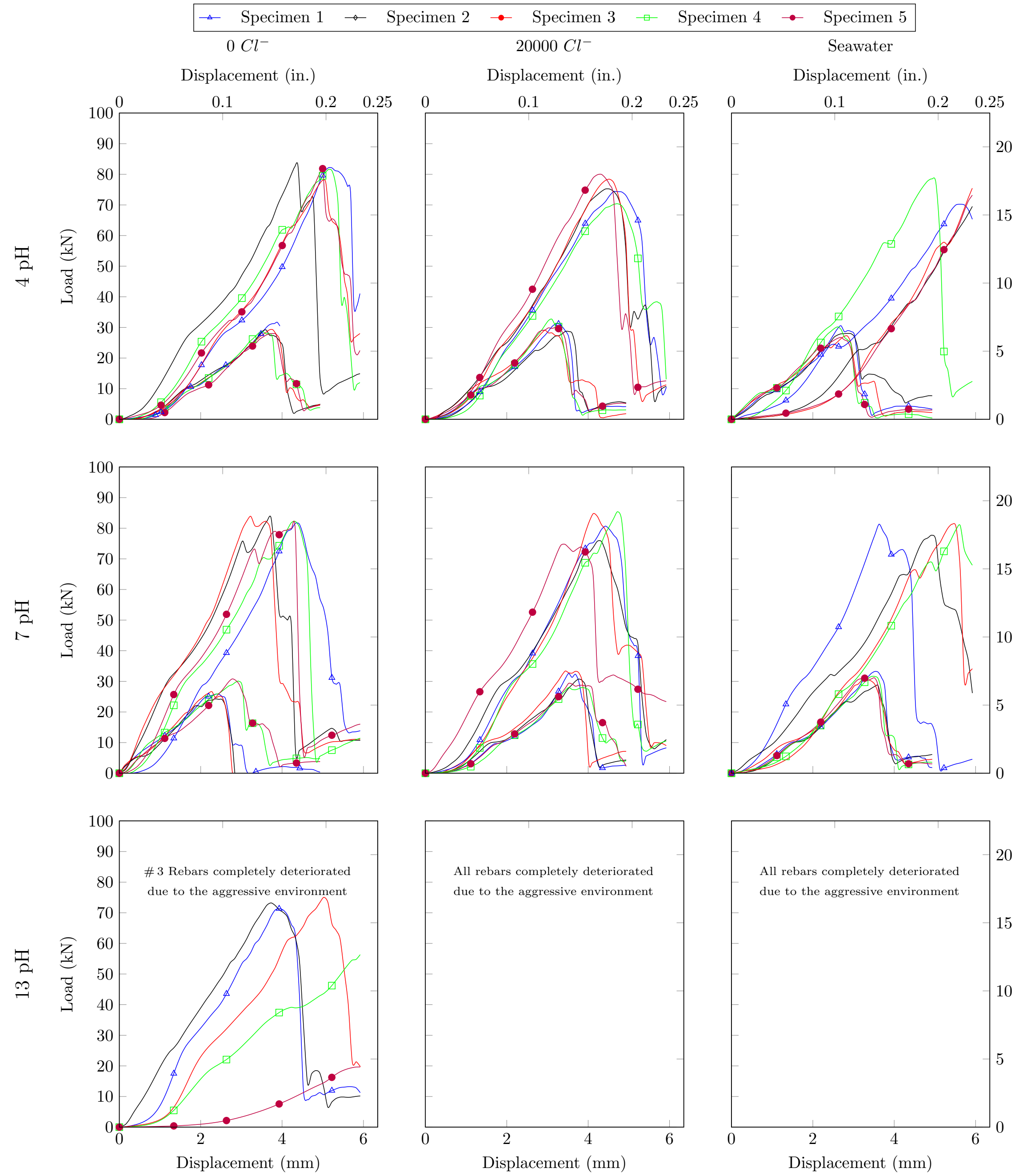

Figure 7.78: 300Day Transverse shear force - displacement behavior of Type A Lot1 tested rebars

of transverse shear test of rebar Type A Lot 2. The graphs display a mostly linear behavior until the ultimate failure load was reached. Figure 7.88 shows the stress-displacement behavior of transverse shear test of rebar Type B Lot 2. It can be seen that the data represented a nearly linear behavior until the ultimate failure load was attained. The stress-displacement behavior of failed rebar specimen from both types from Lot 2 in Figures 7.87 and 7.88 show that, although the ultimate failure capacity of the rebars varied significantly, all the rebar samples failed in a identical manner. The graph in Figure 7.89 presents the stress-displacement behavior of transverse shear test of Lot 2 rebars from Type C manufacturer. From the stress-displacement

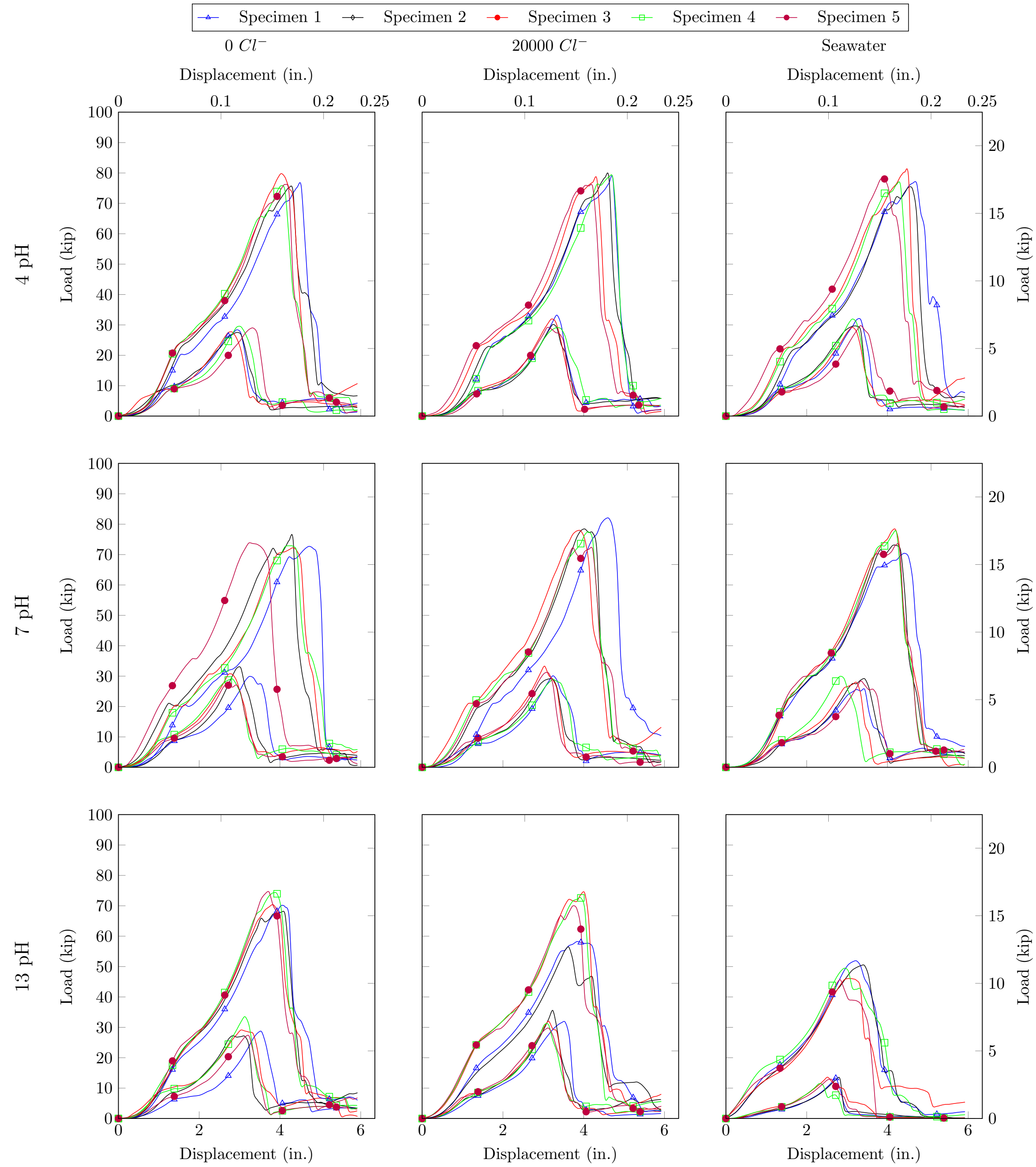

Figure 7.79: 300Day Transverse shear force - displacement behavior of Type B Lot1 tested rebars

behavior of rebar as shown in Figure 7.89, it can be seen that the rebars underwent similar failure behavior.

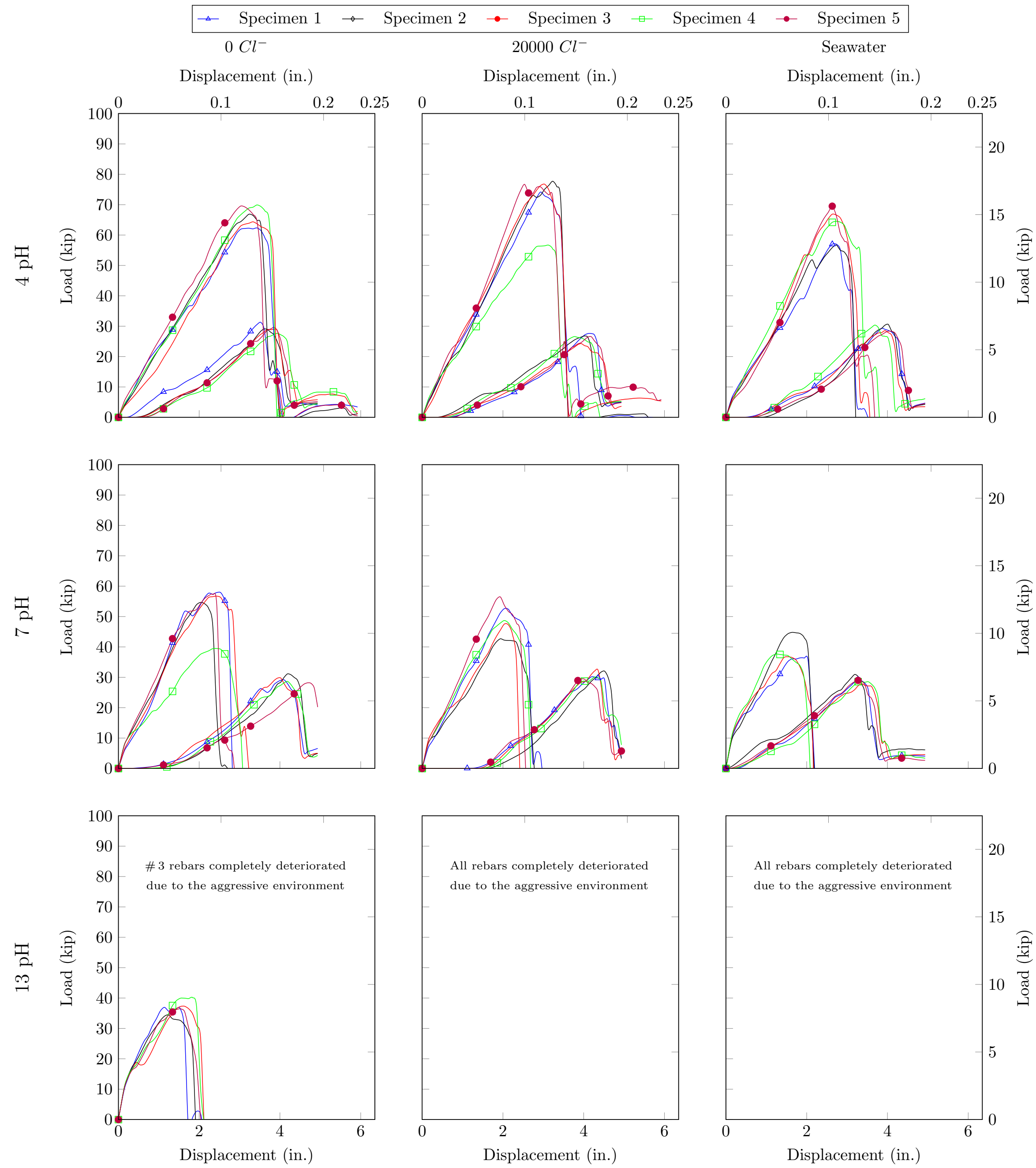

Figure 7.80: 300Day Transverse shear force - displacement behavior of Type C Lot1 tested rebars

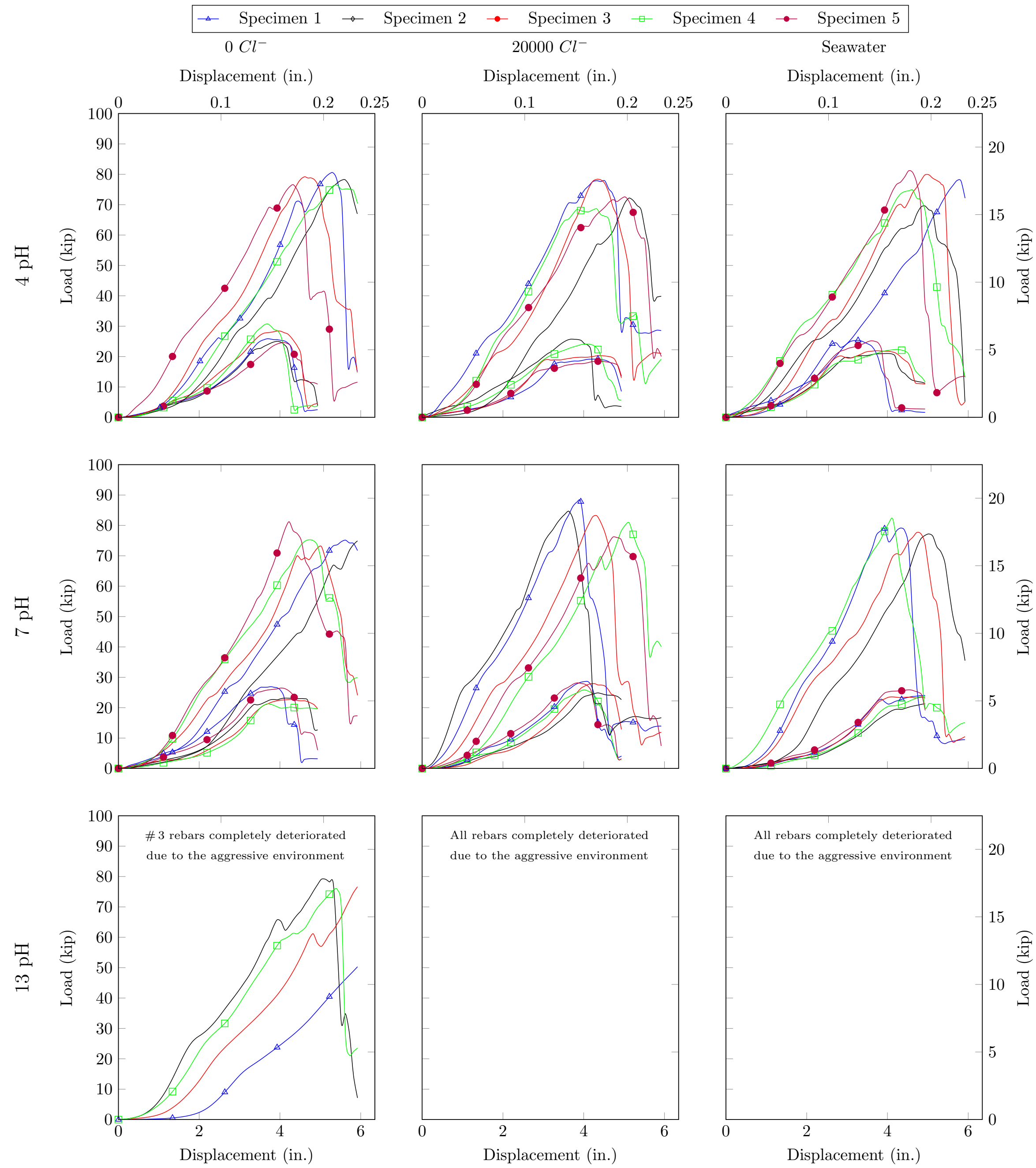

Figure 7.81: 300Day Transverse shear force - displacement behavior of Type A Lot2 tested rebars

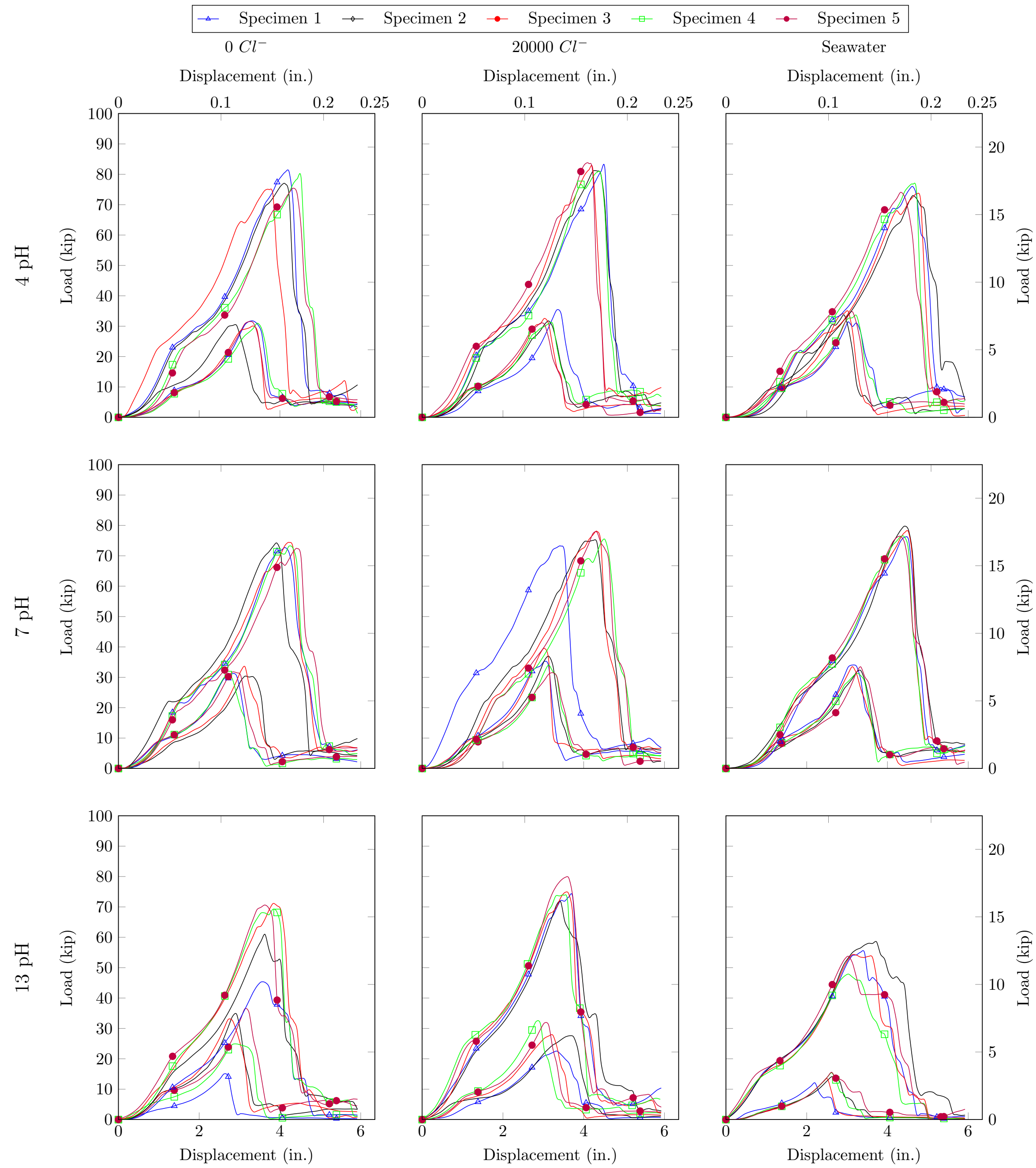

Figure 7.82: 300Day Transverse shear force - displacement behavior of Type B Lot2 tested rebars

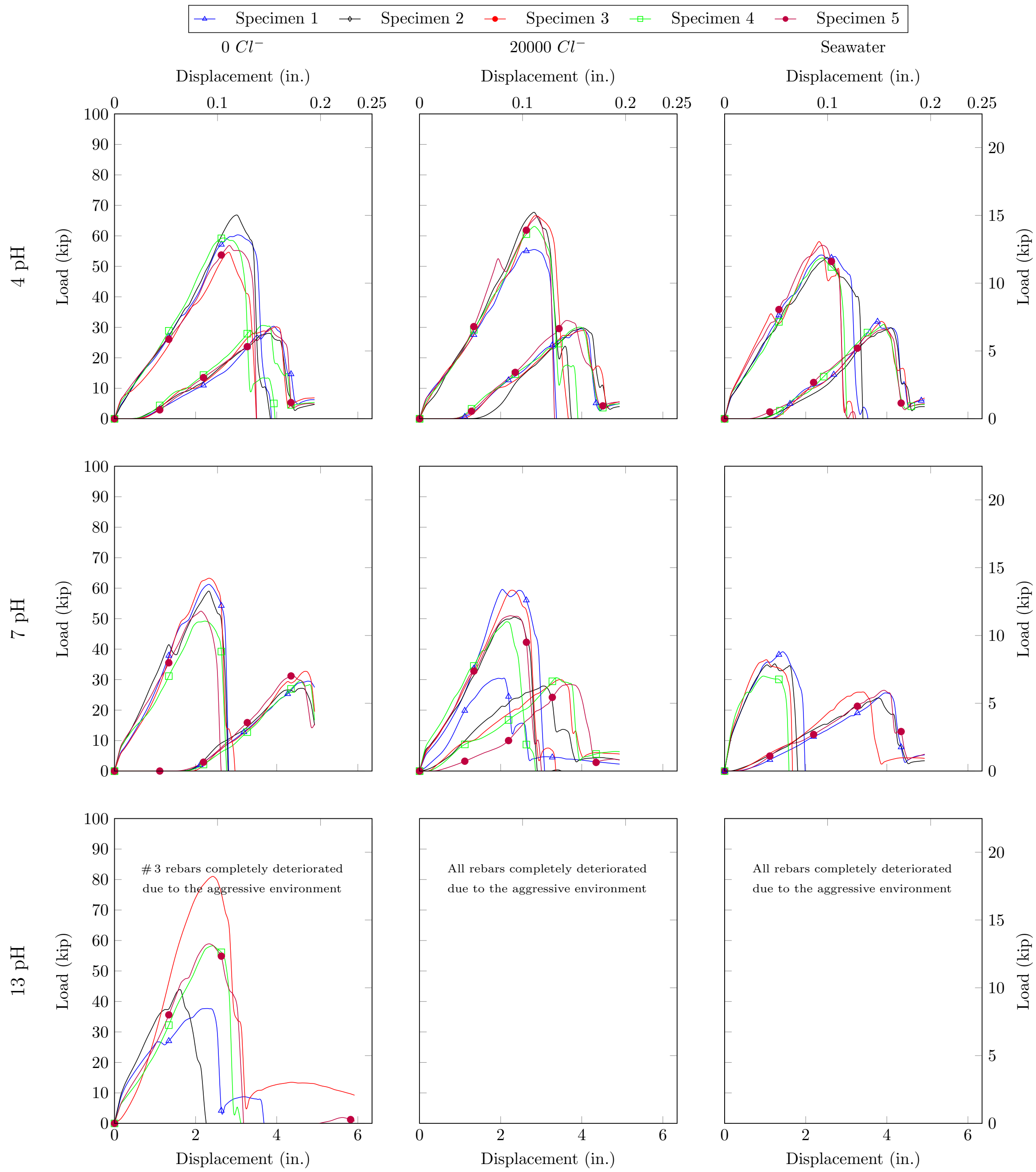

Figure 7.83: 300Day Transverse shear force - displacement behavior of Type C Lot2 tested rebars

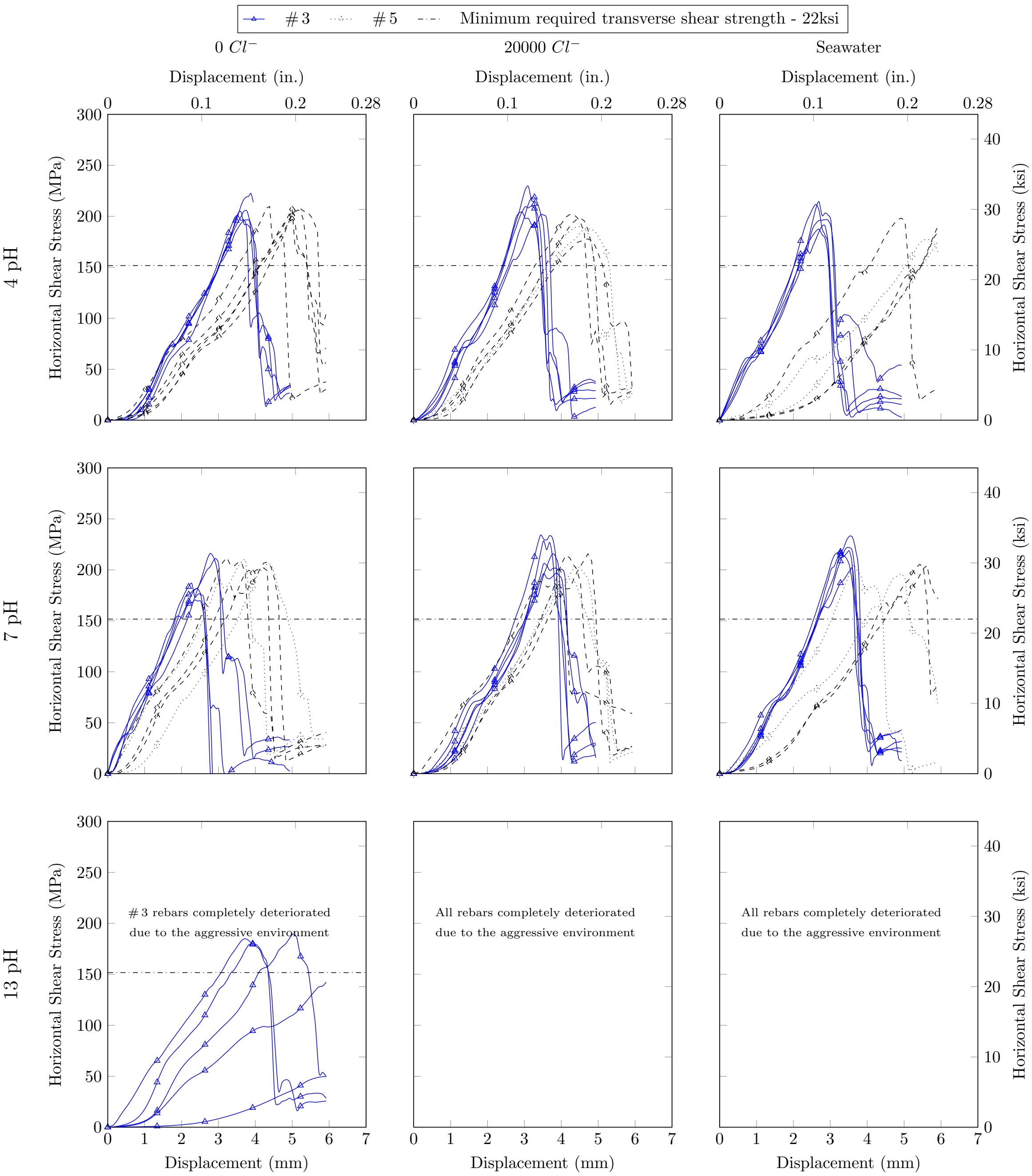

Figure 7.84: 300Day Transverse shear stress - displacement behavior of Type A Lot1 tested rebars

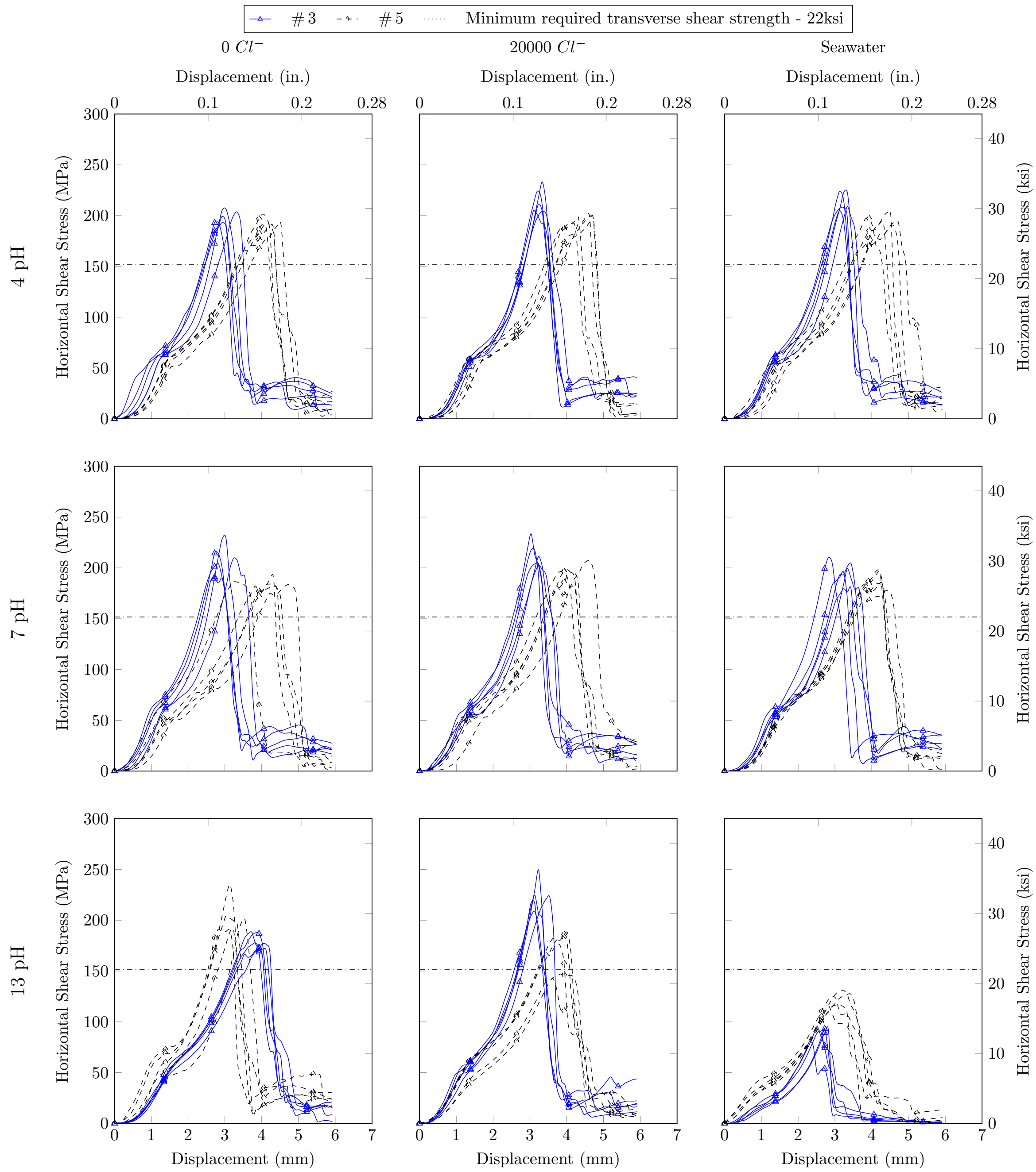

Figure 7.85: 300Day Transverse shear stress - displacement behavior of Type B Lot1 tested rebars

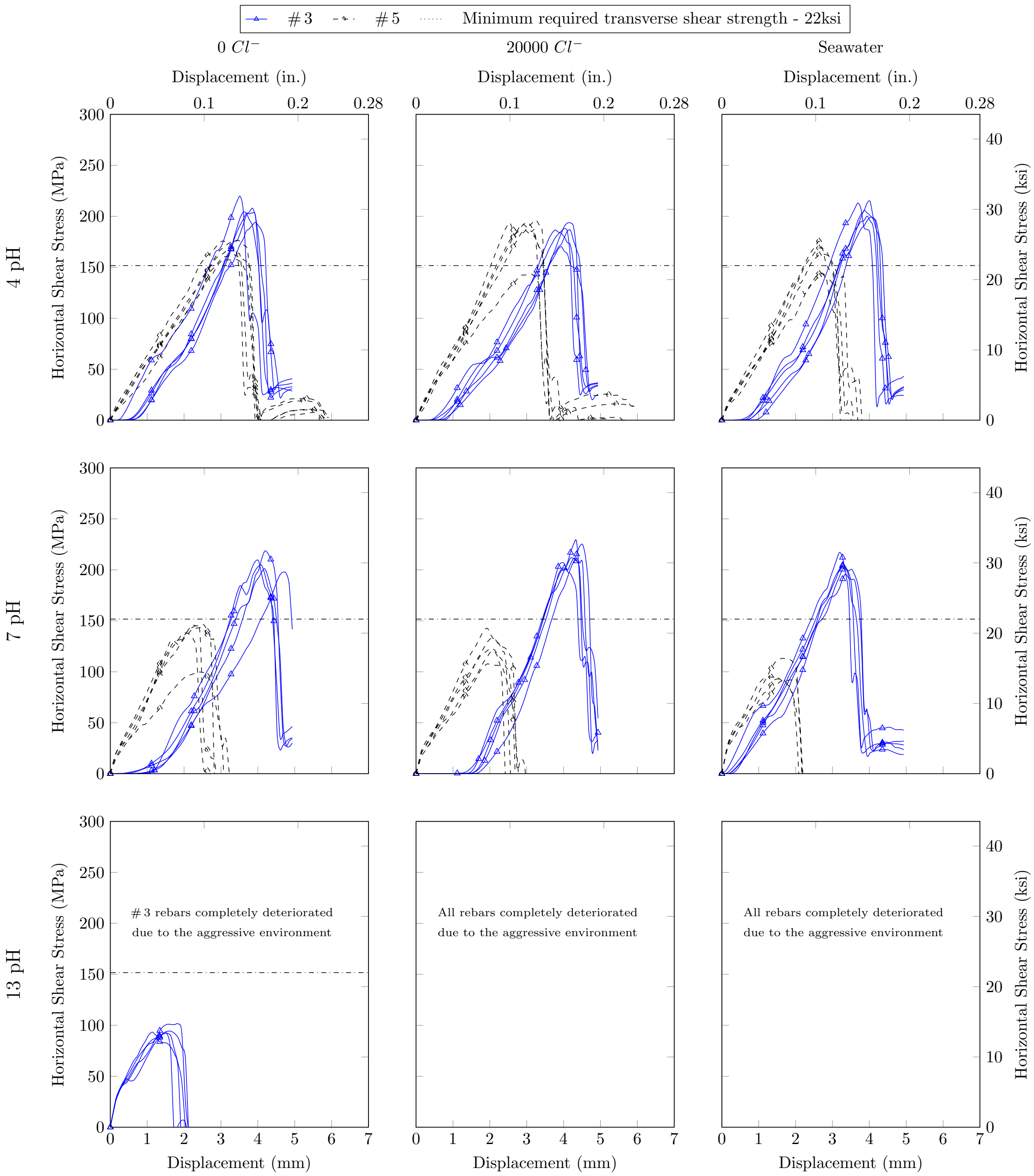

Figure 7.86: 300Day Transverse shear stress - displacement behavior of Type C Lot1 tested rebars

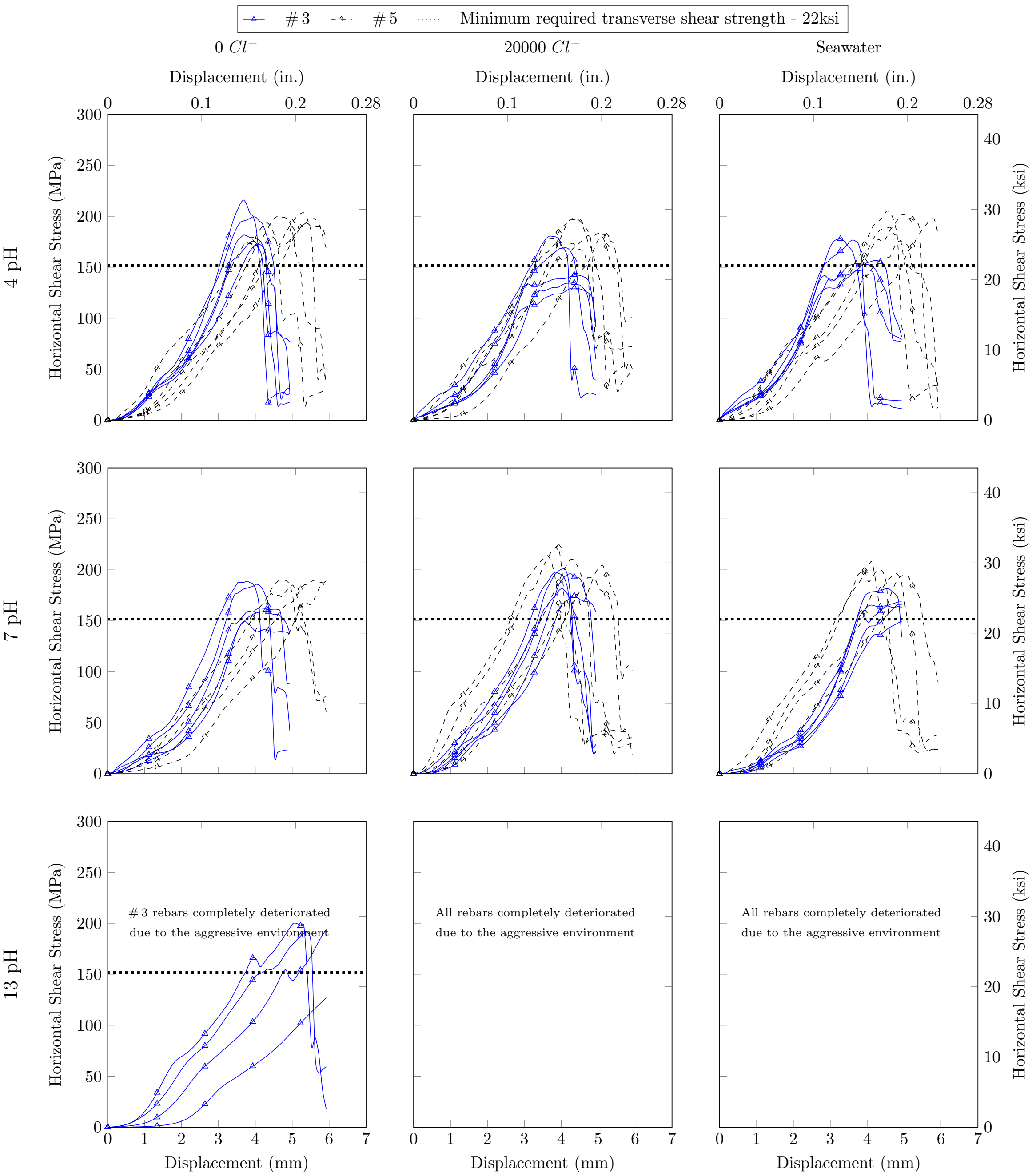

Figure 7.87: 300Day Transverse shear stress - displacement behavior of Type A Lot2 tested rebars

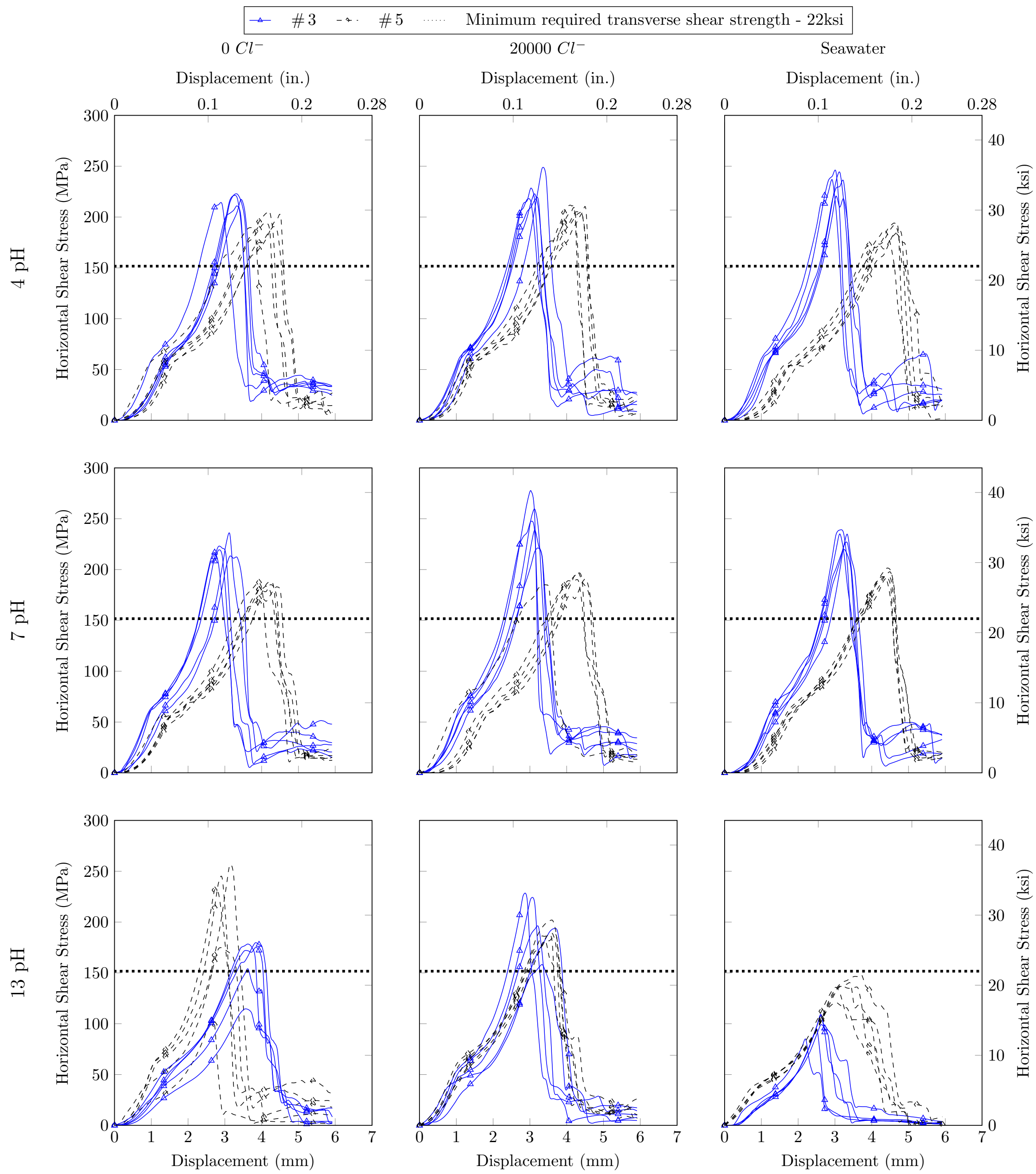

Figure 7.88: 300Day Transverse shear stress - displacement behavior of Type B Lot2 tested rebars

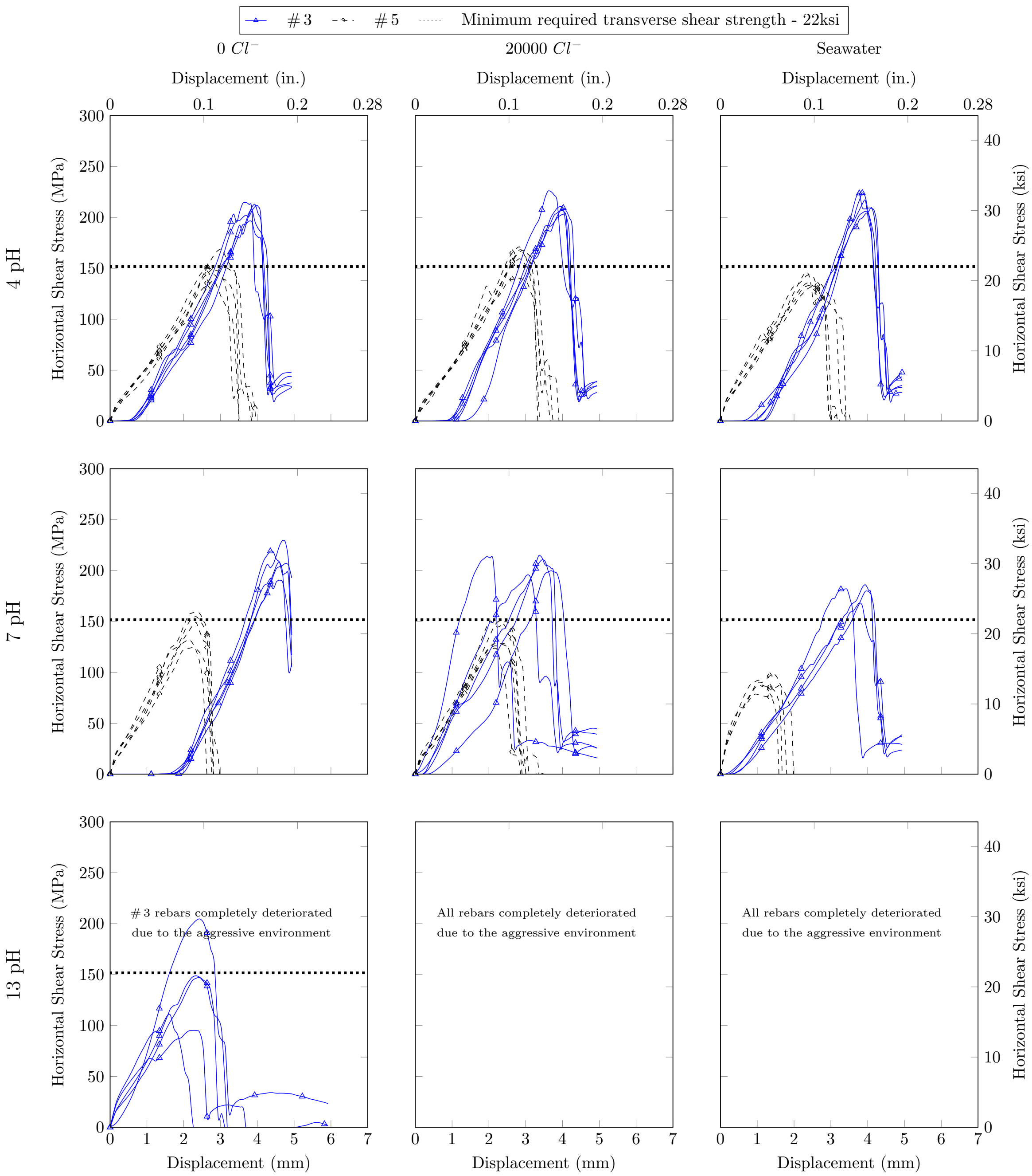

Figure 7.89: 300Day Transverse shear stress - displacement behavior of Type C Lot2 tested rebars

7.5.2 Summary of Transverse Shear Properties

The concentration of the statistical evaluation for the transverse shear strength properties of the tested products are listed in the following Table 7.41. A total of 250 specimen, five for each rebar type, size, lot, and exposure type were tested. The average and all other statistical values were calculated based on a sample size of five specimen, and the corresponding results are shown in the table. For numerical comparison and concluding values, Table 7.41 lists the minimum shear stress ($\wedge$), the maximum shear stress ($\vee$), the average shear stress (μ), the standard deviation (σ), and the coefficient of variation (CV) for each individual test sample.

Table 7.41: Transverse Shear test statistical values for each sample group (US Customary Units)

Sample Group						Statistical Values (Shear Stress)				
Manuf. Type	Resin Type	Size #	Lot No.	pH	Cl^{-}	$\wedge$ ksi	$\vee$ ksi	μ ksi	σ ksi	CV %
TypeA	Epoxy	3	1	4	0	28.6	32.3	30.1	1.4	4.70
TypeA	Epoxy	5	1	4	0	28.7	31.0	30.0	0.8	2.75
TypeB	VinylEster	3	1	4	0	28.1	30.6	29.3	1.0	3.40
TypeB	VinylEster	5	1	4	0	27.6	29.3	28.2	0.6	2.30
TypeC	Epoxy	3	1	4	0	28.2	31.9	30.0	1.3	4.44
TypeC	Epoxy	5	1	4	0	22.9	25.7	24.5	1.2	4.95
TypeA	Epoxy	3	1	4	20000	29.4	33.7	31.1	1.7	5.45
TypeA	Epoxy	5	1	4	20000	25.8	29.3	27.8	1.4	4.92
TypeB	VinylEster	3	1	4	20000	29.8	34.1	31.8	1.7	5.45
TypeB	VinylEster	5	1	4	20000	28.0	29.1	28.7	0.4	1.48
TypeC	Epoxy	3	1	4	20000	24.8	28.2	27.0	1.3	4.74
TypeC	Epoxy	5	1	4	20000	20.8	28.6	26.6	3.3	12.35
TypeA	Epoxy	3	1	4	SeaWater	27.3	31.4	29.2	1.8	6.24
TypeA	Epoxy	5	1	4	SeaWater	25.8	28.8	27.3	1.3	4.79
TypeB	VinylEster	3	1	4	SeaWater	30.0	33.2	31.4	1.5	4.85
TypeB	VinylEster	5	1	4	SeaWater	27.7	29.5	28.5	0.7	2.44
TypeC	Epoxy	3	1	4	SeaWater	28.9	31.5	30.2	1.1	3.74
TypeC	Epoxy	5	1	4	SeaWater	20.8	25.6	23.2	2.1	9.25
TypeA	Epoxy	3	2	4	0	25.1	31.4	27.5	2.6	9.58
TypeA	Epoxy	5	2	4	0	28.1	29.6	28.7	0.6	2.15
TypeB	VinylEster	3	2	4	0	30.7	32.5	31.8	0.8	2.47
TypeB	VinylEster	5	2	4	0	27.6	29.8	28.5	0.9	3.17
TypeC	Epoxy	3	2	4	0	29.0	31.4	30.5	0.9	2.98
TypeC	Epoxy	5	2	4	0	20.3	24.5	21.9	1.6	7.40
TypeA	Epoxy	3	2	4	20000	18.8	26.3	22.0	3.3	14.82
TypeA	Epoxy	5	2	4	20000	25.2	28.7	27.1	1.5	5.59
TypeB	VinylEster	3	2	4	20000	31.9	36.9	33.5	2.0	6.09
TypeB	VinylEster	5	2	4	20000	29.8	30.8	30.1	0.4	1.30
TypeC	Epoxy	3	2	4	20000	29.5	32.9	30.7	1.3	4.16
TypeC	Epoxy	5	2	4	20000	20.4	25.0	23.5	1.9	7.89
TypeA	Epoxy	3	2	4	SeaWater	21.4	25.8	23.6	2.0	8.58

Continued on next page . . .

Table 7.41: Transverse Shear test statistical values for each sample group (US Customary Units)

Sample Group						Statistical Values				
						Shear Stress				
Manuf. Type	Resin Type	Size #	Lot No.	pH	Cl^{-}	$\wedge$ ksi	$\vee$ ksi	μ ksi	σ ksi	CV %
TypeA	Epoxy	5	2	4	SeaWater	25.8	29.9	28.3	1.7	5.85
TypeB	VinylEster	3	2	4	SeaWater	32.6	35.8	34.6	1.3	3.67
TypeB	VinylEster	5	2	4	SeaWater	26.9	28.2	27.5	0.6	2.09
TypeC	Epoxy	3	2	4	SeaWater	29.9	32.7	31.4	1.2	3.84
TypeC	Epoxy	5	2	4	SeaWater	19.3	21.7	20.2	1.0	5.04
TypeA	Epoxy	3	1	7	0	24.8	31.5	28.2	2.8	9.99
TypeA	Epoxy	5	1	7	0	29.3	30.9	30.2	0.6	1.95
TypeB	VinylEster	3	1	7	0	28.3	34.1	31.1	2.2	7.10
TypeB	VinylEster	5	1	7	0	26.6	27.7	27.0	0.4	1.58
TypeC	Epoxy	3	1	7	0	28.8	31.9	30.1	1.2	4.06
TypeC	Epoxy	5	1	7	0	14.5	21.3	19.6	2.8	14.54
TypeA	Epoxy	3	1	7	20000	28.7	34.4	31.8	2.3	7.20
TypeA	Epoxy	5	1	7	20000	27.7	31.4	29.6	1.7	5.81
TypeB	VinylEster	3	1	7	20000	29.8	34.6	31.6	1.9	6.07
TypeB	VinylEster	5	1	7	20000	26.6	30.1	28.6	1.3	4.39
TypeC	Epoxy	3	1	7	20000	30.2	33.1	31.5	1.3	4.11
TypeC	Epoxy	5	1	7	20000	15.7	20.8	18.3	1.9	10.62
TypeA	Epoxy	3	1	7	SeaWater	29.2	33.9	31.7	1.7	5.40
TypeA	Epoxy	5	1	7	SeaWater	28.7	30.3	29.6	0.7	2.26
TypeB	VinylEster	3	1	7	SeaWater	26.7	30.7	29.1	1.5	5.10
TypeB	VinylEster	5	1	7	SeaWater	25.8	29.0	27.4	1.3	4.69
TypeC	Epoxy	3	1	7	SeaWater	28.6	31.8	29.9	1.1	3.81
TypeC	Epoxy	5	1	7	SeaWater	13.4	16.4	14.6	1.5	9.95
TypeA	Epoxy	3	2	7	0	21.8	27.5	24.6	2.5	10.17
TypeA	Epoxy	5	2	7	0	26.9	29.9	28.0	1.1	3.99
TypeB	VinylEster	3	2	7	0	31.3	35.4	32.6	1.6	4.97
TypeB	VinylEster	5	2	7	0	26.6	27.3	27.0	0.3	1.16
TypeC	Epoxy	3	2	7	0	27.8	33.4	30.7	2.1	6.86
TypeC	Epoxy	5	2	7	0	18.0	23.2	21.0	2.2	10.51
TypeA	Epoxy	3	2	7	20000	25.3	29.2	27.6	1.7	6.05
TypeA	Epoxy	5	2	7	20000	28.1	32.3	30.4	1.6	5.17
TypeB	VinylEster	3	2	7	20000	32.3	40.5	36.7	3.2	8.75
TypeB	VinylEster	5	2	7	20000	26.9	28.8	28.0	0.8	2.83
TypeC	Epoxy	3	2	7	20000	28.5	31.4	30.1	1.3	4.29
TypeC	Epoxy	5	2	7	20000	18.2	22.0	19.9	1.9	9.48
TypeA	Epoxy	3	2	7	SeaWater	21.8	26.4	24.2	1.6	6.81
TypeA	Epoxy	5	2	7	SeaWater	28.3	30.2	29.0	0.8	2.81
TypeB	VinylEster	3	2	7	SeaWater	32.2	35.6	34.2	1.3	3.90
TypeB	VinylEster	5	2	7	SeaWater	28.0	29.3	28.4	0.5	1.92
TypeC	Epoxy	3	2	7	SeaWater	24.5	27.0	26.0	1.1	4.19
TypeC	Epoxy	5	2	7	SeaWater	11.6	14.5	13.1	1.0	7.97
TypeA	Epoxy	5	1	13	0	7.2	27.7	21.8	8.5	39.14

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Table 7.41: Transverse Shear test statistical values for each sample group (US Customary Units)

Sample Group						Statistical Values				
						Shear Stress				
Manuf. Type	Resin Type	Size #	Lot No.	pH	Cl^{-}	$\wedge$ ksi	$\vee$ ksi	μ ksi	σ ksi	CV %
TypeB	VinylEster	3	1	13	0	28.0	34.4	30.0	2.6	8.73
TypeB	VinylEster	5	1	13	0	25.0	27.5	26.3	1.1	4.13
TypeC	Epoxy	5	1	13	0	12.8	14.8	13.7	0.7	5.30
TypeB	VinylEster	3	1	13	20000	30.5	36.9	33.3	2.3	7.00
TypeB	VinylEster	5	1	13	20000	20.9	27.4	24.5	3.0	12.34
TypeB	VinylEster	3	1	13	SeaWater	12.8	14.4	13.8	0.6	4.54
TypeB	VinylEster	5	1	13	SeaWater	16.8	19.1	17.9	1.0	5.62
TypeA	Epoxy	5	2	13	0	18.8	29.1	26.0	4.8	18.58
TypeB	VinylEster	3	2	13	0	16.5	38.7	30.5	9.4	30.85
TypeB	VinylEster	5	2	13	0	16.7	26.2	23.4	4.0	17.27
TypeC	Epoxy	5	2	13	0	13.8	29.7	20.6	6.1	29.51
TypeB	VinylEster	3	2	13	20000	23.0	34.4	29.4	4.5	15.27
TypeB	VinylEster	5	2	13	20000	26.5	29.4	27.6	1.1	3.89
TypeB	VinylEster	3	2	13	SeaWater	12.9	16.4	14.9	1.4	9.53
TypeB	VinylEster	5	2	13	SeaWater	17.6	21.6	19.8	1.4	7.28

7.5.3 Apparent Horizontal Shear Test

The FRP rebar products were tested for horizontal shear properties after exposing them to aggressive environments. The horizontal shear test was conducted according to the ASTM D 4475 (ASTM-International, 2012a) standards.

Load-Displacement

The graphs in Figures 7.90, 7.91, 7.92, 7.93, 7.94, and 7.95 plot the load-displacement behavior of short span 3 point bending. Each rebar type is shown individually—and every specimen within the relevant sample is displayed—to compare # 3 and # 5 from the same type. The x-axis of the graph represents the cross-head frame displacement, and the y-axis represents the applied load.

The graph in Figure 7.90 shows a nearly linear behavior until it reached the ultimate failure load. Following the peak load, a descending branch proceeds with individual local peaks and drops. The peaks and drops represent individual layers of fibers engaged and failing in tension located in the lower part of the specimen experiencing pure tension, while the upper part is in compression. Extension-Horizontal shear behavior of rebar Type B can be seen in the graph in Figure 7.91. Similar to Type A, # 5 Type B rebar sustained more load in comparison with # 3 rebars. The failure pattern of # 3 and # 5 Type B rebars was similar and identical to Type A rebar failure pattern. The load - displacement graph of Type C rebar in Figure 7.92 shows a nearly linear behavior until it reached the ultimate failure load. Following the peak load, a descending branch proceeds with individual local peaks and drops. The peaks and drops represent individual layers of fibers engaged and failing in tension located in the lower part of the specimen experiencing pure tension, while the upper part is in compression. The graphs shown in Figures 7.93, 7.94, and 7.95 show the load-displacement behavior of Lot 2 Type A, Type B, and Type C rebars. The graphs show a linear behavior

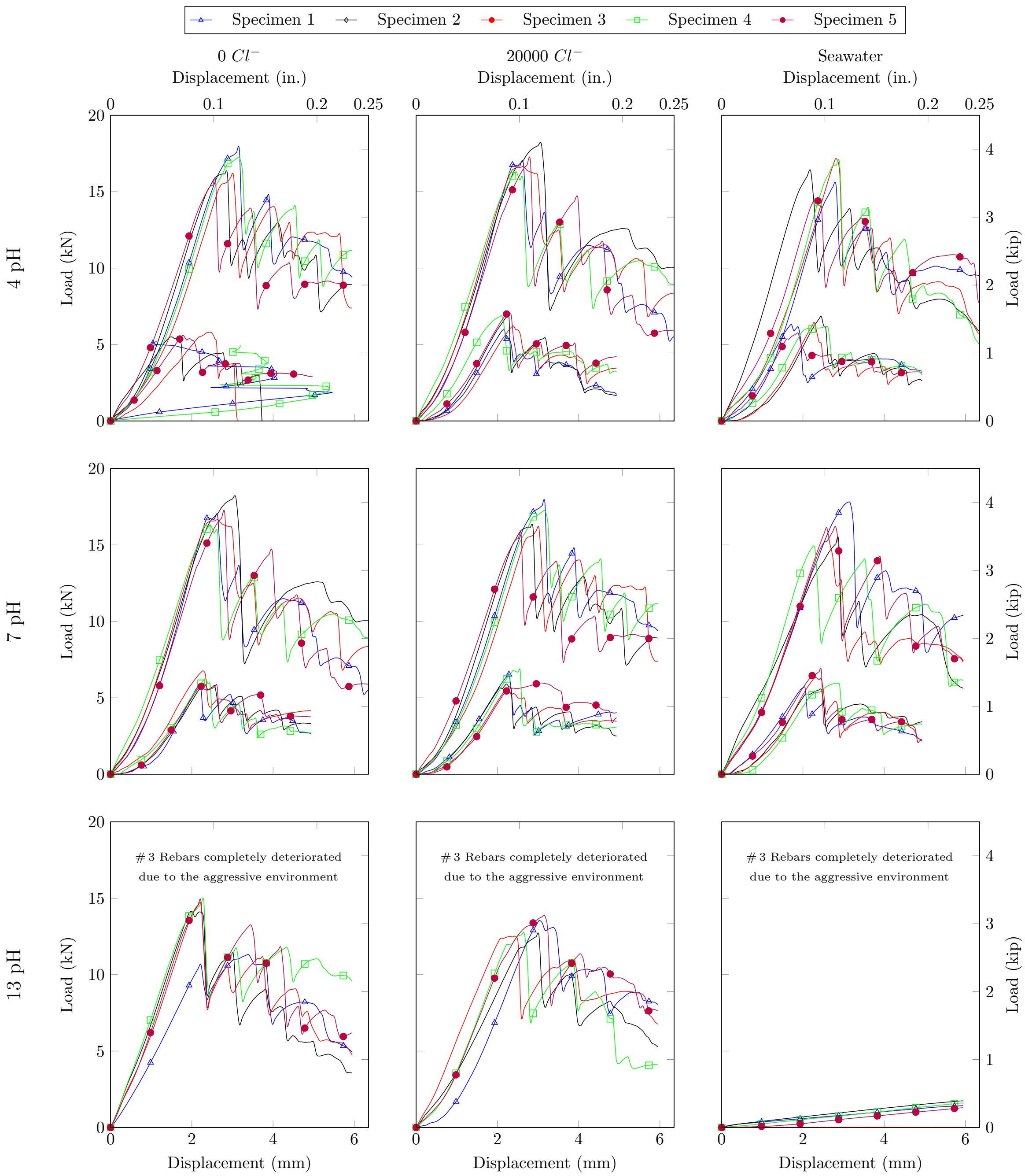

Figure 7.90: 300Day Horizontal shear force - displacement behavior of Type A Lot1 tested rebars

until it reached approximately 90 % of the ultimate failure load. It can be seen in Figures 7.93 and 7.94 that the failure behavior of Type A and Type B rebars is identical irrespective of production lot and rebar size. Extension-Horizontal shear behavior of Lot 2 Type C rebars can be seen in the graph in Figure 7.95. Similar to Lot 1, # 5 Lot 2 rebars sustained more load in comparison with # 3 rebars. The failure pattern of # 3 and # 5 Lot 2 rebars was similar and identical to the failure pattern of rebars from Lot 1.

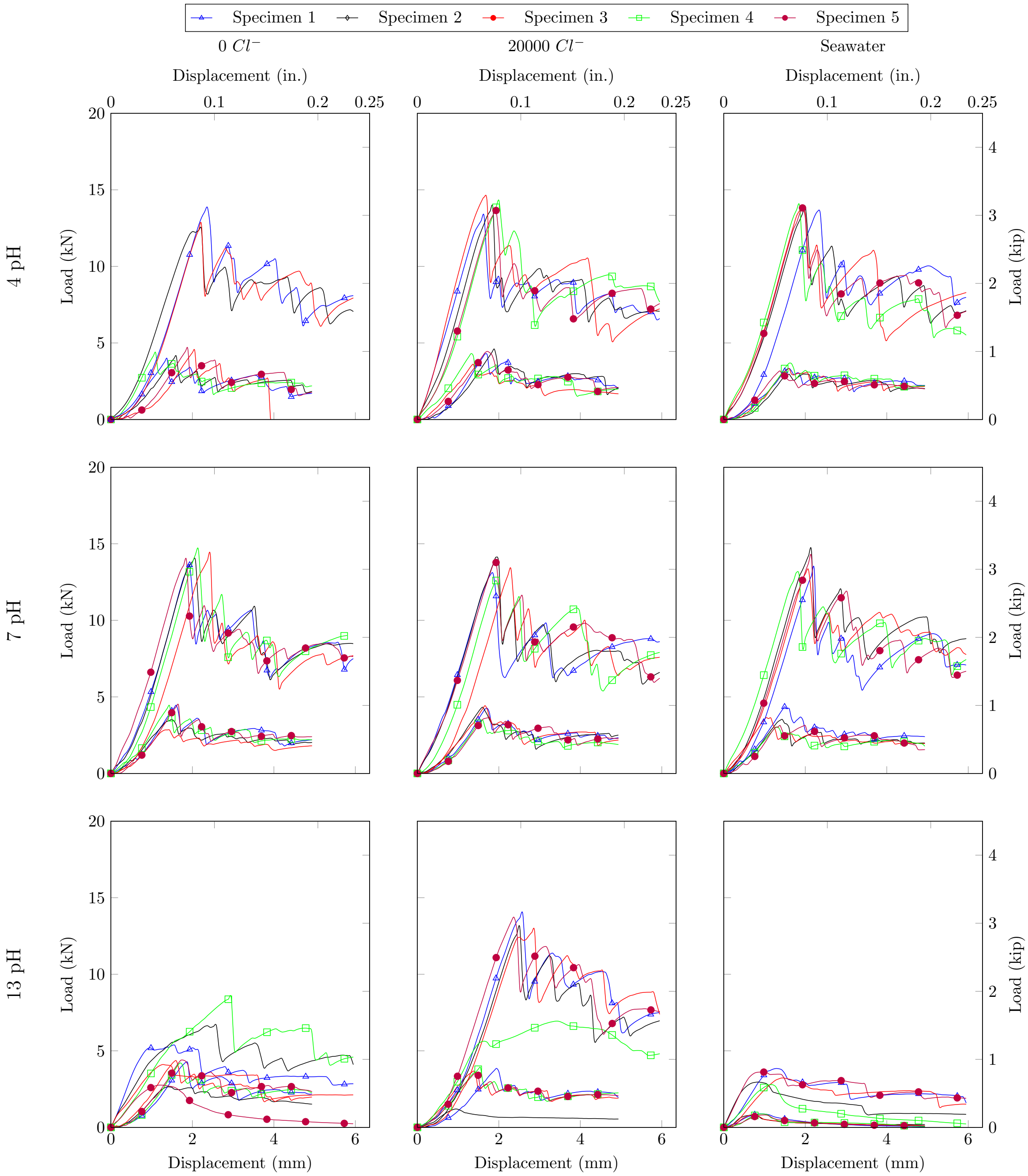

Figure 7.91: 300Day Horizontal shear force - displacement behavior of Type B Lot1 tested rebars

Stress-Displacement

To provide clarity and to compare the horizontal shear strength performance of the two rebar sizes, stress-strain behavior of rebar is shown in this section via graphs. The following graphs in Figures 7.96, 7.97, 7.98, 7.99, 7.100, and 7.101 show the comparison of the stress - cross-head behavior for the tested BFRP rebars. The x-axis of graph represents the cross-head extension, while the y-axis signifies the measured shear stresses.

As expected, a significant difference in peak load between rebar sizes of Type A rebar was observed.

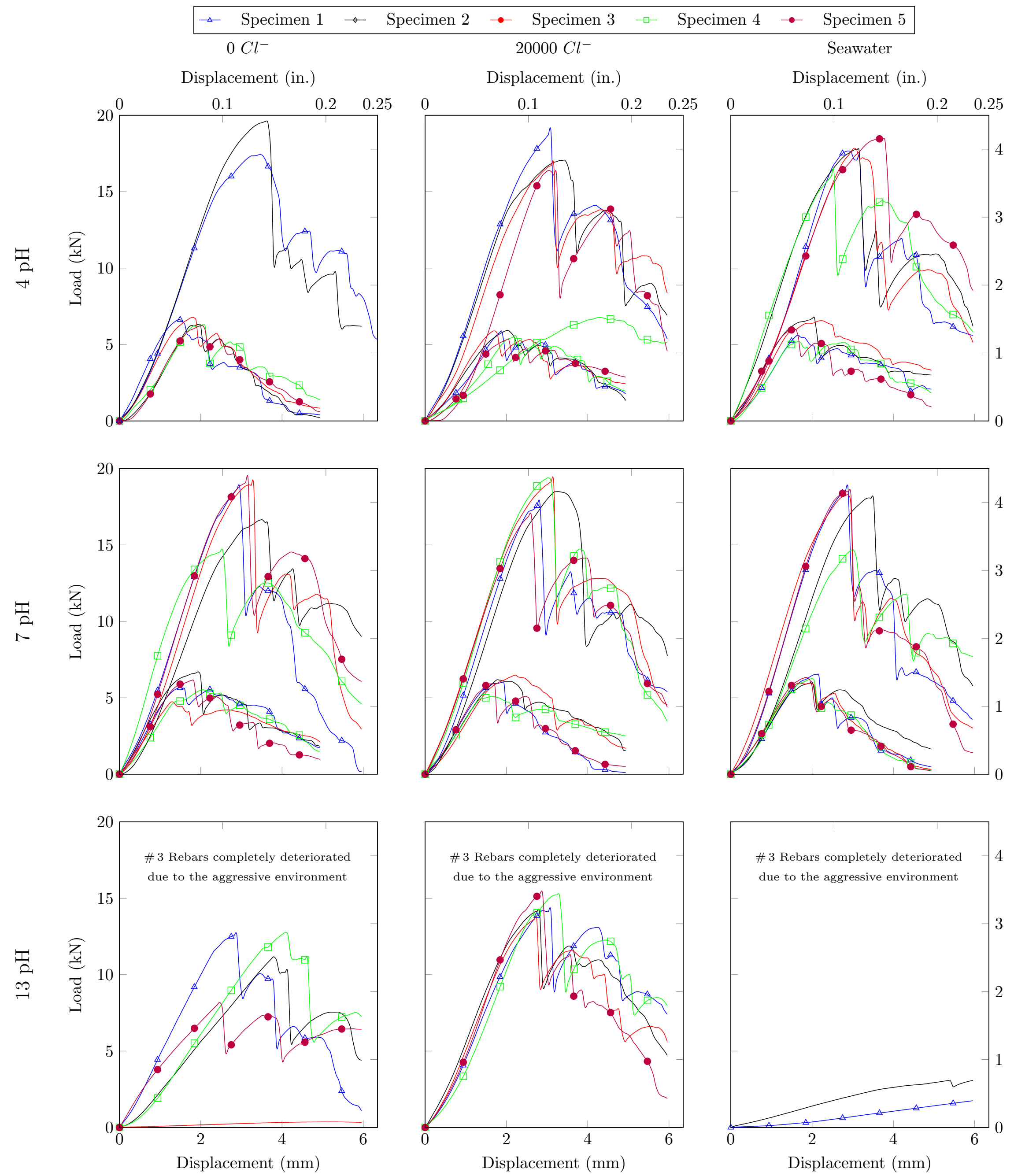

Figure 7.92: 300Day Horizontal shear force - displacement behavior of Type C Lot1 tested rebars

Nevertheless, the resultant horizontal shear stress is approximately the same regardless of the rebar size. The stress-displacement behavior of rebar Type B shows that the failure pattern was identical for both the sizes but # 5 rebars sustained more stress in comparison to # 3 rebars. As expected, a significant difference in peak load between rebar sizes of Type C Lot 1 rebar was observed. Nevertheless, the resultant horizontal shear stress is approximately the same regardless of the rebar size. The graphs in Figures 7.99, 7.100, and 7.101 are used to compare the stress-displacement behavior of horizontal shear test of # 3 and # 5 rebars from Type A, Type B, and Type C from Lot 2.

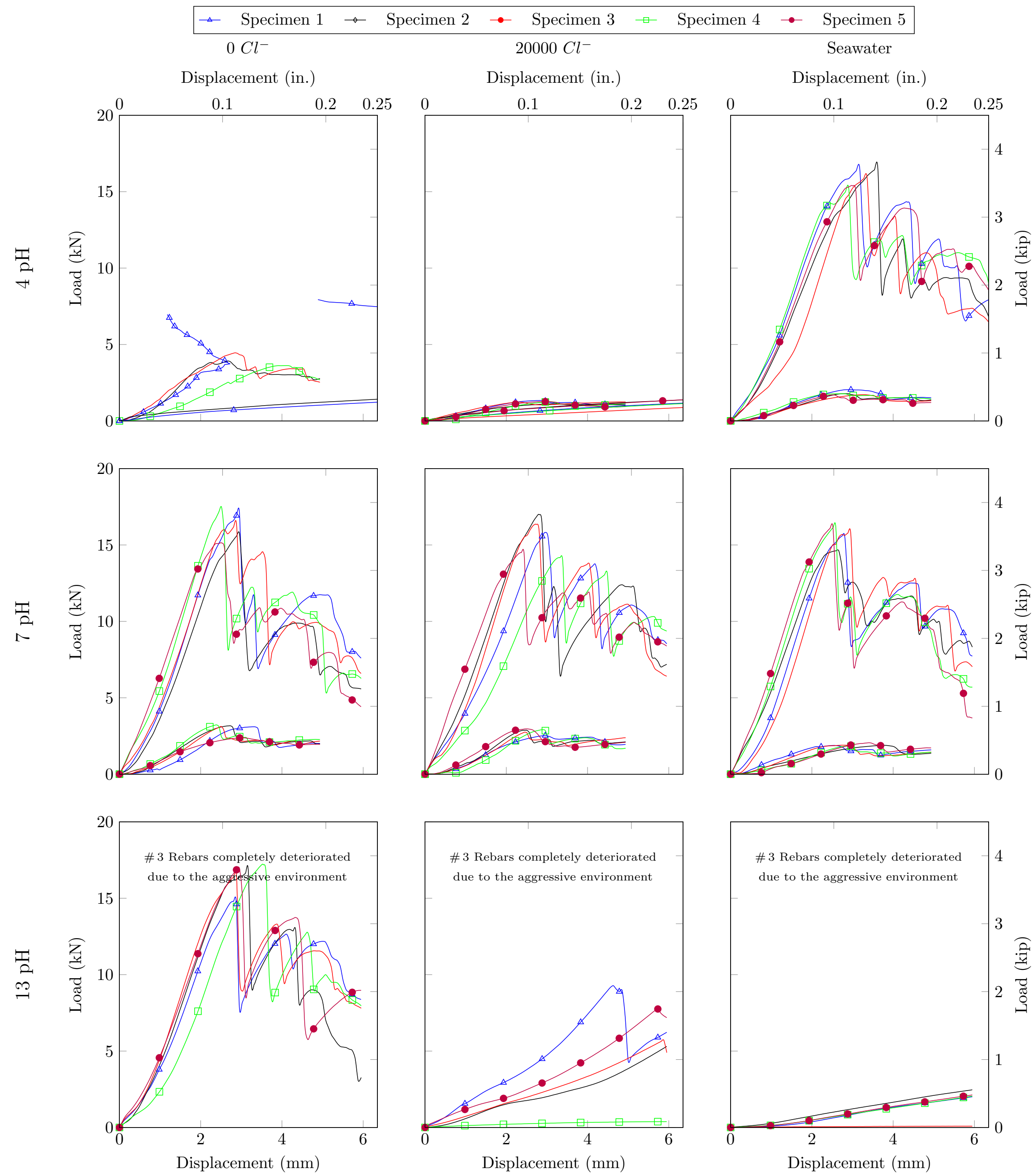

Figure 7.93: 300Day Horizontal shear force - displacement behavior of Type A Lot2 tested rebars

The stress-strain behavior of rebars from Lot 2 show that the failure pattern was identical for both the sizes but # 5 rebars sustained more stress in comparison to # 3 rebars. Figures 7.99 and 7.100 show that all the rebars of Type A and Type B underwent similar stress and strain irrespective of lot and size.

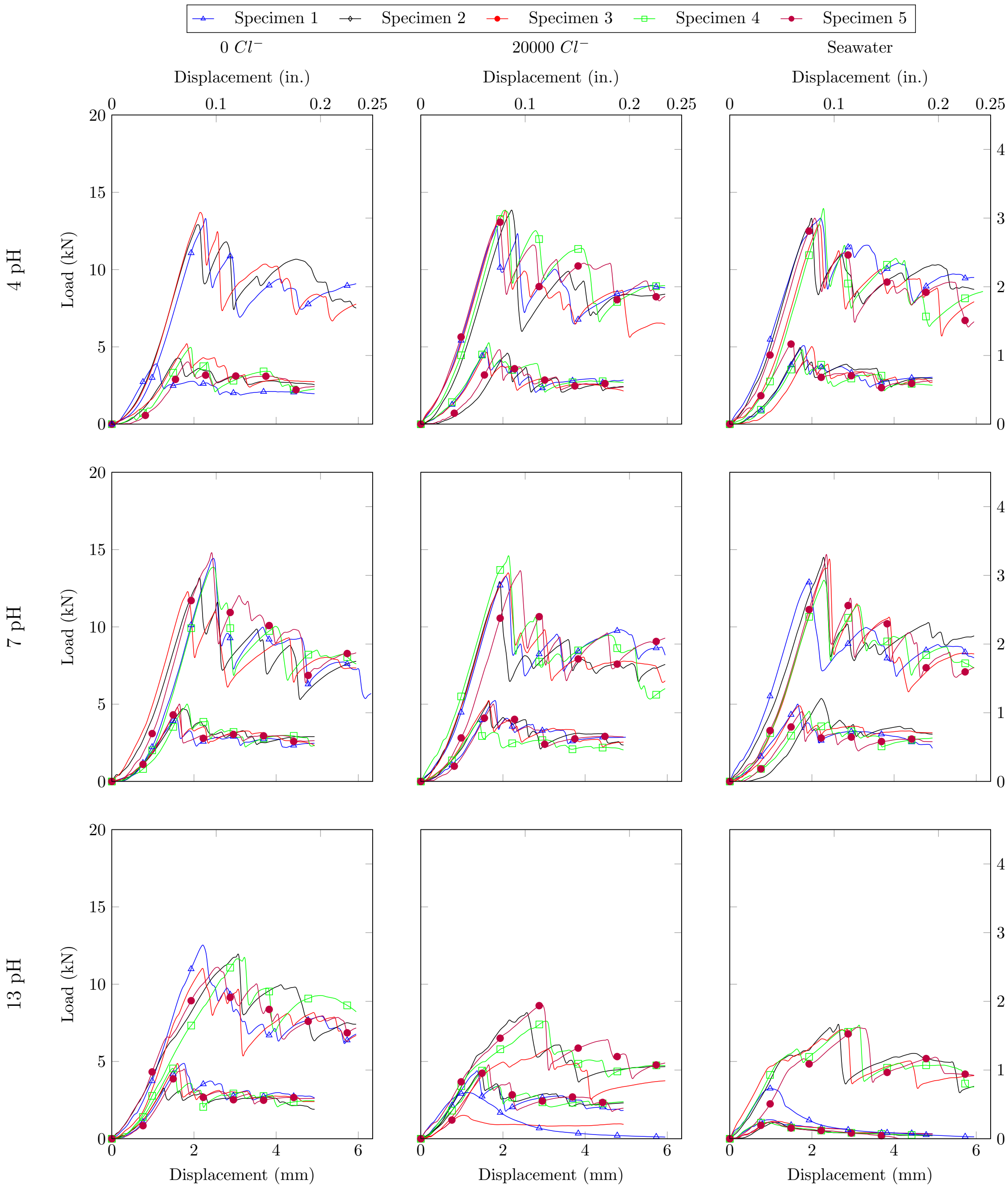

Figure 7.94: 300Day Horizontal shear force - displacement behavior of Type B Lot2 tested rebars

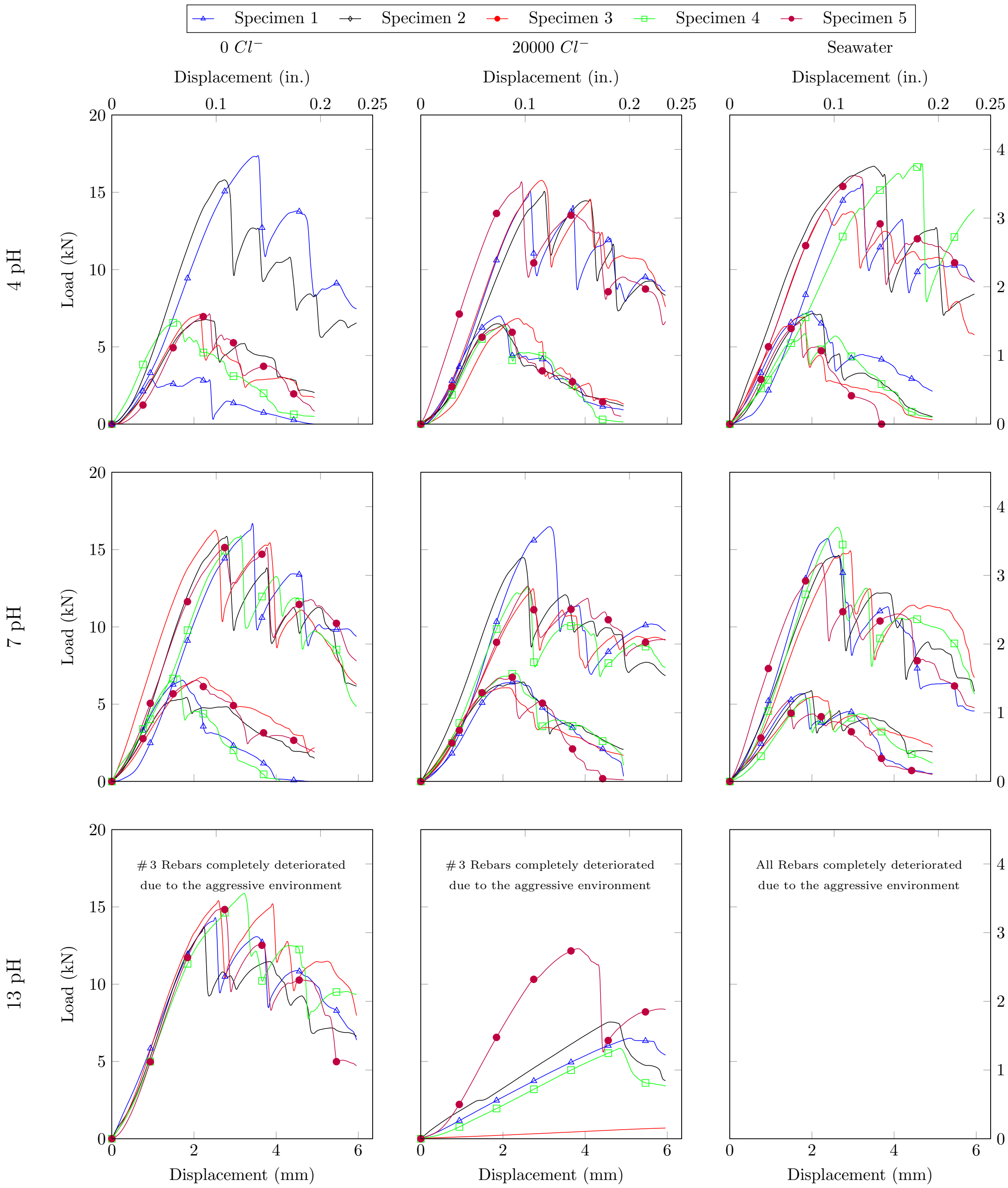

Figure 7.95: 300Day Horizontal shear force - displacement behavior of Type C Lot2 tested rebars

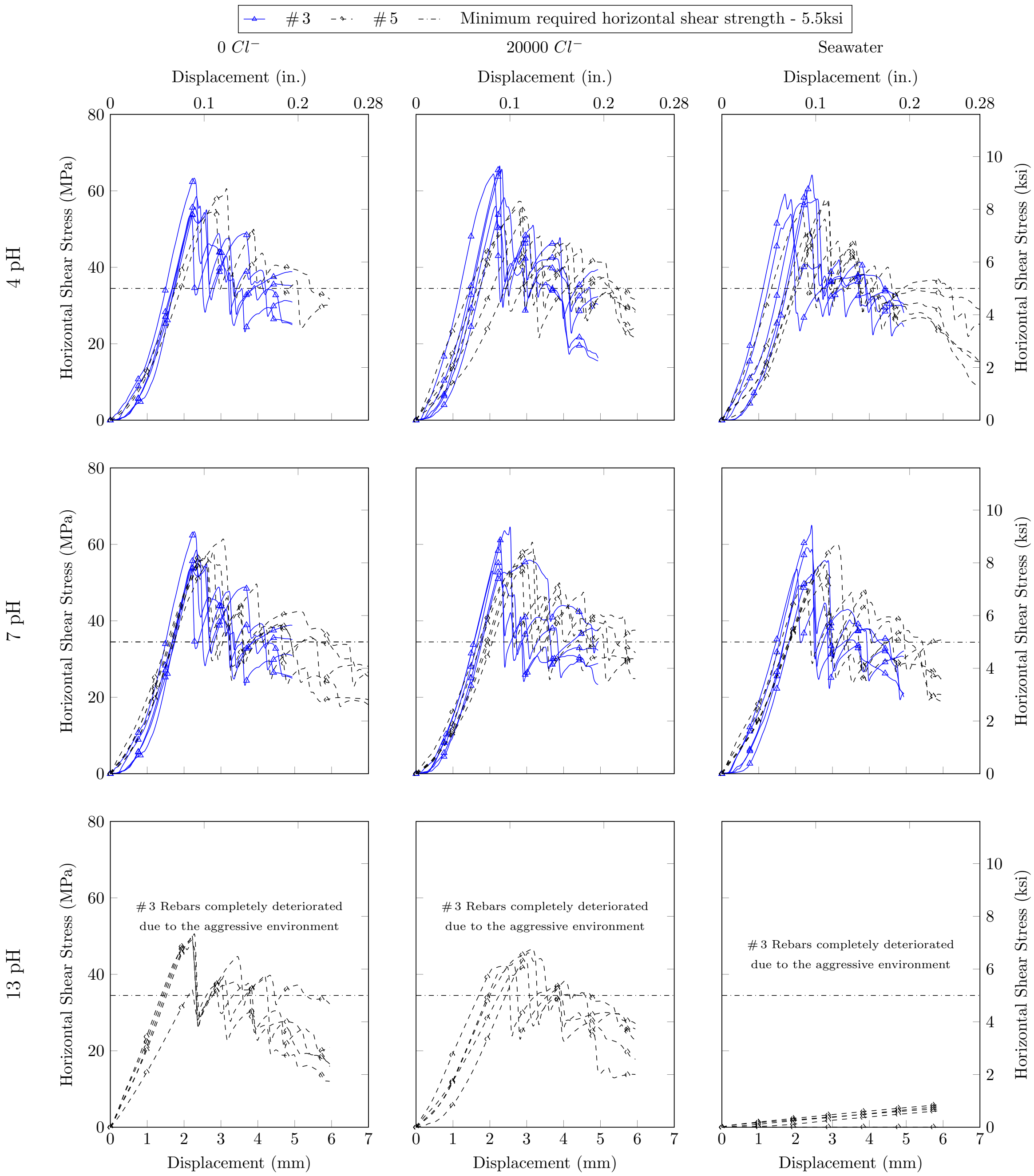

Figure 7.96: 300Day Horizontal shear stress - displacement behavior of Type A Lot1 tested rebars

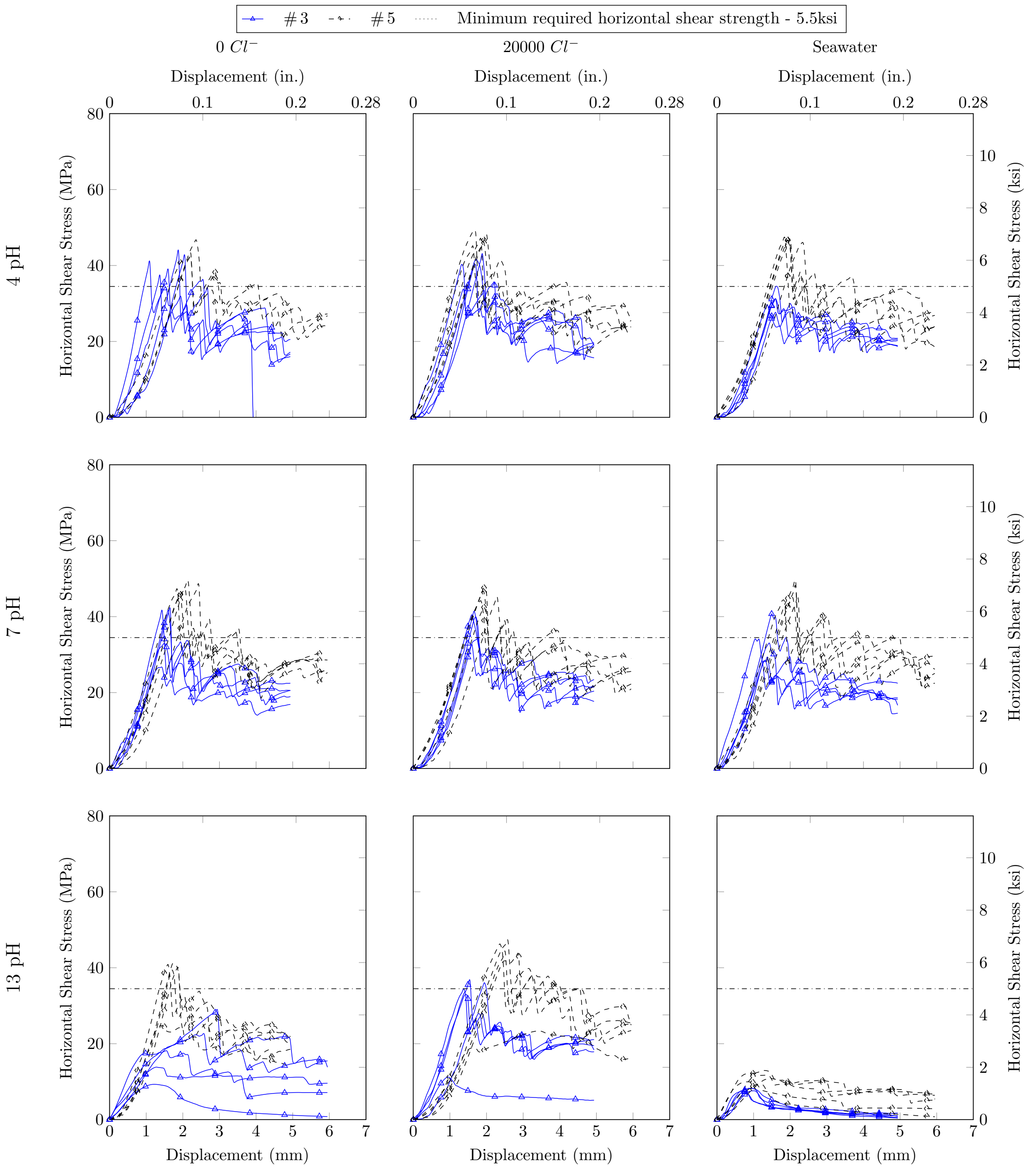

Figure 7.97: 300Day Horizontal shear stress - displacement behavior of Type B Lot1 tested rebars

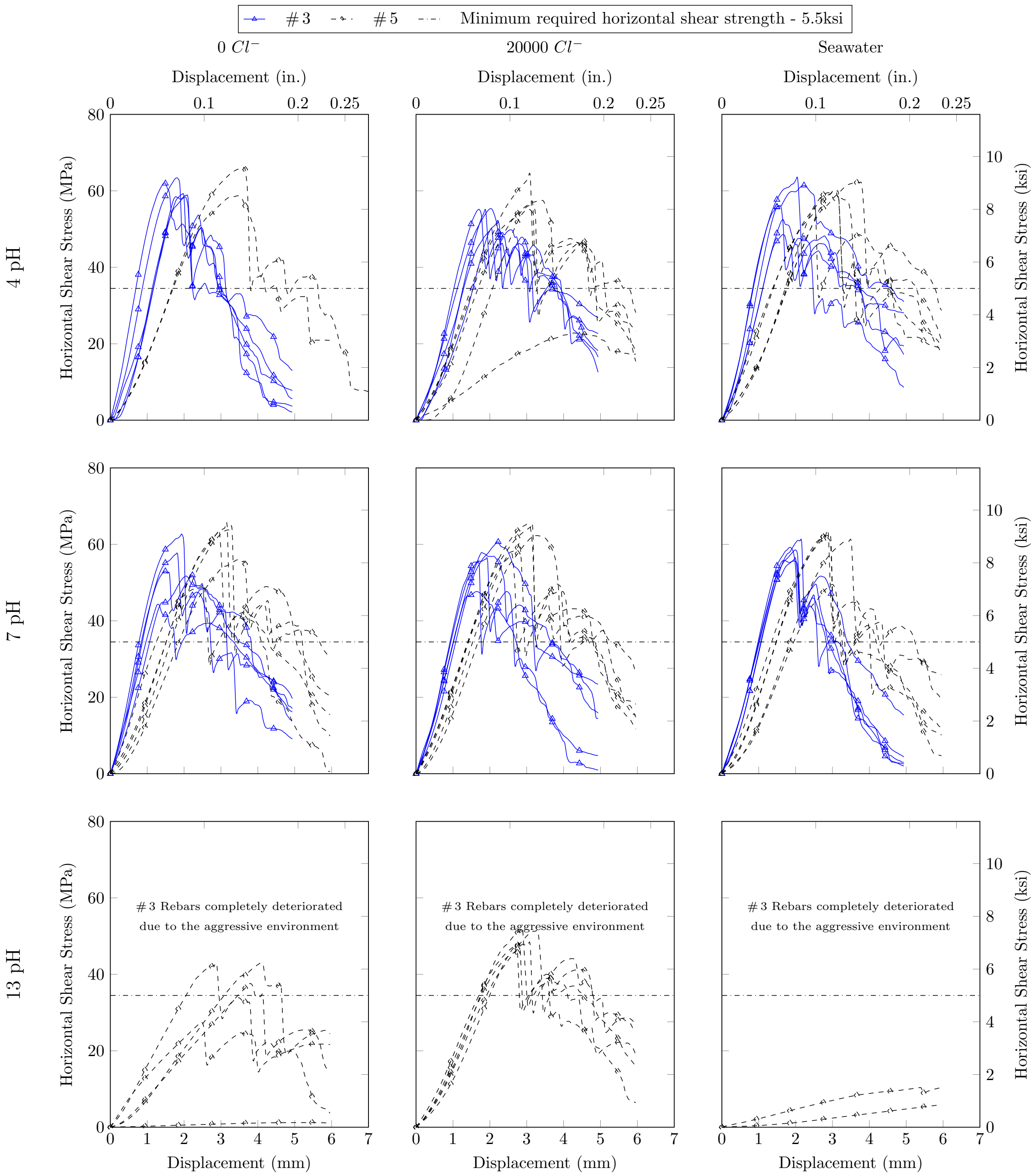

Figure 7.98: 300Day Horizontal shear stress - displacement behavior of Type C Lot1 tested rebars

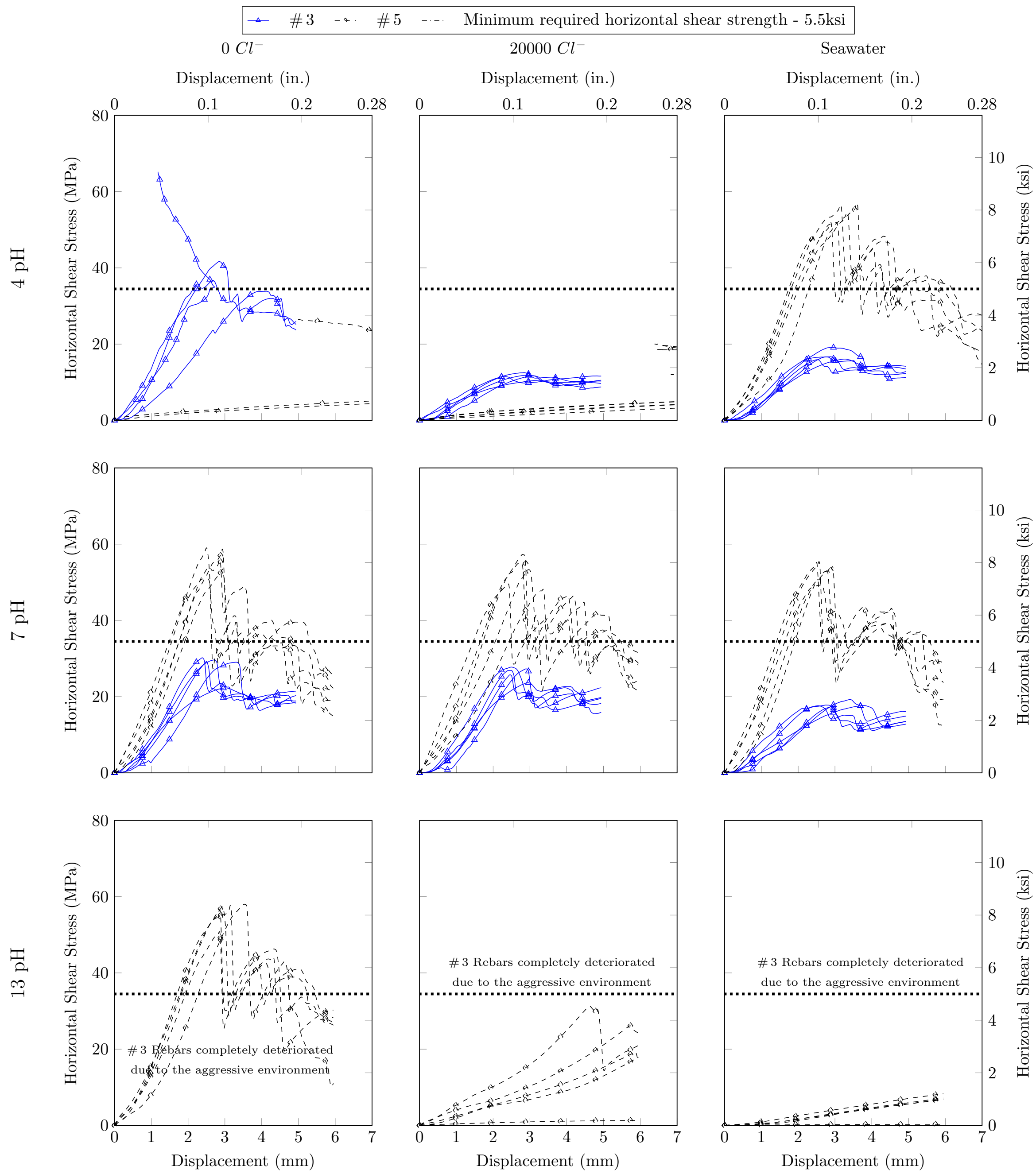

Figure 7.99: 300Day Horizontal shear stress - displacement behavior of Type A Lot2 tested rebars

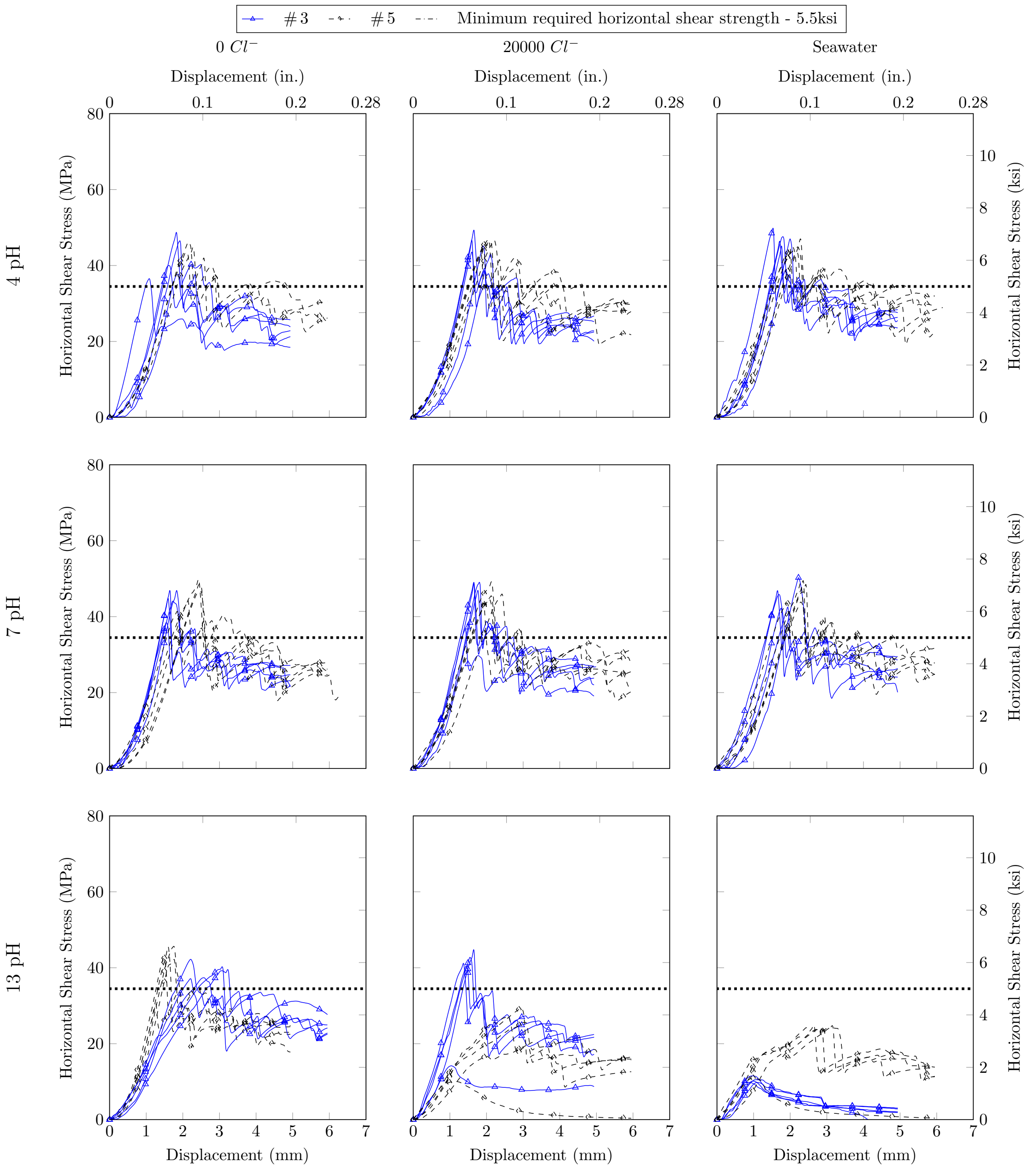

Figure 7.100: 300Day Horizontal shear stress - displacement behavior of Type B Lot2 tested rebars

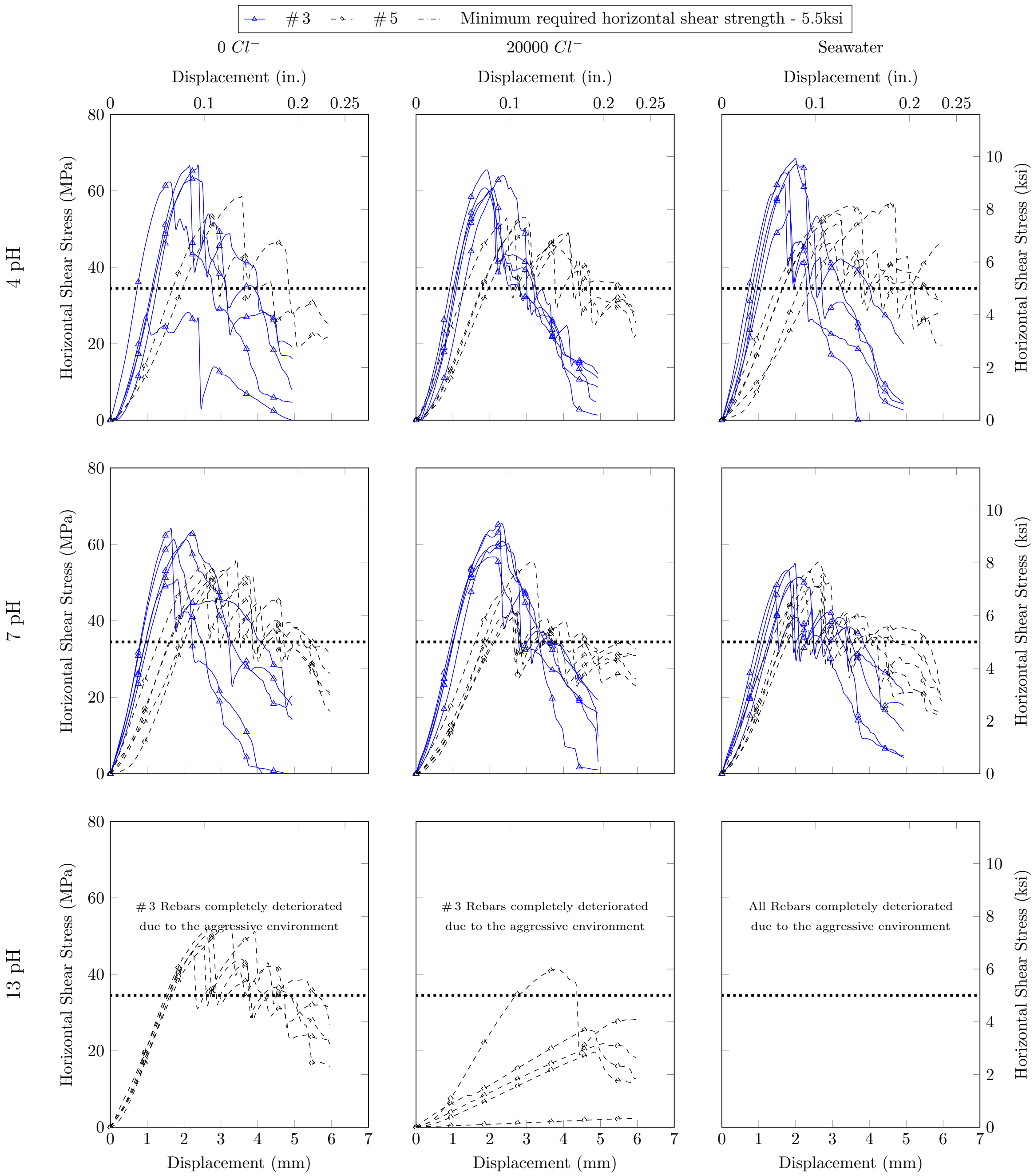

Figure 7.101: 300Day Horizontal shear stress - displacement behavior of Type C Lot2 tested rebars

7.5.4 Summary of Horizontal Shear Strength Properties

The statistical values for the horizontal shear strength properties of the tested products are listed in the following Table 7.42. A total of 250 specimens, five for each type, each size, lot, and exposure type were tested in total. The average of five specimens was assigned to each sample (specimen group) as shown in the table.

Table 7.42: Horizontal Shear test statistical values for each sample group (US Customary Units)

Sample Group						Statistical Values				
						Shear Stress				
Manuf. Type	Resin Type	Size #	Lot No.	pH	Cl^-	$\wedge$ ksi	$\vee$ ksi	μ ksi	σ ksi	CV %
TypeA	Epoxy	3	1	4	0	6.8	7.9	7.4	0.4	6.07
TypeA	Epoxy	5	1	4	0	4.9	5.9	5.4	0.7	12.86
TypeB	VinylEster	3	1	4	0	5.5	6.3	6.0	0.4	5.95
TypeB	VinylEster	5	1	4	0	6.1	6.8	6.4	0.4	6.09
TypeC	Epoxy	3	1	4	0	8.5	9.2	8.8	0.3	3.73
TypeC	Epoxy	5	1	4	0	8.5	9.6	9.0	0.5	5.82
TypeA	Epoxy	3	1	4	20000	8.3	9.6	9.0	0.6	6.81
TypeA	Epoxy	5	1	4	20000	2.9	2.9	2.9	0.0	0.02
TypeB	VinylEster	3	1	4	20000	4.9	6.4	5.9	0.6	9.75
TypeB	VinylEster	5	1	4	20000	6.6	7.3	6.9	0.3	3.89
TypeC	Epoxy	3	1	4	20000	7.3	8.0	7.8	0.3	4.46
TypeC	Epoxy	5	1	4	20000	3.3	9.2	7.6	2.1	28.05
TypeA	Epoxy	3	1	4	SeaWater	7.8	9.4	8.6	0.6	6.74
TypeA	Epoxy	5	1	4	SeaWater	7.1	8.5	7.9	0.6	7.07
TypeB	VinylEster	3	1	4	SeaWater	4.1	5.0	4.5	0.4	7.94
TypeB	VinylEster	5	1	4	SeaWater	6.7	6.9	6.8	0.1	1.59
TypeC	Epoxy	3	1	4	SeaWater	7.1	9.2	8.2	0.9	10.74
TypeC	Epoxy	5	1	4	SeaWater	7.9	9.0	8.6	0.4	4.79
TypeA	Epoxy	3	2	4	0	4.9	9.5	6.5	2.1	32.33
TypeA	Epoxy	5	2	4	0	2.9	3.9	3.4	0.7	20.16
TypeB	VinylEster	3	2	4	0	5.3	7.2	6.1	0.8	13.65
TypeB	VinylEster	5	2	4	0	6.3	6.9	6.6	0.3	4.22
TypeC	Epoxy	3	2	4	0	4.1	9.7	8.5	2.2	25.61
TypeC	Epoxy	5	2	4	0	7.6	8.5	7.9	0.5	5.95
TypeA	Epoxy	3	2	4	20000	1.5	1.8	1.7	0.1	6.12
TypeA	Epoxy	5	2	4	20000	2.9	2.9	2.9	0.0	0.02
TypeB	VinylEster	3	2	4	20000	6.4	7.3	6.7	0.4	5.51
TypeB	VinylEster	5	2	4	20000	6.3	6.9	6.6	0.3	4.30
TypeC	Epoxy	3	2	4	20000	8.7	9.5	9.0	0.4	3.98
TypeC	Epoxy	5	2	4	20000	7.3	7.7	7.5	0.2	2.76
TypeA	Epoxy	3	2	4	SeaWater	2.3	2.8	2.5	0.2	7.72
TypeA	Epoxy	5	2	4	SeaWater	7.4	8.1	7.8	0.3	3.93
TypeB	VinylEster	3	2	4	SeaWater	6.5	7.2	6.9	0.2	3.30
TypeB	VinylEster	5	2	4	SeaWater	6.5	6.9	6.6	0.2	2.80
TypeC	Epoxy	3	2	4	SeaWater	8.1	9.9	9.2	0.8	8.23

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Table 7.42: Horizontal Shear test statistical values for each sample group (US Customary Units)

Sample Group						Statistical Values				
						Shear Stress				
Manuf. Type	Resin Type	Size #	Lot No.	pH	Cl^{-}	$\wedge$ ksi	$\vee$ ksi	μ ksi	σ ksi	CV %
TypeC	Epoxy	5	2	4	SeaWater	6.8	8.2	7.7	0.6	7.49
TypeA	Epoxy	3	1	7	0	7.9	9.2	8.3	0.6	6.66
TypeA	Epoxy	5	1	7	0	8.0	8.8	8.3	0.3	3.80
TypeB	VinylEster	3	1	7	0	3.9	6.2	5.5	1.1	19.76
TypeB	VinylEster	5	1	7	0	6.8	7.3	7.0	0.2	2.45
TypeC	Epoxy	3	1	7	0	6.5	9.1	7.8	1.0	12.50
TypeC	Epoxy	5	1	7	0	7.2	9.4	8.6	1.0	11.07
TypeA	Epoxy	3	1	7	20000	7.9	9.3	8.5	0.6	7.55
TypeA	Epoxy	5	1	7	20000	7.6	8.6	8.1	0.4	5.07
TypeB	VinylEster	3	1	7	20000	4.8	6.1	5.5	0.6	10.43
TypeB	VinylEster	5	1	7	20000	6.2	7.1	6.7	0.3	5.00
TypeC	Epoxy	3	1	7	20000	6.9	8.8	8.1	0.7	8.73
TypeC	Epoxy	5	1	7	20000	8.3	9.5	9.0	0.5	5.39
TypeA	Epoxy	3	1	7	SeaWater	7.5	9.2	8.2	0.7	8.33
TypeA	Epoxy	5	1	7	SeaWater	7.3	8.7	7.9	0.5	6.95
TypeB	VinylEster	3	1	7	SeaWater	4.2	6.0	4.9	0.7	14.72
TypeB	VinylEster	5	1	7	SeaWater	6.6	7.1	6.8	0.2	3.59
TypeC	Epoxy	3	1	7	SeaWater	8.1	8.9	8.4	0.3	3.72
TypeC	Epoxy	5	1	7	SeaWater	7.2	9.1	8.6	0.8	9.37
TypeA	Epoxy	3	2	7	0	3.2	4.4	4.1	0.5	11.64
TypeA	Epoxy	5	2	7	0	7.4	8.6	8.0	0.5	6.01
TypeB	VinylEster	3	2	7	0	5.6	7.0	6.5	0.5	8.12
TypeB	VinylEster	5	2	7	0	6.1	7.3	6.8	0.5	7.51
TypeC	Epoxy	3	2	7	0	7.4	9.2	8.7	0.8	8.79
TypeC	Epoxy	5	2	7	0	7.4	8.0	7.8	0.2	2.99
TypeA	Epoxy	3	2	7	20000	3.4	4.0	3.8	0.2	6.29
TypeA	Epoxy	5	2	7	20000	6.9	8.4	7.6	0.6	7.93
TypeB	VinylEster	3	2	7	20000	5.3	7.3	6.8	0.8	12.21
TypeB	VinylEster	5	2	7	20000	6.4	7.2	6.7	0.3	4.66
TypeC	Epoxy	3	2	7	20000	8.2	9.5	8.9	0.5	5.59
TypeC	Epoxy	5	2	7	20000	6.1	8.1	6.7	0.9	12.90
TypeA	Epoxy	3	2	7	SeaWater	2.5	2.8	2.6	0.1	4.19
TypeA	Epoxy	5	2	7	SeaWater	7.1	7.9	7.7	0.3	4.10
TypeB	VinylEster	3	2	7	SeaWater	6.2	7.4	6.7	0.5	7.54
TypeB	VinylEster	5	2	7	SeaWater	6.3	7.2	6.8	0.4	5.56
TypeC	Epoxy	3	2	7	SeaWater	7.2	7.9	7.5	0.3	3.93
TypeC	Epoxy	5	2	7	SeaWater	6.9	8.1	7.4	0.5	6.35
TypeA	Epoxy	5	1	13	0	5.6	7.3	6.9	0.7	10.64
TypeB	VinylEster	3	1	13	0	3.6	6.1	5.5	1.0	19.11
TypeB	VinylEster	5	1	13	0	1.4	4.1	2.7	1.1	40.30
TypeC	Epoxy	5	1	13	0	0.2	6.3	4.4	2.5	57.26
TypeA	Epoxy	5	1	13	20000	6.1	6.8	6.4	0.3	5.09

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Table 7.42: Horizontal Shear test statistical values for each sample group (US Customary Units)

Sample Group						Statistical Values				
						Shear Stress				
Manuf. Type	Resin Type	Size #	Lot No.	pH	Cl^{-}	$\wedge$ ksi	$\vee$ ksi	μ ksi	σ ksi	CV %
TypeB	VinylEster	3	1	13	20000	1.6	5.3	4.4	1.6	35.48
TypeB	VinylEster	5	1	13	20000	3.4	6.9	5.9	1.4	24.31
TypeC	Epoxy	5	1	13	20000	6.7	7.5	7.1	0.4	5.08
TypeA	Epoxy	5	1	13	SeaWater	0.0	0.9	0.6	0.3	56.38
TypeB	VinylEster	3	1	13	SeaWater	1.1	1.2	1.1	0.1	4.88
TypeB	VinylEster	5	1	13	SeaWater	1.4	1.9	1.6	0.2	13.42
TypeC	Epoxy	5	1	13	SeaWater	0.9	1.5	1.2	0.5	39.04
TypeA	Epoxy	5	2	13	0	7.2	8.4	8.0	0.5	5.85
TypeB	VinylEster	3	2	13	0	4.6	6.7	6.1	0.9	14.45
TypeB	VinylEster	5	2	13	0	5.4	6.1	5.7	0.3	5.26
TypeC	Epoxy	5	2	13	0	6.6	7.7	7.2	0.5	6.46
TypeA	Epoxy	5	2	13	20000	0.2	4.6	2.8	1.7	59.19
TypeB	VinylEster	3	2	13	20000	2.1	6.6	5.4	1.9	34.88
TypeB	VinylEster	5	2	13	20000	1.5	4.3	3.3	1.1	34.91
TypeC	Epoxy	5	2	13	20000	0.3	6.0	3.2	2.0	62.83
TypeA	Epoxy	5	2	13	SeaWater	0.0	1.2	0.9	0.5	53.97
TypeB	VinylEster	3	2	13	SeaWater	1.4	1.7	1.5	0.1	6.73
TypeB	VinylEster	5	2	13	SeaWater	1.6	3.6	3.1	0.9	27.59

For numerical comparison and concluding values, Table 7.42 lists the minimum shear stress ($\wedge$), the maximum shear stress ($\vee$), the average shear stress (μ), the standard deviation (σ), and the coefficient of variation (CV) for each individual test sample.

7.5.5 Tensile Test

The rebars were tested according to the ASTM D 7205 (ASTM-International, 2015a) to evaluate the tensile properties. The recorded and processed data of the tensile strength test are shown in this section via graphs and table.

Load-Displacement Behavior

To compare the load-displacement behavior of the different rebar samples and specimens, the graphs in Figures 7.102, 7.103, 7.104, 7.105, 7.106, and 7.107 plot the recorded test data. As shown, the x-axis of the graph represents the cross-head extension—which has to be interpreted with care because it includes the elastic deformation of the load frame and the test fixtures—and the y-axis indicates the applied and measured load. Figure 7.102 shows that # 5 rebar Type A sustained higher failure load in comparison with # 3 rebars and the extension of rebar # 5 was almost thrice that of the # 3 rebars extension. Figure 7.103 shows that the extension of # 5 was more than twice in comparison with # 3 rebars and the peak load was much higher. All the rebars failed in similar fashion. The following graph in Figure 7.104 illustrate the test results for the # 3 and # 5 Type C rebars from Lot 1. After comparing Figures 7.105, 7.106, and 7.107 it can be seen that the rebars of the same size from both the lots of all rebar types sustained the same peak

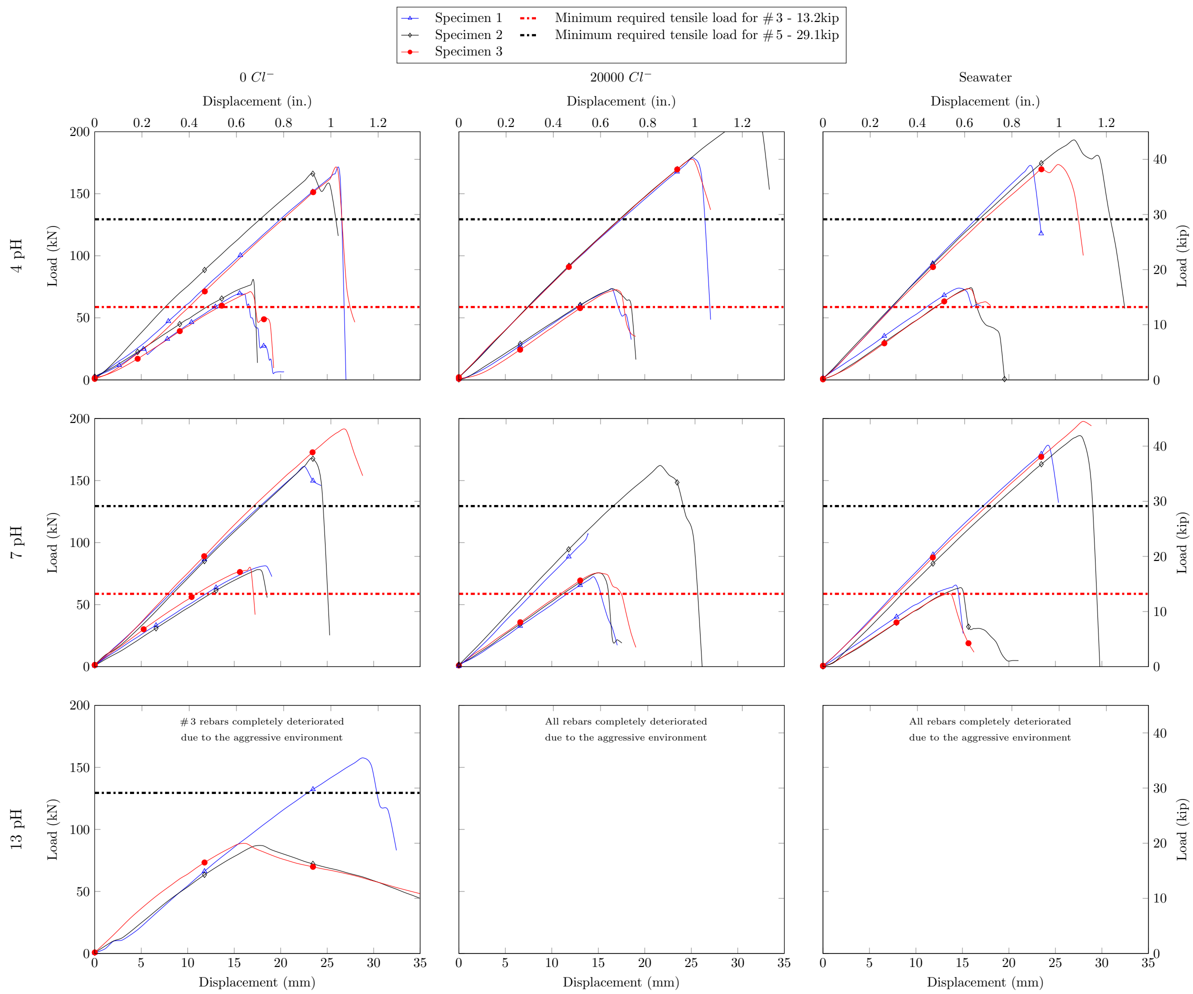

Figure 7.102: 300Day Tensile strength-displacement behavior of rebar Type A Lot 1 size 3 and 5

load and failed in the same mode. The extension of rebars from lot 2 of both types was similar to rebars from lot 1 for both sizes. The specimens demonstrated a linear characteristic at around 10 kN until the peak load. The common behavior after the maximum load was overcome was a stepwise loss of load with little inclines until the next load loss occurred. With increasing cross-head extension in the post-failure region, the load decreased slightly, but then stagnated or even regained some strength throughout further extension, multiple times, until the specimen failed completely. During testing, it was observed that after the maximum load was reached, the rebars delaminated and flared out more and more, as these load-drops occurred.

Stress-Strain Behavior

The stress-strain behavior of the failed rebars of all types was plotted to quantify and compare the elastic moduli of the tested BFRP rebars. The data in Figures 7.108, 7.109, 7.110, 7.111, 7.112, and 7.113 were plotted to compare the stress-strain behavior of the different rebar types. Accordingly, the x-axis shows the applied stress while the y-axis represents the outermost surface strain that was measured with an external extensometer. The results plotted in the graph in Figure 7.108 show that though the load capacities of the different sized rebars vary widely, the slope of the stress-strain curve was identical for all the rebars. It can be seen in Figure 7.109 that stress-strain behavior of rebar Type B are identical for both the rebar sizes.

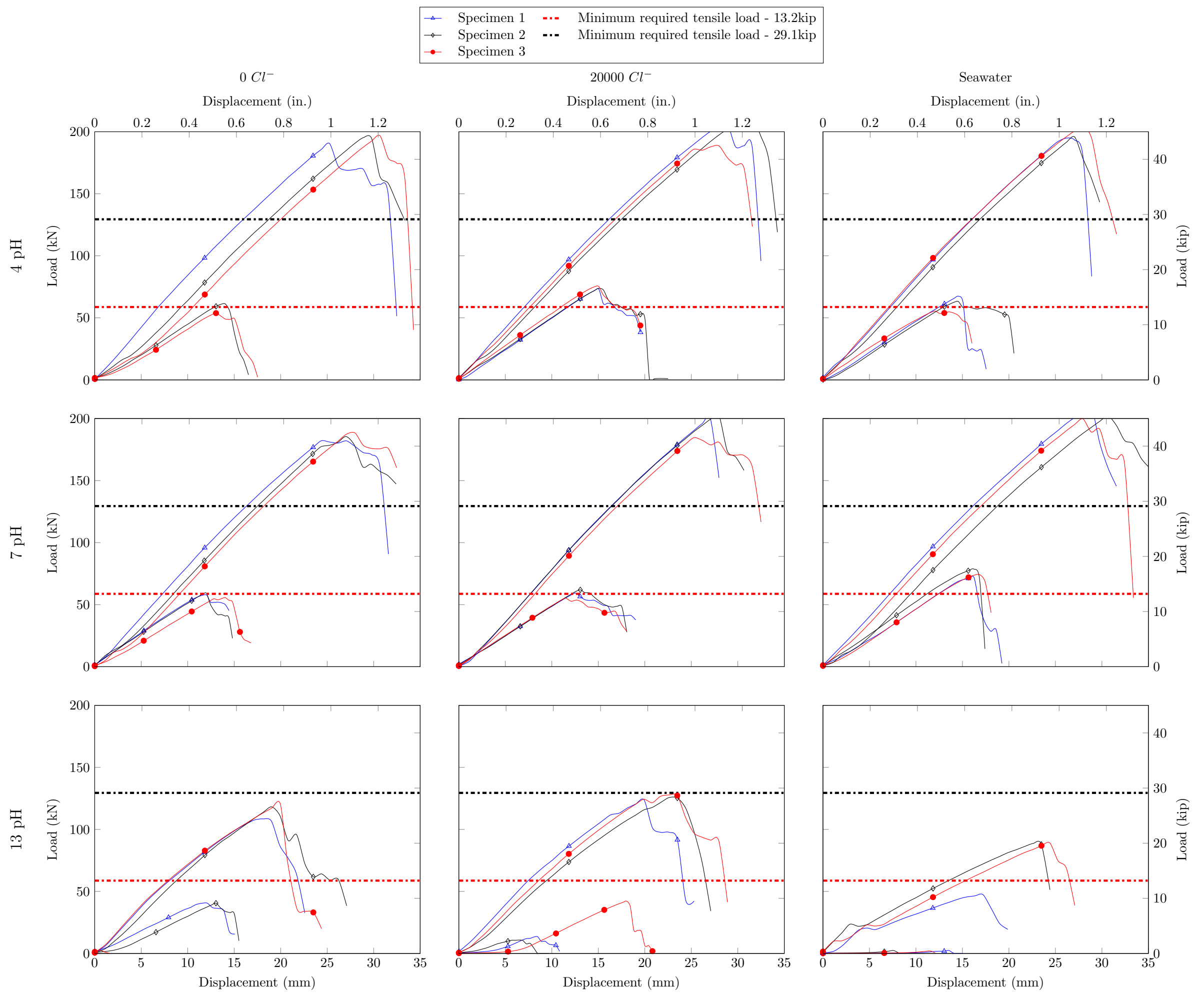

Figure 7.103: 300Day Tensile strength-displacement behavior of rebar Type B Lot 1 size 3 and 5

The stress-strain behavior of rebars from lot 2 as shown in Figures 7.111, 7.112, and 7.113 show that the slopes of bars from Lot 1 and Lot 2 were identical.

7.5.6 Summary of Tensile Properties

The concentration of the statistical evaluation for the measured tensile properties of all products along with the elastic modulus property are listed in the following Table 7.43.

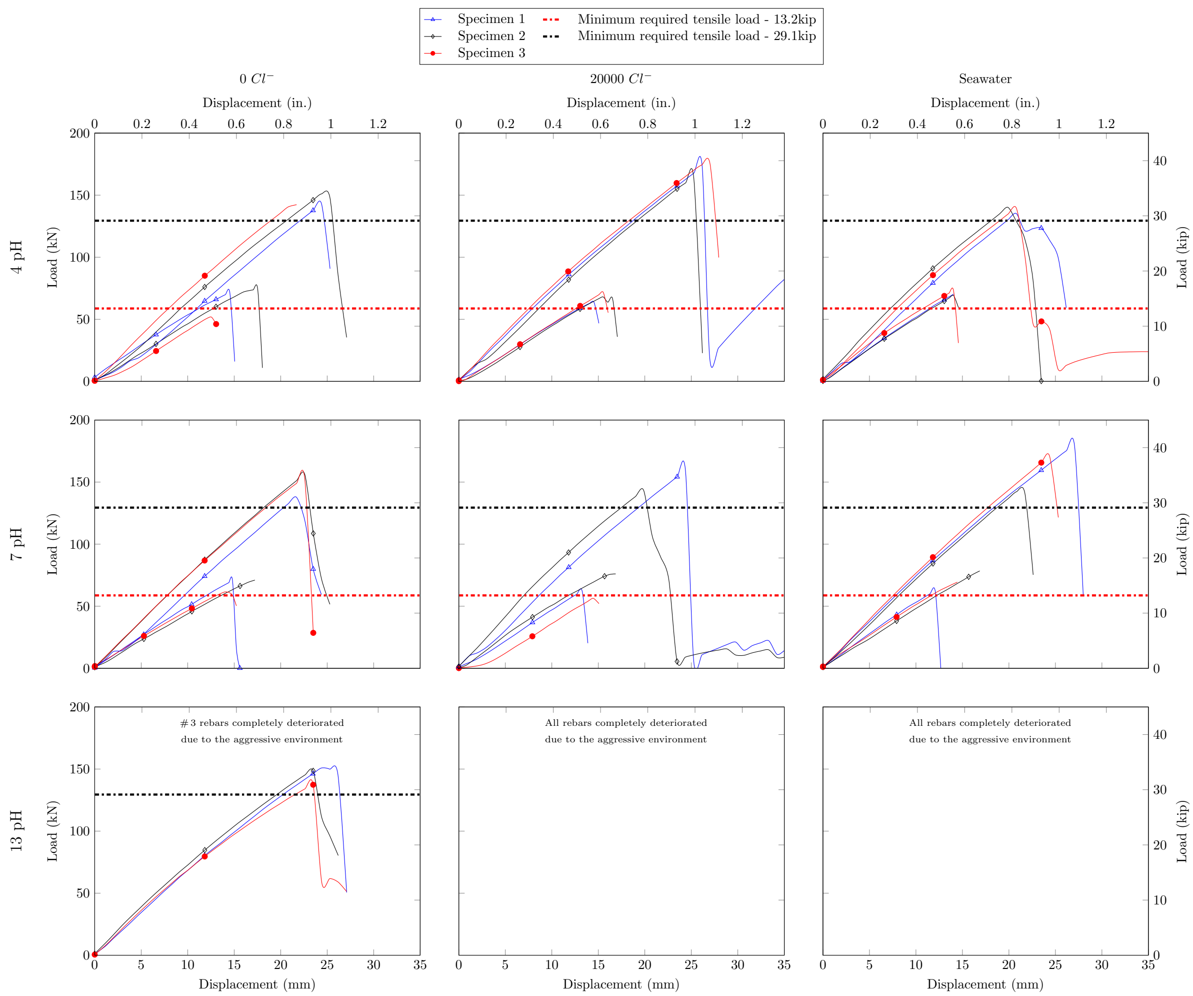

Figure 7.104: 300Day Tensile strength-displacement behavior of rebar Type C Lot 1 size 3 and 5

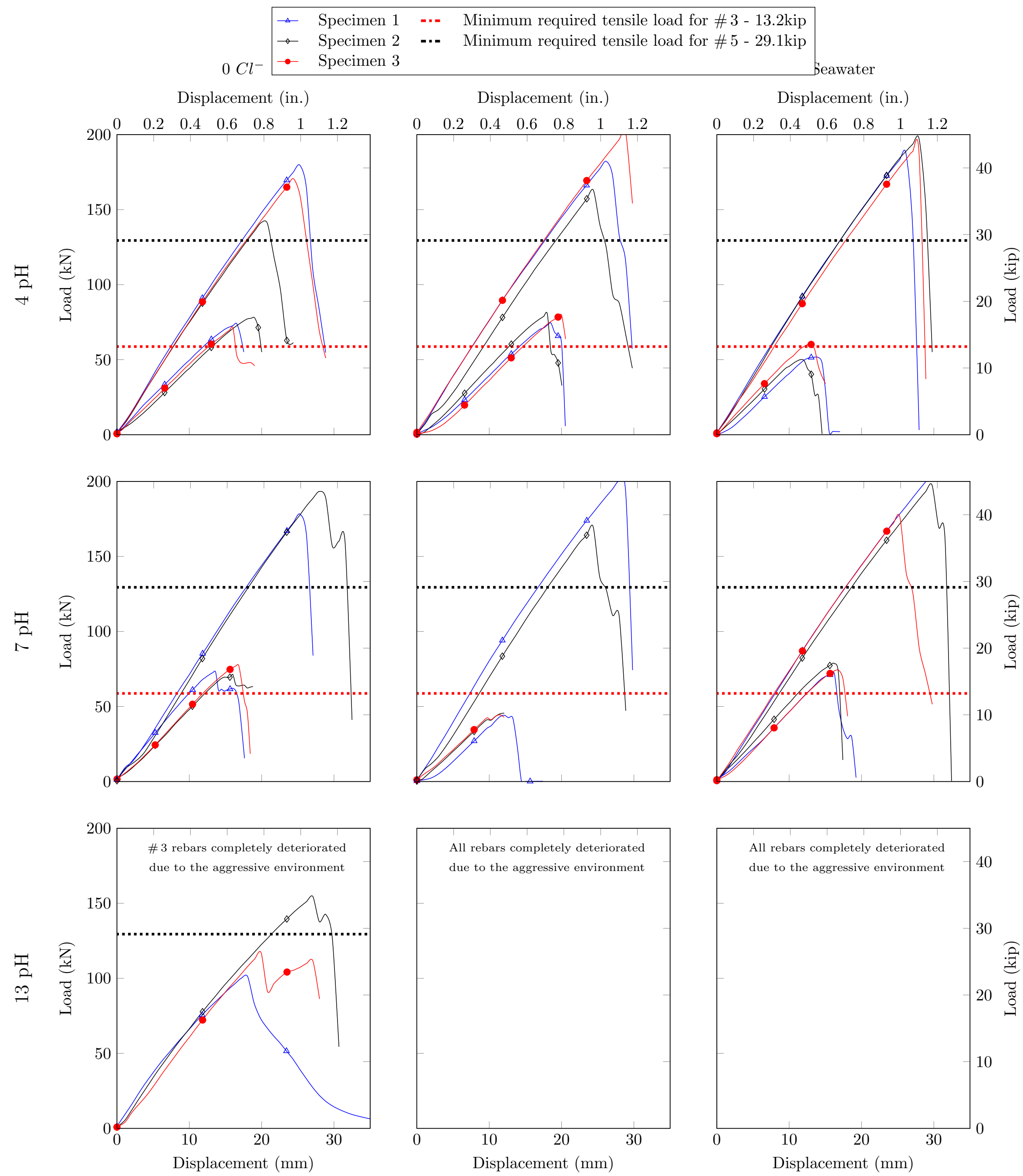

Figure 7.105: 300Day Tensile strength-displacement behavior of rebar Type A Lot 2 size 3 and 5

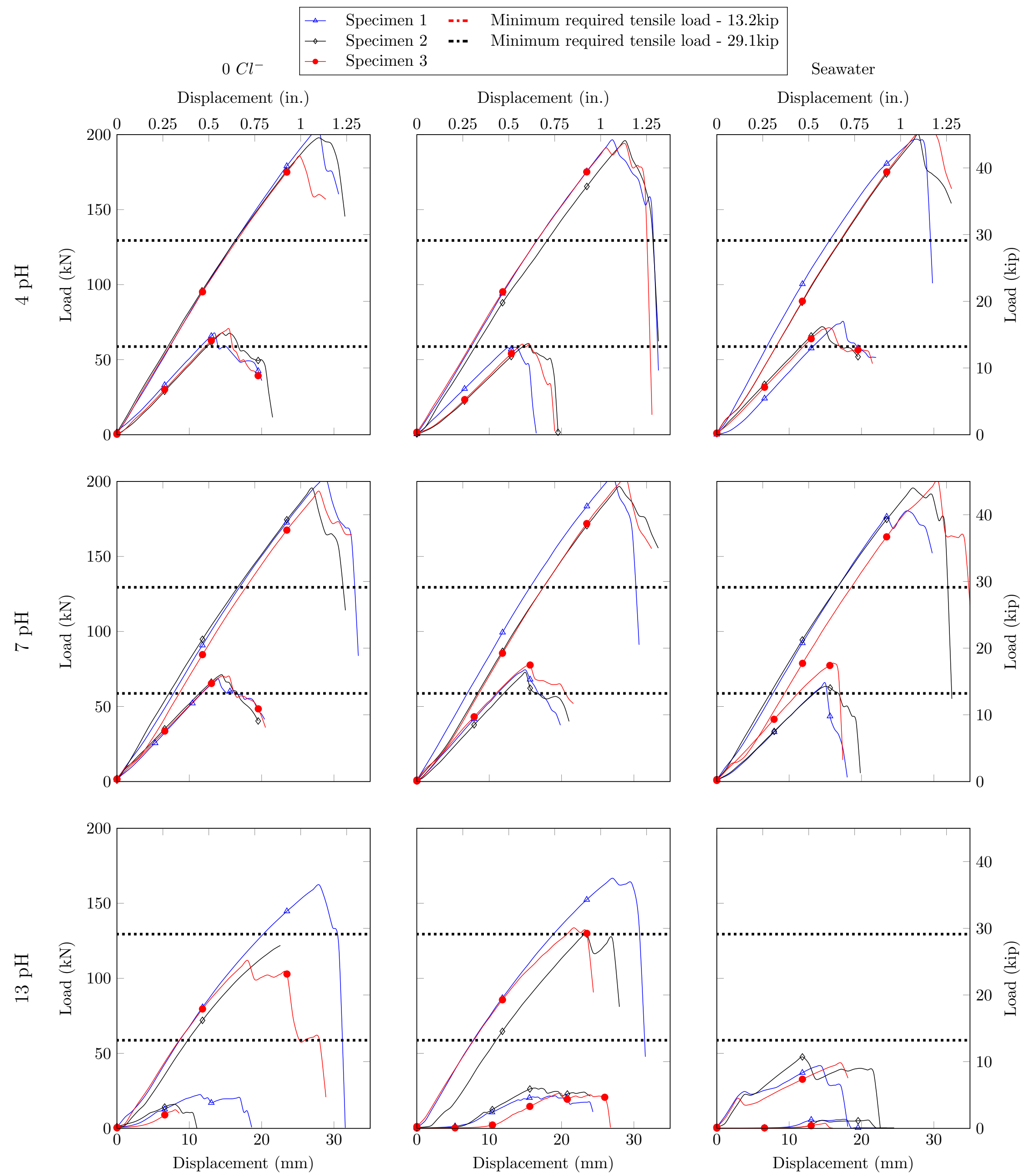

Figure 7.106: 300Day Tensile strength-displacement behavior of rebar Type B Lot 2 size 3 and 5

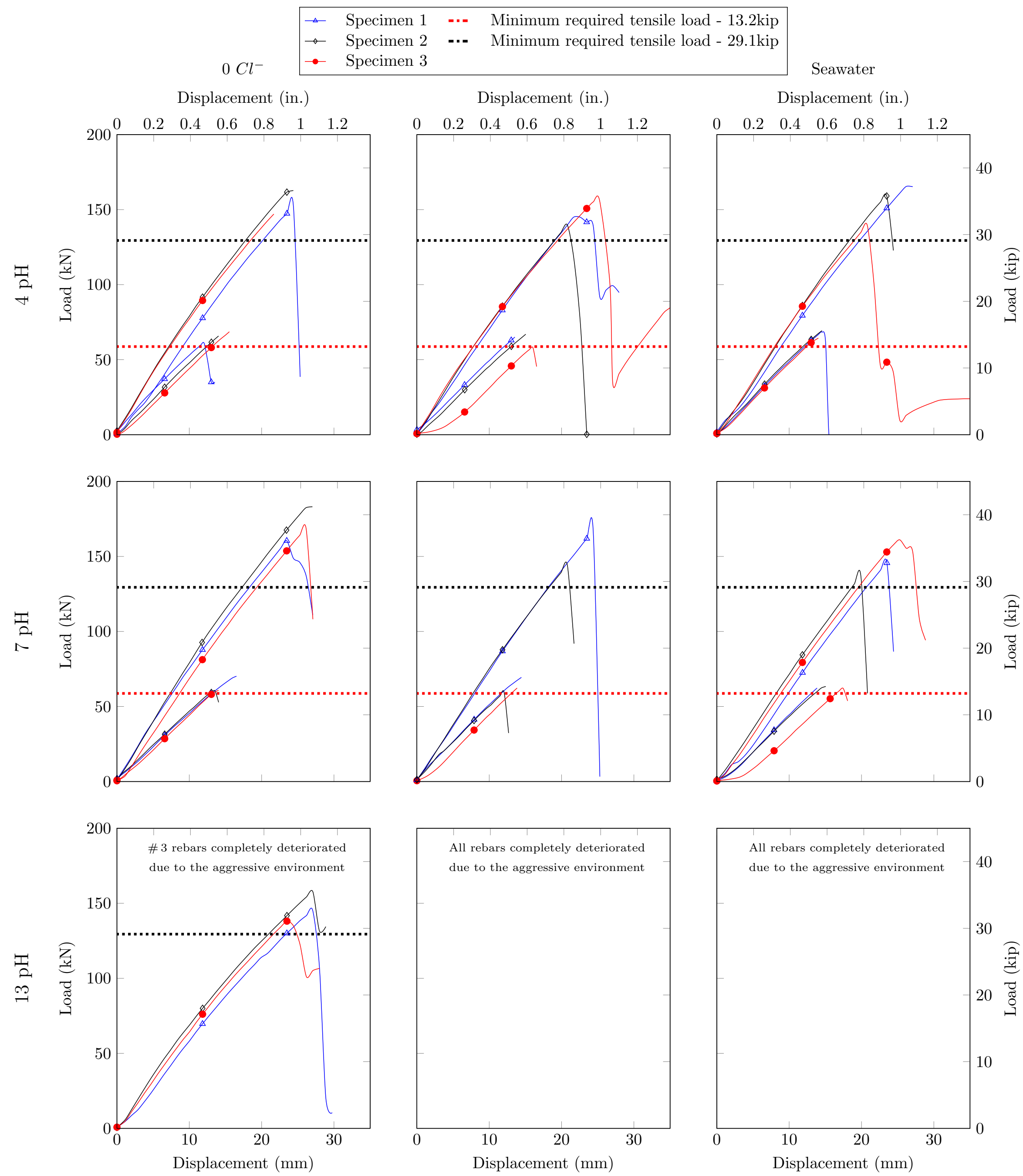

Figure 7.107: 300Day Tensile strength-displacement behavior of rebar Type C Lot 2 size 3 and 5

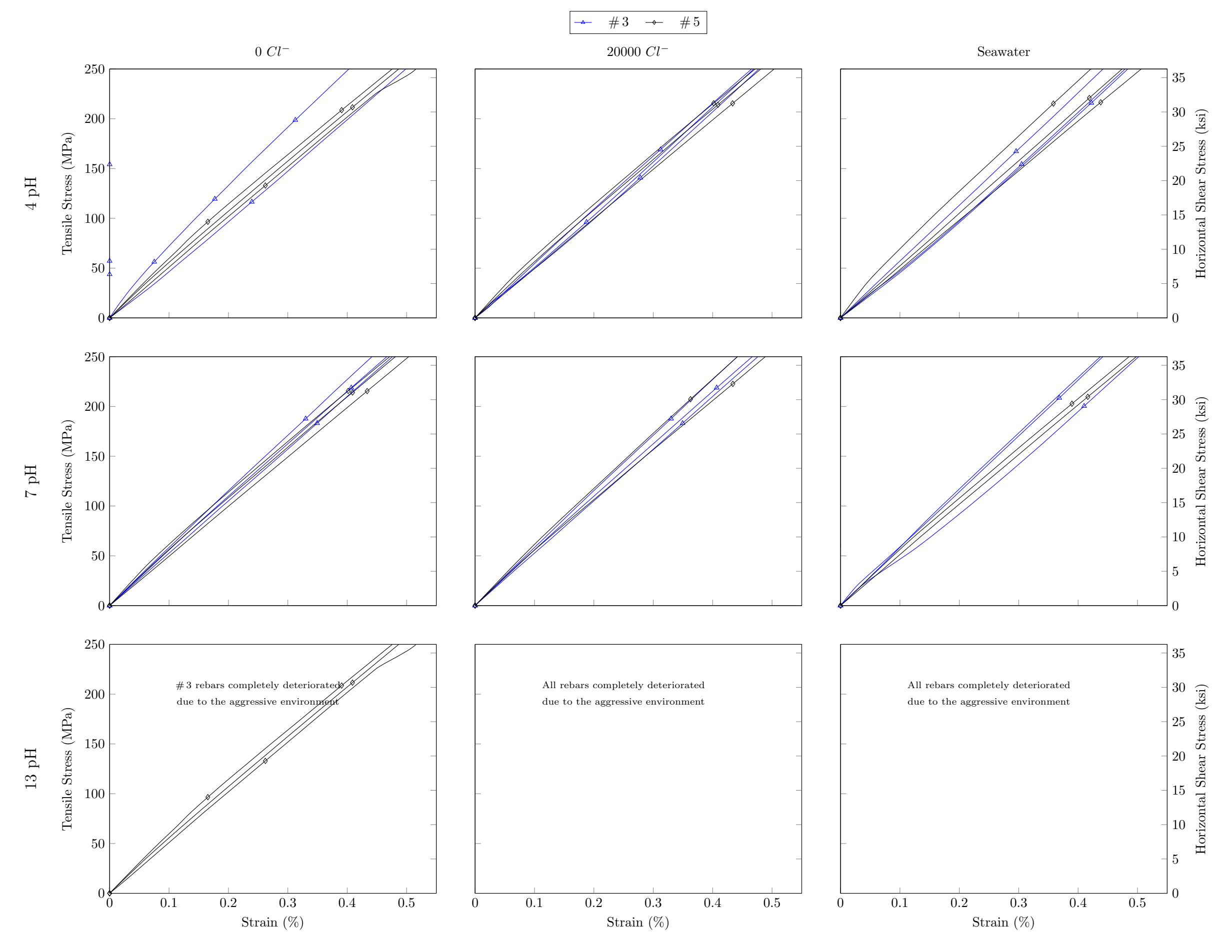

Figure 7.108: 300Day Tensile stress - Strain behavior of rebar Type A Lot 1 size 3 and 5

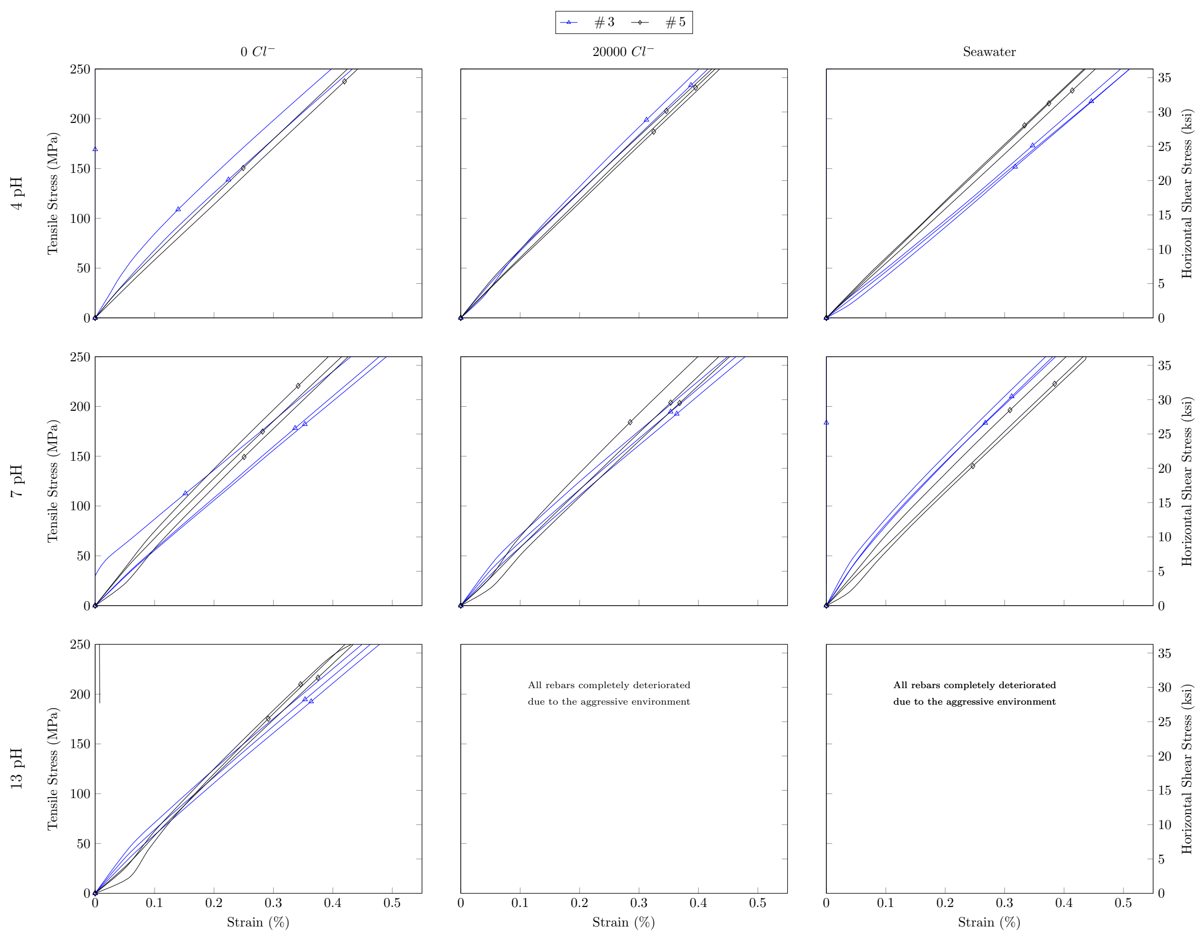

Figure 7.109: 300Day Tensile stress - Strain behavior of rebar Type B Lot 1 size 3 and 5

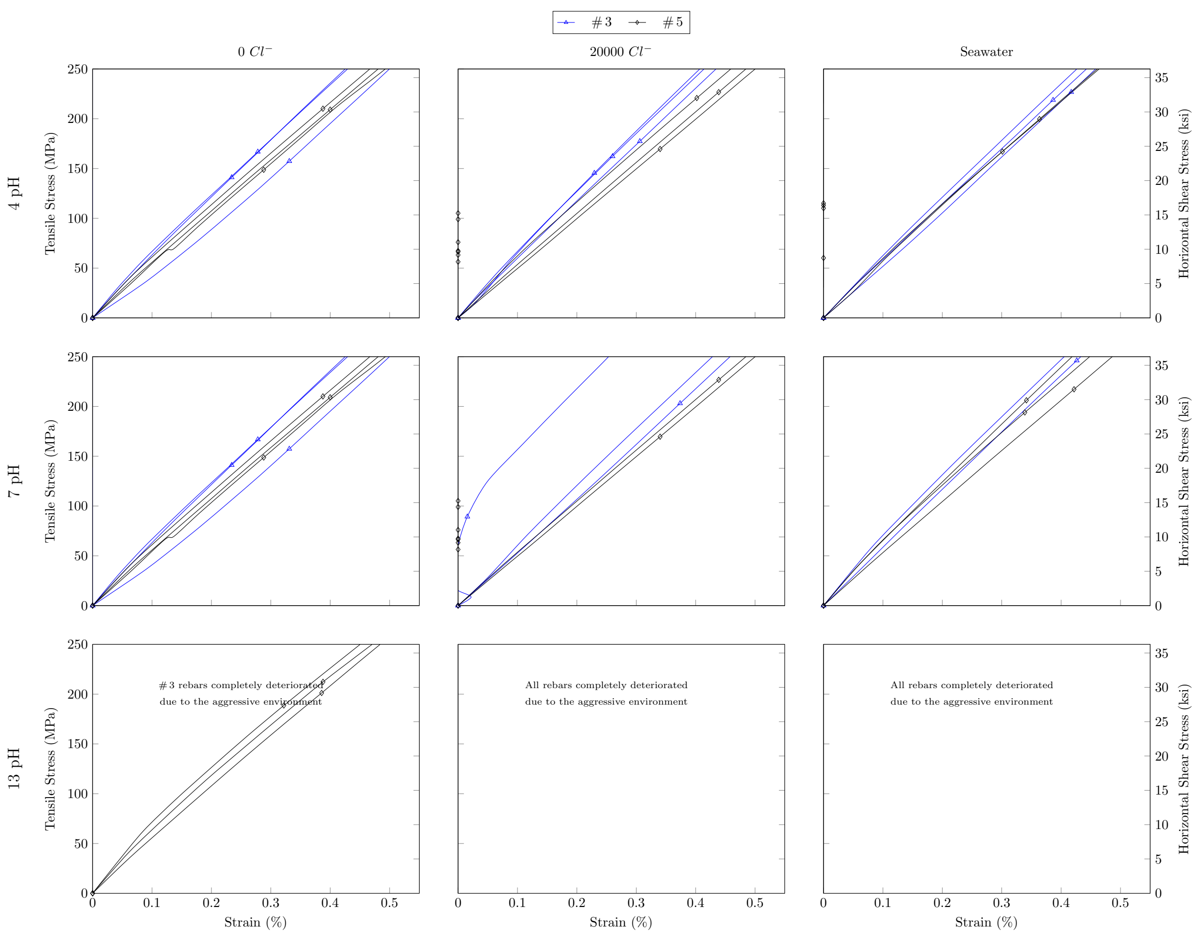

Figure 7.110: 300Day Tensile stress - Strain behavior of rebar Type C Lot 1 size 3 and 5

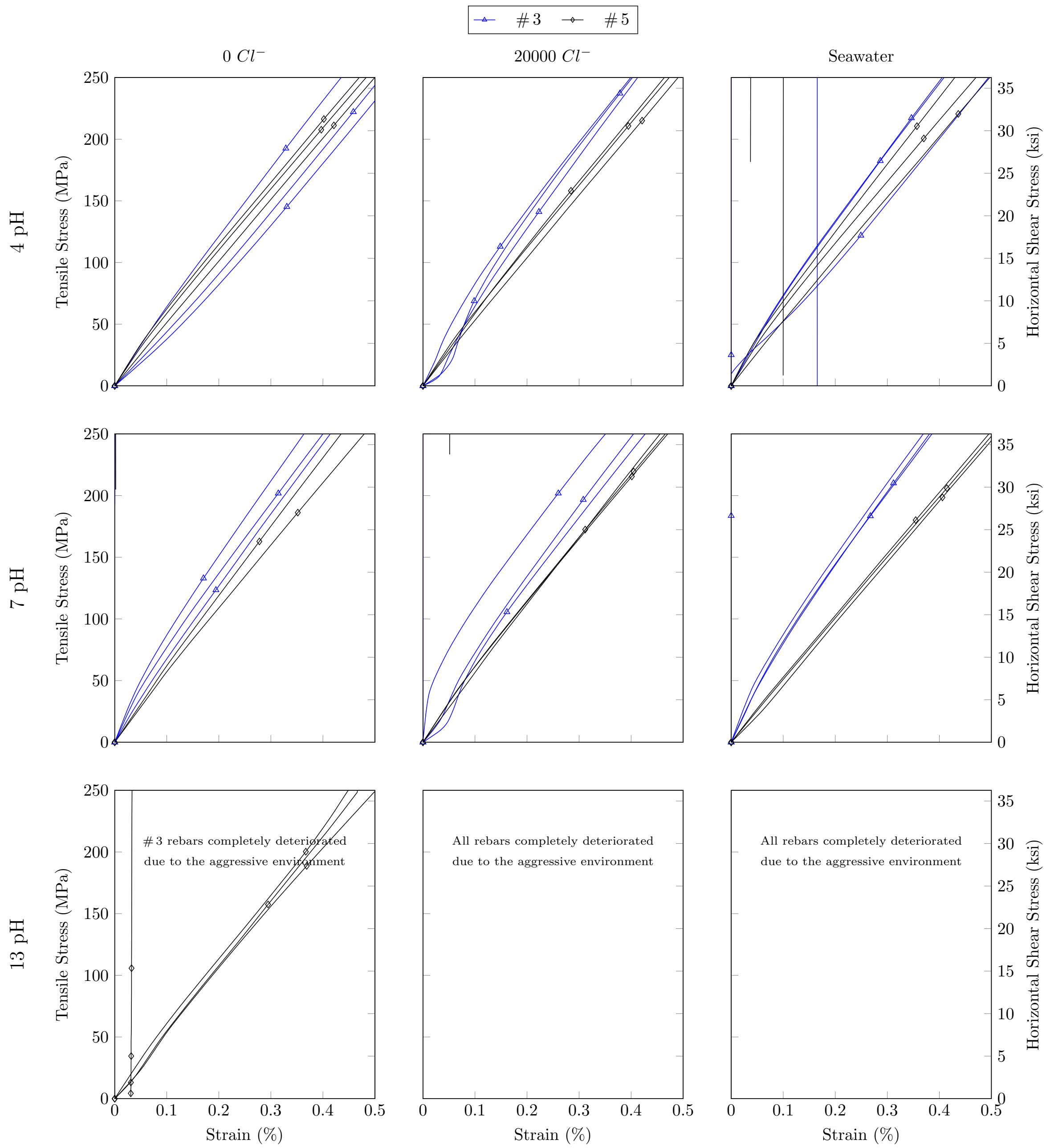

Figure 7.111: 300Day Tensile stress - Strain behavior of rebar Type A Lot 2 size 3 and 5

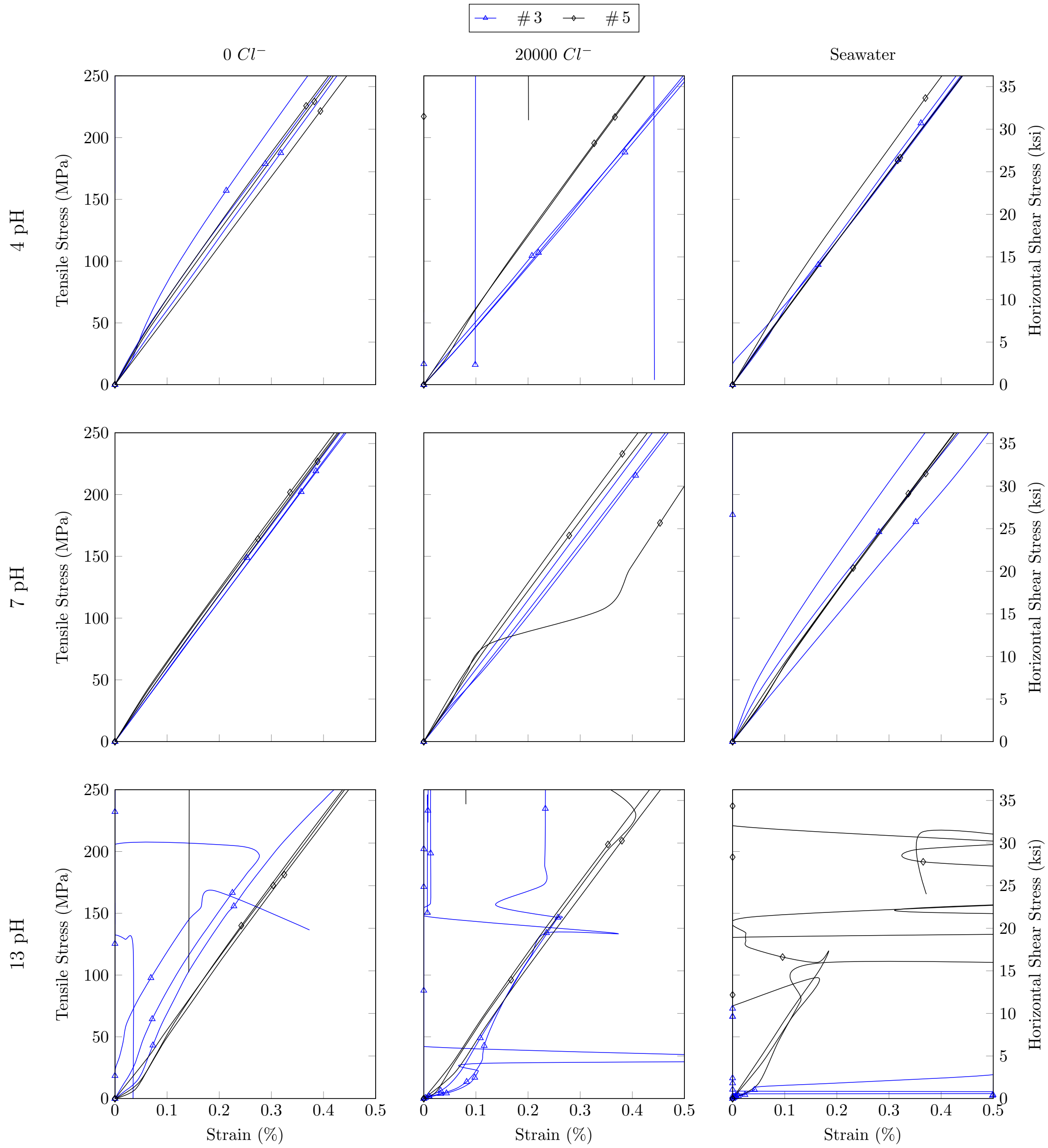

Figure 7.112: 300Day Tensile stress - Strain behavior of rebar Type B Lot 2 size 3 and 5

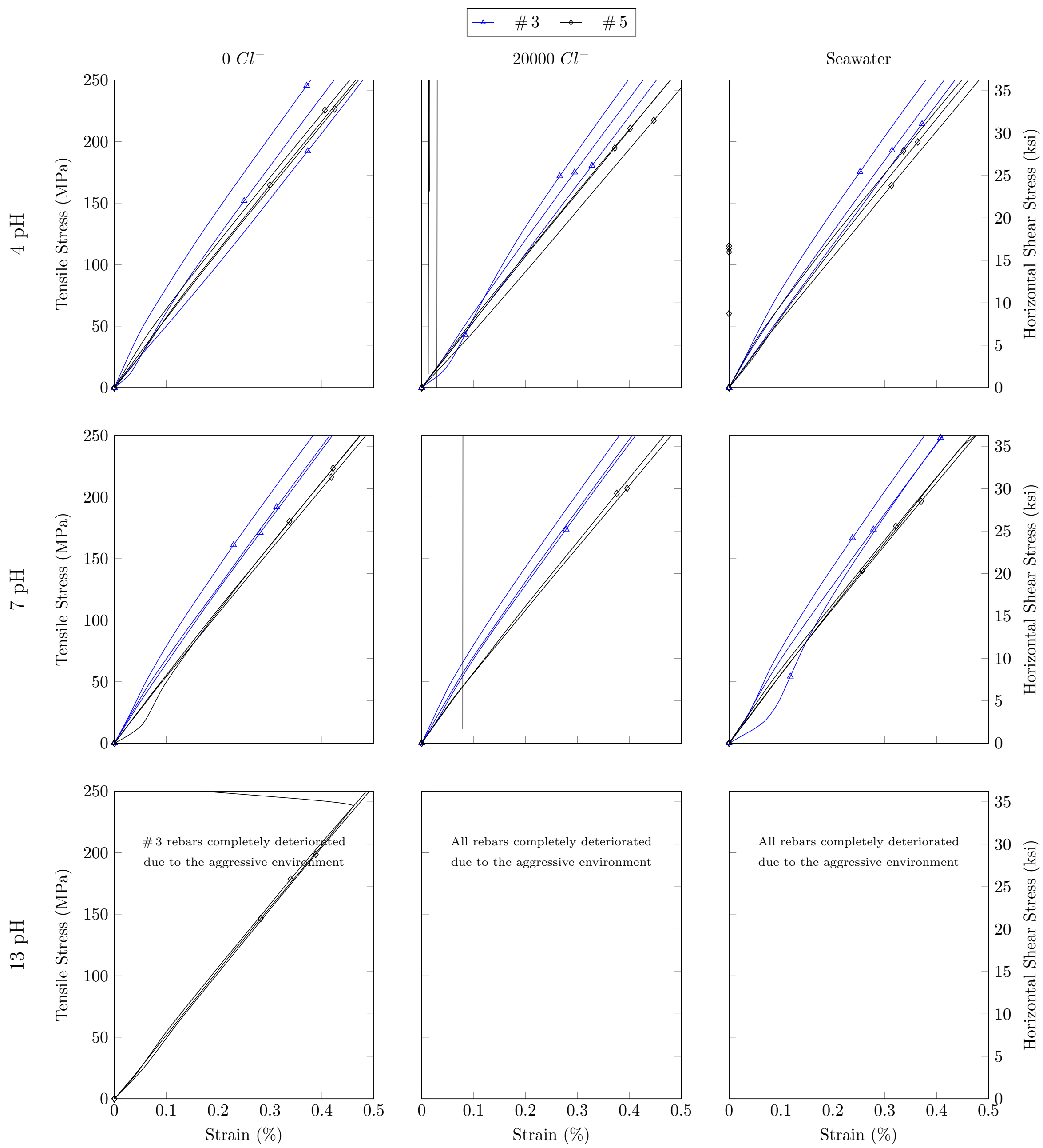

Figure 7.113: 300Day Tensile stress - Strain behavior of rebar Type C Lot 2 size 3 and 5

Table 7.43: 300Day Tensile strength test statistical values for each sample group (US Customary Units)

Sample group						Statistical Values									
						Tensile Strength					Elastic Modulus				
Manuf. Type	Resin Type	Size #	Lot No.	pH	Cl^-	$\wedge$ ksi	$\vee$ ksi	μ ksi	σ ksi	CV %	$\wedge$ ksi	$\vee$ ksi	μ ksi	σ ksi	CV %
TypeA	Epoxy	3	1	4	0	137.5	151.8	143.9	7.3	5.07	7335	8650.9	8139.0	704.9	8.66
TypeA	Epoxy	5	1	4	0	121.1	123.6	122.5	1.3	1.04	7325	7579.4	7431.4	132.2	1.78
TypeA	Epoxy	3	2	4	0	143.9	155.1	150.0	5.7	3.80	6722	8079.0	7281.5	709.0	9.74
TypeA	Epoxy	5	2	4	0	104.2	132.8	121.4	15.2	12.51	7254	7492.9	7345.5	128.9	1.76
TypeB	VinylEster	3	1	4	0	106.9	122.0	114.4	10.7	9.36	8080	8246.6	8163.1	118.1	1.45
TypeB	VinylEster	5	1	4	0	140.3	145.7	143.6	2.9	1.99	8148	8709.9	8406.9	283.6	3.37
TypeB	VinylEster	3	2	4	0	135.1	142.8	138.8	3.8	2.77	8394	9078.5	8654.2	370.6	4.28
TypeB	VinylEster	5	2	4	0	139.1	149.6	144.4	5.3	3.65	8219	8548.6	8395.2	165.9	1.98
TypeC	Epoxy	3	1	4	0	104.6	149.2	130.9	23.4	17.84	8083	9927.6	8893.0	942.7	10.60
TypeC	Epoxy	5	1	4	0	105.1	113.5	108.6	4.3	4.00	6980	7840.8	7520.7	471.1	6.26
TypeC	Epoxy	3	2	4	0	120.3	140.6	131.6	10.3	7.85	7522	8966.3	8353.1	746.1	8.93
TypeC	Epoxy	5	2	4	0	108.7	120.0	113.5	5.8	5.13	7680	7815.7	7745.7	67.9	0.88
TypeA	Epoxy	3	1	4	20000	147.2	150.7	149.0	1.7	1.17	7529	7822.0	7684.0	147.0	1.91
TypeA	Epoxy	5	1	4	20000	131.2	154.9	139.1	13.7	9.84	7256	7489.8	7403.8	128.8	1.74
TypeA	Epoxy	3	2	4	20000	151.4	163.7	158.9	6.6	4.14	8365	9048.4	8719.9	342.3	3.93
TypeA	Epoxy	5	2	4	20000	119.7	148.8	134.1	14.6	10.85	7395	7768.2	7540.5	199.7	2.65
TypeB	VinylEster	3	1	4	20000	148.9	152.0	150.8	1.7	1.11	8280	8918.5	8554.8	328.5	3.84
TypeB	VinylEster	5	1	4	20000	138.8	155.3	148.8	8.7	5.88	8221	8395.2	8318.0	88.5	1.06
TypeB	VinylEster	3	2	4	20000	119.3	124.6	121.9	2.7	2.18	7115	7303.0	7192.0	98.4	1.37
TypeB	VinylEster	5	2	4	20000	141.3	146.4	144.2	2.6	1.81	NA	NA	NA	NA	NA
TypeC	Epoxy	3	1	4	20000	127.1	147.9	137.9	10.4	7.54	8274	8887.2	8581.5	306.5	3.57
TypeC	Epoxy	5	1	4	20000	119.8	130.0	126.0	5.4	4.28	7375	7847.1	7583.5	240.9	3.18
TypeC	Epoxy	3	2	4	20000	117.3	137.3	127.1	10.0	7.87	8042	9853.0	8795.0	943.3	10.73
TypeC	Epoxy	5	2	4	20000	104.7	115.6	109.9	5.5	4.99	7116	7548.0	7385.0	234.7	3.18
TypeA	Epoxy	3	1	4	SeaWater	149.0	149.7	149.3	0.4	0.27	7570	8138.7	7781.7	310.9	4.00
TypeA	Epoxy	5	1	4	SeaWater	126.1	141.6	132.5	8.1	6.12	7158	8230.2	7700.0	536.1	6.96
TypeA	Epoxy	3	2	4	SeaWater	100.8	121.9	109.1	11.2	10.28	6960	8509.4	7981.9	885.3	11.09
TypeA	Epoxy	5	2	4	SeaWater	138.1	145.6	141.7	3.8	2.66	7293	8037.3	7604.2	386.7	5.09
TypeB	VinylEster	3	1	4	SeaWater	113.2	137.8	126.7	12.5	9.88	7170	7300.4	7231.7	65.5	0.91
TypeB	VinylEster	5	1	4	SeaWater	143.1	152.1	146.4	4.9	3.35	7970	8269.1	8164.7	168.3	2.06
TypeB	VinylEster	3	2	4	SeaWater	143.6	153.2	148.0	4.8	3.26	7715	8724.4	8198.9	505.9	6.17
TypeB	VinylEster	5	2	4	SeaWater	143.8	152.5	147.5	4.5	3.03	8191	8720.9	8375.1	299.7	3.58

Continued on next page . . .

Table 7.43: 300Day Tensile strength test statistical values for each sample group (US Customary Units)

Sample group						Statistical Values									
						Tensile Strength					Elastic Modulus				
Manuf. Type	Resin Type	Size #	Lot No.	pH	Cl^-	$\wedge$ ksi	$\vee$ ksi	μ ksi	σ ksi	CV %	$\wedge$ ksi	$\vee$ ksi	μ ksi	σ ksi	CV %
TypeC	Epoxy	3	1	4	SeaWater	144.0	148.4	145.6	2.4	1.67	7938	8361.2	8139.6	212.3	2.61
TypeC	Epoxy	5	1	4	SeaWater	100.1	104.0	102.7	2.2	2.17	7549	7921.2	7715.8	189.0	2.45
TypeC	Epoxy	3	2	4	SeaWater	130.4	141.1	136.7	5.6	4.12	8308	9059.3	8633.2	385.7	4.47
TypeC	Epoxy	5	2	4	SeaWater	104.0	122.5	114.4	9.4	8.25	7480	7921.2	7722.8	223.9	2.90
TypeA	Epoxy	3	1	7	0	156.5	164.1	159.7	4.0	2.50	7581	8125.6	7808.7	283.0	3.62
TypeA	Epoxy	5	1	7	0	120.4	141.4	128.6	11.2	8.74	7023	7875.1	7315.2	485.0	6.63
TypeA	Epoxy	3	2	7	0	143.2	154.9	148.0	6.2	4.16	8452	9082.3	8686.9	344.4	3.96
TypeA	Epoxy	5	2	7	0	133.0	142.1	137.5	6.4	4.69	7500	8249.7	7875.1	529.8	6.73
TypeB	VinylEster	3	1	7	0	112.1	119.6	115.9	3.8	3.24	7139	7488.2	7313.6	174.7	2.39
TypeB	VinylEster	5	1	7	0	135.7	140.1	137.6	2.2	1.64	8527	8897.3	8707.7	185.5	2.13
TypeB	VinylEster	3	2	7	0	138.2	141.5	140.3	1.8	1.29	8181	8348.9	8239.9	94.5	1.15
TypeB	VinylEster	5	2	7	0	143.2	149.5	145.8	3.3	2.25	8262	8450.9	8362.6	94.9	1.14
TypeC	Epoxy	3	1	7	0	123.1	143.7	136.7	11.8	8.62	7224	8323.0	7913.0	600.4	7.59
TypeC	Epoxy	5	1	7	0	103.8	116.7	110.8	6.5	5.89	7258	7608.4	7444.4	176.5	2.37
TypeC	Epoxy	3	2	7	0	121.7	139.1	127.7	9.9	7.73	8442	8961.4	8652.8	273.1	3.16
TypeC	Epoxy	5	2	7	0	119.2	136.2	126.7	8.6	6.83	7398	8085.7	7698.9	351.7	4.57
TypeA	Epoxy	3	1	7	20000	145.4	152.5	149.5	3.7	2.46	7575	7844.3	7703.7	135.2	1.76
TypeA	Epoxy	5	1	7	20000	78.3	119.9	99.1	29.4	29.63	7334	8095.6	7715.0	538.3	6.98
TypeA	Epoxy	3	2	7	20000	88.3	92.5	90.1	2.1	2.39	8255	8625.8	8440.1	185.4	2.20
TypeA	Epoxy	5	2	7	20000	125.2	148.1	134.3	12.2	9.06	7447	7919.7	7660.6	239.6	3.13
TypeB	VinylEster	3	1	7	20000	112.4	125.3	118.5	6.4	5.44	7465	7585.7	7529.4	61.0	0.81
TypeB	VinylEster	5	1	7	20000	136.2	148.6	144.1	6.9	4.77	8253	8973.9	8538.1	383.4	4.49
TypeB	VinylEster	3	2	7	20000	148.6	157.6	152.3	4.7	3.08	7620	8183.1	7870.7	286.6	3.64
TypeB	VinylEster	5	2	7	20000	146.6	149.6	148.6	1.7	1.13	1198	8501.6	5991.4	4152.9	69.31
TypeC	Epoxy	3	1	7	20000	118.6	155.6	133.4	19.5	14.65	7894	8851.5	8423.6	487.1	5.78
TypeC	Epoxy	5	1	7	20000	93.3	115.8	104.8	11.2	10.72	7274	7752.0	7503.1	239.5	3.19
TypeC	Epoxy	3	2	7	20000	122.0	139.1	129.3	8.8	6.81	8574	8927.9	8724.8	182.6	2.09
TypeC	Epoxy	5	2	7	20000	106.0	129.6	119.4	12.2	10.18	7347	7726.3	7490.7	205.7	2.75
TypeA	Epoxy	3	1	7	SeaWater	118.2	129.5	125.2	6.1	4.84	6981	8388.0	7815.1	738.9	9.46
TypeA	Epoxy	5	1	7	SeaWater	132.3	148.7	139.9	8.3	5.91	7292	7781.3	7459.9	278.4	3.73
TypeA	Epoxy	3	2	7	SeaWater	144.4	159.1	151.5	7.4	4.87	8633	8951.0	8825.8	169.1	1.92
TypeA	Epoxy	5	2	7	SeaWater	129.6	157.1	144.0	13.8	9.59	7198	7282.3	7251.6	46.9	0.65

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Table 7.43: 300Day Tensile strength test statistical values for each sample group (US Customary Units)

Sample group						Statistical Values									
						Tensile Strength					Elastic Modulus				
Manuf. Type	Resin Type	Size #	Lot No.	pH	Cl^{-}	$\wedge$ ksi	$\vee$ ksi	μ ksi	σ ksi	CV %	$\wedge$ ksi	$\vee$ ksi	μ ksi	σ ksi	CV %
TypeB	VinylEster	3	1	7	SeaWater	144.4	159.1	151.5	7.4	4.87	8633	8951.0	8825.8	169.1	1.92
TypeB	VinylEster	5	1	7	SeaWater	147.3	154.5	150.5	3.6	2.42	8354	8795.9	8539.8	229.2	2.68
TypeB	VinylEster	3	2	7	SeaWater	128.8	159.1	139.8	16.8	12.03	7393	8892.9	8063.8	762.4	9.46
TypeB	VinylEster	5	2	7	SeaWater	132.7	146.1	141.4	7.5	5.33	8435	8495.9	8465.1	30.5	0.36
TypeC	Epoxy	3	1	7	SeaWater	123.4	159.3	140.6	18.0	12.80	8354	8955.1	8660.3	300.9	3.47
TypeC	Epoxy	5	1	7	SeaWater	106.9	130.8	121.8	13.0	10.65	7421	8482.8	7899.6	538.7	6.82
TypeC	Epoxy	3	2	7	SeaWater	126.9	127.8	127.5	0.5	0.40	8574	10 700.4	9543.3	1075.4	11.27
TypeC	Epoxy	5	2	7	SeaWater	102.3	119.1	109.5	8.7	7.93	7610	7714.0	7646.5	58.6	0.77
TypeA	Epoxy	5	1	13	0	63.9	117.4	82.0	30.7	37.38	7064	8242.2	7489.8	653.4	8.72
TypeA	Epoxy	5	2	13	0	73.8	113.8	91.1	20.5	22.50	7424	7602.5	7513.4	89.1	1.19
TypeB	VinylEster	3	1	13	0	3.1	83.3	55.6	45.5	81.84	NA	NA	NA	NA	NA
TypeB	VinylEster	5	1	13	0	80.7	89.2	86.1	4.7	5.44	8443	9266.8	8841.7	412.5	4.67
TypeB	VinylEster	3	2	13	0	26.3	44.9	33.8	9.8	29.10	NA	NA	NA	NA	NA
TypeB	VinylEster	5	2	13	0	82.3	118.8	96.8	19.4	20.05	8356	8807.6	8552.0	231.5	2.71
TypeC	Epoxy	5	1	13	0	100.6	111.9	107.1	5.9	5.50	7492	7702.9	7598.9	105.7	1.39
TypeC	Epoxy	5	2	13	0	101.8	116.1	108.7	7.2	6.61	7516	7580.7	7545.3	32.9	0.44
TypeB	VinylEster	3	1	13	20000	21.8	87.3	45.7	36.2	79.33	NA	NA	NA	NA	NA
TypeB	VinylEster	5	1	13	20000	90.9	95.0	92.6	2.1	2.32	8112	8961.1	8455.2	447.2	5.29
TypeB	VinylEster	3	2	13	20000	44.2	55.3	49.0	5.7	11.61	728	8583.2	5820.2	4415.0	75.86
TypeB	VinylEster	5	2	13	20000	95.9	122.7	105.7	14.8	14.03	8388	8536.5	8455.2	75.2	0.89
TypeB	VinylEster	3	1	13	SeaWater	3.9	5.0	4.5	0.6	12.85	NA	NA	NA	NA	NA
TypeB	VinylEster	5	1	13	SeaWater	35.0	65.0	55.0	17.3	31.50	2356	11 629.1	5689.7	5156.6	90.63
TypeB	VinylEster	3	2	13	SeaWater	6.8	12.3	10.2	3.0	29.32	NA	NA	NA	NA	NA
TypeB	VinylEster	5	2	13	SeaWater	30.1	36.4	33.0	3.2	9.66	4487	6684.6	5697.9	1115.6	19.58

A total of 356 specimen, 5 per rebar size, type, lot, and exposure type were tested and analyzed to determine the results shown in the table. For numerical comparison and concluding values, Table 7.43 lists the minimum tensile stress ($\wedge$), the maximum tensile stress ($\vee$), the average tensile stress (μ), the standard deviation (σ), and the coefficient of variation (CV) for each individual test sample.

7.5.7 Bond-to-Concrete Strength

The bond stress τ_{max} (MPa or lbs./in.^{2}) for a circular bar diameter d (mm or in.) is given by Equation 8.1, in which F represents the recorded pullout load (N or lbs.) and L is the accurately measured bond length (mm or in.).

$$\tau_{max} = \frac{F}{d\pi L} \qquad [in\text{MPa } or \text{ psi}] \tag{7.1}$$

This formula was used to determine the bond behavior development and is the basis for the following graphs; Figure 7.114, 7.115, 7.116, 7.117, 7.118, and 7.119 depict the measured bond stresses along the rebar surfaces relative to the rebar slip at the free end. For clarity, the post failure measurements (at the onset of a 50 % load drop) were removed from these graphs. All tested specimens failed at the rebar-concrete interface in bond slip, without splitting the concrete open or without tensile failure. The bond capacity and the failure behavior of the BFRP rebar-concrete interface were affected by the surface enhancement features.

Bond-to-Concrete Behavior — Slip at Free End

The graphs in this section compare the bond stress - slip at free end of rebar. Graphs in Figure 7.114, 7.115, 7.116, 7.117, 7.118, and 7.119 portray bond stresses - slip at free end of the rebars of both the sizes. The x-axis of the graph signifies the measured bond stress, while the y-axis represents the slip of rebar at the free end. Generally, from the graphs in Figure 7.114, 7.115, and 7.116 it can be seen that each rebar type resulted in a consistent but distinct failure mode with ultimate stresses that were characteristic for each rebar type. All of the sand-coated rebars (Type B) showed a soft failure while the rebars with a deformed surface (Type A and C) failed suddenly with abrupt pullout.

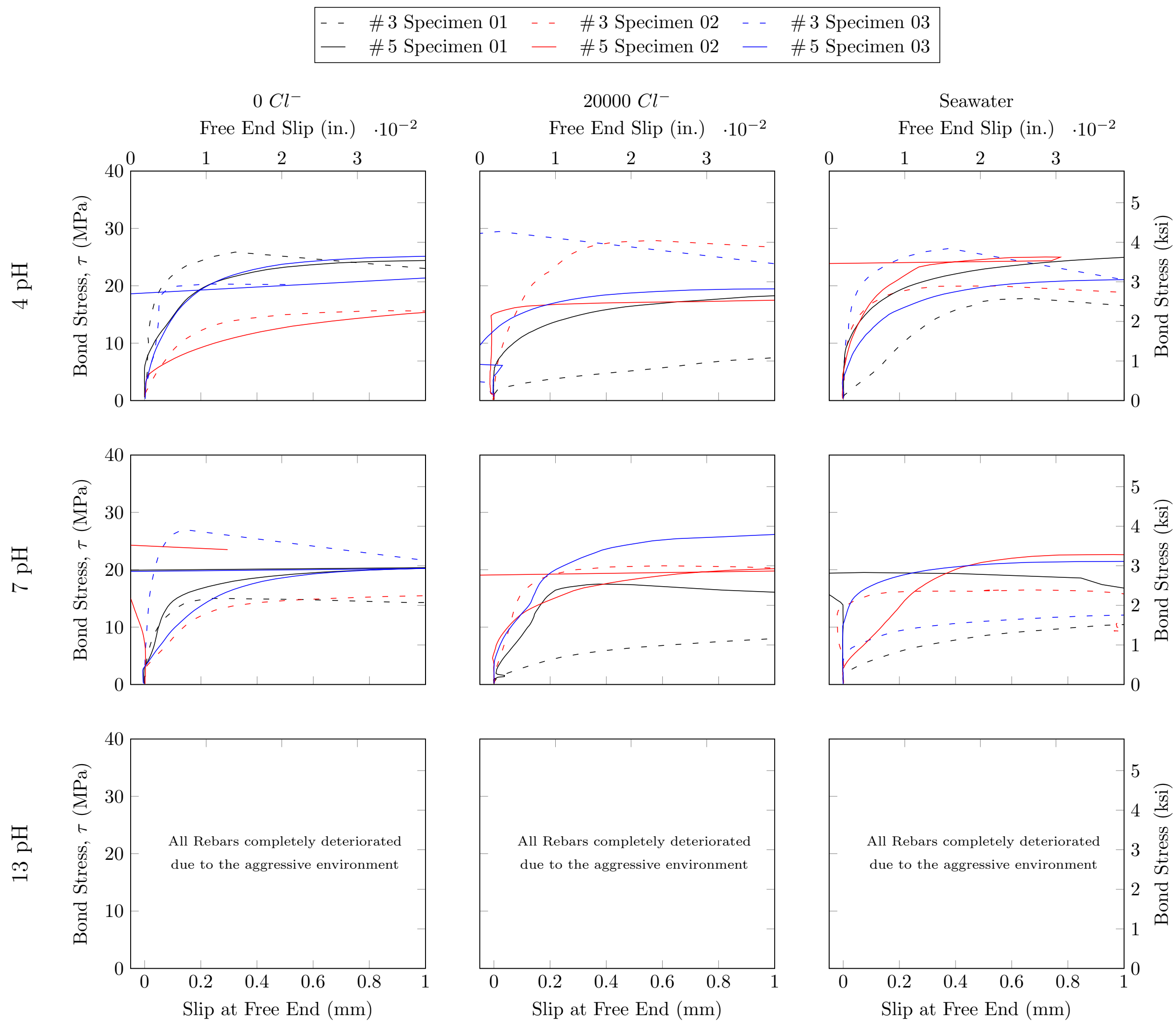

Figure 7.114: Bond stress - slippage behavior of rebar Type A Lot 1 rebars

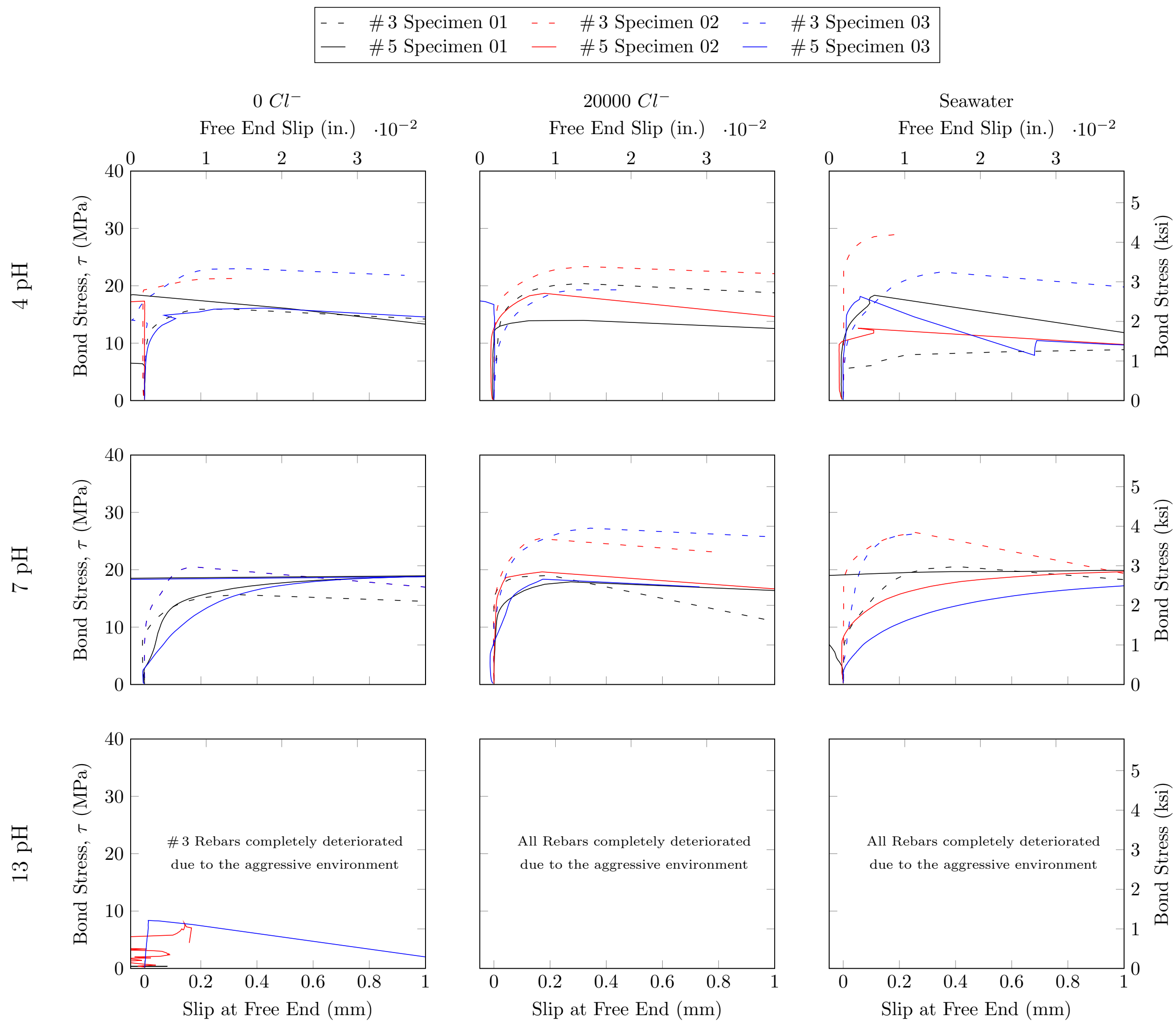

Figure 7.115: Bond stress - slippage behavior of rebar Type B Lot 1 rebars

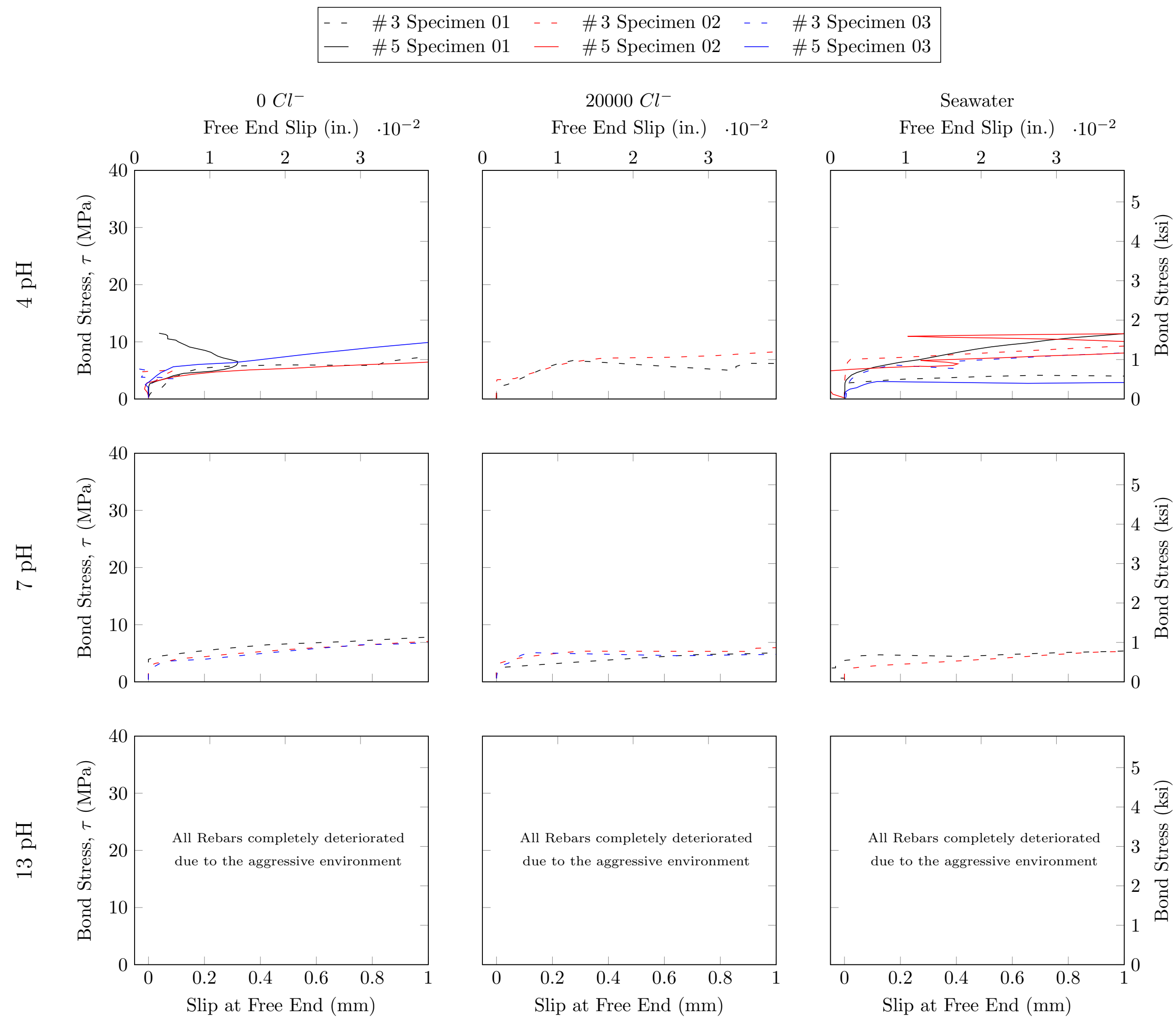

Figure 7.116: Bond stress - slippage behavior of rebar Type C Lot 1 rebars

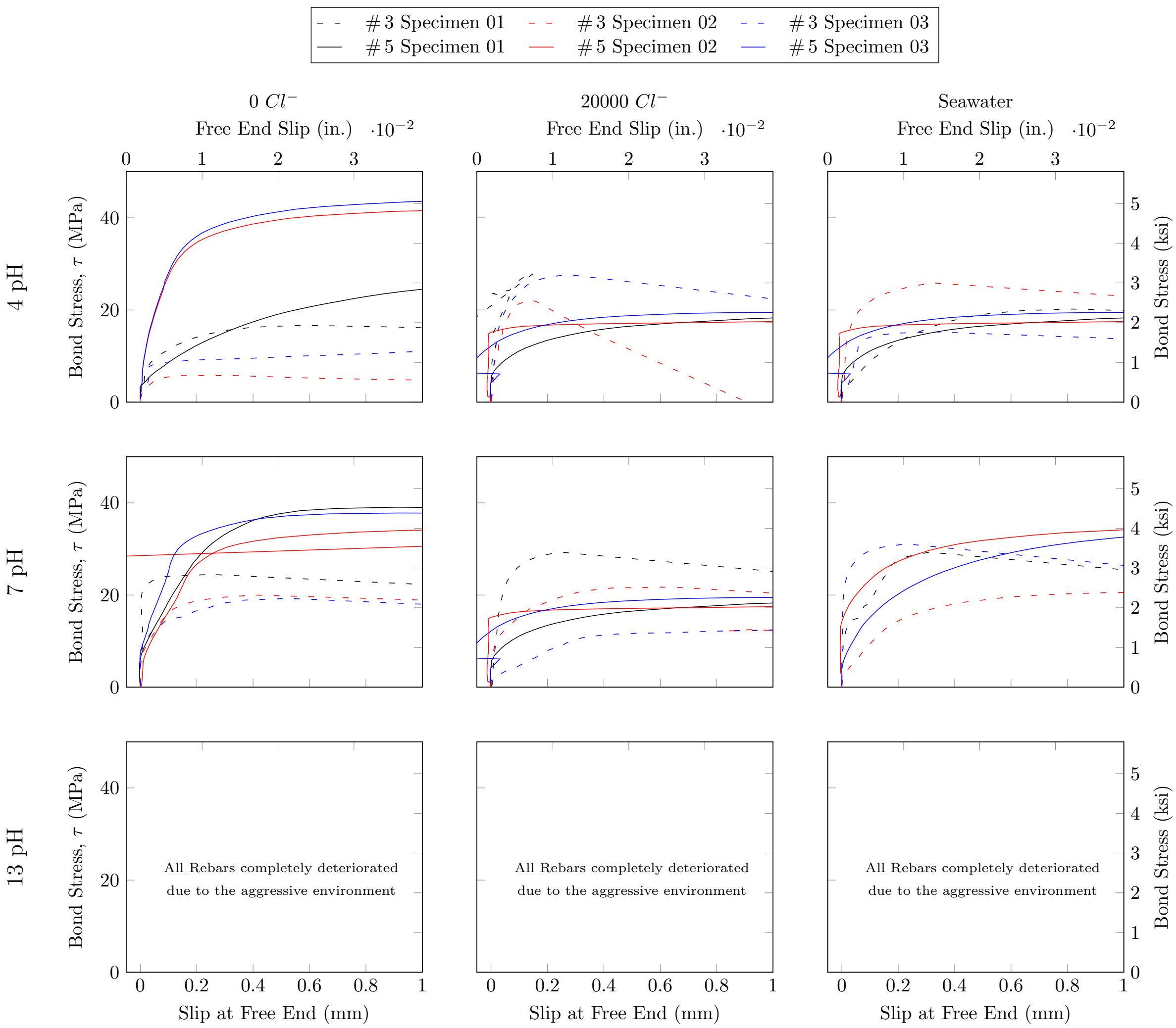

Figure 7.117: Bond stress - slippage behavior of rebar Type A Lot 2 rebars

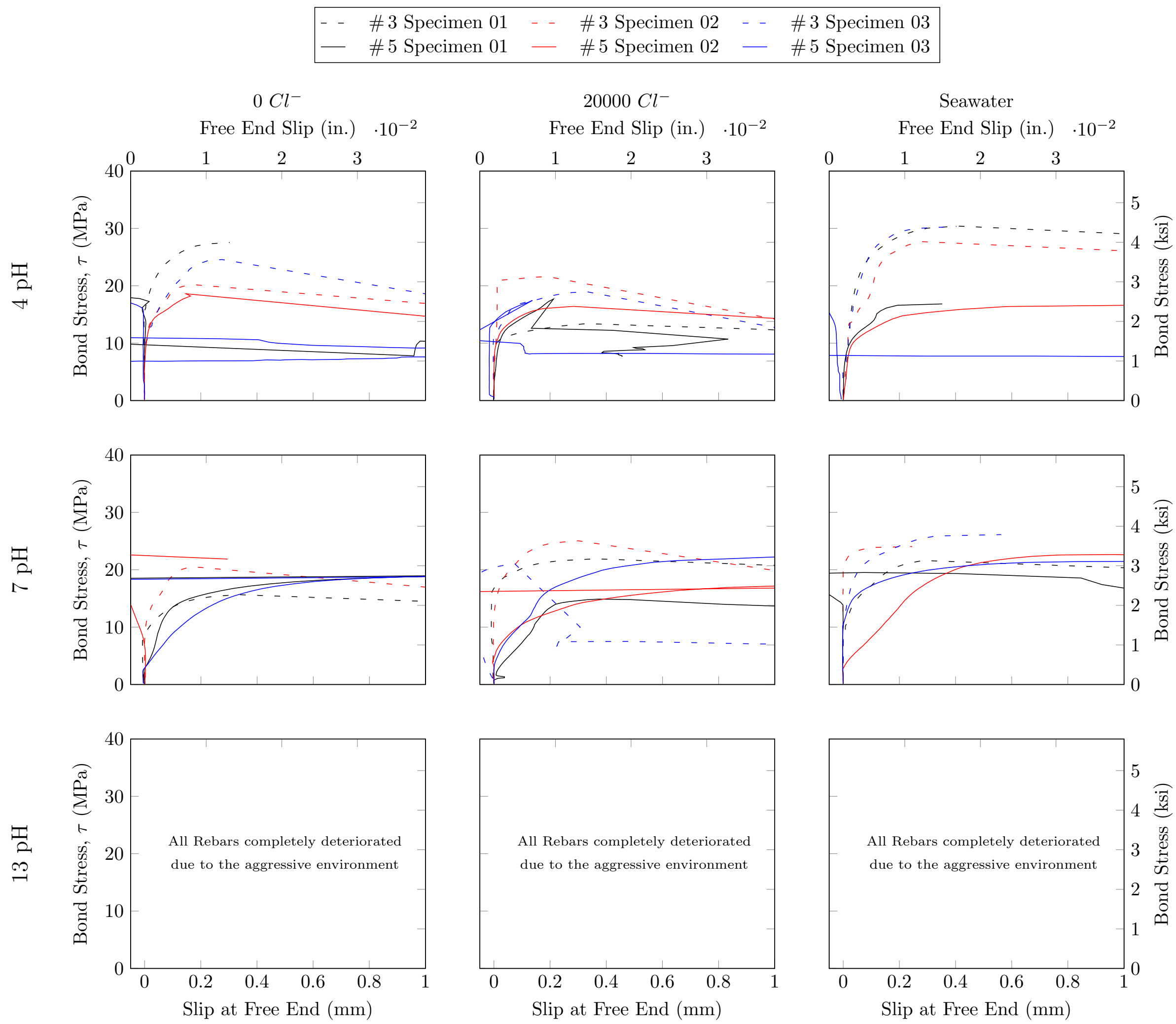

Figure 7.118: Bond stress - slippage behavior of rebar Type B Lot 2 rebars

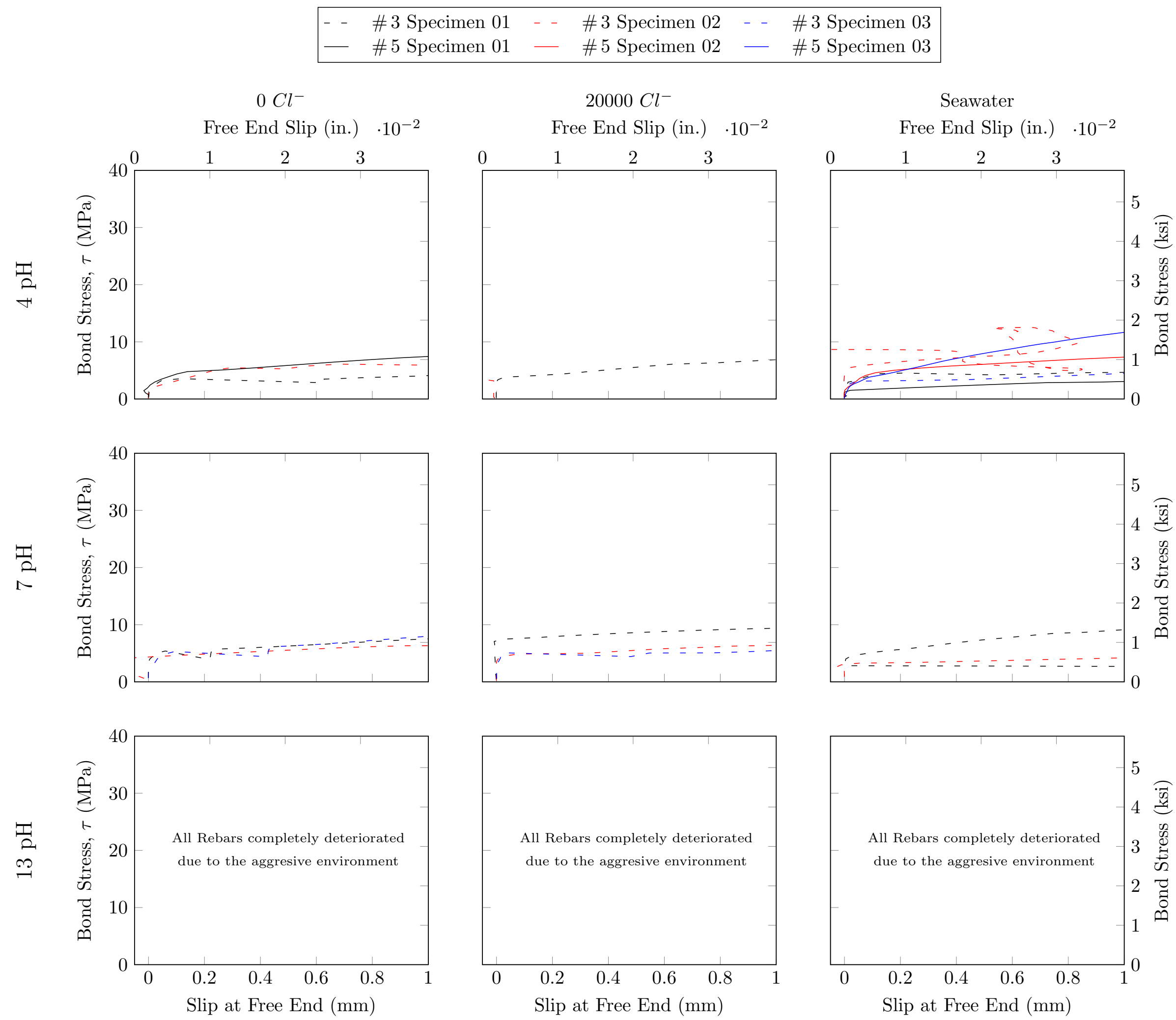

Figure 7.119: Bond stress - slippage behavior of rebar Type C Lot 2 rebars

Chapter 8

Chemical, Physical, and Material Properties of Rebar and Components After Exposure to Aggressive Environments for 600 Days

8.1 Introduction

The performance evaluation of BFRP rebars after exposing them to aggressive environments for 600 days at 60 °C is described throughout this chapter. Several physical, mechanical, and chemical tests were executed for each rebar sample, raw material, and exposure solution after exposure to various combinations of saline and alkaline environments. Accordingly, this chapter addresses three major aspects: 1) the characterization of exposure solutions, 2) the characterization of BFRP rebar components, and 3) the characterization of BFRP rebar specimens.

8.2 Properties of Exposure Environments after 600 Day Exposure

This section presents the chemical properties of all exposure environments used in the research to expose rebars and rebar components.

8.2.1 pH

The pH of the chemical environments was measured after 600 days of exposure. Tables 8.1, 8.2, and 8.3 below shows the pH data of environments in which rebars, resins, and fibers were exposed.

Table 8.1: pH Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						pH			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$	$\vee$	μ	σ
A	Epoxy	1	600	4	0	3.08	3.14	3.11	0.03
B	Vinyl Ester	1	600	4	0	4.66	4.70	4.68	0.02
C	Epoxy	1	600	4	0	3.46	3.48	3.47	0.01
A	Epoxy	1	600	4	200	3.04	3.08	3.06	0.02
B	Vinyl Ester	1	600	4	200	4.67	4.73	4.70	0.03
C	Epoxy	1	600	4	200	3.37	3.41	3.39	0.02
A	Epoxy	1	600	4	20000	3.02	3.08	3.05	0.03
B	Vinyl Ester	1	600	4	20000	4.76	4.82	4.79	0.03
C	Epoxy	1	600	4	20000	3.32	3.34	3.33	0.01
A	Epoxy	1	600	4	SeaWater	2.97	3.01	2.99	0.02
B	Vinyl Ester	1	600	4	SeaWater	4.88	4.89	4.88	0.01
C	Epoxy	1	600	4	SeaWater	3.23	3.25	3.24	0.01
A	Epoxy	2	600	4	0	2.96	3.02	2.99	0.03
B	Vinyl Ester	2	600	4	0	4.74	4.78	4.76	0.02
C	Epoxy	2	600	4	0	3.33	3.36	3.35	0.02
A	Epoxy	2	600	4	200	2.99	3.05	3.02	0.03
B	Vinyl Ester	2	600	4	200	4.75	4.79	4.77	0.02
C	Epoxy	2	600	4	200	3.26	3.27	3.26	0.01
A	Epoxy	2	600	4	20000	3.08	3.12	3.10	0.02
B	Vinyl Ester	2	600	4	20000	4.78	4.80	4.79	0.01
C	Epoxy	2	600	4	20000	3.19	3.26	3.23	0.04
A	Epoxy	2	600	4	SeaWater	3.03	3.06	3.04	0.02
B	Vinyl Ester	2	600	4	SeaWater	4.86	4.87	4.86	0.01
C	Epoxy	2	600	4	SeaWater	3.13	3.19	3.16	0.03
A	Epoxy	1	600	7	0	6.28	6.34	6.31	0.03
B	Vinyl Ester	1	600	7	0	7.56	7.62	7.59	0.03
C	Epoxy	1	600	7	0	6.46	6.48	6.47	0.01
A	Epoxy	1	600	7	200	6.17	6.21	6.19	0.02
B	Vinyl Ester	1	600	7	200	7.59	7.65	7.62	0.03
C	Epoxy	1	600	7	200	6.43	6.45	6.44	0.01
A	Epoxy	1	600	7	20000	6.16	6.18	6.17	0.01
B	Vinyl Ester	1	600	7	20000	7.67	7.73	7.70	0.03
C	Epoxy	1	600	7	20000	6.31	6.36	6.34	0.02
A	Epoxy	1	600	7	SeaWater	5.99	6.07	6.03	0.04
B	Vinyl Ester	1	600	7	SeaWater	7.75	7.81	7.78	0.03
C	Epoxy	1	600	7	SeaWater	6.22	6.25	6.23	0.02
A	Epoxy	2	600	7	0	6.10	6.12	6.11	0.01
B	Vinyl Ester	2	600	7	0	7.84	7.90	7.87	0.03
C	Epoxy	2	600	7	0	6.16	6.22	6.19	0.03
A	Epoxy	2	600	7	200	5.88	5.90	5.89	0.01
B	Vinyl Ester	2	600	7	200	7.87	7.95	7.91	0.04

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Table 8.1: pH Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						pH			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^{-} ppm	$\wedge$	$\vee$	μ	σ
C	Epoxy	2	600	7	200	6.14	6.15	6.14	0.01
A	Epoxy	2	600	7	20000	5.82	5.83	5.83	0.01
B	Vinyl Ester	2	600	7	20000	7.97	8.01	7.99	0.02
C	Epoxy	2	600	7	20000	5.94	5.98	5.96	0.02
A	Epoxy	2	600	7	SeaWater	5.78	5.82	5.80	0.02
B	Vinyl Ester	2	600	7	SeaWater	8.05	8.09	8.07	0.02
C	Epoxy	2	600	7	SeaWater	5.90	5.94	5.92	0.02
A	Epoxy	1	600	10	0	9.39	9.45	9.42	0.03
B	Vinyl Ester	1	600	10	0	10.70	10.78	10.74	0.04
C	Epoxy	1	600	10	0	9.52	9.55	9.54	0.02
A	Epoxy	1	600	10	200	9.27	9.34	9.30	0.04
B	Vinyl Ester	1	600	10	200	10.86	10.92	10.89	0.03
C	Epoxy	1	600	10	200	9.42	9.44	9.43	0.01
A	Epoxy	1	600	10	20000	9.17	9.20	9.18	0.02
B	Vinyl Ester	1	600	10	20000	10.97	11.01	10.99	0.02
C	Epoxy	1	600	10	20000	9.33	9.37	9.35	0.02
A	Epoxy	1	600	10	SeaWater	9.00	9.06	9.03	0.03
B	Vinyl Ester	1	600	10	SeaWater	11.01	11.07	11.04	0.03
C	Epoxy	1	600	10	SeaWater	9.20	9.21	9.20	0.01
A	Epoxy	2	600	10	0	9.29	9.31	9.30	0.01
B	Vinyl Ester	2	600	10	0	10.73	10.79	10.76	0.03
C	Epoxy	2	600	10	0	9.35	9.39	9.37	0.02
A	Epoxy	2	600	10	200	9.07	9.11	9.09	0.02
B	Vinyl Ester	2	600	10	200	10.79	10.83	10.81	0.02
C	Epoxy	2	600	10	200	9.32	9.33	9.32	0.01
A	Epoxy	2	600	10	20000	9.02	9.04	9.03	0.01
B	Vinyl Ester	2	600	10	20000	10.90	10.91	10.90	0.01
C	Epoxy	2	600	10	20000	9.07	9.11	9.09	0.02
A	Epoxy	2	600	10	SeaWater	8.93	9.00	8.96	0.04
B	Vinyl Ester	2	600	10	SeaWater	10.92	11.00	10.96	0.04
C	Epoxy	2	600	10	SeaWater	9.03	9.06	9.04	0.02
A	Epoxy	1	600	13	0	9.81	9.87	9.84	0.03
B	Vinyl Ester	1	600	13	0	11.84	11.88	11.86	0.02
C	Epoxy	1	600	13	0	10.44	10.45	10.45	0.01
A	Epoxy	1	600	13	200	9.78	9.82	9.80	0.02
B	Vinyl Ester	1	600	13	200	11.99	12.07	12.03	0.04
C	Epoxy	1	600	13	200	10.37	10.38	10.37	0.01
A	Epoxy	1	600	13	20000	9.71	9.79	9.75	0.04
B	Vinyl Ester	1	600	13	20000	12.03	12.05	12.04	0.01
C	Epoxy	1	600	13	20000	10.16	10.19	10.18	0.02
A	Epoxy	1	600	13	SeaWater	9.67	9.73	9.70	0.03
B	Vinyl Ester	1	600	13	SeaWater	12.18	12.26	12.22	0.04

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Table 8.1: pH Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						pH			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$	$\vee$	μ	σ
C	Epoxy	1	600	13	SeaWater	10.13	10.17	10.15	0.02
A	Epoxy	2	600	13	0	9.54	9.57	9.56	0.02
B	Vinyl Ester	2	600	13	0	11.98	12.02	12.00	0.02
C	Epoxy	2	600	13	0	10.09	10.11	10.10	0.01
A	Epoxy	2	600	13	200	9.48	9.54	9.51	0.03
B	Vinyl Ester	2	600	13	200	12.01	12.05	12.03	0.02
C	Epoxy	2	600	13	200	10.00	10.04	10.02	0.02
A	Epoxy	2	600	13	20000	9.39	9.45	9.42	0.03
B	Vinyl Ester	2	600	13	20000	12.09	12.11	12.10	0.01
C	Epoxy	2	600	13	20000	9.56	9.59	9.58	0.02
A	Epoxy	2	600	13	SeaWater	9.34	9.40	9.37	0.03
B	Vinyl Ester	2	600	13	SeaWater	12.14	12.21	12.17	0.04
C	Epoxy	2	600	13	SeaWater	9.77	9.80	9.79	0.02

Table 8.2: pH Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					pH			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$	$\vee$	μ	σ
A	Epoxy	600	4	0	3.62	3.68	3.65	0.03
B	Vinyl Ester	600	4	0	3.55	3.63	3.59	0.04
A	Epoxy	600	4	200	3.59	3.65	3.62	0.03
B	Vinyl Ester	600	4	200	3.48	3.52	3.50	0.02
A	Epoxy	600	4	20000	3.55	3.61	3.58	0.03
B	Vinyl Ester	600	4	20000	3.39	3.45	3.42	0.03
A	Epoxy	600	4	SeaWater	3.50	3.56	3.53	0.03
B	Vinyl Ester	600	4	SeaWater	3.36	3.44	3.40	0.04
A	Epoxy	600	7	0	6.41	6.47	6.44	0.03
B	Vinyl Ester	600	7	0	6.25	6.33	6.29	0.04
A	Epoxy	600	7	200	6.33	6.41	6.37	0.04
B	Vinyl Ester	600	7	200	6.22	6.26	6.24	0.02
A	Epoxy	600	7	20000	6.28	6.34	6.31	0.03
B	Vinyl Ester	600	7	20000	6.17	6.18	6.17	0.01
A	Epoxy	600	7	SeaWater	6.23	6.27	6.25	0.02
B	Vinyl Ester	600	7	SeaWater	6.10	6.14	6.12	0.02
A	Epoxy	600	10	0	9.32	9.40	9.36	0.04
B	Vinyl Ester	600	10	0	9.24	9.32	9.28	0.04

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Table 8.2: pH Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					pH			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$	$\vee$	μ	σ
A	Epoxy	600	10	200	9.28	9.30	9.29	0.01
B	Vinyl Ester	600	10	200	9.17	9.21	9.19	0.02
A	Epoxy	600	10	20000	9.18	9.24	9.21	0.03
B	Vinyl Ester	600	10	20000	9.04	9.12	9.08	0.04
A	Epoxy	600	10	SeaWater	9.14	9.18	9.16	0.02
B	Vinyl Ester	600	10	SeaWater	9.00	9.04	9.02	0.02
A	Epoxy	600	13	0	12.38	12.40	12.39	0.01
B	Vinyl Ester	600	13	0	12.29	12.35	12.32	0.03
A	Epoxy	600	13	200	12.33	12.37	12.35	0.02
B	Vinyl Ester	600	13	200	12.28	12.32	12.30	0.02
A	Epoxy	600	13	20000	12.29	12.33	12.31	0.02
B	Vinyl Ester	600	13	20000	12.21	12.23	12.22	0.01
A	Epoxy	600	13	SeaWater	12.25	12.31	12.28	0.03
B	Vinyl Ester	600	13	SeaWater	12.17	12.23	12.20	0.03

Table 8.3: pH Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					pH			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$	$\vee$	μ	σ
A	Sized	600	4	0	4.61	4.67	4.64	0.03
B	Sized	600	4	0	4.59	4.61	4.60	0.01
C	Sized	600	4	0	4.71	4.75	4.73	0.02
A	Sized	600	4	200	4.71	4.72	4.72	0.01
B	Sized	600	4	200	4.69	4.70	4.69	0.01
C	Sized	600	4	200	4.77	4.79	4.78	0.01
A	Sized	600	4	20000	4.93	5.01	4.97	0.04
B	Sized	600	4	20000	4.91	4.92	4.91	0.01
C	Sized	600	4	20000	4.94	4.98	4.96	0.02
A	Sized	600	4	SeaWater	4.96	5.02	4.99	0.03
B	Sized	600	4	SeaWater	4.93	4.94	4.94	0.01
C	Sized	600	4	SeaWater	4.99	5.03	5.01	0.02
A	Unsized	600	4	0	4.83	4.84	4.83	0.01
B	Unsized	600	4	0	4.75	4.79	4.77	0.02
A	Unsized	600	4	200	4.84	4.92	4.88	0.04
B	Unsized	600	4	200	4.77	4.81	4.79	0.02
A	Unsized	600	4	20000	4.93	4.97	4.95	0.02

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Table 8.3: pH Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					pH			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$	$\vee$	μ	σ
B	Unsized	600	4	20000	4.78	4.82	4.80	0.02
A	Unsized	600	4	SeaWater	4.91	4.97	4.94	0.03
B	Unsized	600	4	SeaWater	4.85	4.91	4.88	0.03
A	Sized	600	7	0	7.70	7.74	7.72	0.02
B	Sized	600	7	0	7.66	7.70	7.68	0.02
C	Sized	600	7	0	7.76	7.77	7.77	0.01
A	Sized	600	7	200	7.85	7.93	7.89	0.04
B	Sized	600	7	200	7.80	7.86	7.83	0.03
C	Sized	600	7	200	7.95	7.97	7.96	0.01
A	Sized	600	7	20000	7.92	8.00	7.96	0.04
B	Sized	600	7	20000	7.88	7.89	7.88	0.01
C	Sized	600	7	20000	8.04	8.07	8.05	0.02
A	Sized	600	7	SeaWater	8.01	8.07	8.04	0.03
B	Sized	600	7	SeaWater	7.92	7.93	7.92	0.01
C	Sized	600	7	SeaWater	8.14	8.16	8.15	0.01
A	Unsized	600	7	0	7.82	7.90	7.86	0.04
B	Unsized	600	7	0	7.67	7.68	7.67	0.01
A	Unsized	600	7	200	7.91	7.95	7.93	0.02
B	Unsized	600	7	200	7.72	7.76	7.74	0.02
A	Unsized	600	7	20000	7.91	7.99	7.95	0.04
B	Unsized	600	7	20000	7.78	7.86	7.82	0.04
A	Unsized	600	7	SeaWater	7.95	8.03	7.99	0.04
B	Unsized	600	7	SeaWater	7.80	7.88	7.84	0.04
A	Sized	600	10	0	10.63	10.67	10.65	0.02
B	Sized	600	10	0	10.61	10.62	10.61	0.01
C	Sized	600	10	0	11.10	11.14	11.12	0.02
A	Sized	600	10	200	10.80	10.81	10.81	0.01
B	Sized	600	10	200	10.72	10.76	10.74	0.02
C	Sized	600	10	200	11.21	11.23	11.22	0.01
A	Sized	600	10	20000	10.88	10.92	10.90	0.02
B	Sized	600	10	20000	10.81	10.82	10.81	0.01
C	Sized	600	10	20000	11.26	11.28	11.27	0.01
A	Sized	600	10	SeaWater	11.01	11.05	11.03	0.02
B	Sized	600	10	SeaWater	10.94	10.95	10.94	0.01
C	Sized	600	10	SeaWater	11.27	11.32	11.30	0.03
A	Unsized	600	10	0	10.72	10.80	10.76	0.04
B	Unsized	600	10	0	10.57	10.63	10.60	0.03
A	Unsized	600	10	200	10.79	10.83	10.81	0.02
B	Unsized	600	10	200	10.63	10.64	10.63	0.01
A	Unsized	600	10	20000	10.80	10.88	10.84	0.04
B	Unsized	600	10	20000	10.65	10.73	10.69	0.04
A	Unsized	600	10	SeaWater	10.86	10.92	10.89	0.03

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Table 8.3: pH Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					pH			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$	$\vee$	μ	σ
B	Unsized	600	10	SeaWater	10.76	10.80	10.78	0.02
A	Sized	600	13	0	12.07	12.11	12.09	0.02
B	Sized	600	13	0	12.07	12.08	12.07	0.01
C	Sized	600	13	0	12.20	12.24	12.22	0.02
A	Sized	600	13	200	12.21	12.25	12.23	0.02
B	Sized	600	13	200	12.20	12.24	12.22	0.02
C	Sized	600	13	200	12.35	12.36	12.36	0.01
A	Sized	600	13	20000	12.23	12.27	12.25	0.02
B	Sized	600	13	20000	12.24	12.25	12.25	0.01
C	Sized	600	13	20000	12.38	12.42	12.40	0.02
A	Sized	600	13	SeaWater	12.27	12.31	12.29	0.02
B	Sized	600	13	SeaWater	12.25	12.31	12.28	0.03
C	Sized	600	13	SeaWater	12.47	12.48	12.47	0.01
A	Unsized	600	13	0	11.95	11.99	11.97	0.02
B	Unsized	600	13	0	11.86	11.91	11.88	0.03
A	Unsized	600	13	200	11.96	12.02	11.99	0.03
B	Unsized	600	13	200	11.94	11.95	11.94	0.01
A	Unsized	600	13	20000	12.11	12.12	12.11	0.01
B	Unsized	600	13	20000	12.07	12.13	12.10	0.03
A	Unsized	600	13	SeaWater	12.15	12.21	12.18	0.03
B	Unsized	600	13	SeaWater	12.17	12.23	12.20	0.03

The change in pH of exposure environments after the exposure period was calculated and the data was plotted in the following Figures 8.1, 8.2, and 8.3. From Table 1.1 it can be noticed that the pH drops significantly more for the Epoxy rebars in Lots A and C than the vinyl-ester rebar in Lots B. Resin is generally a composition carbon (C), hydrogen (H) and oxygen (O). The pH will decrease if more C and O is released into the solution. For epoxy rebars, it is anticipated that the resin has degraded more into the solution which has led to more release of C and O that has ultimately resulted in more pH drop than the vinyl-ester rebar.

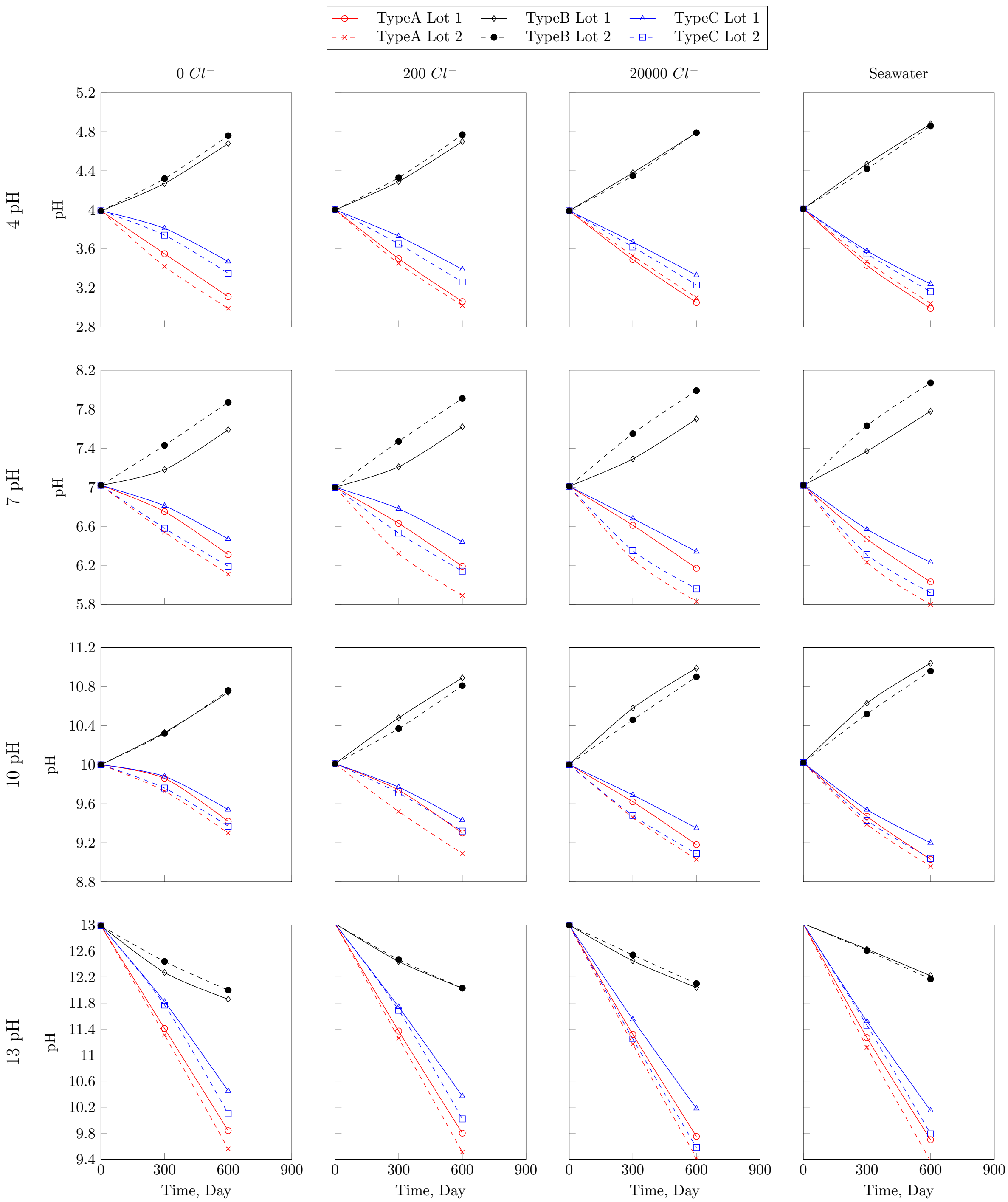

Figure 8.1: pH of environments after exposure of rebars

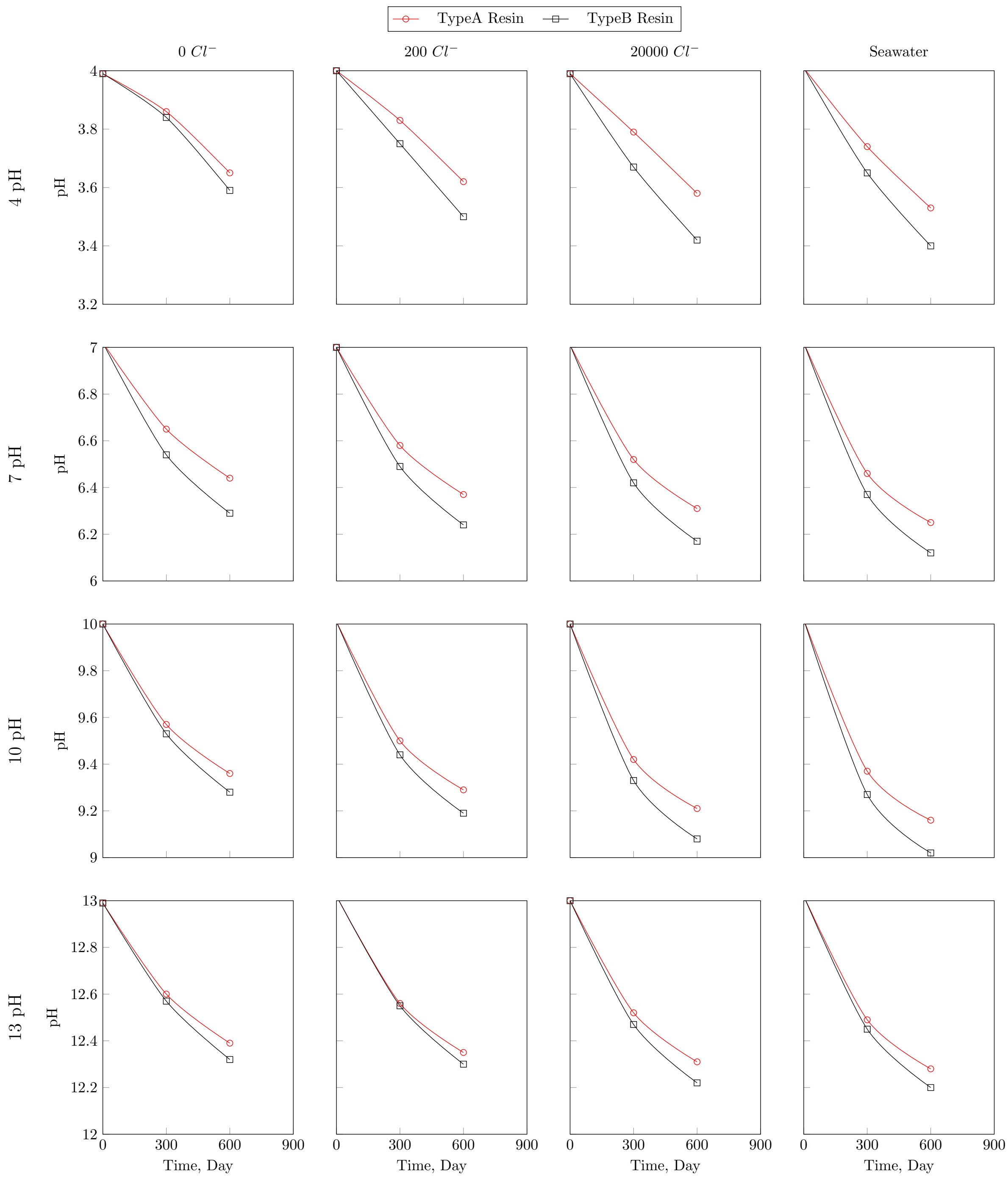

Figure 8.2: pH of environments after exposure of resins

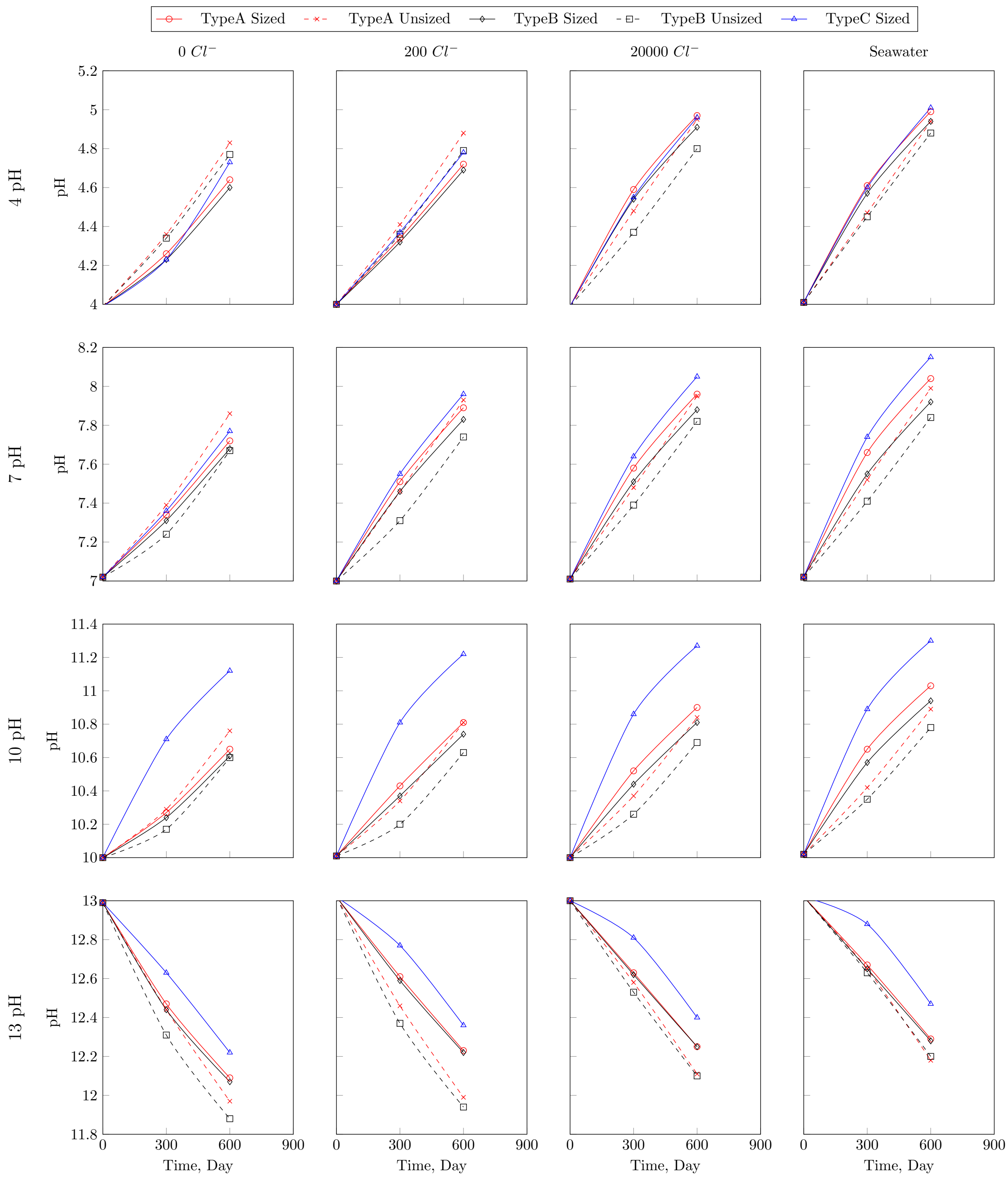

Figure 8.3: pH of environments after exposure of sized and unsized fibers

8.2.2 Salinity

Salinity of the chemical environments was measured after 600 days of exposure. Tables 8.4, 8.5, and 8.6 below shows the salinity data of environments in which rebars, resins, and fibers were exposed.

Table 8.4: Salinity Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Salinity			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	4	0	69.09	70.24	69.67	0.58
B	Vinyl Ester	1	600	4	0	92.51	94.82	93.67	1.15
C	Epoxy	1	600	4	0	82.09	83.24	82.67	0.58
A	Epoxy	1	600	4	200	415.14	418.19	416.67	1.53
B	Vinyl Ester	1	600	4	200	420.00	424.00	422.00	2.00
C	Epoxy	1	600	4	200	427.14	430.19	428.67	1.53
A	Epoxy	1	600	4	20000	34 130.00	34 150.00	34 140.00	10.00
B	Vinyl Ester	1	600	4	20000	34 157.56	34 169.11	34 163.33	5.77
C	Epoxy	1	600	4	20000	34 360.00	34 380.00	34 370.00	10.00
A	Epoxy	1	600	4	SeaWater	34 948.17	34 998.50	34 973.33	25.17
B	Vinyl Ester	1	600	4	SeaWater	36 458.06	36 488.61	36 473.33	15.28
C	Epoxy	1	600	4	SeaWater	35 178.17	35 228.50	35 203.33	25.17
A	Epoxy	2	600	4	0	55.59	59.75	57.67	2.08
B	Vinyl Ester	2	600	4	0	110.09	111.24	110.67	0.58
C	Epoxy	2	600	4	0	93.27	96.73	95.00	1.73
A	Epoxy	2	600	4	200	397.51	399.82	398.67	1.15
B	Vinyl Ester	2	600	4	200	396.51	398.82	397.67	1.15
C	Epoxy	2	600	4	200	461.35	466.65	464.00	2.65
A	Epoxy	2	600	4	20000	33 750.00	33 770.00	33 760.00	10.00
B	Vinyl Ester	2	600	4	20000	33 992.68	34 027.32	34 010.00	17.32
C	Epoxy	2	600	4	20000	33 883.54	33 936.46	33 910.00	26.46
A	Epoxy	2	600	4	SeaWater	33 868.17	33 918.50	33 893.33	25.17
B	Vinyl Ester	2	600	4	SeaWater	35 205.85	35 247.48	35 226.67	20.82
C	Epoxy	2	600	4	SeaWater	34 753.54	34 806.46	34 780.00	26.46
A	Epoxy	1	600	7	0	80.51	82.82	81.67	1.15
B	Vinyl Ester	1	600	7	0	79.27	82.73	81.00	1.73
C	Epoxy	1	600	7	0	93.51	95.82	94.67	1.15

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Table 8.4: Salinity Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Salinity			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	7	200	427.81	430.86	429.33	1.53
B	Vinyl Ester	1	600	7	200	436.00	438.00	437.00	1.00
C	Epoxy	1	600	7	200	439.81	442.86	441.33	1.53
A	Epoxy	1	600	7	20000	33 948.06	33 978.61	33 963.33	15.28
B	Vinyl Ester	1	600	7	20000	34 163.54	34 216.46	34 190.00	26.46
C	Epoxy	1	600	7	20000	34 178.06	34 208.61	34 193.33	15.28
A	Epoxy	1	600	7	SeaWater	35 022.52	35 064.15	35 043.33	20.82
B	Vinyl Ester	1	600	7	SeaWater	35 170.00	35 190.00	35 180.00	10.00
C	Epoxy	1	600	7	SeaWater	35 252.52	35 294.15	35 273.33	20.82
A	Epoxy	2	600	7	0	67.51	69.82	68.67	1.15
B	Vinyl Ester	2	600	7	0	70.09	71.24	70.67	0.58
C	Epoxy	2	600	7	0	104.36	108.98	106.67	2.31
A	Epoxy	2	600	7	200	410.81	413.86	412.33	1.53
B	Vinyl Ester	2	600	7	200	410.81	413.86	412.33	1.53
C	Epoxy	2	600	7	200	505.25	509.41	507.33	2.08
A	Epoxy	2	600	7	20000	33 981.79	34 004.88	33 993.33	11.55
B	Vinyl Ester	2	600	7	20000	33 673.54	33 726.46	33 700.00	26.46
C	Epoxy	2	600	7	20000	34 031.79	34 054.88	34 043.33	11.55
A	Epoxy	2	600	7	SeaWater	34 142.52	34 184.15	34 163.33	20.82
B	Vinyl Ester	2	600	7	SeaWater	34 977.56	34 989.11	34 983.33	5.77
C	Epoxy	2	600	7	SeaWater	35 042.68	35 077.32	35 060.00	17.32
A	Epoxy	1	600	10	0	73.36	77.98	75.67	2.31
B	Vinyl Ester	1	600	10	0	95.81	98.86	97.33	1.53
C	Epoxy	1	600	10	0	86.36	90.98	88.67	2.31
A	Epoxy	1	600	10	200	426.14	429.19	427.67	1.53
B	Vinyl Ester	1	600	10	200	428.25	432.41	430.33	2.08
C	Epoxy	1	600	10	200	438.14	441.19	439.67	1.53

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Table 8.4: Salinity Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Salinity			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	10	20000	33 991.39	34 021.94	34 006.67	15.28
B	Vinyl Ester	1	600	10	20000	34 380.00	34 420.00	34 400.00	20.00
C	Epoxy	1	600	10	20000	34 221.39	34 251.94	34 236.67	15.28
A	Epoxy	1	600	10	SeaWater	35 751.79	35 774.88	35 763.33	11.55
B	Vinyl Ester	1	600	10	SeaWater	35 841.79	35 864.88	35 853.33	11.55
C	Epoxy	1	600	10	SeaWater	35 981.79	36 004.88	35 993.33	11.55
A	Epoxy	2	600	10	0	69.51	71.82	70.67	1.15
B	Vinyl Ester	2	600	10	0	68.14	71.19	69.67	1.53
C	Epoxy	2	600	10	0	88.18	90.49	89.33	1.15
A	Epoxy	2	600	10	200	418.25	422.41	420.33	2.08
B	Vinyl Ester	2	600	10	200	409.09	410.24	409.67	0.58
C	Epoxy	2	600	10	200	501.59	505.75	503.67	2.08
A	Epoxy	2	600	10	20000	34 246.08	34 340.59	34 293.33	47.26
B	Vinyl Ester	2	600	10	20000	34 018.17	34 068.50	34 043.33	25.17
C	Epoxy	2	600	10	20000	34 535.12	34 558.21	34 546.67	11.55
A	Epoxy	2	600	10	SeaWater	34 571.39	34 601.94	34 586.67	15.28
B	Vinyl Ester	2	600	10	SeaWater	35 861.79	35 884.88	35 873.33	11.55
C	Epoxy	2	600	10	SeaWater	36 110.00	36 130.00	36 120.00	10.00
A	Epoxy	1	600	13	0	1199.59	1203.75	1201.67	2.08
B	Vinyl Ester	1	600	13	0	854.51	856.82	855.67	1.15
C	Epoxy	1	600	13	0	1779.59	1783.75	1781.67	2.08
A	Epoxy	1	600	13	200	2003.25	2007.41	2005.33	2.08
B	Vinyl Ester	1	600	13	200	1227.27	1230.73	1229.00	1.73
C	Epoxy	1	600	13	200	2345.25	2349.41	2347.33	2.08
A	Epoxy	1	600	13	20000	15 530.00	15 570.00	15 550.00	20.00
B	Vinyl Ester	1	600	13	20000	23 571.79	23 594.88	23 583.33	11.55
C	Epoxy	1	600	13	20000	18 490.00	18 530.00	18 510.00	20.00

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Table 8.4: Salinity Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Salinity			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	13	SeaWater	19 702.52	19 744.15	19 723.33	20.82
B	Vinyl Ester	1	600	13	SeaWater	25 412.78	25 473.88	25 443.33	30.55
C	Epoxy	1	600	13	SeaWater	21 662.52	21 704.15	21 683.33	20.82
A	Epoxy	2	600	13	0	994.55	1002.12	998.33	3.79
B	Vinyl Ester	2	600	13	0	911.00	915.00	913.00	2.00
C	Epoxy	2	600	13	0	1989.59	1993.75	1991.67	2.08
A	Epoxy	2	600	13	200	1940.25	1944.41	1942.33	2.08
B	Vinyl Ester	2	600	13	200	1409.14	1412.19	1410.67	1.53
C	Epoxy	2	600	13	200	2241.59	2245.75	2243.67	2.08
A	Epoxy	2	600	13	20000	15 130.00	15 150.00	15 140.00	10.00
B	Vinyl Ester	2	600	13	20000	23 178.06	23 208.61	23 193.33	15.28
C	Epoxy	2	600	13	20000	20 671.39	20 701.94	20 686.67	15.28
A	Epoxy	2	600	13	SeaWater	19 191.39	19 221.94	19 206.67	15.28
B	Vinyl Ester	2	600	13	SeaWater	25 988.06	26 018.61	26 003.33	15.28
C	Epoxy	2	600	13	SeaWater	22 903.54	22 956.46	22 930.00	26.46

Table 8.5: Salinity Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Salinity			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	600	4	0	46.76	47.91	47.33	0.58
B	Vinyl Ester	600	4	0	55.81	58.86	57.33	1.53
A	Epoxy	600	4	200	404.76	405.91	405.33	0.58
B	Vinyl Ester	600	4	200	391.81	394.86	393.33	1.53
A	Epoxy	600	4	20000	35 241.39	35 271.94	35 256.67	15.28
B	Vinyl Ester	600	4	20000	34 800.00	34 820.00	34 810.00	10.00
A	Epoxy	600	4	SeaWater	36 321.39	36 351.94	36 336.67	15.28
B	Vinyl Ester	600	4	SeaWater	36 228.06	36 258.61	36 243.33	15.28
A	Epoxy	600	7	0	46.00	48.00	47.00	1.00
B	Vinyl Ester	600	7	0	54.76	55.91	55.33	0.58
A	Epoxy	600	7	200	411.00	413.00	412.00	1.00
B	Vinyl Ester	600	7	200	405.09	406.24	405.67	0.58
A	Epoxy	600	7	20000	35 288.06	35 318.61	35 303.33	15.28
B	Vinyl Ester	600	7	20000	35 310.89	35 322.44	35 316.67	5.77
A	Epoxy	600	7	SeaWater	36 650.89	36 662.44	36 656.67	5.77
B	Vinyl Ester	600	7	SeaWater	35 768.06	35 798.61	35 783.33	15.28
A	Epoxy	600	10	0	35.81	38.86	37.33	1.53
B	Vinyl Ester	600	10	0	38.09	39.24	38.67	0.58
A	Epoxy	600	10	200	402.14	405.19	403.67	1.53
B	Vinyl Ester	600	10	200	392.18	394.49	393.33	1.15
A	Epoxy	600	10	20000	35 255.12	35 278.21	35 266.67	11.55
B	Vinyl Ester	600	10	20000	34 805.85	34 847.48	34 826.67	20.82
A	Epoxy	600	10	SeaWater	37 818.06	37 848.61	37 833.33	15.28
B	Vinyl Ester	600	10	SeaWater	36 180.00	36 200.00	36 190.00	10.00
A	Epoxy	600	13	0	4830.89	4842.44	4836.67	5.77
B	Vinyl Ester	600	13	0	4687.56	4699.11	4693.33	5.77
A	Epoxy	600	13	200	4984.51	4986.82	4985.67	1.15

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Table 8.5: Salinity Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Salinity			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	600	13	200	4918.09	4919.24	4918.67	0.58
A	Epoxy	600	13	20000	41 538.06	41 568.61	41 553.33	15.28
B	Vinyl Ester	600	13	20000	39 151.39	39 181.94	39 166.67	15.28
A	Epoxy	600	13	SeaWater	45 273.94	45 346.06	45 310.00	36.06
B	Vinyl Ester	600	13	SeaWater	39 913.94	39 986.06	39 950.00	36.06

Table 8.6: Salinity Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Salinity			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Sized	600	4	0	49.02	53.64	51.33	2.31
B	Sized	600	4	0	70.76	71.91	71.33	0.58
C	Sized	600	4	0	54.02	58.64	56.33	2.31
A	Sized	600	4	200	383.59	387.75	385.67	2.08
B	Sized	600	4	200	401.09	402.24	401.67	0.58
C	Sized	600	4	200	390.59	394.75	392.67	2.08
A	Sized	600	4	20000	33 981.39	34 011.94	33 996.67	15.28
B	Sized	600	4	20000	34 215.12	34 238.21	34 226.67	11.55
C	Sized	600	4	20000	34 081.39	34 111.94	34 096.67	15.28
A	Sized	600	4	SeaWater	34 951.39	34 981.94	34 966.67	15.28
B	Sized	600	4	SeaWater	34 722.78	34 783.88	34 753.33	30.55
C	Sized	600	4	SeaWater	35 051.39	35 081.94	35 066.67	15.28
A	Unsized	600	4	0	39.76	40.91	40.33	0.58
B	Unsized	600	4	0	46.14	49.19	47.67	1.53
A	Unsized	600	4	200	387.81	390.86	389.33	1.53
B	Unsized	600	4	200	390.81	393.86	392.33	1.53
A	Unsized	600	4	20000	33 995.85	34 037.48	34 016.67	20.82
B	Unsized	600	4	20000	34 187.56	34 199.11	34 193.33	5.77
A	Unsized	600	4	SeaWater	35 172.68	35 207.32	35 190.00	17.32
B	Unsized	600	4	SeaWater	34 968.06	34 998.61	34 983.33	15.28
A	Sized	600	7	0	45.09	46.24	45.67	0.58
B	Sized	600	7	0	64.00	66.00	65.00	1.00
C	Sized	600	7	0	50.09	51.24	50.67	0.58
A	Sized	600	7	200	393.00	395.00	394.00	1.00
B	Sized	600	7	200	405.09	406.24	405.67	0.58
C	Sized	600	7	200	400.00	402.00	401.00	1.00
A	Sized	600	7	20000	34 515.85	34 557.48	34 536.67	20.82
B	Sized	600	7	20000	34 171.55	34 241.79	34 206.67	35.12
C	Sized	600	7	20000	34 615.85	34 657.48	34 636.67	20.82
A	Sized	600	7	SeaWater	34 730.89	34 742.44	34 736.67	5.77
B	Sized	600	7	SeaWater	35 365.47	35 441.19	35 403.33	37.86
C	Sized	600	7	SeaWater	34 830.89	34 842.44	34 836.67	5.77
A	Unsized	600	7	0	49.00	51.00	50.00	1.00
B	Unsized	600	7	0	55.76	56.91	56.33	0.58
A	Unsized	600	7	200	406.27	409.73	408.00	1.73
B	Unsized	600	7	200	398.76	399.91	399.33	0.58
A	Unsized	600	7	20000	34 320.00	34 340.00	34 330.00	10.00
B	Unsized	600	7	20000	34 501.39	34 531.94	34 516.67	15.28
A	Unsized	600	7	SeaWater	34 958.06	34 988.61	34 973.33	15.28
B	Unsized	600	7	SeaWater	35 078.06	35 108.61	35 093.33	15.28
A	Sized	600	10	0	41.81	44.86	43.33	1.53

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Table 8.6: Salinity Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Salinity			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Sized	600	10	0	54.25	58.41	56.33	2.08
C	Sized	600	10	0	46.81	49.86	48.33	1.53
A	Sized	600	10	200	392.51	394.82	393.67	1.15
B	Sized	600	10	200	403.76	404.91	404.33	0.58
C	Sized	600	10	200	399.51	401.82	400.67	1.15
A	Sized	600	10	20000	34 890.89	34 902.44	34 896.67	5.77
B	Sized	600	10	20000	34 822.52	34 864.15	34 843.33	20.82
C	Sized	600	10	20000	34 990.89	35 002.44	34 996.67	5.77
A	Sized	600	10	SeaWater	35 732.68	35 767.32	35 750.00	17.32
B	Sized	600	10	SeaWater	36 121.55	36 191.79	36 156.67	35.12
C	Sized	600	10	SeaWater	35 832.68	35 867.32	35 850.00	17.32
A	Unsized	600	10	0	41.14	44.19	42.67	1.53
B	Unsized	600	10	0	42.76	43.91	43.33	0.58
A	Unsized	600	10	200	398.81	401.86	400.33	1.53
B	Unsized	600	10	200	396.09	397.24	396.67	0.58
A	Unsized	600	10	20000	34 517.56	34 529.11	34 523.33	5.77
B	Unsized	600	10	20000	34 640.24	34 686.43	34 663.33	23.09
A	Unsized	600	10	SeaWater	36 555.85	36 597.48	36 576.67	20.82
B	Unsized	600	10	SeaWater	36 281.79	36 304.88	36 293.33	11.55
A	Sized	600	13	0	3157.56	3169.11	3163.33	5.77
B	Sized	600	13	0	2908.17	2958.50	2933.33	25.17
C	Sized	600	13	0	3387.56	3399.11	3393.33	5.77
A	Sized	600	13	200	3571.27	3574.73	3573.00	1.73
B	Sized	600	13	200	3480.15	3487.18	3483.67	3.51
C	Sized	600	13	200	3620.27	3623.73	3622.00	1.73
A	Sized	600	13	20000	33 460.00	33 480.00	33 470.00	10.00
B	Sized	600	13	20000	34 074.52	34 138.81	34 106.67	32.15
C	Sized	600	13	20000	33 640.00	33 660.00	33 650.00	10.00
A	Sized	600	13	SeaWater	34 626.41	34 713.59	34 670.00	43.59
B	Sized	600	13	SeaWater	35 176.12	35 237.22	35 206.67	30.55
C	Sized	600	13	SeaWater	34 806.41	34 893.59	34 850.00	43.59
A	Unsized	600	13	0	2650.24	2696.43	2673.33	23.09
B	Unsized	600	13	0	3007.56	3019.11	3013.33	5.77
A	Unsized	600	13	200	3115.00	3121.00	3118.00	3.00
B	Unsized	600	13	200	3345.12	3351.55	3348.33	3.21
A	Unsized	600	13	20000	33 951.39	33 981.94	33 966.67	15.28
B	Unsized	600	13	20000	34 162.52	34 204.15	34 183.33	20.82
A	Unsized	600	13	SeaWater	34 854.00	34 952.66	34 903.33	49.33
B	Unsized	600	13	SeaWater	35 380.00	35 400.00	35 390.00	10.00

For a better understanding, change in the salinity content of the environments was plotted in graphs in

Figure 8.4, 8.5, and 8.6.

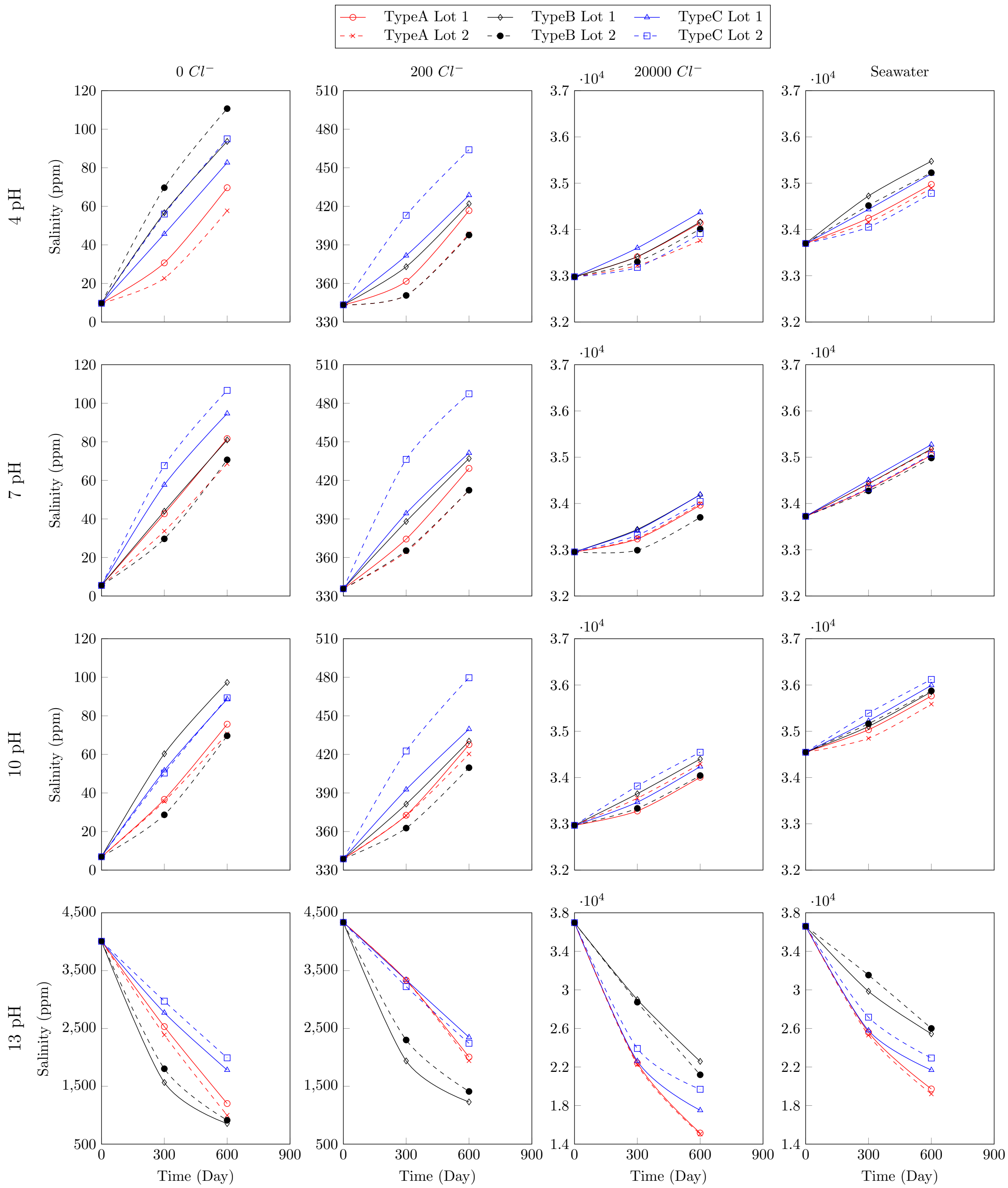

Figure 8.4: Salinity of environments after exposure of rebars

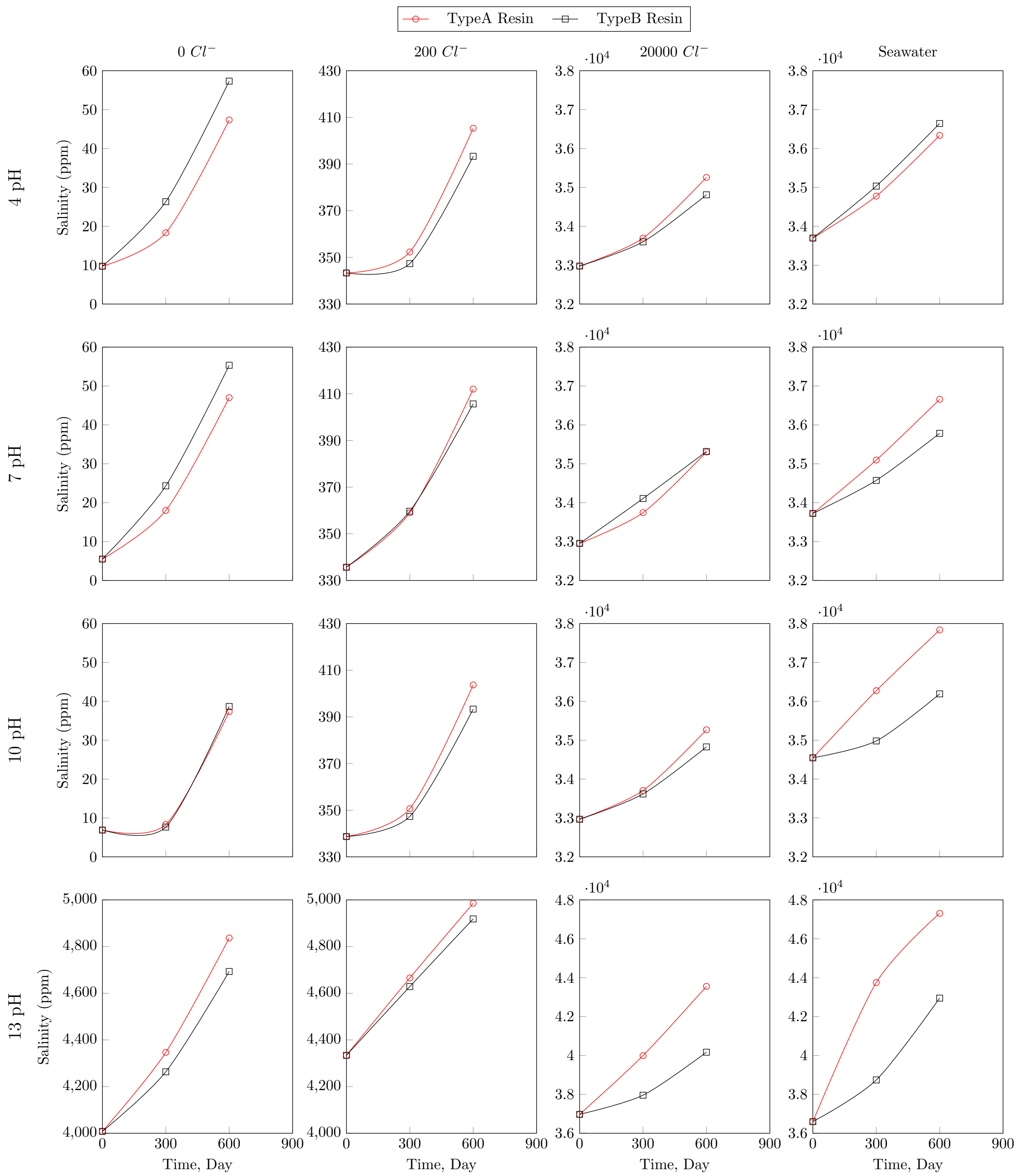

Figure 8.5: Salinity of environments after exposure of resins

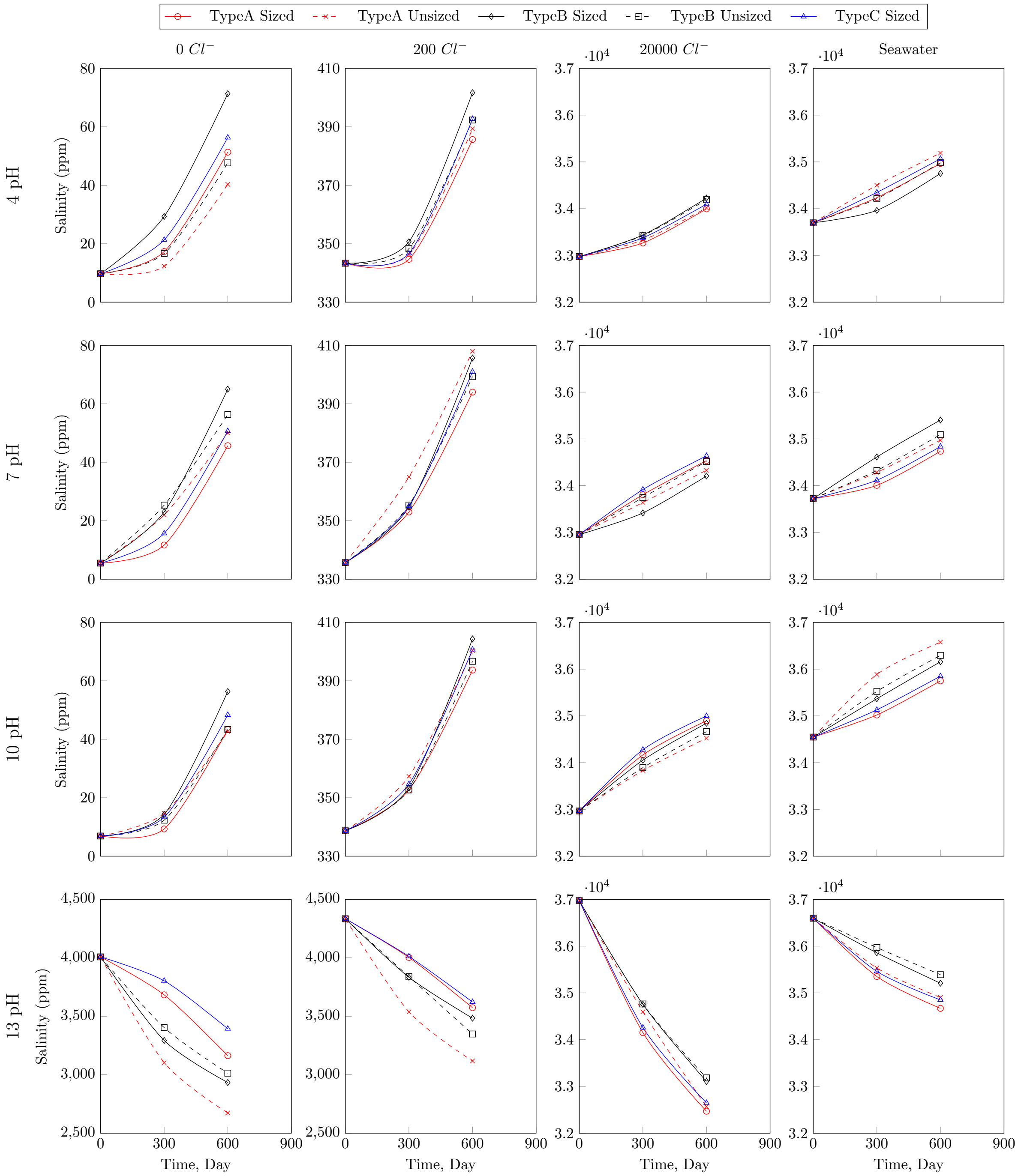

Figure 8.6: Salinity of environments after exposure of sized and unsized fibers

8.2.3 Dissolved oxygen (DO)

DO of the chemical environments was measured after 600 days of exposure. Tables 8.7, 8.8, and 8.9 below shows the DO data of environments in which rebars, resins, and fibers were exposed.

Table 8.7: Dissolved Oxygen Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Dissolved Oxygen			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	4	0	7.39	7.43	7.41	0.02
B	Vinyl Ester	1	600	4	0	7.99	8.02	8.01	0.02
C	Epoxy	1	600	4	0	7.44	7.50	7.47	0.03
A	Epoxy	1	600	4	200	7.33	7.37	7.35	0.02
B	Vinyl Ester	1	600	4	200	7.93	8.07	8.00	0.07
C	Epoxy	1	600	4	200	7.38	7.41	7.39	0.02
A	Epoxy	1	600	4	20000	7.24	7.25	7.25	0.01
B	Vinyl Ester	1	600	4	20000	7.94	7.95	7.94	0.01
C	Epoxy	1	600	4	20000	7.27	7.33	7.30	0.03
A	Epoxy	1	600	4	SeaWater	7.20	7.26	7.23	0.03
B	Vinyl Ester	1	600	4	SeaWater	7.79	7.85	7.82	0.03
C	Epoxy	1	600	4	SeaWater	7.19	7.21	7.20	0.01
A	Epoxy	2	600	4	0	6.85	6.93	6.89	0.04
B	Vinyl Ester	2	600	4	0	7.90	8.02	7.96	0.06
C	Epoxy	2	600	4	0	6.92	7.02	6.97	0.05
A	Epoxy	2	600	4	200	6.81	6.84	6.82	0.02
B	Vinyl Ester	2	600	4	200	7.92	7.93	7.93	0.01
C	Epoxy	2	600	4	200	6.95	6.97	6.96	0.01
A	Epoxy	2	600	4	20000	6.72	6.77	6.75	0.03
B	Vinyl Ester	2	600	4	20000	7.88	7.94	7.91	0.03
C	Epoxy	2	600	4	20000	6.92	6.93	6.93	0.01
A	Epoxy	2	600	4	SeaWater	6.60	6.63	6.62	0.02
B	Vinyl Ester	2	600	4	SeaWater	7.67	7.77	7.72	0.05
C	Epoxy	2	600	4	SeaWater	6.21	6.28	6.24	0.04
A	Epoxy	1	600	7	0	7.39	7.41	7.40	0.01
B	Vinyl Ester	1	600	7	0	7.96	8.06	8.01	0.05
C	Epoxy	1	600	7	0	7.39	7.43	7.41	0.02
A	Epoxy	1	600	7	200	7.30	7.34	7.32	0.02
B	Vinyl Ester	1	600	7	200	7.96	8.04	8.00	0.04
C	Epoxy	1	600	7	200	7.28	7.34	7.31	0.03
A	Epoxy	1	600	7	20000	7.25	7.26	7.25	0.01
B	Vinyl Ester	1	600	7	20000	7.91	7.93	7.92	0.01
C	Epoxy	1	600	7	20000	7.23	7.27	7.25	0.02
A	Epoxy	1	600	7	SeaWater	7.14	7.16	7.15	0.01
B	Vinyl Ester	1	600	7	SeaWater	7.80	7.81	7.80	0.01
C	Epoxy	1	600	7	SeaWater	7.12	7.14	7.13	0.01
A	Epoxy	2	600	7	0	6.80	6.86	6.83	0.03

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Table 8.7: Dissolved Oxygen Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Dissolved Oxygen			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	2	600	7	0	7.92	7.96	7.94	0.02
C	Epoxy	2	600	7	0	6.91	6.97	6.94	0.03
A	Epoxy	2	600	7	200	6.71	6.77	6.74	0.03
B	Vinyl Ester	2	600	7	200	7.90	7.93	7.92	0.02
C	Epoxy	2	600	7	200	6.88	6.97	6.93	0.05
A	Epoxy	2	600	7	20000	6.64	6.70	6.67	0.03
B	Vinyl Ester	2	600	7	20000	7.86	7.87	7.87	0.01
C	Epoxy	2	600	7	20000	6.85	6.87	6.86	0.01
A	Epoxy	2	600	7	SeaWater	6.54	6.57	6.55	0.02
B	Vinyl Ester	2	600	7	SeaWater	7.71	7.73	7.72	0.01
C	Epoxy	2	600	7	SeaWater	5.92	5.96	5.94	0.02
A	Epoxy	1	600	10	0	7.35	7.42	7.39	0.03
B	Vinyl Ester	1	600	10	0	7.97	8.03	8.00	0.03
C	Epoxy	1	600	10	0	7.26	7.33	7.29	0.04
A	Epoxy	1	600	10	200	7.29	7.34	7.31	0.03
B	Vinyl Ester	1	600	10	200	7.97	8.02	7.99	0.03
C	Epoxy	1	600	10	200	7.16	7.23	7.20	0.03
A	Epoxy	1	600	10	20000	7.14	7.22	7.18	0.04
B	Vinyl Ester	1	600	10	20000	7.84	7.96	7.90	0.06
C	Epoxy	1	600	10	20000	7.09	7.16	7.13	0.03
A	Epoxy	1	600	10	SeaWater	6.77	6.81	6.79	0.02
B	Vinyl Ester	1	600	10	SeaWater	7.77	7.81	7.79	0.02
C	Epoxy	1	600	10	SeaWater	6.99	7.03	7.01	0.02
A	Epoxy	2	600	10	0	6.69	6.76	6.72	0.04
B	Vinyl Ester	2	600	10	0	7.86	7.87	7.87	0.01
C	Epoxy	2	600	10	0	6.91	6.94	6.93	0.02
A	Epoxy	2	600	10	200	6.61	6.65	6.63	0.02
B	Vinyl Ester	2	600	10	200	7.86	7.87	7.87	0.01
C	Epoxy	2	600	10	200	6.89	6.90	6.90	0.01
A	Epoxy	2	600	10	20000	6.53	6.60	6.56	0.04
B	Vinyl Ester	2	600	10	20000	7.77	7.85	7.81	0.04
C	Epoxy	2	600	10	20000	6.76	6.88	6.82	0.06
A	Epoxy	2	600	10	SeaWater	6.39	6.46	6.43	0.04
B	Vinyl Ester	2	600	10	SeaWater	7.66	7.71	7.68	0.02
C	Epoxy	2	600	10	SeaWater	5.88	5.89	5.88	0.01
A	Epoxy	1	600	13	0	7.35	7.36	7.35	0.01
B	Vinyl Ester	1	600	13	0	7.96	7.97	7.97	0.01
C	Epoxy	1	600	13	0	6.67	6.71	6.69	0.02
A	Epoxy	1	600	13	200	7.17	7.21	7.19	0.02
B	Vinyl Ester	1	600	13	200	7.91	7.99	7.95	0.04
C	Epoxy	1	600	13	200	6.59	6.61	6.60	0.01
A	Epoxy	1	600	13	20000	6.86	6.89	6.87	0.02

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Table 8.7: Dissolved Oxygen Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Dissolved Oxygen			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	1	600	13	20000	7.85	7.93	7.89	0.04
C	Epoxy	1	600	13	20000	6.49	6.51	6.50	0.01
A	Epoxy	1	600	13	SeaWater	6.29	6.34	6.31	0.03
B	Vinyl Ester	1	600	13	SeaWater	7.73	7.79	7.76	0.03
C	Epoxy	1	600	13	SeaWater	6.31	6.37	6.34	0.03
A	Epoxy	2	600	13	0	6.08	6.14	6.11	0.03
B	Vinyl Ester	2	600	13	0	7.83	7.86	7.85	0.02
C	Epoxy	2	600	13	0	6.78	6.88	6.83	0.05
A	Epoxy	2	600	13	200	6.02	6.04	6.03	0.01
B	Vinyl Ester	2	600	13	200	7.78	7.79	7.79	0.01
C	Epoxy	2	600	13	200	6.79	6.82	6.81	0.02
A	Epoxy	2	600	13	20000	5.90	5.95	5.93	0.02
B	Vinyl Ester	2	600	13	20000	7.74	7.80	7.77	0.03
C	Epoxy	2	600	13	20000	6.67	6.70	6.68	0.02
A	Epoxy	2	600	13	SeaWater	5.80	5.85	5.83	0.03
B	Vinyl Ester	2	600	13	SeaWater	7.66	7.68	7.67	0.01
C	Epoxy	2	600	13	SeaWater	5.60	5.70	5.65	0.05

Table 8.8: Dissolved Oxygen Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Dissolved Oxygen			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	600	4	0	8.42	8.44	8.43	0.01
B	Vinyl Ester	600	4	0	8.31	8.39	8.35	0.04
A	Epoxy	600	4	200	8.34	8.42	8.38	0.04
B	Vinyl Ester	600	4	200	8.32	8.33	8.33	0.01
A	Epoxy	600	4	20000	8.33	8.35	8.34	0.01
B	Vinyl Ester	600	4	20000	8.27	8.32	8.30	0.03
A	Epoxy	600	4	SeaWater	8.15	8.16	8.15	0.01
B	Vinyl Ester	600	4	SeaWater	8.11	8.19	8.15	0.04
A	Epoxy	600	7	0	8.39	8.43	8.41	0.02
B	Vinyl Ester	600	7	0	8.31	8.32	8.31	0.01
A	Epoxy	600	7	200	8.34	8.37	8.36	0.02
B	Vinyl Ester	600	7	200	8.27	8.33	8.30	0.03
A	Epoxy	600	7	20000	8.31	8.34	8.32	0.02
B	Vinyl Ester	600	7	20000	8.28	8.31	8.29	0.02

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Table 8.8: Dissolved Oxygen Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Dissolved Oxygen			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	600	7	SeaWater	8.13	8.15	8.14	0.01
B	Vinyl Ester	600	7	SeaWater	8.09	8.19	8.14	0.05
A	Epoxy	600	10	0	8.33	8.38	8.35	0.03
B	Vinyl Ester	600	10	0	8.26	8.32	8.29	0.03
A	Epoxy	600	10	200	8.29	8.33	8.31	0.02
B	Vinyl Ester	600	10	200	8.29	8.32	8.30	0.02
A	Epoxy	600	10	20000	8.28	8.30	8.29	0.01
B	Vinyl Ester	600	10	20000	8.24	8.30	8.27	0.03
A	Epoxy	600	10	SeaWater	8.08	8.20	8.14	0.06
B	Vinyl Ester	600	10	SeaWater	8.10	8.12	8.11	0.01
A	Epoxy	600	13	0	8.34	8.35	8.35	0.01
B	Vinyl Ester	600	13	0	8.25	8.31	8.28	0.03
A	Epoxy	600	13	200	8.30	8.31	8.30	0.01
B	Vinyl Ester	600	13	200	8.24	8.30	8.27	0.03
A	Epoxy	600	13	20000	8.22	8.32	8.27	0.05
B	Vinyl Ester	600	13	20000	8.20	8.22	8.21	0.01
A	Epoxy	600	13	SeaWater	8.12	8.15	8.13	0.02
B	Vinyl Ester	600	13	SeaWater	8.09	8.13	8.11	0.02

Table 8.9: Dissolved Oxygen Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Dissolved Oxygen			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Sized	600	4	0	8.23	8.24	8.24	0.01
B	Sized	600	4	0	8.29	8.30	8.29	0.01
C	Sized	600	4	0	8.13	8.17	8.15	0.02
A	Sized	600	4	200	8.20	8.23	8.21	0.02
B	Sized	600	4	200	8.19	8.20	8.20	0.01
C	Sized	600	4	200	8.07	8.10	8.09	0.02
A	Sized	600	4	20000	8.18	8.20	8.19	0.01
B	Sized	600	4	20000	8.12	8.19	8.15	0.04
C	Sized	600	4	20000	8.04	8.06	8.05	0.01
A	Sized	600	4	SeaWater	8.01	8.04	8.02	0.02
B	Sized	600	4	SeaWater	8.04	8.06	8.05	0.01
C	Sized	600	4	SeaWater	8.00	8.02	8.01	0.01
A	Unsized	600	4	0	8.33	8.34	8.34	0.01

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Table 8.9: Dissolved Oxygen Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Dissolved Oxygen			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Unsized	600	4	0	8.27	8.31	8.29	0.02
A	Unsized	600	4	200	8.28	8.32	8.30	0.02
B	Unsized	600	4	200	8.26	8.28	8.27	0.01
A	Unsized	600	4	20000	8.22	8.29	8.26	0.04
B	Unsized	600	4	20000	8.22	8.26	8.24	0.02
A	Unsized	600	4	SeaWater	8.05	8.09	8.07	0.02
B	Unsized	600	4	SeaWater	8.05	8.07	8.06	0.01
A	Sized	600	7	0	8.23	8.25	8.24	0.01
B	Sized	600	7	0	8.19	8.25	8.22	0.03
C	Sized	600	7	0	8.13	8.14	8.13	0.01
A	Sized	600	7	200	8.16	8.19	8.18	0.02
B	Sized	600	7	200	8.17	8.21	8.19	0.02
C	Sized	600	7	200	8.04	8.06	8.05	0.01
A	Sized	600	7	20000	8.14	8.20	8.17	0.03
B	Sized	600	7	20000	8.12	8.16	8.14	0.02
C	Sized	600	7	20000	7.96	8.00	7.98	0.02
A	Sized	600	7	SeaWater	7.97	7.98	7.97	0.01
B	Sized	600	7	SeaWater	7.98	8.06	8.02	0.04
C	Sized	600	7	SeaWater	7.93	7.95	7.94	0.01
A	Unsized	600	7	0	8.33	8.34	8.33	0.01
B	Unsized	600	7	0	8.26	8.32	8.29	0.03
A	Unsized	600	7	200	8.27	8.28	8.28	0.01
B	Unsized	600	7	200	8.25	8.26	8.25	0.01
A	Unsized	600	7	20000	8.20	8.28	8.24	0.04
B	Unsized	600	7	20000	8.22	8.24	8.23	0.01
A	Unsized	600	7	SeaWater	8.01	8.06	8.04	0.03
B	Unsized	600	7	SeaWater	8.02	8.10	8.06	0.04
A	Sized	600	10	0	8.20	8.22	8.21	0.01
B	Sized	600	10	0	8.19	8.20	8.20	0.01
C	Sized	600	10	0	8.05	8.08	8.06	0.02
A	Sized	600	10	200	8.15	8.19	8.17	0.02
B	Sized	600	10	200	8.18	8.19	8.19	0.01
C	Sized	600	10	200	7.96	7.99	7.98	0.02
A	Sized	600	10	20000	8.12	8.20	8.16	0.04
B	Sized	600	10	20000	8.12	8.16	8.14	0.02
C	Sized	600	10	20000	7.92	7.94	7.93	0.01
A	Sized	600	10	SeaWater	7.94	7.98	7.96	0.02
B	Sized	600	10	SeaWater	7.98	8.02	8.00	0.02
C	Sized	600	10	SeaWater	7.82	7.86	7.84	0.02
A	Unsized	600	10	0	8.29	8.31	8.30	0.01
B	Unsized	600	10	0	8.24	8.32	8.28	0.04
A	Unsized	600	10	200	8.26	8.28	8.27	0.01

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Table 8.9: Dissolved Oxygen Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Dissolved Oxygen			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Unsized	600	10	200	8.22	8.27	8.25	0.03
A	Unsized	600	10	20000	8.22	8.26	8.24	0.02
B	Unsized	600	10	20000	8.21	8.22	8.21	0.01
A	Unsized	600	10	SeaWater	8.03	8.05	8.04	0.01
B	Unsized	600	10	SeaWater	8.03	8.08	8.06	0.02
A	Sized	600	13	0	8.15	8.16	8.16	0.01
B	Sized	600	13	0	8.17	8.21	8.19	0.02
C	Sized	600	13	0	8.02	8.04	8.03	0.01
A	Sized	600	13	200	8.14	8.17	8.16	0.02
B	Sized	600	13	200	8.17	8.20	8.18	0.02
C	Sized	600	13	200	7.93	7.96	7.94	0.02
A	Sized	600	13	20000	8.11	8.21	8.16	0.05
B	Sized	600	13	20000	8.10	8.13	8.12	0.02
C	Sized	600	13	20000	7.83	7.86	7.85	0.02
A	Sized	600	13	SeaWater	7.91	8.01	7.96	0.05
B	Sized	600	13	SeaWater	7.94	8.02	7.98	0.04
C	Sized	600	13	SeaWater	7.75	7.79	7.77	0.02
A	Unsized	600	13	0	8.26	8.28	8.27	0.01
B	Unsized	600	13	0	8.24	8.29	8.26	0.02
A	Unsized	600	13	200	8.22	8.26	8.24	0.02
B	Unsized	600	13	200	8.25	8.27	8.26	0.01
A	Unsized	600	13	20000	8.23	8.24	8.23	0.01
B	Unsized	600	13	20000	8.13	8.20	8.17	0.04
A	Unsized	600	13	SeaWater	8.01	8.04	8.02	0.02
B	Unsized	600	13	SeaWater	8.01	8.09	8.05	0.04

For a better understanding, change in the DO content of the environments was plotted in graphs in Figure 8.7, 8.8, and 8.9. It can be seen that dissolved oxygen content of environments has decreased overtime.

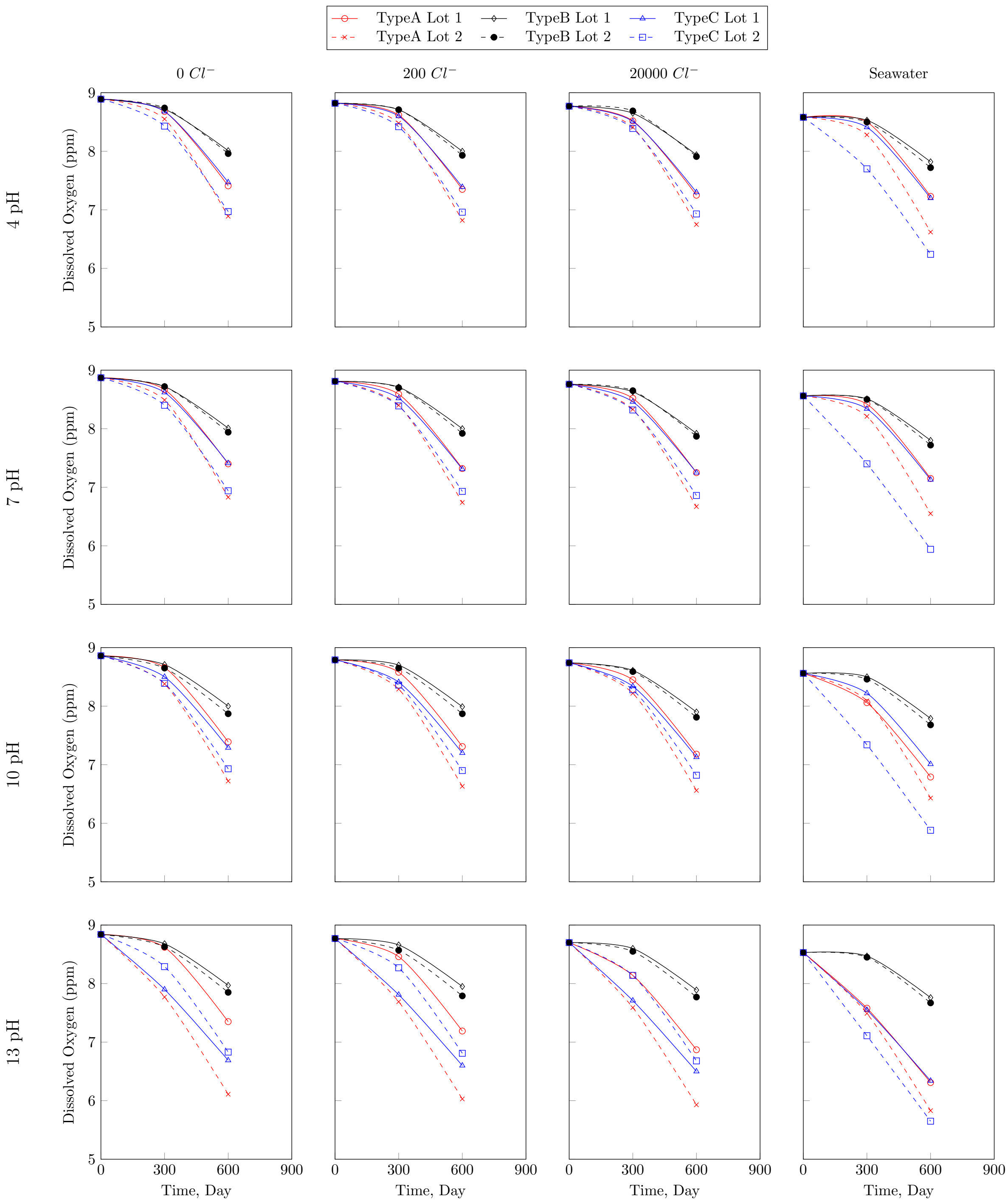

Figure 8.7: Dissolved oxygen concentration of environments after exposure of rebars

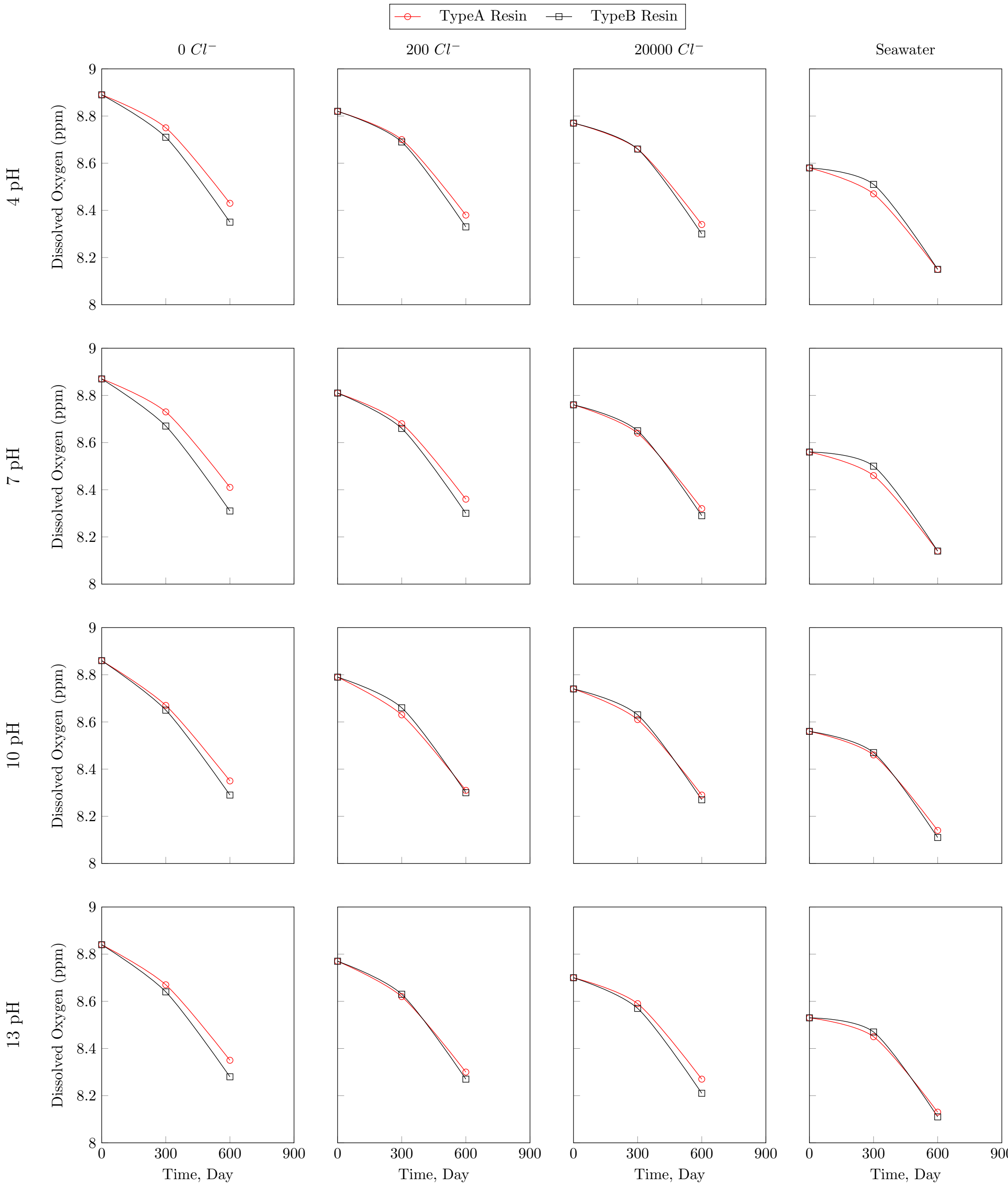

Figure 8.8: Dissolved oxygen concentration of environments after exposure of resins

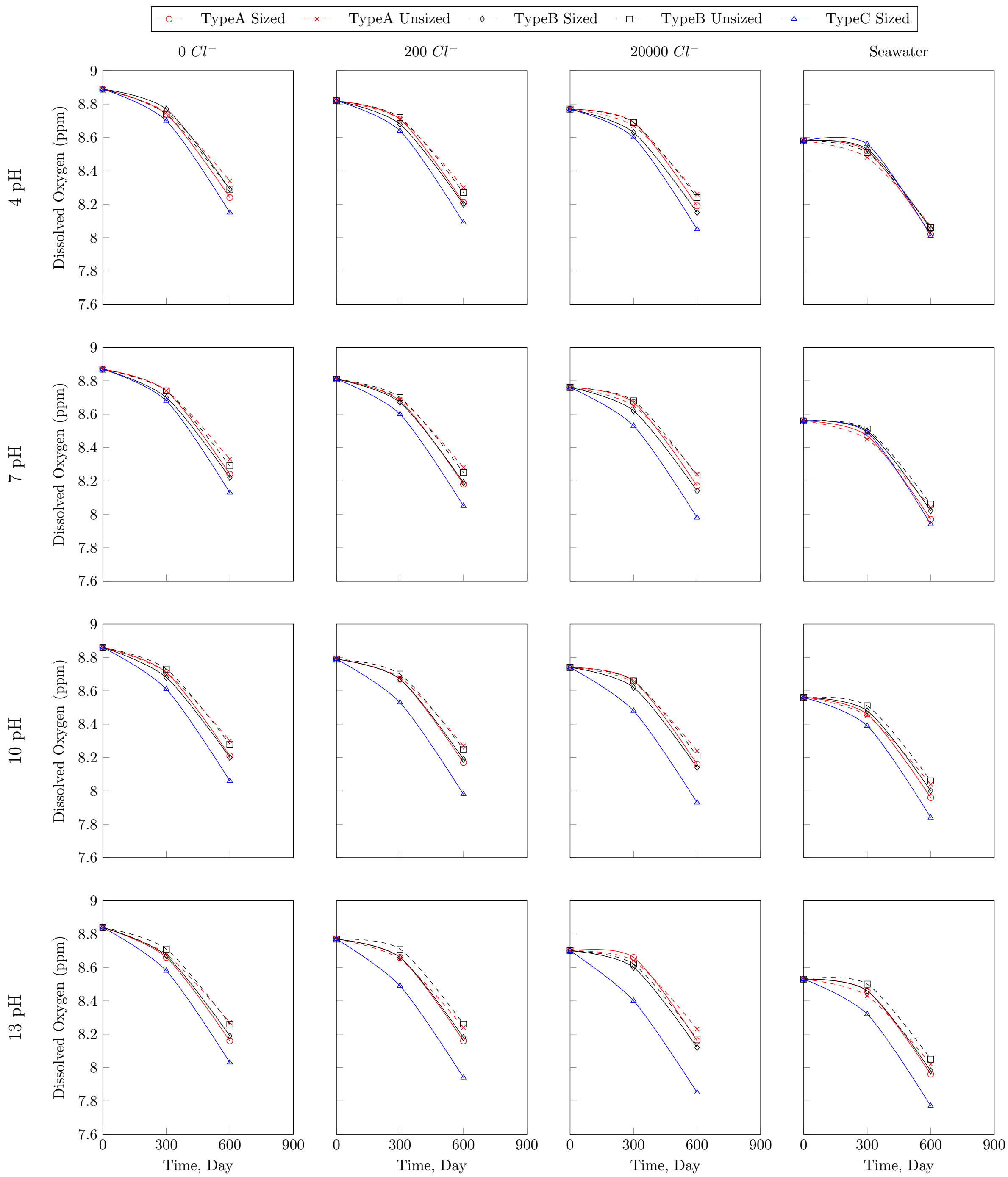

Figure 8.9: Dissolved oxygen concentration of environments after exposure of sized and unsized fibers

8.2.4 Alkalinity

Alkalinity of the chemical environments was measured after 600 days of exposure. Tables 8.10, 8.11, and 8.12 below shows the pH data of environments in which rebars, resins, and fibers were exposed.

Table 8.10: Alkalinity Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Alkalinity			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppmas$CaCO_3$	$\vee$ ppmas$CaCO_3$	μ ppmas$CaCO_3$	σ ppmas$CaCO_3$
A	Epoxy	1	600	4	0	−20.75	−20.56	−20.66	0.09
B	Vinyl Ester	1	600	4	0	−1.29	−1.23	−1.26	0.03
C	Epoxy	1	600	4	0	−14.17	−14.00	−14.08	0.08
A	Epoxy	1	600	4	200	−21.20	−21.06	−21.13	0.07
B	Vinyl Ester	1	600	4	200	−1.05	−1.01	−1.03	0.02
C	Epoxy	1	600	4	200	−15.45	−15.33	−15.39	0.06
A	Epoxy	1	600	4	20000	−22.41	−21.95	−22.18	0.23
B	Vinyl Ester	1	600	4	20000	0.71	2.15	1.43	0.72
C	Epoxy	1	600	4	20000	−16.46	−16.05	−16.25	0.20
A	Epoxy	1	600	4	SeaWater	−24.75	−24.59	−24.67	0.08
B	Vinyl Ester	1	600	4	SeaWater	0.32	1.02	0.67	0.35
C	Epoxy	1	600	4	SeaWater	−18.46	−18.32	−18.39	0.07
A	Epoxy	2	600	4	0	−27.19	−22.57	−24.88	2.31
B	Vinyl Ester	2	600	4	0	−1.14	−0.72	−0.93	0.21
C	Epoxy	2	600	4	0	−20.48	−16.51	−18.50	1.99
A	Epoxy	2	600	4	200	−23.28	−21.72	−22.50	0.78
B	Vinyl Ester	2	600	4	200	−0.86	−0.46	−0.66	0.20
C	Epoxy	2	600	4	200	−19.01	−17.67	−18.34	0.67
A	Epoxy	2	600	4	20000	−21.11	−20.71	−20.91	0.20
B	Vinyl Ester	2	600	4	20000	1.00	2.06	1.53	0.53
C	Epoxy	2	600	4	20000	−18.47	−18.13	−18.30	0.17
A	Epoxy	2	600	4	SeaWater	−21.57	−21.11	−21.34	0.23
B	Vinyl Ester	2	600	4	SeaWater	0.60	0.83	0.71	0.12
C	Epoxy	2	600	4	SeaWater	−19.95	−19.56	−19.75	0.20
A	Epoxy	1	600	7	0	0.62	1.83	1.22	0.60
B	Vinyl Ester	1	600	7	0	4.53	6.03	5.28	0.75
C	Epoxy	1	600	7	0	0.67	1.93	1.30	0.63

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Table 8.10: Alkalinity Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Alkalinity			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppmas$CaCO_3$	$\vee$ ppmas$CaCO_3$	μ ppmas$CaCO_3$	σ ppmas$CaCO_3$
A	Epoxy	1	600	7	200	0.91	1.37	1.14	0.23
B	Vinyl Ester	1	600	7	200	5.85	6.99	6.42	0.57
C	Epoxy	1	600	7	200	0.96	1.45	1.20	0.24
A	Epoxy	1	600	7	20000	0.70	1.18	0.94	0.24
B	Vinyl Ester	1	600	7	20000	7.45	7.95	7.70	0.25
C	Epoxy	1	600	7	20000	0.75	1.26	1.00	0.25
A	Epoxy	1	600	7	SeaWater	41.73	43.17	42.45	0.72
B	Vinyl Ester	1	600	7	SeaWater	83.76	84.72	84.24	0.48
C	Epoxy	1	600	7	SeaWater	44.58	46.10	45.34	0.76
A	Epoxy	2	600	7	0	0.56	1.33	0.95	0.38
B	Vinyl Ester	2	600	7	0	5.74	7.30	6.52	0.78
C	Epoxy	2	600	7	0	0.61	1.43	1.02	0.41
A	Epoxy	2	600	7	200	0.14	1.32	0.73	0.59
B	Vinyl Ester	2	600	7	200	6.43	7.61	7.02	0.59
C	Epoxy	2	600	7	200	0.16	1.41	0.78	0.63
A	Epoxy	2	600	7	20000	0.35	0.54	0.44	0.09
B	Vinyl Ester	2	600	7	20000	8.16	8.68	8.42	0.26
C	Epoxy	2	600	7	20000	0.35	0.55	0.45	0.10
A	Epoxy	2	600	7	SeaWater	40.29	40.97	40.63	0.34
B	Vinyl Ester	2	600	7	SeaWater	92.13	92.68	92.41	0.27
C	Epoxy	2	600	7	SeaWater	42.08	42.80	42.44	0.36
A	Epoxy	1	600	10	0	3.93	4.37	4.15	0.22
B	Vinyl Ester	1	600	10	0	20.89	21.29	21.09	0.20
C	Epoxy	1	600	10	0	5.23	5.69	5.46	0.23
A	Epoxy	1	600	10	200	3.65	3.71	3.68	0.03
B	Vinyl Ester	1	600	10	200	26.68	27.04	26.86	0.18
C	Epoxy	1	600	10	200	4.91	4.97	4.94	0.03

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Table 8.10: Alkalinity Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Alkalinity			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppmas$CaCO_3$	$\vee$ ppmas$CaCO_3$	μ ppmas$CaCO_3$	σ ppmas$CaCO_3$
A	Epoxy	1	600	10	20000	2.87	3.30	3.08	0.21
B	Vinyl Ester	1	600	10	20000	30.20	30.30	30.25	0.05
C	Epoxy	1	600	10	20000	3.29	3.74	3.52	0.22
A	Epoxy	1	600	10	SeaWater	85.89	87.49	86.69	0.80
B	Vinyl Ester	1	600	10	SeaWater	145.91	147.42	146.67	0.75
C	Epoxy	1	600	10	SeaWater	90.84	92.52	91.68	0.84
A	Epoxy	2	600	10	0	3.55	3.73	3.64	0.09
B	Vinyl Ester	2	600	10	0	21.98	22.11	22.05	0.06
C	Epoxy	2	600	10	0	4.57	4.77	4.67	0.10
A	Epoxy	2	600	10	200	2.55	2.71	2.63	0.08
B	Vinyl Ester	2	600	10	200	25.68	26.04	25.86	0.18
C	Epoxy	2	600	10	200	3.91	4.09	4.00	0.09
A	Epoxy	2	600	10	20000	1.88	2.31	2.09	0.21
B	Vinyl Ester	2	600	10	20000	26.90	27.00	26.95	0.05
C	Epoxy	2	600	10	20000	2.69	3.14	2.91	0.23
A	Epoxy	2	600	10	SeaWater	81.01	82.84	81.92	0.92
B	Vinyl Ester	2	600	10	SeaWater	144.39	146.36	145.37	0.98
C	Epoxy	2	600	10	SeaWater	88.48	90.42	89.45	0.97
A	Epoxy	1	600	13	0	10.25	26.42	18.33	8.08
B	Vinyl Ester	1	600	13	0	423.00	439.00	431.00	8.00
C	Epoxy	1	600	13	0	17.84	20.92	19.38	1.54
A	Epoxy	1	600	13	200	12.54	19.46	16.00	3.46
B	Vinyl Ester	1	600	13	200	968.98	980.35	974.67	5.69
C	Epoxy	1	600	13	200	12.56	19.54	16.05	3.49
A	Epoxy	1	600	13	20000	12.18	14.49	13.33	1.15
B	Vinyl Ester	1	600	13	20000	983.85	1004.15	994.00	10.15
C	Epoxy	1	600	13	20000	13.35	15.68	14.52	1.17

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Table 8.10: Alkalinity Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Alkalinity			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppmas$CaCO_3$	$\vee$ ppmas$CaCO_3$	μ ppmas$CaCO_3$	σ ppmas$CaCO_3$
A	Epoxy	1	600	13	SeaWater	7.61	13.72	10.67	3.06
B	Vinyl Ester	1	600	13	SeaWater	3225.51	3279.82	3252.67	27.15
C	Epoxy	1	600	13	SeaWater	12.73	15.66	14.19	1.47
A	Epoxy	2	600	13	0	3.82	10.85	7.33	3.51
B	Vinyl Ester	2	600	13	0	916.00	932.00	924.00	8.00
C	Epoxy	2	600	13	0	3.84	7.95	5.89	2.06
A	Epoxy	2	600	13	200	6.09	7.24	6.67	0.58
B	Vinyl Ester	2	600	13	200	971.31	983.36	977.33	6.03
C	Epoxy	2	600	13	200	3.31	6.69	5.00	1.69
A	Epoxy	2	600	13	20000	2.25	6.41	4.33	2.08
B	Vinyl Ester	2	600	13	20000	1023.85	1044.15	1034.00	10.15
C	Epoxy	2	600	13	20000	4.95	5.00	4.98	0.02
A	Epoxy	2	600	13	SeaWater	2.27	5.73	4.00	1.73
B	Vinyl Ester	2	600	13	SeaWater	3084.19	3120.48	3102.33	18.15
C	Epoxy	2	600	13	SeaWater	12.12	19.73	15.92	3.81

Table 8.11: Alkalinity Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Alkalinity			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ $ppmasCaCO_3$	$\vee$ $ppmasCaCO_3$	μ $ppmasCaCO_3$	σ $ppmasCaCO_3$
A	Epoxy	600	4	0	−9.30	−8.94	−9.12	0.18
B	Vinyl Ester	600	4	0	−10.47	−9.51	−9.99	0.48
A	Epoxy	600	4	200	−10.00	−9.86	−9.93	0.07
B	Vinyl Ester	600	4	200	−11.81	−11.76	−11.78	0.02
A	Epoxy	600	4	20000	−12.60	−11.89	−12.24	0.36
B	Vinyl Ester	600	4	20000	−14.18	−14.04	−14.11	0.07
A	Epoxy	600	4	SeaWater	−14.44	−14.39	−14.42	0.02
B	Vinyl Ester	600	4	SeaWater	−16.45	−16.23	−16.34	0.11
A	Epoxy	600	7	0	0.64	1.70	1.17	0.53
B	Vinyl Ester	600	7	0	0.19	1.52	0.85	0.67
A	Epoxy	600	7	200	0.26	1.37	0.81	0.55
B	Vinyl Ester	600	7	200	−0.10	1.22	0.56	0.66
A	Epoxy	600	7	20000	0.43	0.90	0.66	0.24
B	Vinyl Ester	600	7	20000	−0.06	0.79	0.36	0.43
A	Epoxy	600	7	SeaWater	48.28	48.94	48.61	0.33
B	Vinyl Ester	600	7	SeaWater	46.14	46.81	46.47	0.34
A	Epoxy	600	10	0	3.58	3.94	3.76	0.18
B	Vinyl Ester	600	10	0	3.03	3.39	3.21	0.18
A	Epoxy	600	10	200	2.02	2.44	2.23	0.21
B	Vinyl Ester	600	10	200	1.80	2.28	2.04	0.24
A	Epoxy	600	10	20000	1.86	2.29	2.07	0.21
B	Vinyl Ester	600	10	20000	1.43	1.71	1.57	0.14
A	Epoxy	600	10	SeaWater	86.91	88.08	87.49	0.58
B	Vinyl Ester	600	10	SeaWater	84.33	85.50	84.92	0.59
A	Epoxy	600	13	0	1421.00	1437.00	1429.00	8.00
B	Vinyl Ester	600	13	0	1229.56	1241.78	1235.67	6.11
A	Epoxy	600	13	200	1325.98	1337.35	1331.67	5.69

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Table 8.11: Alkalinity Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Alkalinity			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppmas$CaCO_3$	$\vee$ ppmas$CaCO_3$	μ ppmas$CaCO_3$	σ ppmas$CaCO_3$
B	Vinyl Ester	600	13	200	1138.98	1150.35	1144.67	5.69
A	Epoxy	600	13	20000	1269.37	1297.96	1283.67	14.29
B	Vinyl Ester	600	13	20000	1069.37	1097.96	1083.67	14.29
A	Epoxy	600	13	SeaWater	1176.43	1214.24	1195.33	18.90
B	Vinyl Ester	600	13	SeaWater	1049.76	1087.57	1068.67	18.90

Table 8.12: Alkalinity Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Alkalinity			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppmas$CaCO_3$	$\vee$ ppmas$CaCO_3$	μ ppmas$CaCO_3$	σ ppmas$CaCO_3$
A	Sized	600	4	0	−1.35	−1.16	−1.26	0.09
B	Sized	600	4	0	−1.61	−1.56	−1.58	0.02
C	Sized	600	4	0	−1.17	−1.00	−1.09	0.08
A	Sized	600	4	200	−1.19	−1.13	−1.16	0.03
B	Sized	600	4	200	−1.22	−1.12	−1.17	0.05
C	Sized	600	4	200	−0.84	−0.78	−0.81	0.03
A	Sized	600	4	20000	0.57	0.74	0.66	0.08
B	Sized	600	4	20000	−0.47	0.54	0.04	0.50
C	Sized	600	4	20000	0.43	0.58	0.50	0.07
A	Sized	600	4	SeaWater	0.77	1.42	1.10	0.33
B	Sized	600	4	SeaWater	0.40	1.01	0.70	0.31
C	Sized	600	4	SeaWater	0.95	1.54	1.24	0.29
A	Unsized	600	4	0	−0.90	−0.65	−0.78	0.13
B	Unsized	600	4	0	−1.10	−1.05	−1.07	0.02
A	Unsized	600	4	200	−0.36	0.08	−0.14	0.22
B	Unsized	600	4	200	−1.02	−1.00	−1.01	0.01
A	Unsized	600	4	20000	0.23	0.45	0.34	0.11
B	Unsized	600	4	20000	0.28	0.51	0.40	0.12
A	Unsized	600	4	SeaWater	0.35	0.76	0.55	0.20
B	Unsized	600	4	SeaWater	0.47	0.93	0.70	0.23
A	Sized	600	7	0	5.78	5.98	5.88	0.10
B	Sized	600	7	0	4.83	6.38	5.60	0.77
C	Sized	600	7	0	6.10	6.31	6.20	0.10
A	Sized	600	7	200	8.74	9.12	8.93	0.19
B	Sized	600	7	200	7.61	8.79	8.20	0.59
C	Sized	600	7	200	8.31	8.72	8.52	0.20
A	Sized	600	7	20000	8.58	8.85	8.71	0.13

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Table 8.12: Alkalinity Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Alkalinity			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppmas$CaCO_3$	$\vee$ ppmas$CaCO_3$	μ ppmas$CaCO_3$	σ ppmas$CaCO_3$
B	Sized	600	7	20000	7.99	8.50	8.25	0.25
C	Sized	600	7	20000	8.63	8.91	8.77	0.14
A	Sized	600	7	SeaWater	90.39	91.62	91.01	0.62
B	Sized	600	7	SeaWater	89.66	90.12	89.89	0.23
C	Sized	600	7	SeaWater	95.83	97.13	96.48	0.65
A	Unsized	600	7	0	6.88	8.40	7.64	0.76
B	Unsized	600	7	0	4.72	6.28	5.50	0.78
A	Unsized	600	7	200	7.25	8.44	7.84	0.59
B	Unsized	600	7	200	6.69	7.85	7.27	0.58
A	Unsized	600	7	20000	7.78	8.29	8.03	0.26
B	Unsized	600	7	20000	7.47	7.98	7.72	0.26
A	Unsized	600	7	SeaWater	90.49	91.83	91.16	0.67
B	Unsized	600	7	SeaWater	86.70	88.05	87.37	0.68
A	Sized	600	10	0	20.49	20.80	20.64	0.16
B	Sized	600	10	0	19.69	19.75	19.72	0.03
C	Sized	600	10	0	21.58	21.91	21.75	0.16
A	Sized	600	10	200	25.93	26.21	26.07	0.14
B	Sized	600	10	200	22.33	25.46	23.90	1.56
C	Sized	600	10	200	26.47	26.76	26.62	0.15
A	Sized	600	10	20000	29.02	30.47	29.74	0.73
B	Sized	600	10	20000	25.98	27.70	26.84	0.86
C	Sized	600	10	20000	30.93	32.46	31.69	0.76
A	Sized	600	10	SeaWater	145.89	146.95	146.42	0.53
B	Sized	600	10	SeaWater	145.00	145.38	145.19	0.19
C	Sized	600	10	SeaWater	153.14	154.25	153.70	0.55
A	Unsized	600	10	0	22.79	23.08	22.94	0.14
B	Unsized	600	10	0	18.81	19.21	19.01	0.20

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Table 8.12: Alkalinity Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Alkalinity			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ $ppmasCaCO_3$	$\vee$ $ppmasCaCO_3$	μ $ppmasCaCO_3$	σ $ppmasCaCO_3$
A	Unsized	600	10	200	25.94	26.31	26.12	0.19
B	Unsized	600	10	200	19.62	19.93	19.78	0.16
A	Unsized	600	10	20000	28.10	28.84	28.47	0.37
B	Unsized	600	10	20000	22.80	22.90	22.85	0.05
A	Unsized	600	10	SeaWater	143.11	144.64	143.88	0.76
B	Unsized	600	10	SeaWater	142.75	143.84	143.29	0.54
A	Sized	600	13	0	1103.01	1136.32	1119.67	16.65
B	Sized	600	13	0	1044.56	1056.78	1050.67	6.11
C	Sized	600	13	0	1108.69	1142.16	1125.43	16.74
A	Sized	600	13	200	1558.68	1571.99	1565.33	6.66
B	Sized	600	13	200	1498.98	1510.35	1504.67	5.69
C	Sized	600	13	200	1526.37	1539.77	1533.07	6.70
A	Sized	600	13	20000	1574.69	1603.97	1589.33	14.64
B	Sized	600	13	20000	1572.00	1594.00	1583.00	11.00
C	Sized	600	13	20000	1573.01	1602.49	1587.75	14.74
A	Sized	600	13	SeaWater	3313.00	3353.00	3333.00	20.00
B	Sized	600	13	SeaWater	3269.56	3347.77	3308.67	39.11
C	Sized	600	13	SeaWater	3398.66	3438.78	3418.72	20.06
A	Unsized	600	13	0	651.91	686.09	669.00	17.09
B	Unsized	600	13	0	453.56	465.78	459.67	6.11
A	Unsized	600	13	200	762.73	785.27	774.00	11.27
B	Unsized	600	13	200	758.98	770.35	764.67	5.69
A	Unsized	600	13	20000	1306.72	1338.61	1322.67	15.95
B	Unsized	600	13	20000	1305.00	1327.00	1316.00	11.00
A	Unsized	600	13	SeaWater	3178.51	3232.82	3205.67	27.15
B	Unsized	600	13	SeaWater	3165.43	3205.90	3185.67	20.23

For a better understanding, change in the alkalinity content of the environments was plotted in graphs in Figure 8.10, 8.11, and 8.12. It can be seen from the figures that in general, the alkalinity content continues

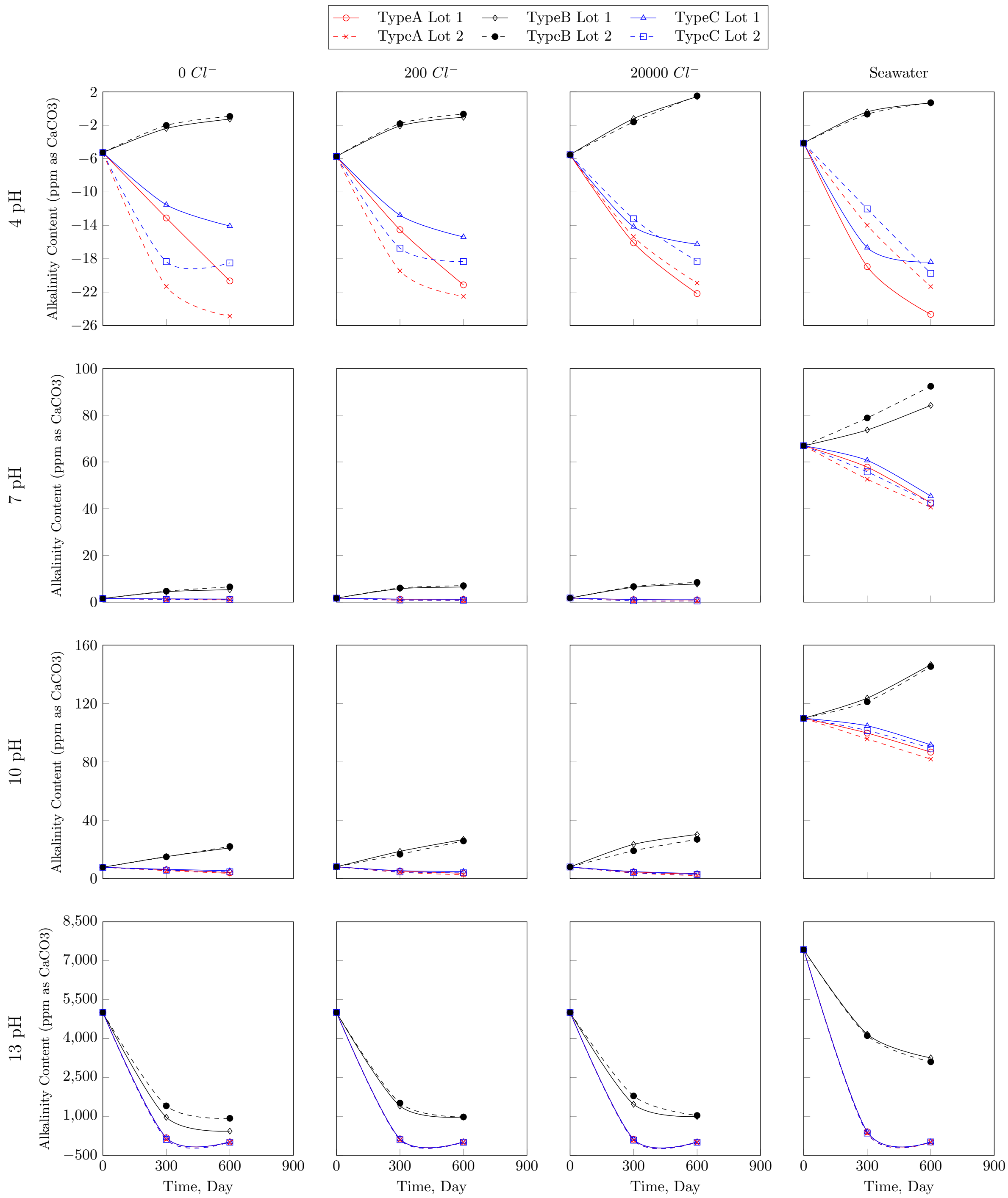

Figure 8.10: Alkalinity of environments after exposure of rebars

to decrease, with a few exceptions (vinyl-ester rebar sample combined in seawater with pH 10 or less, and all fiber only samples with pH 10 or less) but all trending to a slower rate of change, especially for the rebar in the pH 13 environment.

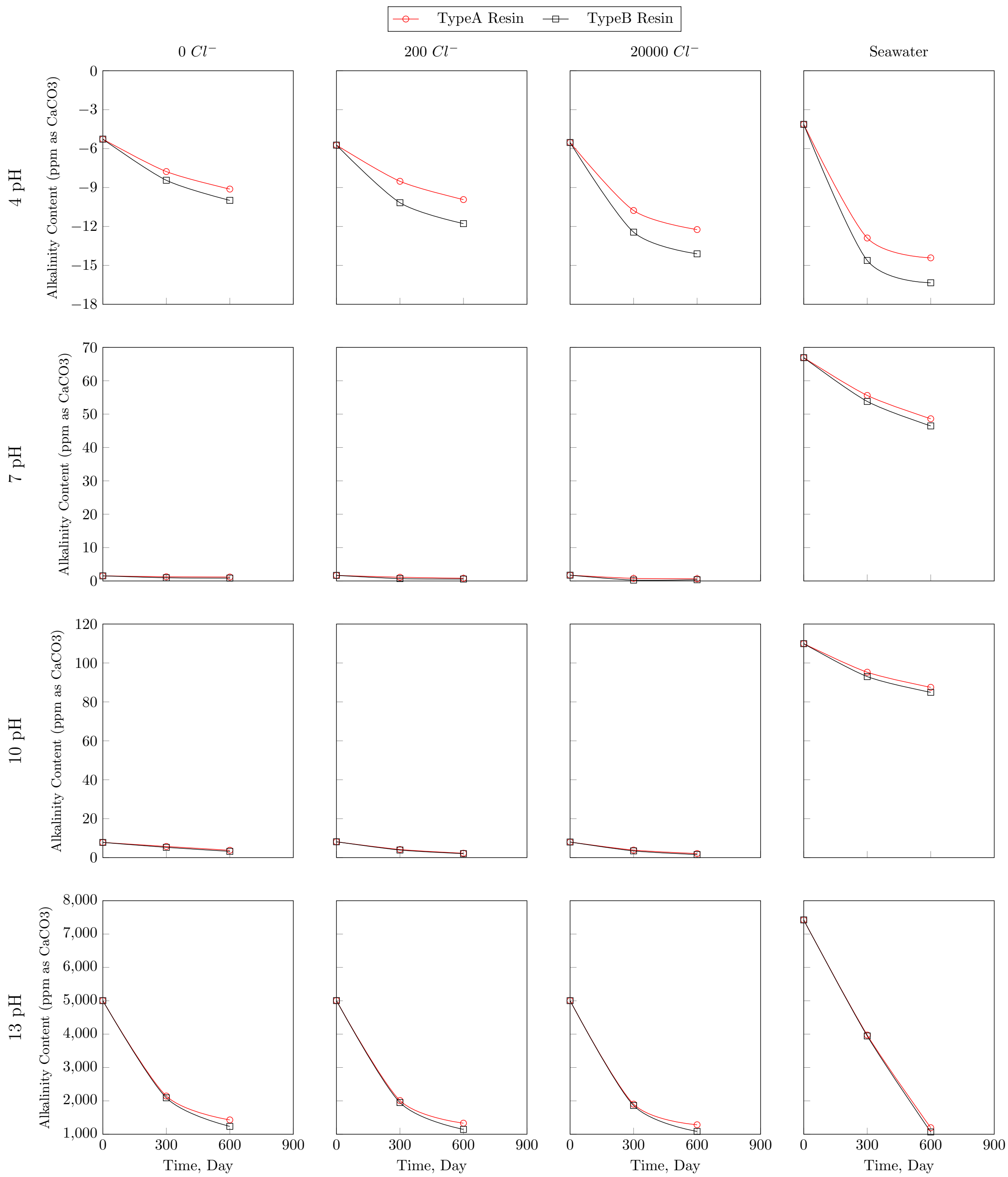

Figure 8.11: Alkalinity of environments after exposure of resins

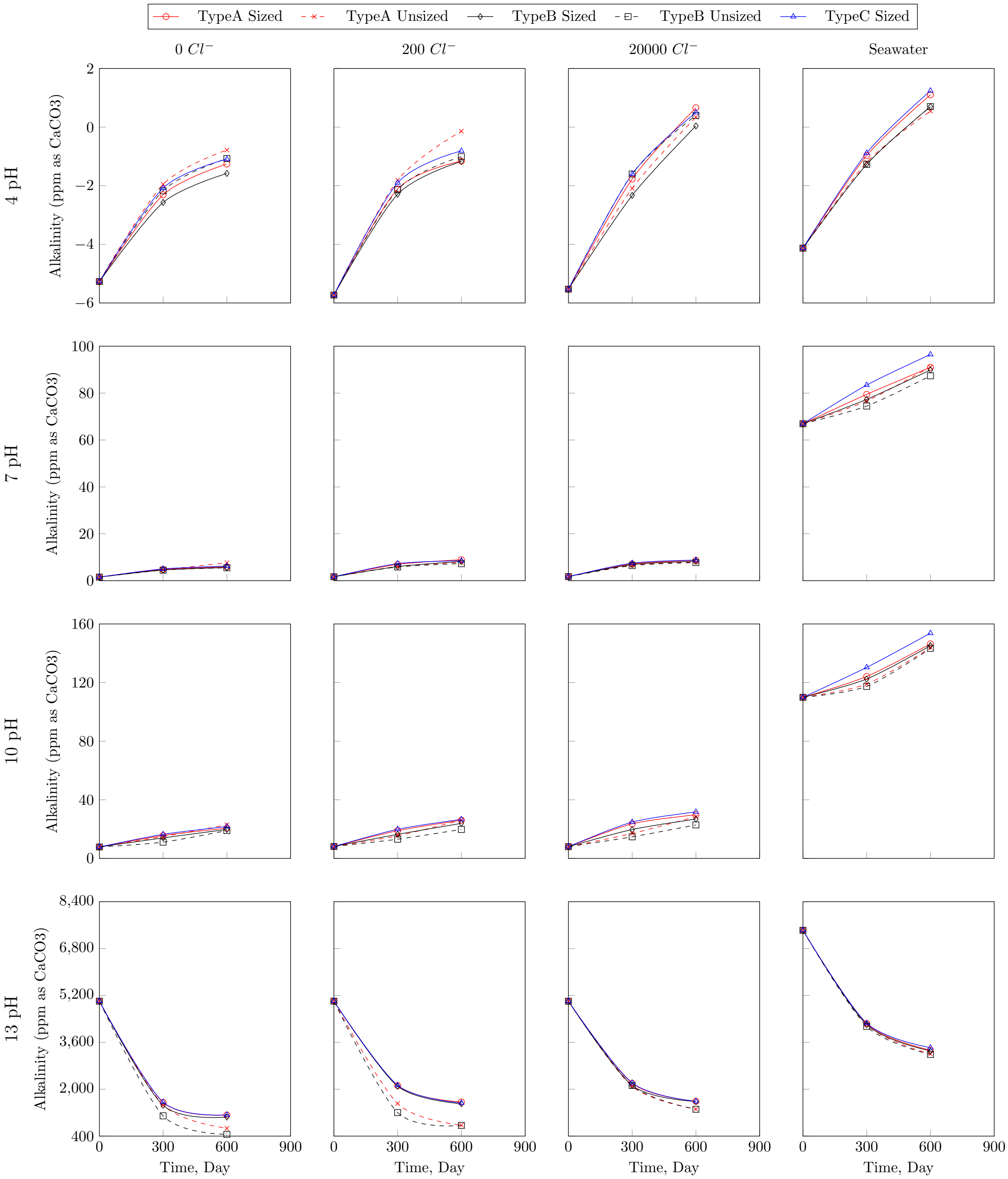

Figure 8.12: Alkalinity of environments after exposure of sized and unsized fibers

8.2.5 Anions

Chloride

Chloride content of the chemical environments was measured after 600 days of exposure. Tables 8.13, 8.14, and 8.15 below shows the Chloride data of environments in which rebars, resins, and fibers were exposed.

Table 8.13: Chloride Ion Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Chloride Ion			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	4	0	3.52	3.54	3.53	0.01
B	Vinyl Ester	1	600	4	0	4.37	4.43	4.40	0.03
C	Epoxy	1	600	4	0	3.86	3.89	3.87	0.01
A	Epoxy	1	600	4	200	220.91	220.99	220.95	0.04
B	Vinyl Ester	1	600	4	200	210.17	212.89	211.53	1.36
C	Epoxy	1	600	4	200	244.85	244.94	244.89	0.04
A	Epoxy	1	600	4	20000	19 734.12	19 757.21	19 745.67	11.55
B	Vinyl Ester	1	600	4	20000	19 678.19	19 742.48	19 710.33	32.15
C	Epoxy	1	600	4	20000	19 758.08	19 781.20	19 769.64	11.56
A	Epoxy	1	600	4	SeaWater	19 558.41	19 652.92	19 605.67	47.26
B	Vinyl Ester	1	600	4	SeaWater	19 628.79	19 651.88	19 640.33	11.55
C	Epoxy	1	600	4	SeaWater	19 582.20	19 676.81	19 629.50	47.31
A	Epoxy	2	600	4	0	3.23	3.26	3.24	0.02
B	Vinyl Ester	2	600	4	0	4.13	4.16	4.15	0.02
C	Epoxy	2	600	4	0	4.47	4.50	4.49	0.02
A	Epoxy	2	600	4	200	211.07	211.13	211.10	0.03
B	Vinyl Ester	2	600	4	200	207.92	208.80	208.36	0.44
C	Epoxy	2	600	4	200	224.15	224.21	224.18	0.03
A	Epoxy	2	600	4	20000	19 733.85	19 775.48	19 754.67	20.82
B	Vinyl Ester	2	600	4	20000	19 666.52	19 708.15	19 687.33	20.82
C	Epoxy	2	600	4	20000	19 739.77	19 781.46	19 760.62	20.85
A	Epoxy	2	600	4	SeaWater	19 584.41	19 671.59	19 628.00	43.59
B	Vinyl Ester	2	600	4	SeaWater	19 552.19	19 612.47	19 582.33	30.14
C	Epoxy	2	600	4	SeaWater	19 590.11	19 677.41	19 633.76	43.65
A	Epoxy	1	600	7	0	3.42	3.48	3.45	0.03
B	Vinyl Ester	1	600	7	0	4.24	4.31	4.28	0.04
C	Epoxy	1	600	7	0	3.73	3.81	3.77	0.04

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Table 8.13: Chloride Ion Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Chloride Ion			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	7	200	218.04	218.07	218.06	0.02
B	Vinyl Ester	1	600	7	200	212.09	212.59	212.34	0.25
C	Epoxy	1	600	7	200	241.90	241.93	241.92	0.02
A	Epoxy	1	600	7	20000	19 689.00	19 709.00	19 699.00	10.00
B	Vinyl Ester	1	600	7	20000	19 692.85	19 734.48	19 713.67	20.82
C	Epoxy	1	600	7	20000	19 712.92	19 732.94	19 722.93	10.01
A	Epoxy	1	600	7	SeaWater	19 572.94	19 645.06	19 609.00	36.06
B	Vinyl Ester	1	600	7	SeaWater	19 579.68	19 614.32	19 597.00	17.32
C	Epoxy	1	600	7	SeaWater	19 596.75	19 668.93	19 632.84	36.09
A	Epoxy	2	600	7	0	3.22	3.24	3.23	0.01
B	Vinyl Ester	2	600	7	0	4.28	4.30	4.29	0.01
C	Epoxy	2	600	7	0	4.45	4.48	4.47	0.01
A	Epoxy	2	600	7	200	209.92	210.02	209.97	0.05
B	Vinyl Ester	2	600	7	200	207.82	208.50	208.16	0.34
C	Epoxy	2	600	7	200	222.97	223.07	223.02	0.05
A	Epoxy	2	600	7	20000	19 700.92	19 781.75	19 741.33	40.41
B	Vinyl Ester	2	600	7	20000	19 658.11	19 693.23	19 675.67	17.56
C	Epoxy	2	600	7	20000	19 706.79	19 787.74	19 747.26	40.48
A	Epoxy	2	600	7	SeaWater	19 620.52	19 662.15	19 641.33	20.82
B	Vinyl Ester	2	600	7	SeaWater	19 545.55	19 615.79	19 580.67	35.12
C	Epoxy	2	600	7	SeaWater	19 626.27	19 667.96	19 647.11	20.85
A	Epoxy	1	600	10	0	3.73	3.77	3.75	0.02
B	Vinyl Ester	1	600	10	0	4.14	4.20	4.17	0.03
C	Epoxy	1	600	10	0	4.14	4.19	4.16	0.03
A	Epoxy	1	600	10	200	211.65	211.69	211.67	0.02
B	Vinyl Ester	1	600	10	200	211.63	213.09	212.36	0.73
C	Epoxy	1	600	10	200	235.31	235.36	235.33	0.02

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Table 8.13: Chloride Ion Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Chloride Ion			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	10	20000	19 663.17	19 754.83	19 709.00	45.83
B	Vinyl Ester	1	600	10	20000	19 680.94	19 753.06	19 717.00	36.06
C	Epoxy	1	600	10	20000	19 687.07	19 778.81	19 732.94	45.87
A	Epoxy	1	600	10	SeaWater	19 594.47	19 670.19	19 632.33	37.86
B	Vinyl Ester	1	600	10	SeaWater	19 588.50	19 638.83	19 613.67	25.17
C	Epoxy	1	600	10	SeaWater	19 618.30	19 694.09	19 656.20	37.90
A	Epoxy	2	600	10	0	3.70	3.74	3.72	0.02
B	Vinyl Ester	2	600	10	0	4.51	4.54	4.52	0.02
C	Epoxy	2	600	10	0	5.04	5.09	5.07	0.02
A	Epoxy	2	600	10	200	211.89	211.95	211.92	0.03
B	Vinyl Ester	2	600	10	200	205.94	206.75	206.35	0.40
C	Epoxy	2	600	10	200	225.00	225.05	225.03	0.03
A	Epoxy	2	600	10	20000	19 686.81	19 762.53	19 724.67	37.86
B	Vinyl Ester	2	600	10	20000	19 652.17	19 702.50	19 677.33	25.17
C	Epoxy	2	600	10	20000	19 692.66	19 768.49	19 730.57	37.92
A	Epoxy	2	600	10	SeaWater	19 628.00	19 668.00	19 648.00	20.00
B	Vinyl Ester	2	600	10	SeaWater	19 559.47	19 635.19	19 597.33	37.86
C	Epoxy	2	600	10	SeaWater	19 633.76	19 673.82	19 653.79	20.03
A	Epoxy	1	600	13	0	3.51	3.55	3.53	0.02
B	Vinyl Ester	1	600	13	0	4.34	4.40	4.37	0.03
C	Epoxy	1	600	13	0	3.85	3.90	3.88	0.03
A	Epoxy	1	600	13	200	218.54	218.58	218.56	0.02
B	Vinyl Ester	1	600	13	200	210.16	211.29	210.72	0.57
C	Epoxy	1	600	13	200	242.41	242.45	242.43	0.02
A	Epoxy	1	600	13	20000	19 686.15	19 778.52	19 732.33	46.19
B	Vinyl Ester	1	600	13	20000	19 679.78	19 740.88	19 710.33	30.55
C	Epoxy	1	600	13	20000	19 710.06	19 802.53	19 756.30	46.23

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Table 8.13: Chloride Ion Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Chloride Ion			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	13	SeaWater	19 590.53	19 650.81	19 620.67	30.14
B	Vinyl Ester	1	600	13	SeaWater	19 574.80	19 632.53	19 603.67	28.87
C	Epoxy	1	600	13	SeaWater	19 614.35	19 674.69	19 644.52	30.17
A	Epoxy	2	600	13	0	3.35	3.38	3.36	0.02
B	Vinyl Ester	2	600	13	0	4.61	4.68	4.64	0.03
C	Epoxy	2	600	13	0	4.61	4.65	4.63	0.02
A	Epoxy	2	600	13	200	213.18	213.22	213.20	0.02
B	Vinyl Ester	2	600	13	200	207.34	209.13	208.23	0.90
C	Epoxy	2	600	13	200	226.32	226.37	226.34	0.02
A	Epoxy	2	600	13	20000	19 699.19	19 763.48	19 731.33	32.15
B	Vinyl Ester	2	600	13	20000	19 645.70	19 728.97	19 687.33	41.63
C	Epoxy	2	600	13	20000	19 705.05	19 769.44	19 737.25	32.19
A	Epoxy	2	600	13	SeaWater	19 640.52	19 682.15	19 661.33	20.82
B	Vinyl Ester	2	600	13	SeaWater	19 544.81	19 619.86	19 582.33	37.53
C	Epoxy	2	600	13	SeaWater	19 646.30	19 687.99	19 667.14	20.85

Table 8.14: Chloride Ion Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Chloride Ion			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	600	4	0	5.68	5.73	5.71	0.03
B	Vinyl Ester	600	4	0	3.84	3.95	3.89	0.06
A	Epoxy	600	4	200	211.51	212.68	212.10	0.59
B	Vinyl Ester	600	4	200	213.21	214.19	213.70	0.49
A	Epoxy	600	4	20000	19 661.68	19 696.32	19 679.00	17.32
B	Vinyl Ester	600	4	20000	19 719.39	19 749.94	19 734.67	15.28
A	Epoxy	600	4	SeaWater	19 597.06	19 627.61	19 612.33	15.28
B	Vinyl Ester	600	4	SeaWater	19 603.47	19 679.19	19 641.33	37.86
A	Epoxy	600	7	0	5.72	5.76	5.74	0.02
B	Vinyl Ester	600	7	0	3.76	3.83	3.80	0.04
A	Epoxy	600	7	200	212.90	212.94	212.92	0.02
B	Vinyl Ester	600	7	200	210.62	212.97	211.80	1.17
A	Epoxy	600	7	20000	19 661.52	19 703.15	19 682.33	20.82
B	Vinyl Ester	600	7	20000	19 706.21	19 776.45	19 741.33	35.12
A	Epoxy	600	7	SeaWater	19 551.78	19 612.88	19 582.33	30.55
B	Vinyl Ester	600	7	SeaWater	19 609.50	19 659.83	19 634.67	25.17
A	Epoxy	600	10	0	5.84	5.88	5.86	0.02
B	Vinyl Ester	600	10	0	4.08	4.17	4.12	0.05
A	Epoxy	600	10	200	213.34	214.65	213.99	0.65
B	Vinyl Ester	600	10	200	213.55	214.54	214.05	0.49
A	Epoxy	600	10	20000	19 670.50	19 720.83	19 695.67	25.17
B	Vinyl Ester	600	10	20000	19 726.06	19 756.61	19 741.33	15.28
A	Epoxy	600	10	SeaWater	19 592.54	19 645.46	19 619.00	26.46
B	Vinyl Ester	600	10	SeaWater	19 595.34	19 694.00	19 644.67	49.33
A	Epoxy	600	13	0	5.48	5.52	5.50	0.02
B	Vinyl Ester	600	13	0	3.90	4.06	3.98	0.08
A	Epoxy	600	13	200	216.83	217.98	217.40	0.58

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Table 8.14: Chloride Ion Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Chloride Ion			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	600	13	200	209.14	215.31	212.22	3.08
A	Epoxy	600	13	20000	19 650.50	19 700.83	19 675.67	25.17
B	Vinyl Ester	600	13	20000	19 689.50	19 739.83	19 714.67	25.17
A	Epoxy	600	13	SeaWater	19 587.06	19 617.61	19 602.33	15.28
B	Vinyl Ester	600	13	SeaWater	19 618.24	19 664.43	19 641.33	23.09

Table 8.15: Chloride Ion Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Chloride Ion			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Sized	600	4	0	4.42	4.43	4.42	0.01
B	Sized	600	4	0	4.23	4.25	4.24	0.01
C	Sized	600	4	0	4.02	4.03	4.03	0.01
A	Sized	600	4	200	212.13	212.19	212.16	0.03
B	Sized	600	4	200	211.03	212.06	211.54	0.51
C	Sized	600	4	200	219.95	220.01	219.98	0.03
A	Sized	600	4	20000	19 659.81	19 735.53	19 697.67	37.86
B	Sized	600	4	20000	19 664.85	19 706.48	19 685.67	20.82
C	Sized	600	4	20000	19 635.58	19 711.46	19 673.52	37.94
A	Sized	600	4	SeaWater	19 574.94	19 647.06	19 611.00	36.06
B	Sized	600	4	SeaWater	19 520.19	19 584.48	19 552.33	32.15
C	Sized	600	4	SeaWater	19 550.55	19 622.81	19 586.68	36.13
A	Unsized	600	4	0	6.39	6.43	6.41	0.02
B	Unsized	600	4	0	4.81	4.84	4.82	0.02
A	Unsized	600	4	200	211.87	211.89	211.88	0.01
B	Unsized	600	4	200	210.04	211.06	210.55	0.51
A	Unsized	600	4	20000	19 690.39	19 720.94	19 705.67	15.28
B	Unsized	600	4	20000	19 641.11	19 676.23	19 658.67	17.56
A	Unsized	600	4	SeaWater	19 557.81	19 633.53	19 595.67	37.86
B	Unsized	600	4	SeaWater	19 510.23	19 590.44	19 550.33	40.10
A	Sized	600	7	0	4.45	4.49	4.47	0.02
B	Sized	600	7	0	4.23	4.27	4.25	0.02
C	Sized	600	7	0	4.06	4.10	4.08	0.02
A	Sized	600	7	200	214.96	215.01	214.98	0.02
B	Sized	600	7	200	210.41	211.69	211.05	0.64
C	Sized	600	7	200	222.84	222.88	222.86	0.02
A	Sized	600	7	20000	19 657.41	19 744.59	19 701.00	43.59
B	Sized	600	7	20000	19 679.89	19 691.44	19 685.67	5.77
C	Sized	600	7	20000	19 633.18	19 720.54	19 676.86	43.68
A	Sized	600	7	SeaWater	19 614.54	19 667.46	19 641.00	26.46
B	Sized	600	7	SeaWater	19 532.94	19 605.06	19 569.00	36.06
C	Sized	600	7	SeaWater	19 590.23	19 643.25	19 616.74	26.51
A	Unsized	600	7	0	6.23	6.26	6.25	0.02
B	Unsized	600	7	0	4.76	4.82	4.79	0.03
A	Unsized	600	7	200	214.30	214.34	214.32	0.02
B	Unsized	600	7	200	211.57	213.29	212.43	0.86
A	Unsized	600	7	20000	19 691.52	19 733.15	19 712.33	20.82
B	Unsized	600	7	20000	19 651.11	19 686.23	19 668.67	17.56
A	Unsized	600	7	SeaWater	19 555.41	19 642.59	19 599.00	43.59
B	Unsized	600	7	SeaWater	19 544.09	19 589.91	19 567.00	22.91
A	Sized	600	10	0	4.61	4.67	4.64	0.03

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Table 8.15: Chloride Ion Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Chloride Ion			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Sized	600	10	0	4.21	4.24	4.22	0.02
C	Sized	600	10	0	4.25	4.33	4.29	0.04
A	Sized	600	10	200	214.21	214.25	214.23	0.02
B	Sized	600	10	200	210.31	211.97	211.14	0.83
C	Sized	600	10	200	222.07	222.11	222.09	0.02
A	Sized	600	10	20000	19 706.85	19 748.48	19 727.67	20.82
B	Sized	600	10	20000	19 677.06	19 707.61	19 692.33	15.28
C	Sized	600	10	20000	19 682.72	19 724.44	19 703.58	20.86
A	Sized	600	10	SeaWater	19 560.41	19 654.92	19 607.67	47.26
B	Sized	600	10	SeaWater	19 590.39	19 620.94	19 605.67	15.28
C	Sized	600	10	SeaWater	19 535.99	19 630.69	19 583.34	47.35
A	Unsized	600	10	0	6.24	6.28	6.26	0.02
B	Unsized	600	10	0	4.79	4.83	4.81	0.02
A	Unsized	600	10	200	212.95	213.00	212.97	0.03
B	Unsized	600	10	200	211.66	213.76	212.71	1.05
A	Unsized	600	10	20000	19 669.00	19 709.00	19 689.00	20.00
B	Unsized	600	10	20000	19 664.68	19 699.32	19 682.00	17.32
A	Unsized	600	10	SeaWater	19 582.94	19 655.06	19 619.00	36.06
B	Unsized	600	10	SeaWater	19 532.24	19 578.43	19 555.33	23.09
A	Sized	600	13	0	4.83	4.90	4.87	0.03
B	Sized	600	13	0	4.26	4.27	4.27	0.01
C	Sized	600	13	0	4.52	4.60	4.56	0.04
A	Sized	600	13	200	214.21	214.62	214.42	0.21
B	Sized	600	13	200	210.17	211.84	211.00	0.84
C	Sized	600	13	200	222.07	222.49	222.28	0.21
A	Sized	600	13	20000	19 692.19	19 756.48	19 724.33	32.15
B	Sized	600	13	20000	19 660.39	19 690.94	19 675.67	15.28
C	Sized	600	13	20000	19 668.03	19 732.45	19 700.24	32.21
A	Sized	600	13	SeaWater	19 575.17	19 666.83	19 621.00	45.83
B	Sized	600	13	SeaWater	19 518.41	19 612.92	19 565.67	47.26
C	Sized	600	13	SeaWater	19 550.78	19 642.62	19 596.70	45.92
A	Unsized	600	13	0	6.27	6.31	6.29	0.02
B	Unsized	600	13	0	4.76	4.84	4.80	0.04
A	Unsized	600	13	200	215.86	215.94	215.90	0.04
B	Unsized	600	13	200	209.89	212.52	211.20	1.32
A	Unsized	600	13	20000	19 694.85	19 736.48	19 715.67	20.82
B	Unsized	600	13	20000	19 672.75	19 697.92	19 685.33	12.58
A	Unsized	600	13	SeaWater	19 564.47	19 640.19	19 602.33	37.86
B	Unsized	600	13	SeaWater	19 554.52	19 596.15	19 575.33	20.82

For a better understanding, change in the chloride content of the environments was plotted in graphs in

Figure 8.13, 8.14, and 8.15. It can be seen that the chloride content of all samples has increased except for

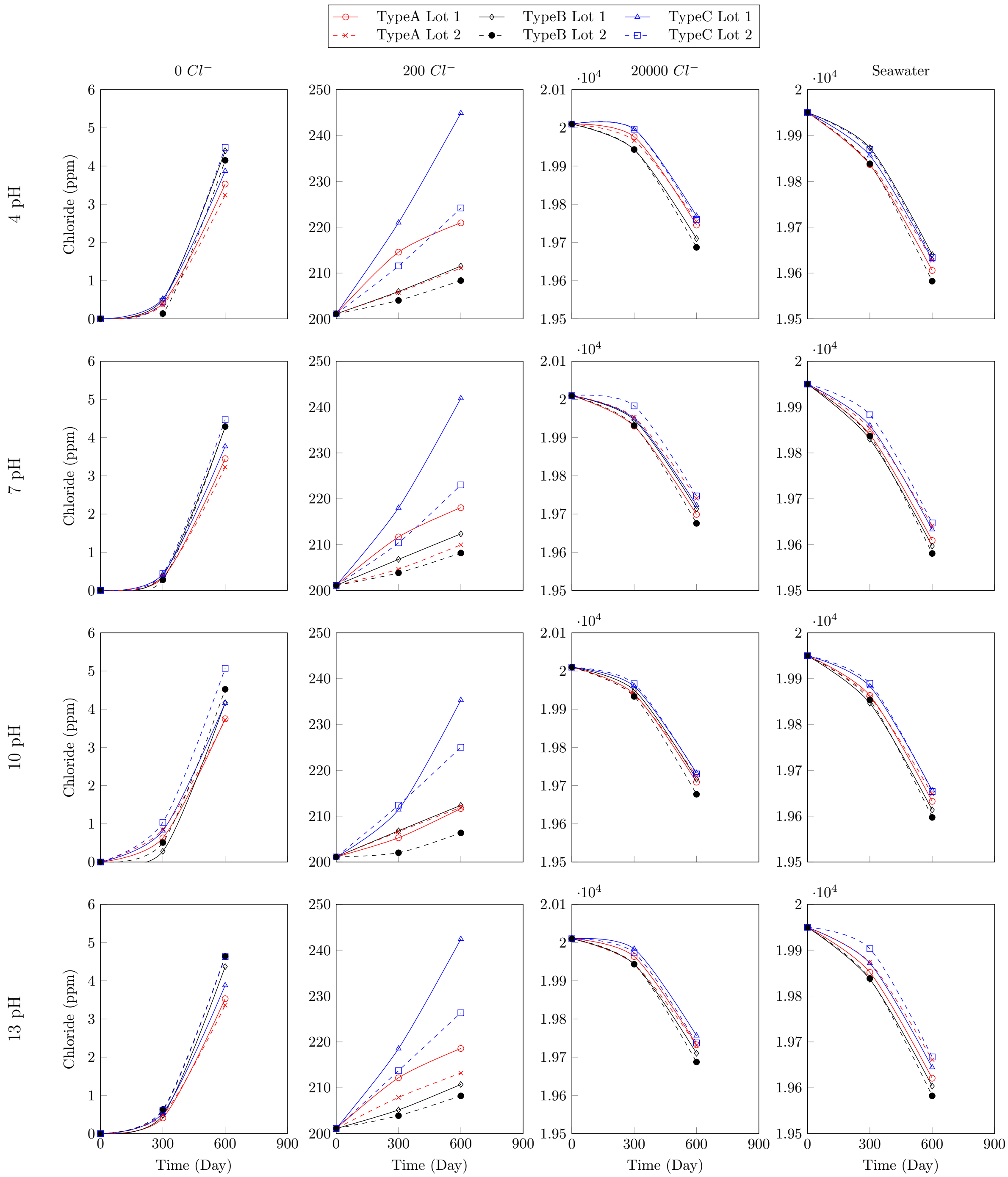

Figure 8.13: Chloride concentration of all environments after exposure of rebars

the 20000ppm synthetic solution and the seawater solution.

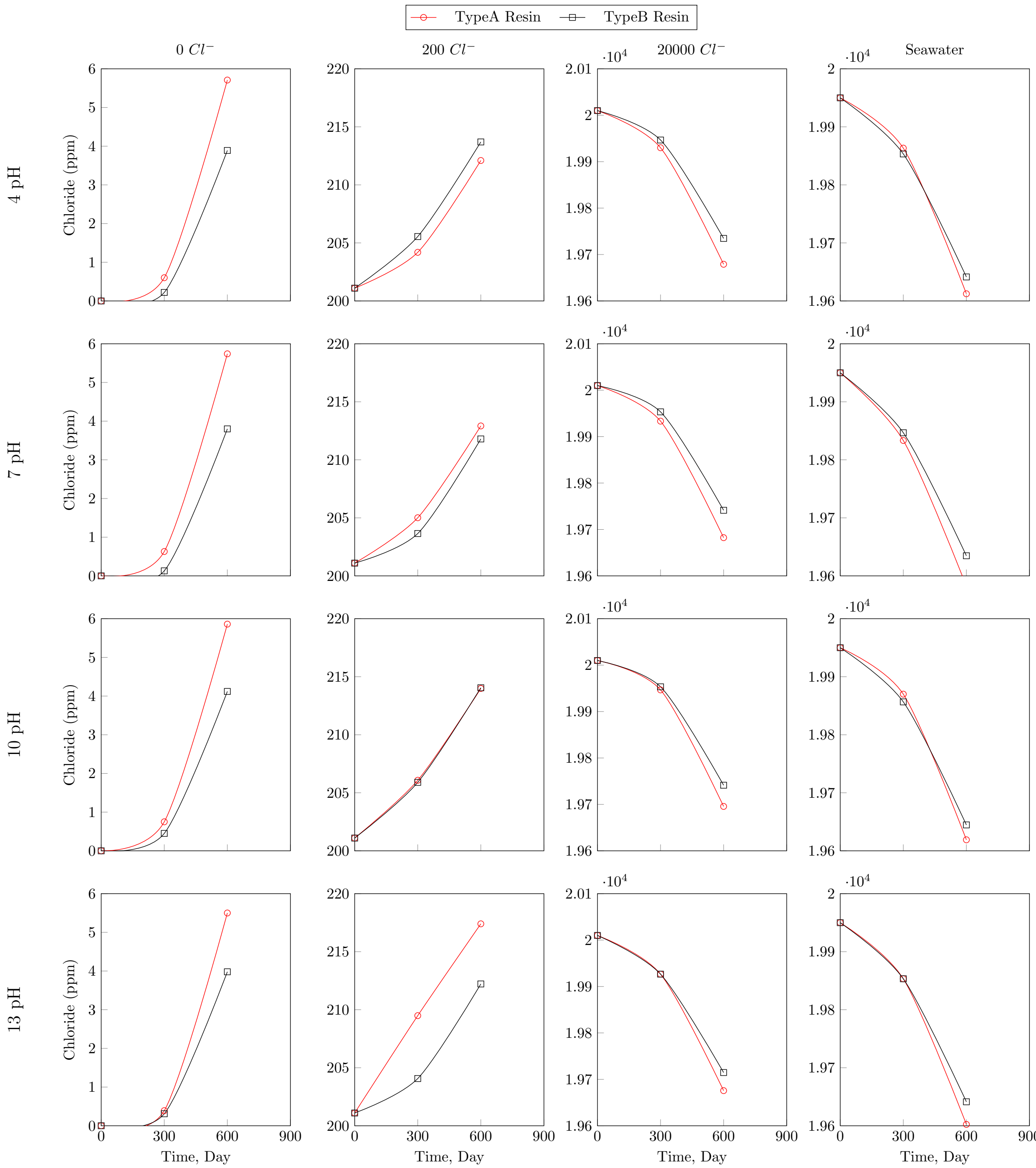

Figure 8.14: Chloride concentration of all environments after exposure of resins

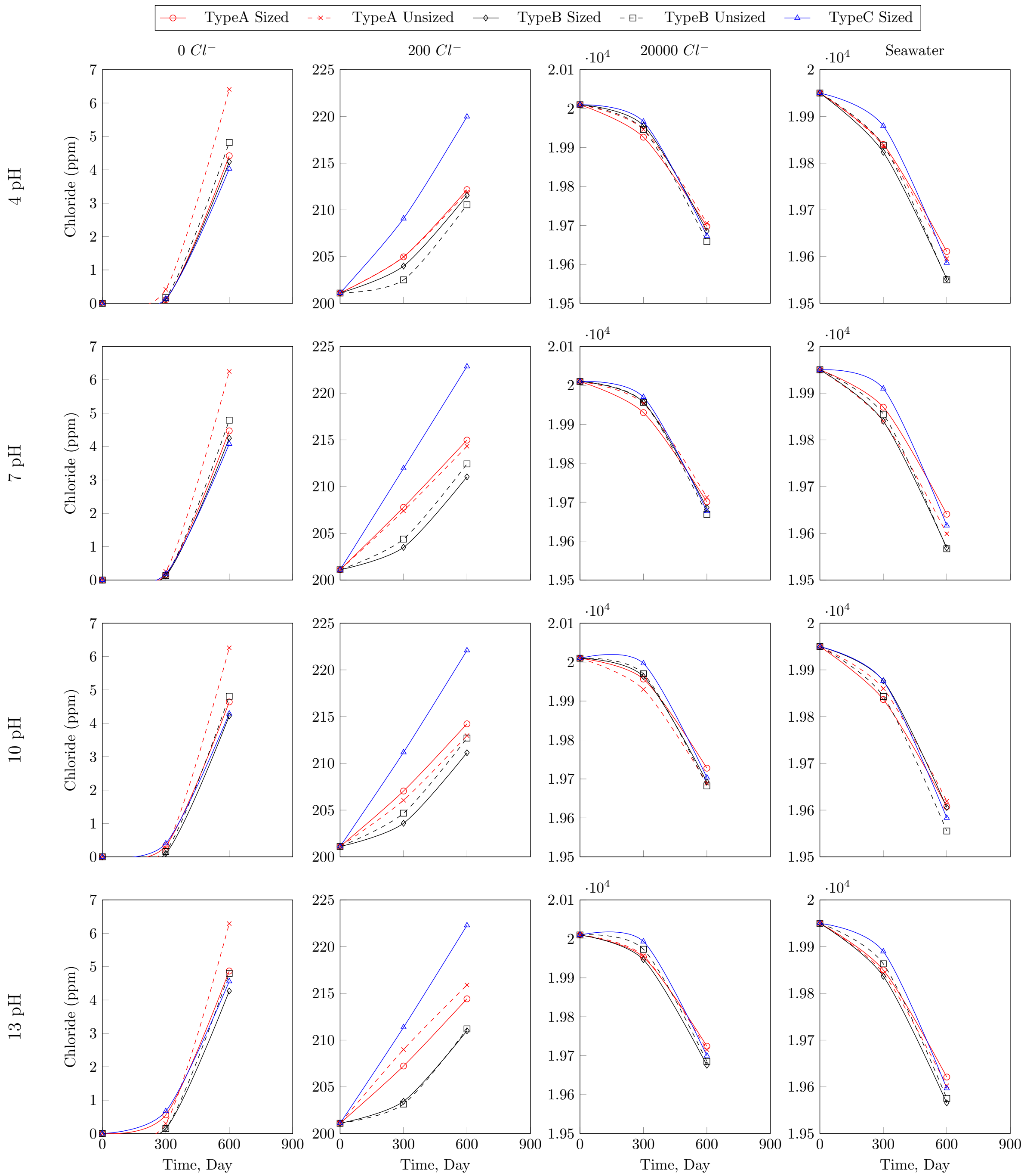

Figure 8.15: Chloride concentration of all environments after exposure of sized and unsized fibers

Sulfate

Sulfate content of the chemical environments was measured after 600 days of exposure. Tables 8.16, 8.17, and 8.18 below shows the sulfate data of environments in which rebars, resins, and fibers were exposed.

Table 8.16: Sulfate Ion Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Sulfate Ion			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	4	0	12.21	12.24	12.23	0.02
B	Vinyl Ester	1	600	4	0	10.79	11.01	10.90	0.11
C	Epoxy	1	600	4	0	16.45	16.49	16.47	0.02
A	Epoxy	1	600	4	200	12.18	12.23	12.21	0.03
B	Vinyl Ester	1	600	4	200	12.82	13.02	12.92	0.10
C	Epoxy	1	600	4	200	14.87	14.93	14.90	0.03
A	Epoxy	1	600	4	20000	12.27	12.32	12.30	0.03
B	Vinyl Ester	1	600	4	20000	11.69	12.22	11.96	0.27
C	Epoxy	1	600	4	20000	15.38	15.44	15.41	0.03
A	Epoxy	1	600	4	SeaWater	2326.81	2402.53	2364.67	37.86
B	Vinyl Ester	1	600	4	SeaWater	2379.12	2402.21	2390.67	11.55
C	Epoxy	1	600	4	SeaWater	2355.79	2431.67	2393.73	37.94
A	Epoxy	2	600	4	0	12.51	12.54	12.52	0.02
B	Vinyl Ester	2	600	4	0	11.79	12.41	12.10	0.31
C	Epoxy	2	600	4	0	15.83	15.87	15.85	0.02
A	Epoxy	2	600	4	200	12.63	12.67	12.65	0.02
B	Vinyl Ester	2	600	4	200	11.87	12.55	12.21	0.34
C	Epoxy	2	600	4	200	15.13	15.18	15.15	0.03
A	Epoxy	2	600	4	20000	11.92	11.96	11.94	0.02
B	Vinyl Ester	2	600	4	20000	11.46	12.16	11.81	0.35
C	Epoxy	2	600	4	20000	15.20	15.26	15.23	0.03
A	Epoxy	2	600	4	SeaWater	2363.00	2383.00	2373.00	10.00
B	Vinyl Ester	2	600	4	SeaWater	2405.16	2426.17	2415.67	10.50
C	Epoxy	2	600	4	SeaWater	2386.61	2406.67	2396.64	10.03
A	Epoxy	1	600	7	0	4.32	4.36	4.34	0.02
B	Vinyl Ester	1	600	7	0	3.65	3.73	3.69	0.04
C	Epoxy	1	600	7	0	4.33	4.39	4.36	0.03

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Table 8.16: Sulfate Ion Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Sulfate Ion			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	7	200	4.55	4.59	4.57	0.02
B	Vinyl Ester	1	600	7	200	4.73	4.79	4.76	0.03
C	Epoxy	1	600	7	200	4.93	4.98	4.95	0.03
A	Epoxy	1	600	7	20000	4.84	4.87	4.86	0.02
B	Vinyl Ester	1	600	7	20000	4.95	5.00	4.97	0.02
C	Epoxy	1	600	7	20000	4.28	4.32	4.30	0.02
A	Epoxy	1	600	7	SeaWater	2330.41	2424.92	2377.67	47.26
B	Vinyl Ester	1	600	7	SeaWater	2395.73	2418.27	2407.00	11.27
C	Epoxy	1	600	7	SeaWater	2359.40	2454.11	2406.76	47.35
A	Epoxy	2	600	7	0	3.98	4.02	4.00	0.02
B	Vinyl Ester	2	600	7	0	4.48	4.57	4.52	0.05
C	Epoxy	2	600	7	0	5.17	5.22	5.20	0.03
A	Epoxy	2	600	7	200	3.89	3.92	3.90	0.02
B	Vinyl Ester	2	600	7	200	4.12	4.16	4.14	0.02
C	Epoxy	2	600	7	200	4.75	4.79	4.77	0.02
A	Epoxy	2	600	7	20000	4.62	4.67	4.64	0.02
B	Vinyl Ester	2	600	7	20000	4.59	4.77	4.68	0.09
C	Epoxy	2	600	7	20000	5.17	5.23	5.20	0.03
A	Epoxy	2	600	7	SeaWater	2338.52	2380.15	2359.33	20.82
B	Vinyl Ester	2	600	7	SeaWater	2387.85	2429.48	2408.67	20.82
C	Epoxy	2	600	7	SeaWater	2362.05	2403.81	2382.93	20.88
A	Epoxy	1	600	10	0	4.06	4.09	4.07	0.02
B	Vinyl Ester	1	600	10	0	4.31	4.36	4.34	0.03
C	Epoxy	1	600	10	0	4.01	4.04	4.03	0.02
A	Epoxy	1	600	10	200	4.14	4.17	4.16	0.02
B	Vinyl Ester	1	600	10	200	4.87	4.95	4.91	0.04
C	Epoxy	1	600	10	200	4.41	4.45	4.43	0.02

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Table 8.16: Sulfate Ion Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Sulfate Ion			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	10	20000	4.46	4.49	4.48	0.02
B	Vinyl Ester	1	600	10	20000	4.76	4.82	4.79	0.03
C	Epoxy	1	600	10	20000	3.80	3.84	3.82	0.02
A	Epoxy	1	600	10	SeaWater	2333.00	2373.00	2353.00	20.00
B	Vinyl Ester	1	600	10	SeaWater	2395.16	2412.17	2403.67	8.50
C	Epoxy	1	600	10	SeaWater	2362.00	2402.08	2382.04	20.04
A	Epoxy	2	600	10	0	3.76	3.78	3.77	0.01
B	Vinyl Ester	2	600	10	0	4.80	4.88	4.84	0.04
C	Epoxy	2	600	10	0	4.89	4.92	4.90	0.01
A	Epoxy	2	600	10	200	3.72	3.74	3.73	0.01
B	Vinyl Ester	2	600	10	200	4.04	4.12	4.08	0.04
C	Epoxy	2	600	10	200	4.53	4.56	4.55	0.01
A	Epoxy	2	600	10	20000	4.29	4.32	4.30	0.02
B	Vinyl Ester	2	600	10	20000	4.37	4.39	4.38	0.01
C	Epoxy	2	600	10	20000	4.74	4.78	4.76	0.02
A	Epoxy	2	600	10	SeaWater	2339.79	2362.88	2351.33	11.55
B	Vinyl Ester	2	600	10	SeaWater	2419.83	2444.17	2432.00	12.17
C	Epoxy	2	600	10	SeaWater	2363.32	2386.48	2374.90	11.58
A	Epoxy	1	600	13	0	4.34	4.38	4.36	0.02
B	Vinyl Ester	1	600	13	0	3.96	4.03	4.00	0.04
C	Epoxy	1	600	13	0	4.36	4.42	4.39	0.03
A	Epoxy	1	600	13	200	4.36	4.39	4.37	0.02
B	Vinyl Ester	1	600	13	200	4.71	4.78	4.74	0.03
C	Epoxy	1	600	13	200	4.69	4.73	4.71	0.02
A	Epoxy	1	600	13	20000	4.58	4.61	4.59	0.02
B	Vinyl Ester	1	600	13	20000	4.94	4.98	4.96	0.02
C	Epoxy	1	600	13	20000	3.95	3.99	3.97	0.02

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Table 8.16: Sulfate Ion Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Sulfate Ion			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	13	SeaWater	2380.17	2430.50	2405.33	25.17
B	Vinyl Ester	1	600	13	SeaWater	2378.56	2390.11	2384.33	5.77
C	Epoxy	1	600	13	SeaWater	2409.26	2459.69	2434.48	25.22
A	Epoxy	2	600	13	0	3.67	3.69	3.68	0.01
B	Vinyl Ester	2	600	13	0	4.62	4.66	4.64	0.02
C	Epoxy	2	600	13	0	4.77	4.80	4.79	0.01
A	Epoxy	2	600	13	200	3.57	3.60	3.59	0.02
B	Vinyl Ester	2	600	13	200	3.79	3.87	3.83	0.04
C	Epoxy	2	600	13	200	4.34	4.38	4.36	0.02
A	Epoxy	2	600	13	20000	4.25	4.29	4.27	0.02
B	Vinyl Ester	2	600	13	20000	4.55	4.61	4.58	0.03
C	Epoxy	2	600	13	20000	4.70	4.75	4.72	0.03
A	Epoxy	2	600	13	SeaWater	2382.12	2405.21	2393.67	11.55
B	Vinyl Ester	2	600	13	SeaWater	2412.65	2432.68	2422.67	10.02
C	Epoxy	2	600	13	SeaWater	2405.78	2428.95	2417.36	11.58

Table 8.17: Sulfate Ion Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Sulfate Ion			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	600	4	0	11.78	11.87	11.82	0.05
B	Vinyl Ester	600	4	0	11.11	11.45	11.28	0.17
A	Epoxy	600	4	200	12.07	12.10	12.09	0.02
B	Vinyl Ester	600	4	200	10.62	11.46	11.04	0.42
A	Epoxy	600	4	20000	11.06	11.13	11.10	0.04
B	Vinyl Ester	600	4	20000	12.25	13.31	12.78	0.53
A	Epoxy	600	4	SeaWater	2411.16	2432.17	2421.67	10.50
B	Vinyl Ester	600	4	SeaWater	2448.56	2460.11	2454.33	5.77
A	Epoxy	600	7	0	4.76	4.81	4.78	0.02
B	Vinyl Ester	600	7	0	3.76	3.82	3.79	0.03
A	Epoxy	600	7	200	4.01	4.07	4.04	0.03
B	Vinyl Ester	600	7	200	4.82	4.88	4.85	0.03
A	Epoxy	600	7	20000	4.30	4.33	4.32	0.02
B	Vinyl Ester	600	7	20000	3.71	3.76	3.74	0.03
A	Epoxy	600	7	SeaWater	2428.14	2456.52	2442.33	14.19
B	Vinyl Ester	600	7	SeaWater	2437.70	2452.97	2445.33	7.64
A	Epoxy	600	10	0	4.95	5.02	4.99	0.04
B	Vinyl Ester	600	10	0	3.35	3.43	3.39	0.04
A	Epoxy	600	10	200	3.90	3.93	3.92	0.02
B	Vinyl Ester	600	10	200	4.56	4.64	4.60	0.04
A	Epoxy	600	10	20000	4.21	4.24	4.23	0.02
B	Vinyl Ester	600	10	20000	3.79	3.87	3.83	0.04
A	Epoxy	600	10	SeaWater	2422.12	2445.21	2433.67	11.55
B	Vinyl Ester	600	10	SeaWater	2432.39	2462.94	2447.67	15.28
A	Epoxy	600	13	0	4.80	4.85	4.82	0.02
B	Vinyl Ester	600	13	0	3.54	3.58	3.56	0.02
A	Epoxy	600	13	200	3.90	3.92	3.91	0.01
B	Vinyl Ester	600	13	200	4.98	5.00	4.99	0.01
A	Epoxy	600	13	20000	4.13	4.17	4.15	0.02
B	Vinyl Ester	600	13	20000	3.73	3.77	3.75	0.02
A	Epoxy	600	13	SeaWater	2406.89	2418.44	2412.67	5.77
B	Vinyl Ester	600	13	SeaWater	2422.32	2448.35	2435.33	13.01

Table 8.18: Sulfate Ion Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Sulfate Ion			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^{-} ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Sized	600	4	0	13.73	13.79	13.76	0.03
B	Sized	600	4	0	12.33	12.46	12.39	0.07
C	Sized	600	4	0	14.66	14.75	14.71	0.04
A	Sized	600	4	200	12.34	12.39	12.36	0.03
B	Sized	600	4	200	12.08	12.63	12.36	0.28
C	Sized	600	4	200	14.12	14.19	14.15	0.03
A	Sized	600	4	20000	11.33	11.37	11.35	0.02
B	Sized	600	4	20000	11.62	12.62	12.12	0.50
C	Sized	600	4	20000	13.29	13.34	13.32	0.03
A	Sized	600	4	SeaWater	2339.39	2369.94	2354.67	15.28
B	Sized	600	4	SeaWater	2425.93	2443.40	2434.67	8.74
C	Sized	600	4	SeaWater	2390.02	2420.73	2405.38	15.35
A	Unsized	600	4	0	12.71	12.83	12.77	0.06
B	Unsized	600	4	0	10.28	11.22	10.75	0.47
A	Unsized	600	4	200	11.59	11.67	11.63	0.04
B	Unsized	600	4	200	12.53	12.96	12.75	0.21
A	Unsized	600	4	20000	11.20	11.25	11.22	0.03
B	Unsized	600	4	20000	10.75	10.99	10.87	0.12
A	Unsized	600	4	SeaWater	2369.39	2399.94	2384.67	15.28
B	Unsized	600	4	SeaWater	2429.39	2459.94	2444.67	15.28
A	Sized	600	7	0	4.09	4.11	4.10	0.01
B	Sized	600	7	0	3.05	3.13	3.09	0.04
C	Sized	600	7	0	3.78	3.81	3.80	0.01
A	Sized	600	7	200	2.53	4.27	3.40	0.87
B	Sized	600	7	200	3.78	3.99	3.89	0.11
C	Sized	600	7	200	3.40	3.45	3.43	0.03
A	Sized	600	7	20000	4.02	4.05	4.03	0.02
B	Sized	600	7	20000	4.07	4.14	4.11	0.03
C	Sized	600	7	20000	3.95	3.99	3.97	0.02
A	Sized	600	7	SeaWater	2366.12	2389.21	2377.67	11.55
B	Sized	600	7	SeaWater	2434.55	2442.12	2438.33	3.79
C	Sized	600	7	SeaWater	2416.89	2440.09	2428.49	11.60
A	Unsized	600	7	0	3.79	3.83	3.81	0.02
B	Unsized	600	7	0	3.67	3.73	3.70	0.03
A	Unsized	600	7	200	3.48	3.53	3.51	0.03
B	Unsized	600	7	200	4.05	4.10	4.07	0.03
A	Unsized	600	7	20000	3.77	3.80	3.79	0.02
B	Unsized	600	7	20000	4.75	4.81	4.78	0.03
A	Unsized	600	7	SeaWater	2352.55	2422.79	2387.67	35.12
B	Unsized	600	7	SeaWater	2434.89	2446.44	2440.67	5.77
A	Sized	600	10	0	4.04	4.07	4.05	0.02

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Table 8.18: Sulfate Ion Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Sulfate Ion			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Sized	600	10	0	3.03	3.31	3.17	0.14
C	Sized	600	10	0	3.72	3.76	3.74	0.02
A	Sized	600	10	200	4.27	4.33	4.30	0.03
B	Sized	600	10	200	3.41	4.18	3.80	0.38
C	Sized	600	10	200	3.90	3.97	3.94	0.03
A	Sized	600	10	20000	3.66	3.72	3.69	0.03
B	Sized	600	10	20000	3.97	4.07	4.02	0.05
C	Sized	600	10	20000	3.51	3.57	3.54	0.03
A	Sized	600	10	SeaWater	2343.70	2358.97	2351.33	7.64
B	Sized	600	10	SeaWater	2432.17	2440.50	2436.33	4.16
C	Sized	600	10	SeaWater	2394.35	2409.70	2402.03	7.68
A	Unsized	600	10	0	3.66	3.70	3.68	0.02
B	Unsized	600	10	0	3.82	3.90	3.86	0.04
A	Unsized	600	10	200	3.12	3.18	3.15	0.03
B	Unsized	600	10	200	4.11	4.12	4.12	0.01
A	Unsized	600	10	20000	3.48	3.50	3.49	0.01
B	Unsized	600	10	20000	4.58	4.64	4.61	0.03
A	Unsized	600	10	SeaWater	2358.85	2400.48	2379.67	20.82
B	Unsized	600	10	SeaWater	2442.30	2457.04	2449.67	7.37
A	Sized	600	13	0	3.82	3.83	3.82	0.01
B	Sized	600	13	0	2.99	3.08	3.04	0.05
C	Sized	600	13	0	3.44	3.46	3.45	0.01
A	Sized	600	13	200	4.24	4.28	4.26	0.02
B	Sized	600	13	200	4.01	4.13	4.07	0.06
C	Sized	600	13	200	3.85	3.91	3.88	0.03
A	Sized	600	13	20000	3.68	3.74	3.71	0.03
B	Sized	600	13	20000	4.00	4.01	4.01	0.01
C	Sized	600	13	20000	3.53	3.60	3.57	0.03
A	Sized	600	13	SeaWater	2373.79	2396.88	2385.33	11.55
B	Sized	600	13	SeaWater	2432.35	2437.65	2435.00	2.65
C	Sized	600	13	SeaWater	2424.59	2447.80	2436.20	11.60
A	Unsized	600	13	0	3.61	3.65	3.63	0.02
B	Unsized	600	13	0	3.77	3.79	3.78	0.01
A	Unsized	600	13	200	3.23	3.27	3.25	0.02
B	Unsized	600	13	200	4.51	4.56	4.54	0.02
A	Unsized	600	13	20000	3.47	3.49	3.48	0.01
B	Unsized	600	13	20000	4.68	4.77	4.73	0.05
A	Unsized	600	13	SeaWater	2374.68	2409.32	2392.00	17.32
B	Unsized	600	13	SeaWater	2435.58	2451.75	2443.67	8.08

For a better understanding, change in the sulfate content of the environments was plotted in graphs in

Figure 8.16, 8.17, and 8.18. It can be seen that sulfate concentration of all samples has increased except the

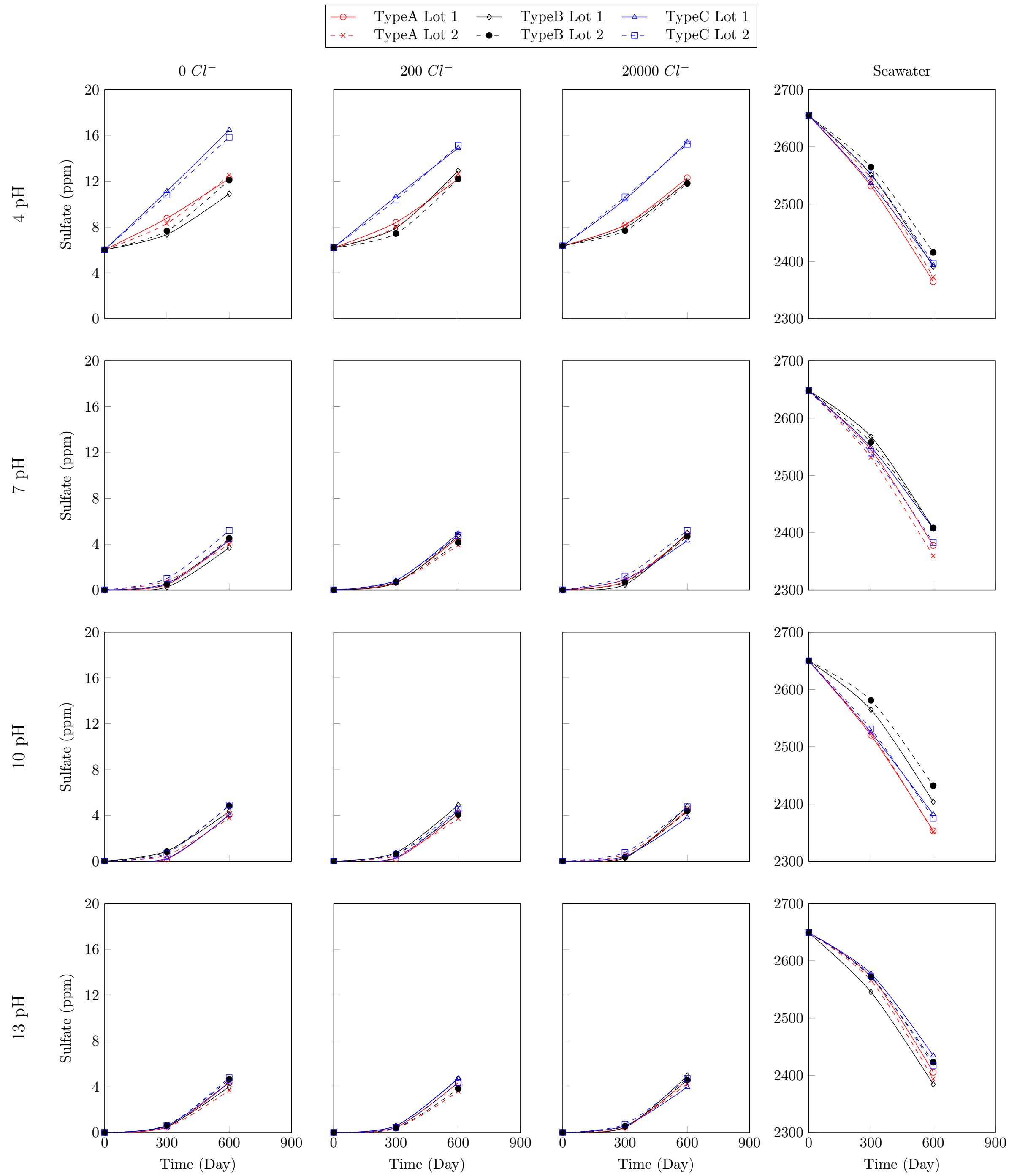

Figure 8.16: Sulfate concentration of all environments after exposure of rebars

seawater samples.

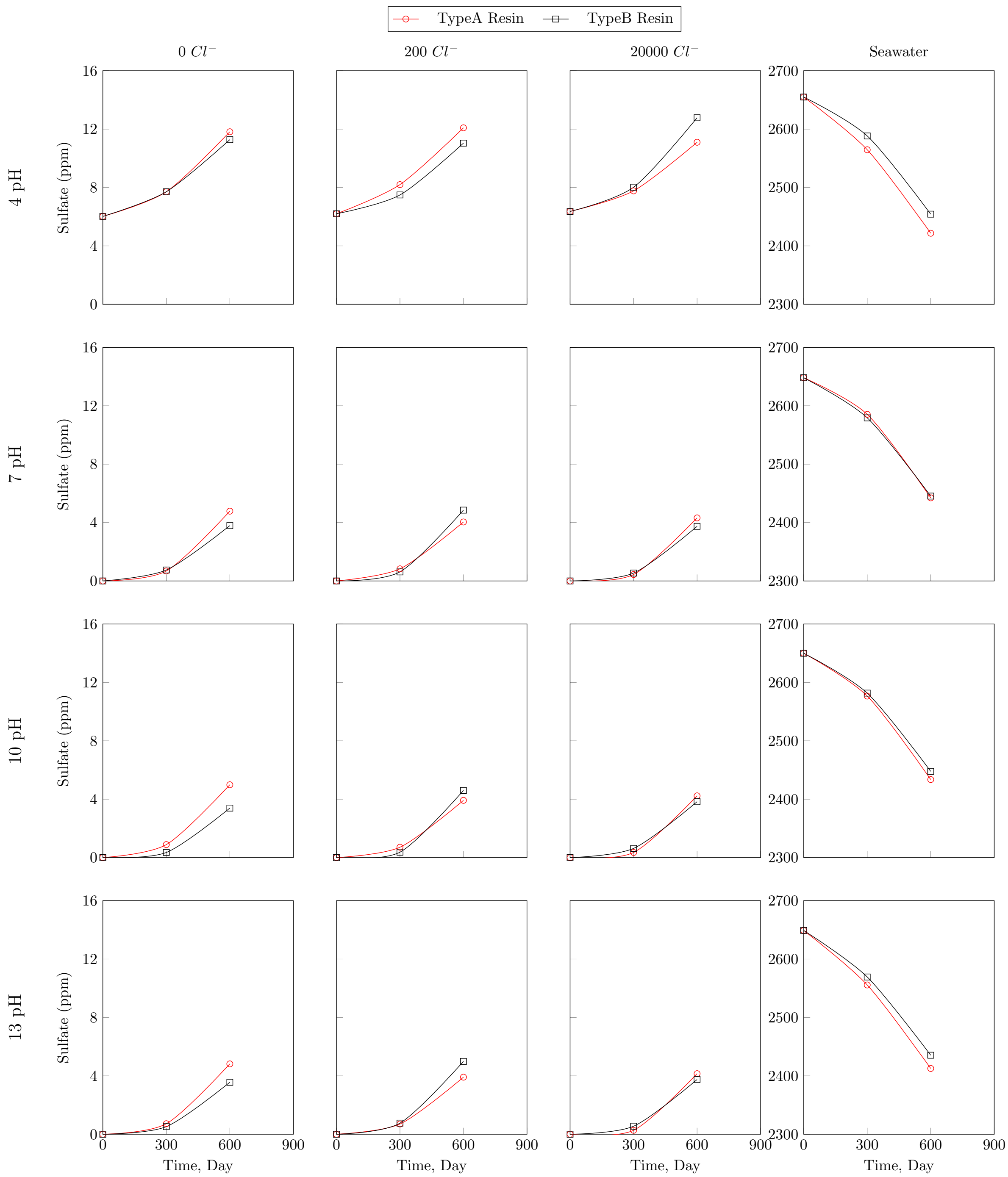

Figure 8.17: Sulfate concentration of all environments after exposure of resins

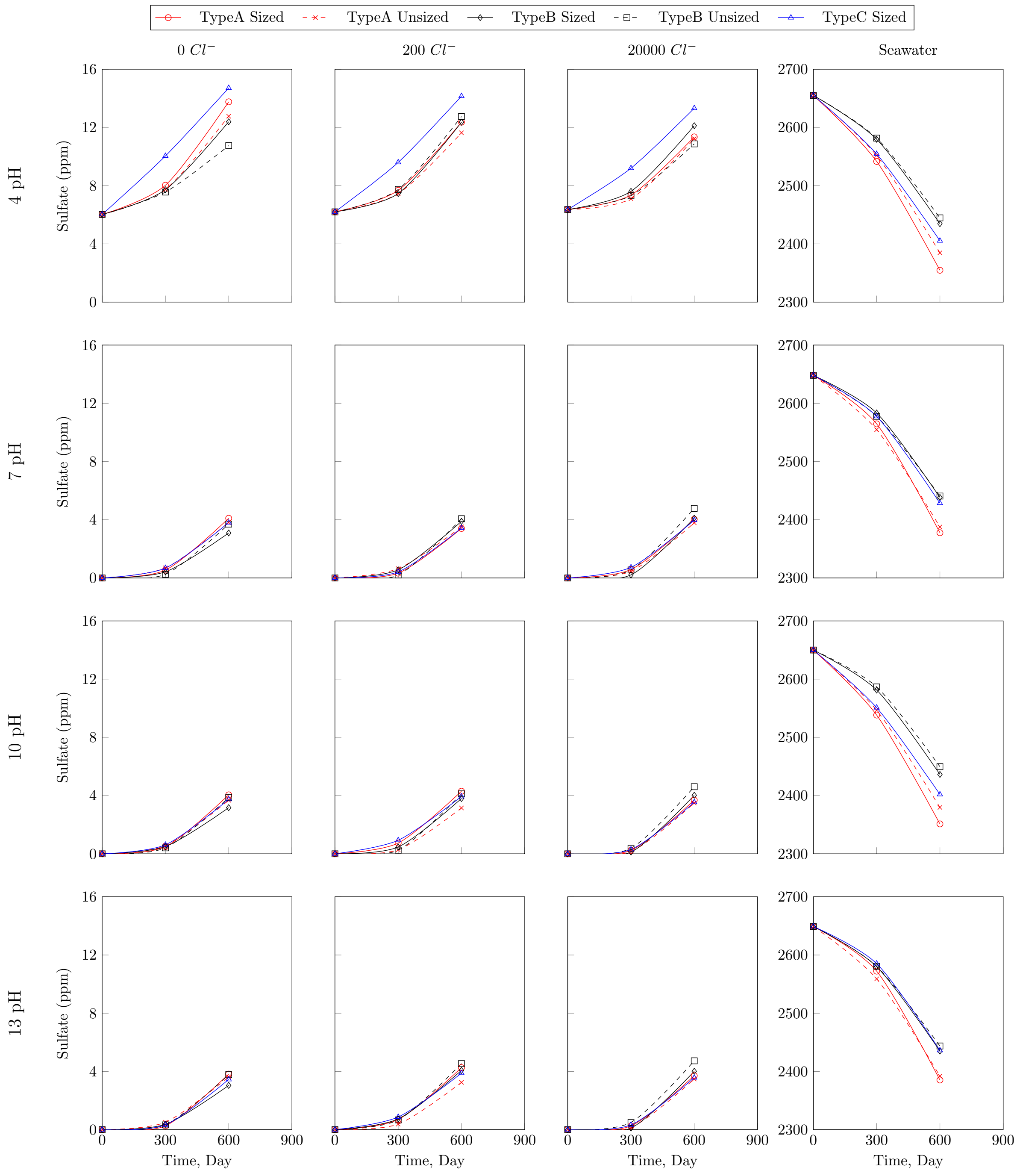

Figure 8.18: Sulfate concentration of all environments after exposure of sized and unsized fibers

8.2.6 Metals

Metals such as Aluminum, Calcium, Chromium, Iron, Magnesium, Potassium, Silicon, and Sodium were measured after 600 days of exposure and the results are tabulated in this subsection.

Aluminum

Aluminum content of the chemical environments was measured after 600 days of exposure. Tables 8.19, 8.20, and 8.21 below shows the pH data of environments in which rebars, resins, and fibers were exposed.

Table 8.19: Aluminum Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Aluminum			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	4	0	34.57	41.56	38.07	3.50
B	Vinyl Ester	1	600	4	0	26.60	31.20	28.90	2.30
C	Epoxy	1	600	4	0	45.85	54.88	50.36	4.52
A	Epoxy	1	600	4	200	37.57	47.40	42.49	4.92
B	Vinyl Ester	1	600	4	200	28.36	34.37	31.37	3.00
C	Epoxy	1	600	4	200	50.04	62.62	56.33	6.29
A	Epoxy	1	600	4	20000	42.53	50.83	46.68	4.15
B	Vinyl Ester	1	600	4	20000	30.82	36.07	33.44	2.62
C	Epoxy	1	600	4	20000	56.66	67.32	61.99	5.33
A	Epoxy	1	600	4	SeaWater	51.47	59.44	55.45	3.98
B	Vinyl Ester	1	600	4	SeaWater	35.54	40.62	38.08	2.54
C	Epoxy	1	600	4	SeaWater	68.71	78.96	73.83	5.13
A	Epoxy	2	600	4	0	47.98	54.72	51.35	3.37
B	Vinyl Ester	2	600	4	0	33.02	40.57	36.80	3.77
C	Epoxy	2	600	4	0	54.07	60.36	57.21	3.14
A	Epoxy	2	600	4	200	54.19	63.80	59.00	4.81
B	Vinyl Ester	2	600	4	200	35.07	44.23	39.65	4.58
C	Epoxy	2	600	4	200	61.23	71.54	66.39	5.15
A	Epoxy	2	600	4	20000	62.97	71.02	66.99	4.03
B	Vinyl Ester	2	600	4	20000	37.90	46.19	42.05	4.14
C	Epoxy	2	600	4	20000	71.92	80.04	75.98	4.06
A	Epoxy	2	600	4	SeaWater	79.40	87.13	83.26	3.86
B	Vinyl Ester	2	600	4	SeaWater	43.35	51.45	47.40	4.05
C	Epoxy	2	600	4	SeaWater	91.67	99.34	95.50	3.83
A	Epoxy	1	600	7	0	38.01	46.96	42.48	4.47
B	Vinyl Ester	1	600	7	0	29.06	34.63	31.84	2.78
C	Epoxy	1	600	7	0	50.59	62.06	56.33	5.74
A	Epoxy	1	600	7	200	39.26	53.64	46.45	7.19
B	Vinyl Ester	1	600	7	200	29.70	37.96	33.83	4.13
C	Epoxy	1	600	7	200	52.55	70.82	61.69	9.14
A	Epoxy	1	600	7	20000	48.75	57.61	53.18	4.43
B	Vinyl Ester	1	600	7	20000	34.58	40.10	37.34	2.76

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Table 8.19: Aluminum Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Aluminum			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
C	Epoxy	1	600	7	20000	65.08	76.45	70.77	5.68
A	Epoxy	1	600	7	SeaWater	57.27	67.02	62.15	4.88
B	Vinyl Ester	1	600	7	SeaWater	38.86	44.83	41.85	2.98
C	Epoxy	1	600	7	SeaWater	76.63	89.12	82.87	6.24
A	Epoxy	2	600	7	0	53.62	62.32	57.97	4.35
B	Vinyl Ester	2	600	7	0	35.87	44.53	40.20	4.33
C	Epoxy	2	600	7	0	60.63	69.67	65.15	4.52
A	Epoxy	2	600	7	200	58.27	72.47	65.37	7.10
B	Vinyl Ester	2	600	7	200	36.61	48.38	42.49	5.88
C	Epoxy	2	600	7	200	65.66	82.40	74.03	8.37
A	Epoxy	2	600	7	20000	73.51	82.14	77.82	4.31
B	Vinyl Ester	2	600	7	20000	42.25	50.86	46.55	4.31
C	Epoxy	2	600	7	20000	84.51	93.44	88.98	4.46
A	Epoxy	2	600	7	SeaWater	90.35	99.88	95.11	4.76
B	Vinyl Ester	2	600	7	SeaWater	47.20	56.32	51.76	4.56
C	Epoxy	2	600	7	SeaWater	104.63	114.82	109.72	5.10
A	Epoxy	1	600	10	0	41.04	49.49	45.27	4.23
B	Vinyl Ester	1	600	10	0	30.92	36.25	33.59	2.66
C	Epoxy	1	600	10	0	54.65	65.52	60.09	5.43
A	Epoxy	1	600	10	200	47.32	55.37	51.35	4.02
B	Vinyl Ester	1	600	10	200	34.26	39.39	36.82	2.56
C	Epoxy	1	600	10	200	63.11	73.47	68.29	5.18
A	Epoxy	1	600	10	20000	52.49	65.90	59.19	6.70
B	Vinyl Ester	1	600	10	20000	36.95	44.72	40.83	3.89
C	Epoxy	1	600	10	20000	70.36	87.41	78.88	8.53
A	Epoxy	1	600	10	SeaWater	63.20	75.56	69.38	6.18
B	Vinyl Ester	1	600	10	SeaWater	42.22	49.47	45.84	3.63
C	Epoxy	1	600	10	SeaWater	84.77	100.50	92.64	7.87
A	Epoxy	2	600	10	0	58.27	66.48	62.38	4.11
B	Vinyl Ester	2	600	10	0	38.03	46.41	42.22	4.19
C	Epoxy	2	600	10	0	66.26	74.62	70.44	4.18
A	Epoxy	2	600	10	200	69.43	77.23	73.33	3.90
B	Vinyl Ester	2	600	10	200	41.89	50.03	45.96	4.07
C	Epoxy	2	600	10	200	79.69	87.47	83.58	3.89
A	Epoxy	2	600	10	20000	81.51	94.73	88.12	6.61
B	Vinyl Ester	2	600	10	20000	44.99	56.20	50.59	5.60
C	Epoxy	2	600	10	20000	93.65	109.01	101.33	7.68
A	Epoxy	2	600	10	SeaWater	102.07	114.22	108.14	6.08
B	Vinyl Ester	2	600	10	SeaWater	51.08	61.68	56.38	5.30
C	Epoxy	2	600	10	SeaWater	118.43	132.30	125.36	6.93
A	Epoxy	1	600	13	0	45.51	57.86	51.69	6.18
B	Vinyl Ester	1	600	13	0	34.11	41.37	37.74	3.63

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Table 8.19: Aluminum Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Aluminum			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
C	Epoxy	1	600	13	0	60.88	76.62	68.75	7.87
A	Epoxy	1	600	13	200	53.74	63.58	58.66	4.92
B	Vinyl Ester	1	600	13	200	38.29	44.30	41.30	3.00
C	Epoxy	1	600	13	200	71.87	84.46	78.17	6.29
A	Epoxy	1	600	13	20000	58.46	71.95	65.20	6.74
B	Vinyl Ester	1	600	13	20000	40.33	48.15	44.24	3.91
C	Epoxy	1	600	13	20000	78.42	95.57	87.00	8.58
A	Epoxy	1	600	13	SeaWater	71.50	80.36	75.93	4.43
B	Vinyl Ester	1	600	13	SeaWater	46.59	52.12	49.35	2.76
C	Epoxy	1	600	13	SeaWater	95.80	107.17	101.48	5.68
A	Epoxy	2	600	13	0	66.19	78.35	72.27	6.08
B	Vinyl Ester	2	600	13	0	41.72	52.32	47.02	5.30
C	Epoxy	2	600	13	0	75.38	89.25	82.31	6.93
A	Epoxy	2	600	13	200	80.46	90.07	85.26	4.81
B	Vinyl Ester	2	600	13	200	46.55	55.72	51.13	4.58
C	Epoxy	2	600	13	200	92.75	103.05	97.90	5.15
A	Epoxy	2	600	13	20000	92.00	105.30	98.65	6.65
B	Vinyl Ester	2	600	13	20000	48.91	60.16	54.53	5.63
C	Epoxy	2	600	13	20000	106.23	121.71	113.97	7.74
A	Epoxy	2	600	13	SeaWater	115.98	124.61	120.29	4.31
B	Vinyl Ester	2	600	13	SeaWater	56.13	64.74	60.43	4.31
C	Epoxy	2	600	13	SeaWater	135.47	144.40	139.94	4.46

Table 8.20: Aluminum Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Aluminum			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	600	4	SeaWater	1.71	1.91	1.81	0.10
B	Vinyl Ester	600	4	SeaWater	1.57	1.97	1.77	0.20
A	Epoxy	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	600	7	SeaWater	1.63	2.03	1.83	0.20
B	Vinyl Ester	600	7	SeaWater	1.61	2.01	1.81	0.20
A	Epoxy	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	600	10	SeaWater	1.56	2.16	1.86	0.30
B	Vinyl Ester	600	10	SeaWater	1.54	2.14	1.84	0.30
A	Epoxy	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.00

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Table 8.20: Aluminum Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Aluminum			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	600	13	SeaWater	1.61	2.21	1.91	0.30
B	Vinyl Ester	600	13	SeaWater	1.78	1.98	1.88	0.10

Table 8.21: Aluminum Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Aluminum			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^{-} ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Sized	600	4	0	11.48	13.94	12.71	1.23
B	Sized	600	4	0	6.88	10.32	8.60	1.72
C	Sized	600	4	0	12.98	17.65	15.31	2.34
A	Sized	600	4	200	11.59	14.85	13.22	1.63
B	Sized	600	4	200	7.08	11.22	9.15	2.07
C	Sized	600	4	200	13.10	18.68	15.89	2.79
A	Sized	600	4	20000	12.55	15.39	13.97	1.42
B	Sized	600	4	20000	7.73	11.49	9.61	1.88
C	Sized	600	4	20000	14.19	19.28	16.74	2.54
A	Sized	600	4	SeaWater	15.51	18.25	16.88	1.37
B	Sized	600	4	SeaWater	8.80	12.48	10.64	1.84
C	Sized	600	4	SeaWater	17.53	22.52	20.03	2.49
A	Unsized	600	4	0	8.75	13.08	10.92	2.16
B	Unsized	600	4	0	5.68	10.13	7.90	2.23
A	Unsized	600	4	200	8.72	14.04	11.38	2.66
B	Unsized	600	4	200	5.88	11.06	8.47	2.59
A	Unsized	600	4	20000	9.67	14.45	12.06	2.39
B	Unsized	600	4	20000	6.49	11.28	8.88	2.39
A	Unsized	600	4	SeaWater	12.36	17.03	14.69	2.33
B	Unsized	600	4	SeaWater	7.49	12.19	9.84	2.35
A	Sized	600	7	0	11.92	14.94	13.43	1.51
B	Sized	600	7	0	7.30	11.22	9.26	1.96
C	Sized	600	7	0	13.48	18.78	16.13	2.65
A	Sized	600	7	200	11.82	16.36	14.09	2.27
B	Sized	600	7	200	7.07	12.33	9.70	2.63
C	Sized	600	7	200	13.36	20.39	16.87	3.51
A	Sized	600	7	20000	13.26	16.26	14.76	1.50
B	Sized	600	7	20000	8.53	12.43	10.48	1.95
C	Sized	600	7	20000	15.00	20.27	17.63	2.64
A	Sized	600	7	SeaWater	16.03	19.27	17.65	1.62
B	Sized	600	7	SeaWater	9.42	13.54	11.48	2.06
C	Sized	600	7	SeaWater	18.12	23.67	20.90	2.78
A	Unsized	600	7	0	9.05	14.06	11.55	2.50
B	Unsized	600	7	0	6.06	11.01	8.54	2.48
A	Unsized	600	7	200	8.69	15.61	12.15	3.46
B	Unsized	600	7	200	5.83	12.19	9.01	3.18
A	Unsized	600	7	20000	10.27	15.25	12.76	2.49
B	Unsized	600	7	20000	7.24	12.17	9.70	2.47
A	Unsized	600	7	SeaWater	12.75	18.04	15.40	2.65
B	Unsized	600	7	SeaWater	8.06	13.23	10.65	2.58
A	Sized	600	10	0	12.44	15.32	13.88	1.44

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Table 8.21: Aluminum Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Aluminum			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Sized	600	10	0	7.75	11.55	9.65	1.90
C	Sized	600	10	0	14.07	19.21	16.64	2.57
A	Sized	600	10	200	13.82	16.58	15.20	1.38
B	Sized	600	10	200	8.52	12.22	10.37	1.85
C	Sized	600	10	200	15.62	20.63	18.13	2.51
A	Sized	600	10	20000	13.83	18.09	15.96	2.13
B	Sized	600	10	20000	8.75	13.77	11.26	2.51
C	Sized	600	10	20000	15.63	22.34	18.99	3.36
A	Sized	600	10	SeaWater	16.31	20.29	18.30	1.99
B	Sized	600	10	SeaWater	9.99	14.75	12.37	2.38
C	Sized	600	10	SeaWater	18.44	24.82	21.63	3.19
A	Unsized	600	10	0	9.53	14.37	11.95	2.42
B	Unsized	600	10	0	6.50	11.33	8.92	2.41
A	Unsized	600	10	200	10.79	15.49	13.14	2.35
B	Unsized	600	10	200	7.31	12.04	9.68	2.36
A	Unsized	600	10	20000	10.56	17.13	13.84	3.29
B	Unsized	600	10	20000	7.40	13.51	10.46	3.05
A	Unsized	600	10	SeaWater	12.90	19.10	16.00	3.10
B	Unsized	600	10	SeaWater	8.59	14.42	11.50	2.92
A	Sized	600	13	0	13.00	16.98	14.99	1.99
B	Sized	600	13	0	8.20	12.96	10.58	2.38
C	Sized	600	13	0	14.70	21.08	17.89	3.19
A	Sized	600	13	200	14.50	17.76	16.13	1.63
B	Sized	600	13	200	9.30	13.44	11.37	2.07
C	Sized	600	13	200	16.39	21.97	19.18	2.79
A	Sized	600	13	20000	14.84	19.14	16.99	2.15
B	Sized	600	13	20000	9.50	14.54	12.02	2.52
C	Sized	600	13	20000	16.78	23.52	20.15	3.37
A	Sized	600	13	SeaWater	18.42	21.42	19.92	1.50
B	Sized	600	13	SeaWater	11.20	15.10	13.15	1.95
C	Sized	600	13	SeaWater	20.83	26.10	23.46	2.64
A	Unsized	600	13	0	9.84	16.04	12.94	3.10
B	Unsized	600	13	0	6.91	12.75	9.83	2.92
A	Unsized	600	13	200	11.31	16.63	13.97	2.66
B	Unsized	600	13	200	8.08	13.27	10.67	2.59
A	Unsized	600	13	20000	11.47	18.08	14.78	3.30
B	Unsized	600	13	20000	8.10	14.23	11.17	3.07
A	Unsized	600	13	SeaWater	15.16	20.15	17.65	2.49
B	Unsized	600	13	SeaWater	9.78	14.72	12.25	2.47

For a better understanding, change in the Aluminum content of the environments was plotted in graphs in Figure 8.19, 8.20, and 8.21. It can be seen that the Aluminum concentration has decreased in all

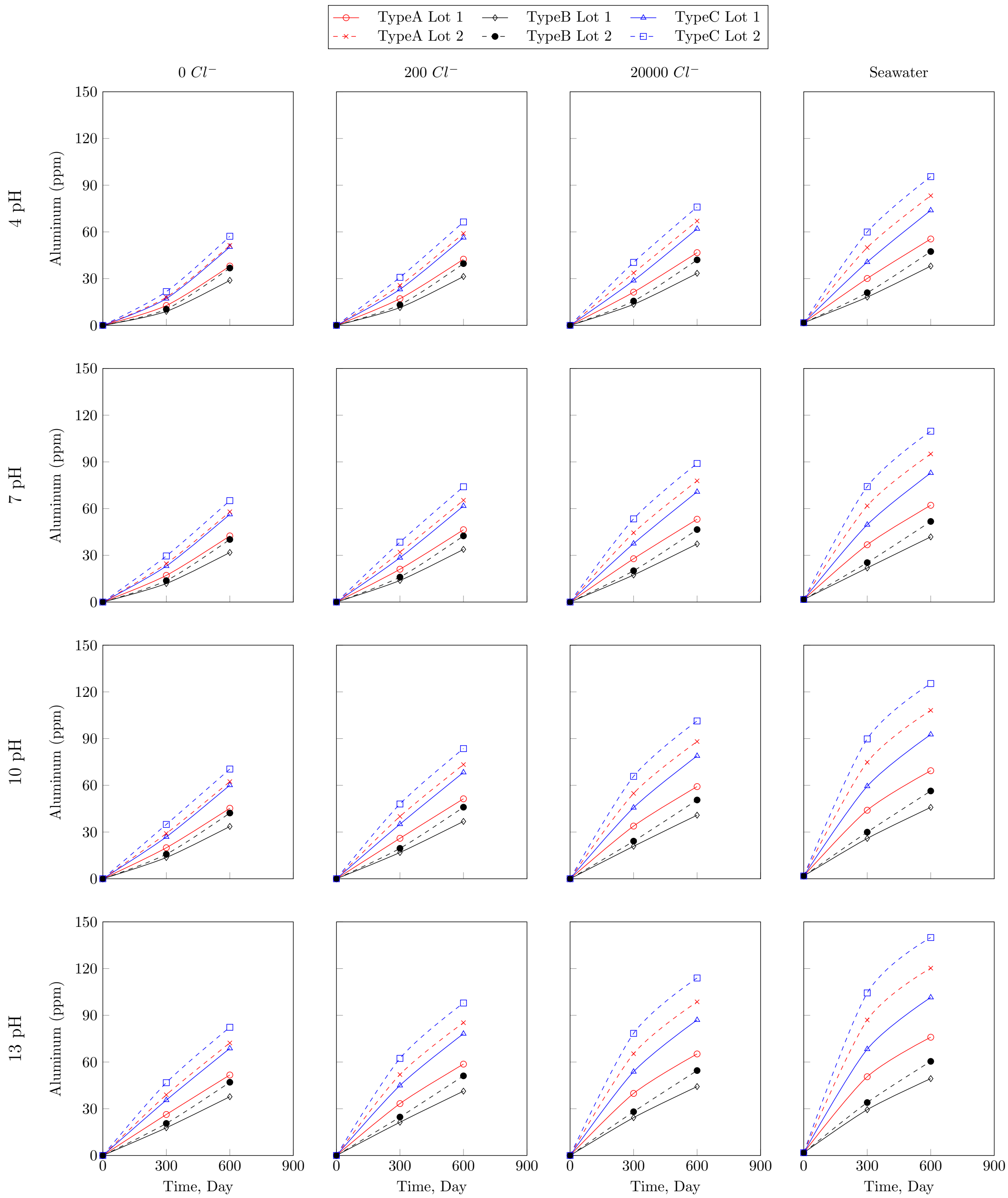

Figure 8.19: Aluminum concentration of all environments after exposure of rebars

environments except the environments that had resin samples.

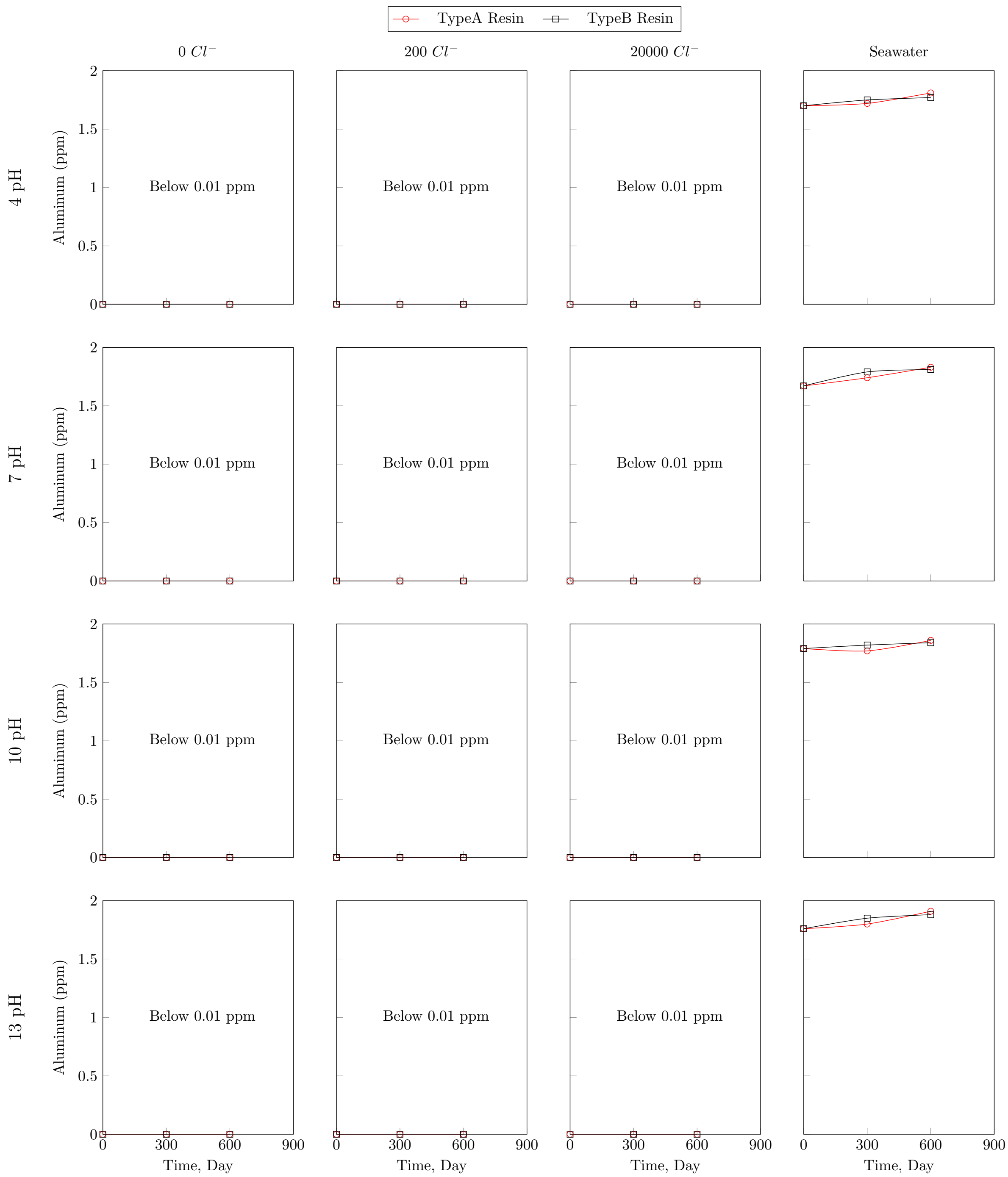

Figure 8.20: Aluminum concentration of all environments after exposure of resins

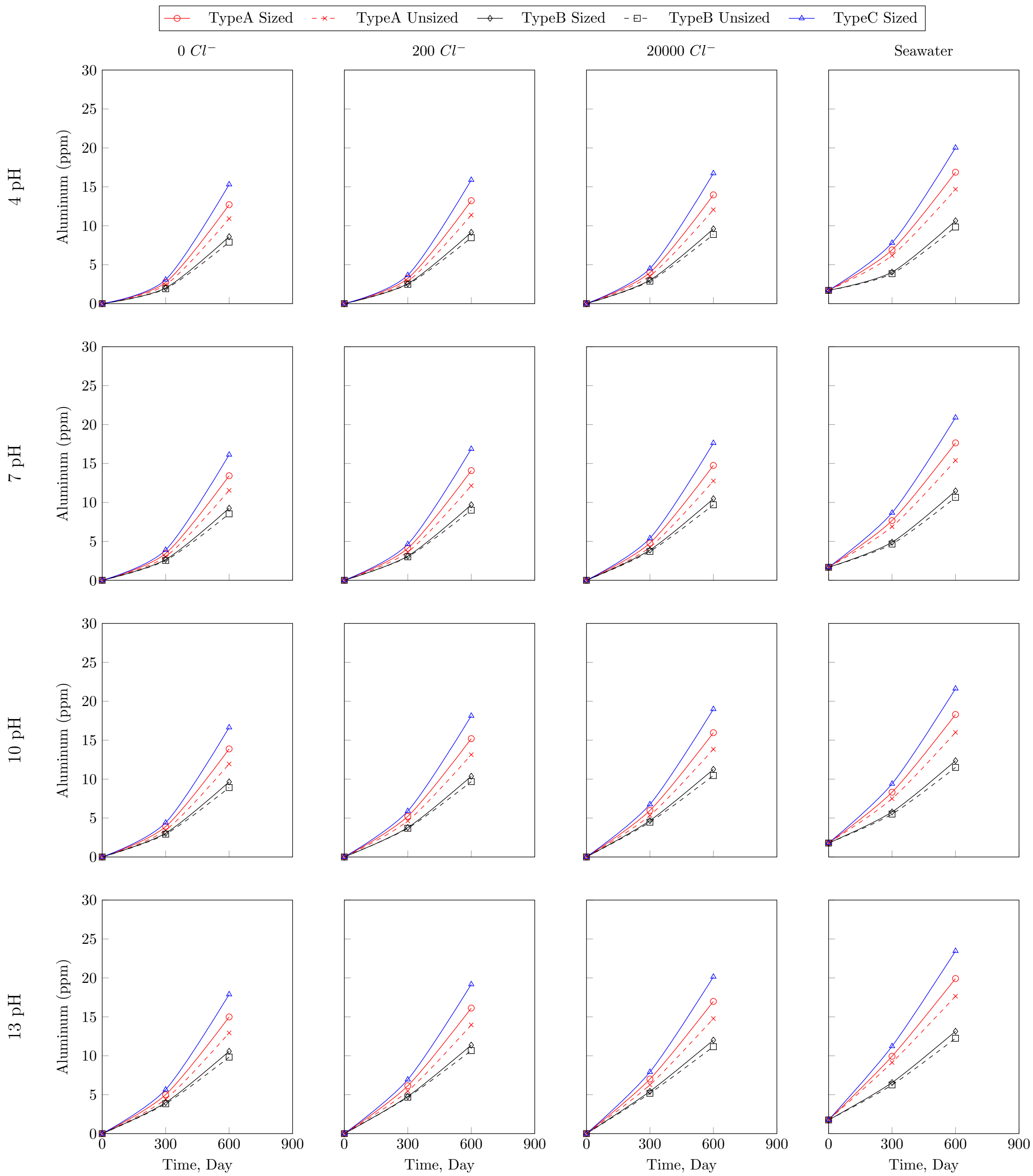

Figure 8.21: Aluminum concentration of all environments after exposure of sized and unsized fibers

Calcium

Calcium content of the chemical environments was measured after 600 days of exposure. Tables 8.22, 8.23, and 8.24 below shows the pH data of environments in which rebars, resins, and fibers were exposed.

Table 8.22: Calcium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values — Calcium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	4	0	13.37	15.06	14.22	0.85
B	Vinyl Ester	1	600	4	0	10.66	13.11	11.88	1.22
C	Epoxy	1	600	4	0	15.42	17.72	16.57	1.15
A	Epoxy	1	600	4	200	13.49	15.98	14.74	1.24
B	Vinyl Ester	1	600	4	200	10.95	13.54	12.25	1.30
C	Epoxy	1	600	4	200	15.51	18.87	17.19	1.68
A	Epoxy	1	600	4	20000	17.87	21.41	19.64	1.77
B	Vinyl Ester	1	600	4	20000	14.30	17.09	15.70	1.40
C	Epoxy	1	600	4	20000	20.60	25.38	22.99	2.39
A	Epoxy	1	600	4	SeaWater	544.38	557.90	551.14	6.76
B	Vinyl Ester	1	600	4	SeaWater	534.63	544.79	539.71	5.08
C	Epoxy	1	600	4	SeaWater	557.93	573.56	565.75	7.81
A	Epoxy	2	600	4	0	21.88	22.84	22.36	0.48
B	Vinyl Ester	2	600	4	0	17.35	20.50	18.92	1.57
C	Epoxy	2	600	4	0	29.48	33.30	31.39	1.91
A	Epoxy	2	600	4	200	21.07	26.39	23.73	2.66
B	Vinyl Ester	2	600	4	200	18.19	21.51	19.85	1.66
C	Epoxy	2	600	4	200	28.48	37.83	33.15	4.67
A	Epoxy	2	600	4	20000	31.16	42.29	36.72	5.57
B	Vinyl Ester	2	600	4	20000	26.87	30.41	28.64	1.77
C	Epoxy	2	600	4	20000	45.91	53.73	49.82	3.91
A	Epoxy	2	600	4	SeaWater	578.19	594.13	586.16	7.97
B	Vinyl Ester	2	600	4	SeaWater	565.39	578.72	572.06	6.66
C	Epoxy	2	600	4	SeaWater	592.55	616.01	604.28	11.73
A	Epoxy	1	600	7	0	13.25	15.34	14.30	1.04
B	Vinyl Ester	1	600	7	0	10.68	13.20	11.94	1.26
C	Epoxy	1	600	7	0	15.25	18.08	16.67	1.41
A	Epoxy	1	600	7	200	13.88	16.63	15.25	1.37
B	Vinyl Ester	1	600	7	200	11.29	13.93	12.61	1.32
C	Epoxy	1	600	7	200	15.94	19.66	17.80	1.86
A	Epoxy	1	600	7	20000	19.10	25.68	22.39	3.29
B	Vinyl Ester	1	600	7	20000	15.95	19.31	17.63	1.68
C	Epoxy	1	600	7	20000	21.82	30.68	26.25	4.43
A	Epoxy	1	600	7	SeaWater	554.63	565.92	560.27	5.65
B	Vinyl Ester	1	600	7	SeaWater	544.54	552.84	548.69	4.15
C	Epoxy	1	600	7	SeaWater	570.18	580.12	575.15	4.97
A	Epoxy	2	600	7	0	21.00	24.14	22.57	1.57

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Table 8.22: Calcium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Calcium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	2	600	7	0	17.45	20.68	19.06	1.62
C	Epoxy	2	600	7	0	28.37	34.96	31.66	3.29
A	Epoxy	2	600	7	200	21.72	28.49	25.11	3.39
B	Vinyl Ester	2	600	7	200	19.09	22.47	20.78	1.69
C	Epoxy	2	600	7	200	29.32	40.51	34.92	5.60
A	Epoxy	2	600	7	20000	40.09	47.92	44.01	3.91
B	Vinyl Ester	2	600	7	20000	31.48	35.67	33.58	2.09
C	Epoxy	2	600	7	20000	51.50	66.85	59.17	7.68
A	Epoxy	2	600	7	SeaWater	589.01	602.44	595.72	6.72
B	Vinyl Ester	2	600	7	SeaWater	576.01	587.23	581.62	5.61
C	Epoxy	2	600	7	SeaWater	605.96	622.44	614.20	8.24
A	Epoxy	1	600	10	0	13.63	15.45	14.54	0.91
B	Vinyl Ester	1	600	10	0	10.87	13.34	12.11	1.23
C	Epoxy	1	600	10	0	15.71	18.19	16.95	1.24
A	Epoxy	1	600	10	200	14.73	17.61	16.17	1.44
B	Vinyl Ester	1	600	10	200	11.92	14.59	13.26	1.33
C	Epoxy	1	600	10	200	16.94	20.83	18.88	1.95
A	Epoxy	1	600	10	20000	19.51	27.01	23.26	3.75
B	Vinyl Ester	1	600	10	20000	16.48	20.01	18.25	1.77
C	Epoxy	1	600	10	20000	22.24	32.34	27.29	5.05
A	Epoxy	1	600	10	SeaWater	553.74	573.91	563.82	10.09
B	Vinyl Ester	1	600	10	SeaWater	544.33	560.03	552.18	7.85
C	Epoxy	1	600	10	SeaWater	568.42	589.19	578.81	10.38
A	Epoxy	2	600	10	0	22.36	24.05	23.20	0.85
B	Vinyl Ester	2	600	10	0	17.91	21.08	19.49	1.59
C	Epoxy	2	600	10	0	30.11	34.85	32.48	2.37
A	Epoxy	2	600	10	200	23.78	31.28	27.53	3.75
B	Vinyl Ester	2	600	10	200	20.72	24.13	22.42	1.70
C	Epoxy	2	600	10	200	31.98	44.09	38.03	6.06
A	Epoxy	2	600	10	20000	39.87	52.78	46.33	6.46
B	Vinyl Ester	2	600	10	20000	32.96	37.34	35.15	2.19
C	Epoxy	2	600	10	20000	53.33	70.98	62.15	8.82
A	Epoxy	2	600	10	SeaWater	587.73	611.15	599.44	11.71
B	Vinyl Ester	2	600	10	SeaWater	575.53	595.15	585.34	9.81
C	Epoxy	2	600	10	SeaWater	603.18	632.94	618.06	14.88
A	Epoxy	1	600	13	0	13.35	17.55	15.45	2.10
B	Vinyl Ester	1	600	13	0	11.29	14.21	12.75	1.46
C	Epoxy	1	600	13	0	15.20	20.87	18.03	2.83
A	Epoxy	1	600	13	200	15.34	22.18	18.76	3.42
B	Vinyl Ester	1	600	13	200	13.37	16.78	15.08	1.71
C	Epoxy	1	600	13	200	18.41	25.49	21.95	3.54
A	Epoxy	1	600	13	20000	25.38	29.84	27.61	2.23

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Table 8.22: Calcium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Calcium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	1	600	13	20000	19.82	22.78	21.30	1.48
C	Epoxy	1	600	13	20000	29.43	35.44	32.44	3.01
A	Epoxy	1	600	13	SeaWater	555.79	577.33	566.56	10.77
B	Vinyl Ester	1	600	13	SeaWater	546.45	563.29	554.87	8.42
C	Epoxy	1	600	13	SeaWater	570.41	592.84	581.62	11.22
A	Epoxy	2	600	13	0	18.25	33.01	25.63	7.38
B	Vinyl Ester	2	600	13	0	19.30	22.98	21.14	1.84
C	Epoxy	2	600	13	0	24.93	46.26	35.59	10.66
A	Epoxy	2	600	13	200	26.75	42.04	34.40	7.64
B	Vinyl Ester	2	600	13	200	24.95	29.19	27.07	2.12
C	Epoxy	2	600	13	200	40.80	52.88	46.84	6.04
A	Epoxy	2	600	13	20000	49.73	65.95	57.84	8.11
B	Vinyl Ester	2	600	13	20000	41.07	44.81	42.94	1.87
C	Epoxy	2	600	13	20000	71.87	81.98	76.93	5.05
A	Epoxy	2	600	13	SeaWater	589.83	614.79	602.31	12.48
B	Vinyl Ester	2	600	13	SeaWater	577.74	598.66	588.20	10.46
C	Epoxy	2	600	13	SeaWater	605.13	636.93	621.03	15.90

Table 8.23: Calcium Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Calcium			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	600	4	0	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	600	4	0	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	600	4	200	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	600	4	200	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	600	4	20000	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	600	4	20000	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	600	4	SeaWater	459.56	462.90	461.23	1.67
B	Vinyl Ester	600	4	SeaWater	458.89	463.13	461.01	2.12
A	Epoxy	600	7	0	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	600	7	0	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	600	7	200	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	600	7	200	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	600	7	20000	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	600	7	20000	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	600	7	SeaWater	466.20	470.44	468.32	2.12
B	Vinyl Ester	600	7	SeaWater	466.34	471.68	469.01	2.67
A	Epoxy	600	10	0	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	600	10	0	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	600	10	200	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	600	10	200	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	600	10	20000	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	600	10	20000	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	600	10	SeaWater	468.22	474.46	471.34	3.12
B	Vinyl Ester	600	10	SeaWater	468.16	474.12	471.14	2.98
A	Epoxy	600	13	0	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	600	13	0	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	600	13	200	Below 0.05	Below 0.05	Below 0.05	0.00

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Table 8.23: Calcium Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Calcium			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	600	13	200	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	600	13	20000	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	600	13	20000	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	600	13	SeaWater	471.00	479.24	475.12	4.12
B	Vinyl Ester	600	13	SeaWater	471.11	477.15	474.13	3.02

Table 8.24: Calcium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Calcium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^{-} ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Sized	600	4	0	2.29	4.34	3.32	1.02
B	Sized	600	4	0	2.00	3.80	2.90	0.90
C	Sized	600	4	0	2.93	4.99	3.96	1.03
A	Sized	600	4	200	2.36	4.57	3.47	1.10
B	Sized	600	4	200	2.07	4.00	3.03	0.97
C	Sized	600	4	200	3.01	5.25	4.13	1.12
A	Sized	600	4	20000	3.68	6.10	4.89	1.21
B	Sized	600	4	20000	3.27	5.38	4.33	1.06
C	Sized	600	4	20000	4.47	6.97	5.72	1.25
A	Sized	600	4	SeaWater	492.95	507.28	500.12	7.17
B	Sized	600	4	SeaWater	478.30	485.68	481.99	3.69
C	Sized	600	4	SeaWater	503.98	514.52	509.25	5.27
A	Unsized	600	4	0	1.75	3.33	2.54	0.79
B	Unsized	600	4	0	1.87	2.97	2.42	0.55
A	Unsized	600	4	200	1.81	3.54	2.67	0.86
B	Unsized	600	4	200	1.93	3.16	2.54	0.62
A	Unsized	600	4	20000	2.97	4.88	3.92	0.95
B	Unsized	600	4	20000	3.00	4.41	3.70	0.70
A	Unsized	600	4	SeaWater	484.15	493.78	488.97	4.81
B	Unsized	600	4	SeaWater	470.35	479.40	474.88	4.53
A	Sized	600	7	0	2.28	4.40	3.34	1.06
B	Sized	600	7	0	1.98	3.85	2.92	0.93
C	Sized	600	7	0	2.91	5.06	3.99	1.07
A	Sized	600	7	200	2.49	4.75	3.62	1.13
B	Sized	600	7	200	2.18	4.16	3.17	0.99
C	Sized	600	7	200	3.14	5.45	4.30	1.15
A	Sized	600	7	20000	4.17	7.20	5.68	1.51
B	Sized	600	7	20000	3.74	6.36	5.05	1.31
C	Sized	600	7	20000	4.99	8.23	6.61	1.62
A	Sized	600	7	SeaWater	502.42	514.77	508.59	6.18
B	Sized	600	7	SeaWater	487.44	493.17	490.30	2.87
C	Sized	600	7	SeaWater	513.85	521.98	517.92	4.06
A	Unsized	600	7	0	1.74	3.39	2.56	0.83
B	Unsized	600	7	0	1.85	3.02	2.44	0.58
A	Unsized	600	7	200	1.92	3.69	2.81	0.88
B	Unsized	600	7	200	2.03	3.30	2.66	0.64
A	Unsized	600	7	20000	3.40	5.85	4.63	1.22
B	Unsized	600	7	20000	3.40	5.31	4.36	0.95
A	Unsized	600	7	SeaWater	493.38	501.26	497.32	3.94
B	Unsized	600	7	SeaWater	479.40	486.82	483.11	3.71
A	Sized	600	10	0	2.37	4.45	3.41	1.04

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Table 8.24: Calcium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Calcium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Sized	600	10	0	2.07	3.89	2.98	0.91
C	Sized	600	10	0	3.02	5.11	4.06	1.04
A	Sized	600	10	200	2.74	5.02	3.88	1.14
B	Sized	600	10	200	2.41	4.41	3.41	1.00
C	Sized	600	10	200	3.42	5.77	4.59	1.17
A	Sized	600	10	20000	4.33	7.54	5.94	1.60
B	Sized	600	10	20000	3.90	6.67	5.28	1.39
C	Sized	600	10	20000	5.16	8.63	6.90	1.73
A	Sized	600	10	SeaWater	501.77	522.02	511.89	10.13
B	Sized	600	10	SeaWater	487.38	499.69	493.54	6.16
C	Sized	600	10	SeaWater	512.41	530.16	521.29	8.88
A	Unsized	600	10	0	1.82	3.43	2.62	0.80
B	Unsized	600	10	0	1.93	3.06	2.49	0.56
A	Unsized	600	10	200	2.14	3.94	3.04	0.90
B	Unsized	600	10	200	2.23	3.53	2.88	0.65
A	Unsized	600	10	20000	3.55	6.15	4.85	1.30
B	Unsized	600	10	20000	3.53	5.59	4.56	1.03
A	Unsized	600	10	SeaWater	493.15	507.98	500.57	7.42
B	Unsized	600	10	SeaWater	479.34	493.27	486.31	6.96
A	Sized	600	13	0	2.40	4.95	3.67	1.27
B	Sized	600	13	0	2.11	4.33	3.22	1.11
C	Sized	600	13	0	3.03	5.69	4.36	1.33
A	Sized	600	13	200	3.09	6.17	4.63	1.54
B	Sized	600	13	200	2.76	5.42	4.09	1.33
C	Sized	600	13	200	3.78	7.09	5.43	1.65
A	Sized	600	13	20000	5.90	8.50	7.20	1.30
B	Sized	600	13	20000	5.29	7.56	6.43	1.13
C	Sized	600	13	20000	6.94	9.67	8.31	1.36
A	Sized	600	13	SeaWater	503.70	525.16	514.43	10.73
B	Sized	600	13	SeaWater	489.37	502.69	496.03	6.66
C	Sized	600	13	SeaWater	514.26	533.50	523.88	9.62
A	Unsized	600	13	0	1.85	3.87	2.86	1.01
B	Unsized	600	13	0	1.95	3.47	2.71	0.76
A	Unsized	600	13	200	2.46	4.95	3.70	1.24
B	Unsized	600	13	200	2.52	4.47	3.50	0.98
A	Unsized	600	13	20000	4.92	6.99	5.96	1.04
B	Unsized	600	13	20000	4.81	6.37	5.59	0.78
A	Unsized	600	13	SeaWater	495.12	511.02	503.07	7.95
B	Unsized	600	13	SeaWater	481.31	496.24	488.77	7.47

For a better understanding, change in the Calcium content of the environments was plotted in graphs in

Figure 8.22, 8.23, and 8.24. It can be seen that the Calcium content has increased in all environments

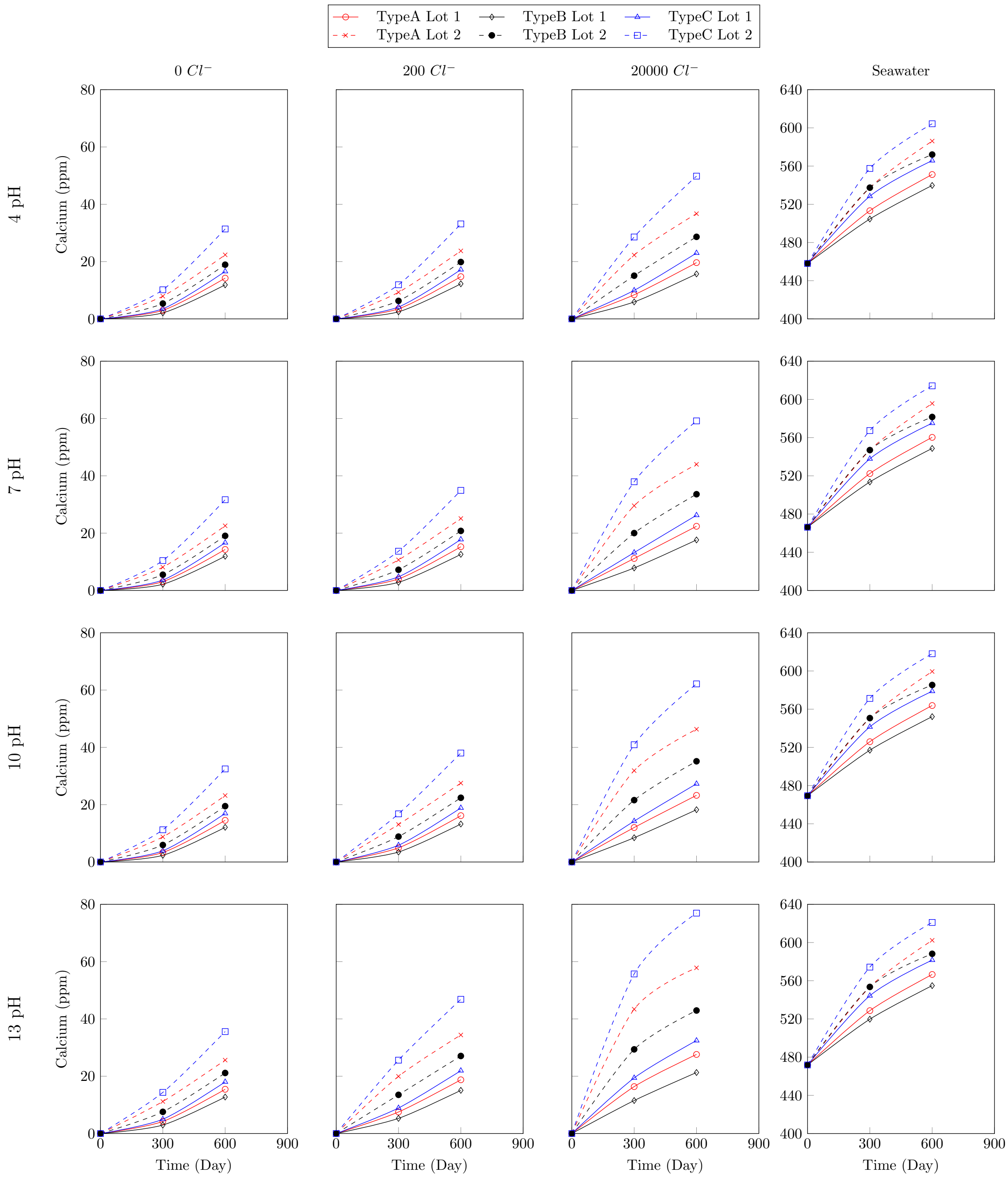

Figure 8.22: Calcium concentration of all environments after exposure of rebars

except the environments that had resin samples.

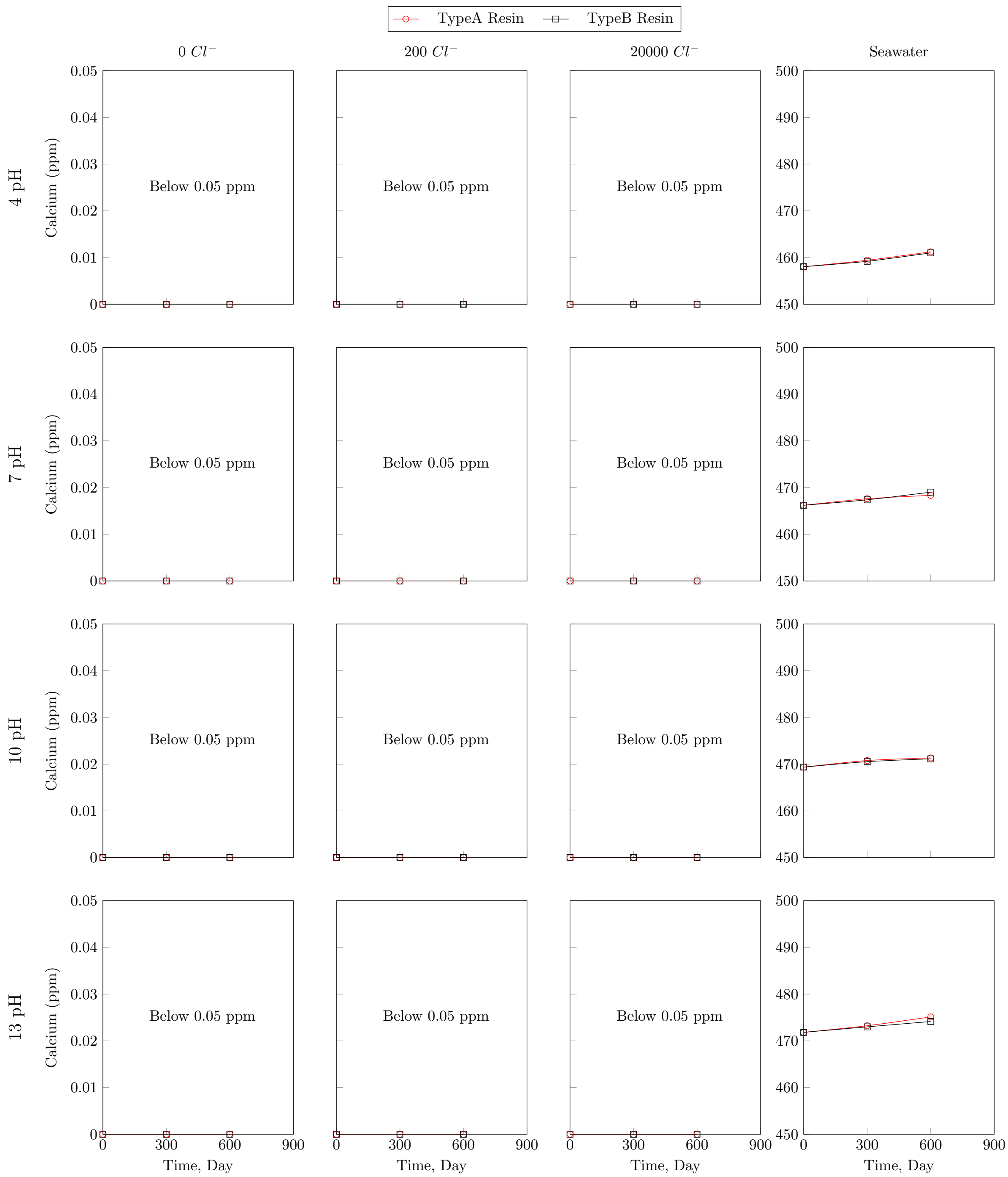

Figure 8.23: Calcium concentration of all environments after exposure of resins

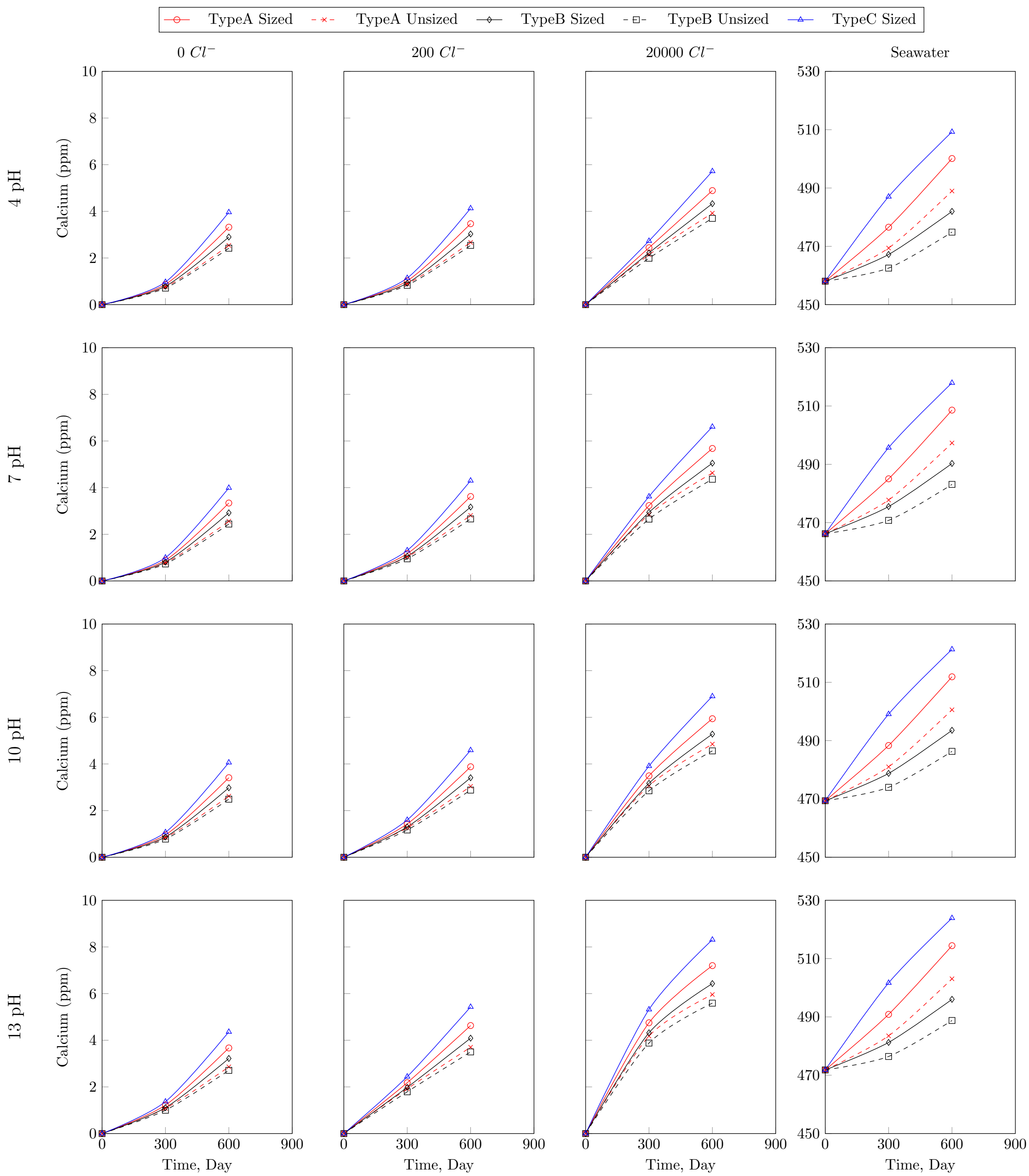

Figure 8.24: Calcium concentration of all environments after exposure of sized and unsized fibers

Chromium

Chromium content of the chemical environments was measured after 600 days of exposure. Tables 8.25, 8.26, and 8.27 below shows the pH data of environments in which rebars, resins, and fibers were exposed.

Table 8.25: Chromium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Chromium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	1	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	1	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	1	600	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	600	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	600	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	600	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	600	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	600	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	1	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.0

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Table 8.25: Chromium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Chromium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	1	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	1	600	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	600	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	600	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	600	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	600	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	600	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	1	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	1	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.0

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Table 8.25: Chromium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Chromium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	1	600	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	600	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	600	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	600	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	600	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	600	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	1	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	1	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	1	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0

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Table 8.25: Chromium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Chromium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	1	600	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	1	600	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	2	600	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	2	600	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
C	Epoxy	2	600	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0

Table 8.26: Chromium Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Chromium			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	600	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	600	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	600	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	600	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	600	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	600	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.0

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Table 8.26: Chromium Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Chromium			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Epoxy	600	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Vinyl Ester	600	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0

Table 8.27: Chromium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values — Chromium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Sized	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	600	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	600	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	600	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	600	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	600	4	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0

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Table 8.27: Chromium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Chromium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Sized	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	600	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	600	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	600	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	600	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	600	7	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	600	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	600	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	600	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.0

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Table 8.27: Chromium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Chromium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Unsized	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	600	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	600	10	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Sized	600	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Sized	600	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
C	Sized	600	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.0
A	Unsized	600	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0
B	Unsized	600	13	SeaWater	Below 0.01	Below 0.01	Below 0.01	0.0

For a better understanding, change in the Chromium content of the environments was plotted in graphs in Figure 8.25, 8.26, and 8.27. It can be seen that the Chromium concentration has not changed over time

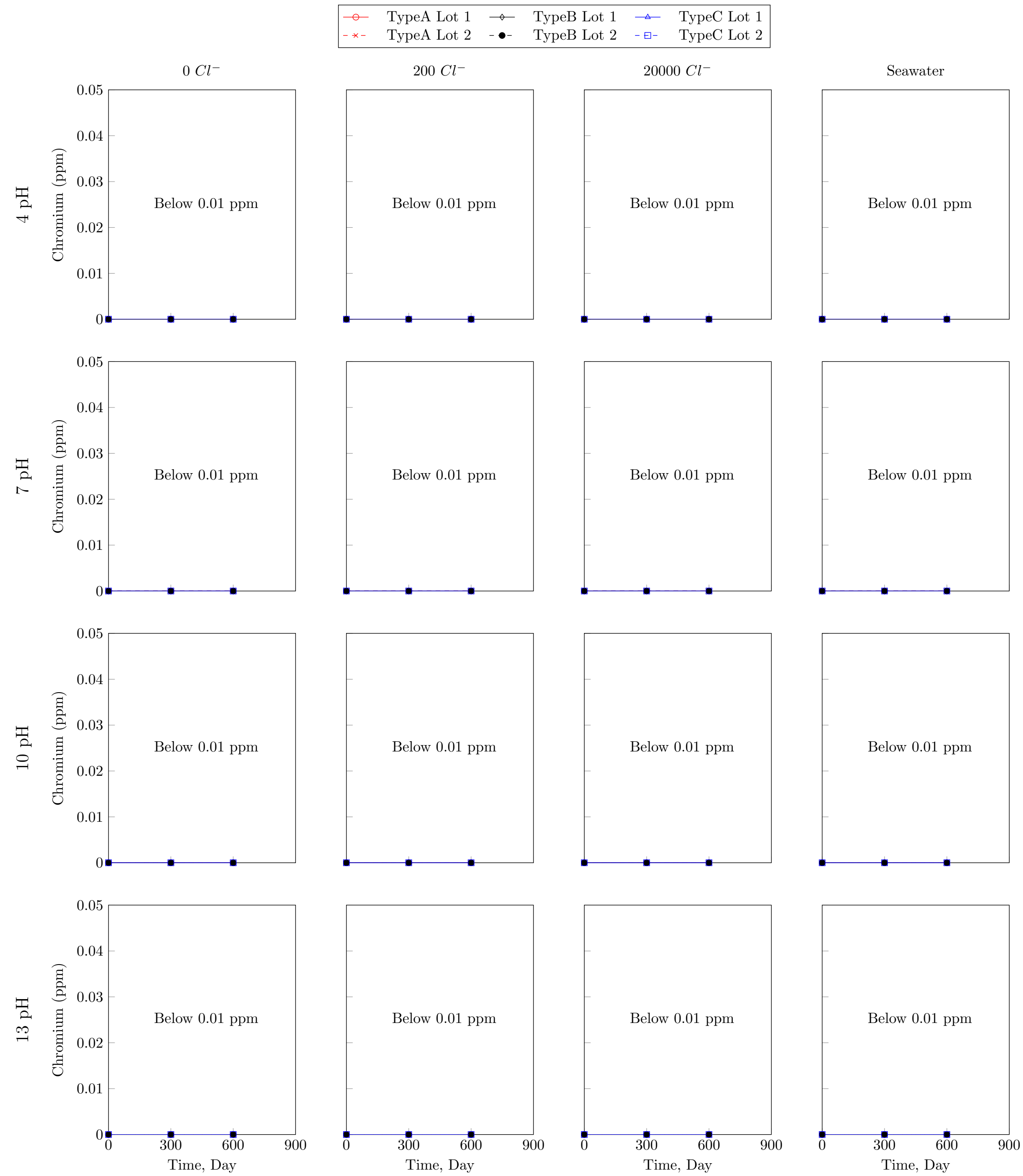

Figure 8.25: Chromium concentration of all environments after exposure of rebars

in all exposure environments.

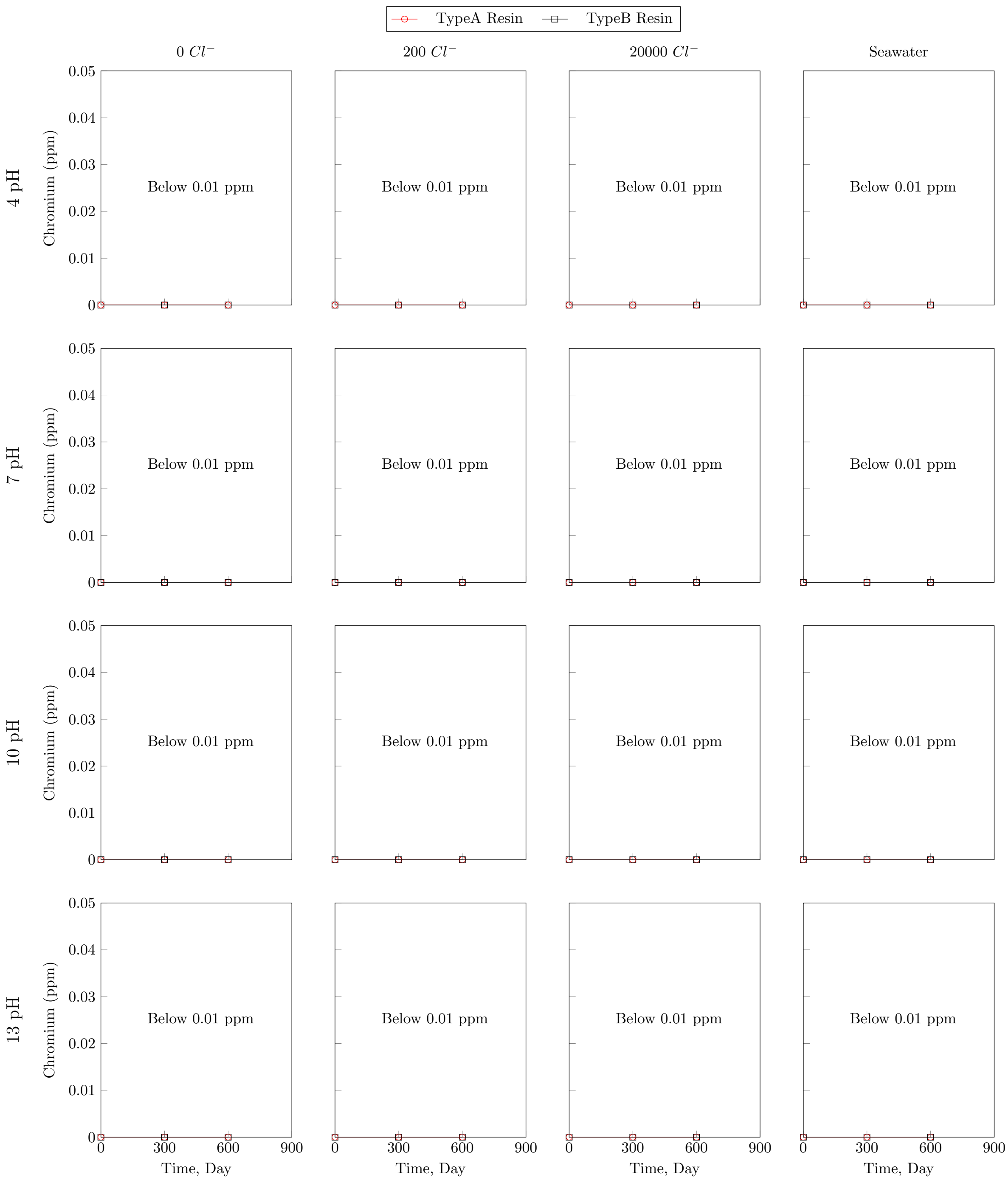

Figure 8.26: Chromium concentration of all environments after exposure of resins

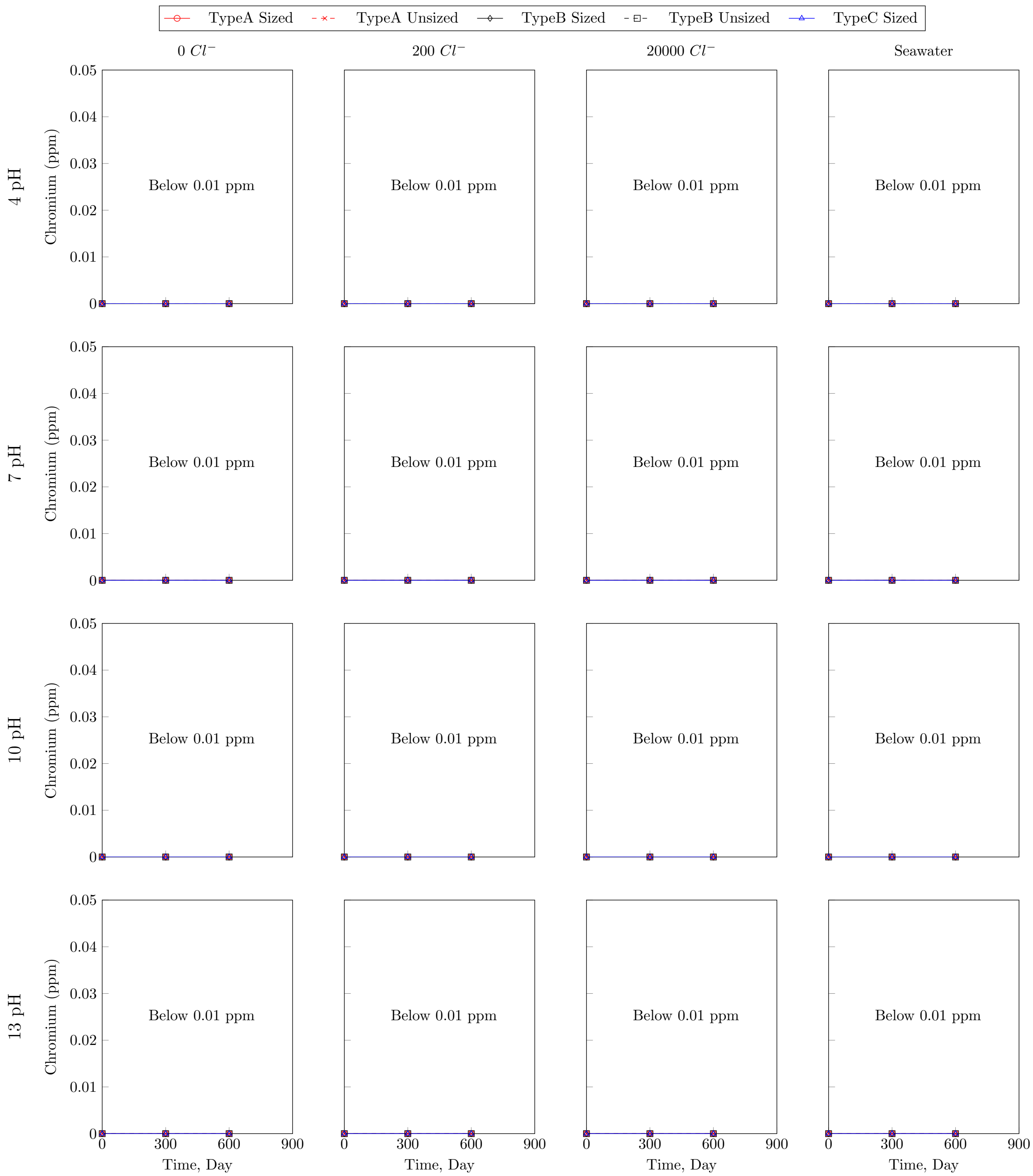

Figure 8.27: Chromium concentration of all environments after exposure of sized and unsized fibers

Iron

Iron content of the chemical environments was measured after 600 days of exposure. Tables 8.28, 8.29, and 8.30 below shows the pH data of environments in which rebars, resins, and fibers were exposed.

Table 8.28: Iron Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Iron			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	4	0	13.84	18.19	16.01	2.18
B	Vinyl Ester	1	600	4	0	10.87	18.70	14.79	3.91
C	Epoxy	1	600	4	0	21.32	27.25	24.28	2.96
A	Epoxy	1	600	4	200	14.77	19.54	17.16	2.39
B	Vinyl Ester	1	600	4	200	11.37	19.38	15.37	4.00
C	Epoxy	1	600	4	200	22.56	28.99	25.77	3.22
A	Epoxy	1	600	4	20000	33.50	38.83	36.17	2.67
B	Vinyl Ester	1	600	4	20000	26.76	34.99	30.88	4.12
C	Epoxy	1	600	4	20000	43.93	51.04	47.48	3.56
A	Epoxy	1	600	4	SeaWater	35.71	44.72	40.22	4.50
B	Vinyl Ester	1	600	4	SeaWater	28.00	37.73	32.86	4.86
C	Epoxy	1	600	4	SeaWater	46.99	58.51	52.75	5.76
A	Epoxy	2	600	4	0	18.91	21.03	19.97	1.06
B	Vinyl Ester	2	600	4	0	14.82	19.35	17.08	2.26
C	Epoxy	2	600	4	0	24.92	27.68	26.30	1.38
A	Epoxy	2	600	4	200	20.70	23.44	22.07	1.37
B	Vinyl Ester	2	600	4	200	15.56	20.38	17.97	2.41
C	Epoxy	2	600	4	200	26.93	30.51	28.72	1.79
A	Epoxy	2	600	4	20000	45.00	48.55	46.77	1.78
B	Vinyl Ester	2	600	4	20000	33.72	38.94	36.33	2.61
C	Epoxy	2	600	4	20000	53.29	57.96	55.62	2.34
A	Epoxy	2	600	4	SeaWater	50.25	59.13	54.69	4.44
B	Vinyl Ester	2	600	4	SeaWater	35.47	43.22	39.35	3.87
C	Epoxy	2	600	4	SeaWater	58.83	70.63	64.73	5.90
A	Epoxy	1	600	7	0	13.93	18.49	16.21	2.28
B	Vinyl Ester	1	600	7	0	10.92	18.84	14.88	3.96
C	Epoxy	1	600	7	0	21.45	27.63	24.54	3.09
A	Epoxy	1	600	7	200	15.66	20.58	18.12	2.46
B	Vinyl Ester	1	600	7	200	11.93	19.99	15.96	4.03
C	Epoxy	1	600	7	200	23.72	30.33	27.03	3.30
A	Epoxy	1	600	7	20000	37.81	44.78	41.30	3.48
B	Vinyl Ester	1	600	7	20000	29.52	38.41	33.97	4.45
C	Epoxy	1	600	7	20000	49.62	58.68	54.15	4.53
A	Epoxy	1	600	7	SeaWater	43.06	49.74	46.40	3.34
B	Vinyl Ester	1	600	7	SeaWater	32.02	40.80	36.41	4.39
C	Epoxy	1	600	7	SeaWater	56.43	65.14	60.79	4.36
A	Epoxy	2	600	7	0	19.14	21.57	20.35	1.21

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Table 8.28: Iron Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Iron			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	2	600	7	0	14.88	19.56	17.22	2.34
C	Epoxy	2	600	7	0	25.15	28.32	26.74	1.58
A	Epoxy	2	600	7	200	22.18	25.12	23.65	1.47
B	Vinyl Ester	2	600	7	200	16.40	21.32	18.86	2.46
C	Epoxy	2	600	7	200	28.61	32.46	30.53	1.93
A	Epoxy	2	600	7	20000	52.33	58.23	55.28	2.95
B	Vinyl Ester	2	600	7	20000	37.85	44.19	41.02	3.17
C	Epoxy	2	600	7	20000	61.49	69.32	65.41	3.91
A	Epoxy	2	600	7	SeaWater	62.70	68.20	65.45	2.75
B	Vinyl Ester	2	600	7	SeaWater	41.66	47.80	44.73	3.07
C	Epoxy	2	600	7	SeaWater	73.46	80.75	77.11	3.64
A	Epoxy	1	600	10	0	14.46	18.88	16.67	2.21
B	Vinyl Ester	1	600	10	0	11.22	19.08	15.15	3.93
C	Epoxy	1	600	10	0	22.14	28.14	25.14	3.00
A	Epoxy	1	600	10	200	17.30	22.29	19.79	2.49
B	Vinyl Ester	1	600	10	200	12.94	21.03	16.99	4.04
C	Epoxy	1	600	10	200	25.86	32.55	29.20	3.34
A	Epoxy	1	600	10	20000	39.42	46.88	43.15	3.73
B	Vinyl Ester	1	600	10	20000	30.41	39.50	34.96	4.55
C	Epoxy	1	600	10	20000	51.74	61.39	56.56	4.83
A	Epoxy	1	600	10	SeaWater	47.78	59.19	53.49	5.70
B	Vinyl Ester	1	600	10	SeaWater	35.05	45.75	40.40	5.35
C	Epoxy	1	600	10	SeaWater	62.80	77.20	70.00	7.20
A	Epoxy	2	600	10	0	20.01	22.24	21.12	1.11
B	Vinyl Ester	2	600	10	0	15.34	19.92	17.63	2.29
C	Epoxy	2	600	10	0	26.18	29.07	27.63	1.45
A	Epoxy	2	600	10	200	24.85	27.89	26.37	1.52
B	Vinyl Ester	2	600	10	200	17.94	22.90	20.42	2.48
C	Epoxy	2	600	10	200	31.66	35.65	33.66	2.00
A	Epoxy	2	600	10	20000	55.37	62.00	58.68	3.31
B	Vinyl Ester	2	600	10	20000	39.19	45.86	42.52	3.34
C	Epoxy	2	600	10	20000	64.93	73.71	69.32	4.39
A	Epoxy	2	600	10	SeaWater	71.83	84.18	78.01	6.18
B	Vinyl Ester	2	600	10	SeaWater	46.09	55.50	50.79	4.70
C	Epoxy	2	600	10	SeaWater	83.31	99.78	91.54	8.23
A	Epoxy	1	600	13	0	15.42	21.11	18.26	2.85
B	Vinyl Ester	1	600	13	0	11.99	20.36	16.18	4.19
C	Epoxy	1	600	13	0	23.45	30.98	27.21	3.77
A	Epoxy	1	600	13	200	20.89	27.99	24.44	3.55
B	Vinyl Ester	1	600	13	200	15.41	24.37	19.89	4.48
C	Epoxy	1	600	13	200	30.62	39.85	35.24	4.61
A	Epoxy	1	600	13	20000	48.51	54.34	51.43	2.92

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Table 8.28: Iron Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Iron			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	1	600	13	20000	35.62	44.05	39.84	4.22
C	Epoxy	1	600	13	20000	63.47	71.17	67.32	3.85
A	Epoxy	1	600	13	SeaWater	59.67	70.30	64.98	5.32
B	Vinyl Ester	1	600	13	SeaWater	41.67	52.06	46.86	5.20
C	Epoxy	1	600	13	SeaWater	78.21	91.67	84.94	6.73
A	Epoxy	2	600	13	0	21.56	25.62	23.59	2.03
B	Vinyl Ester	2	600	13	0	16.46	21.92	19.19	2.73
C	Epoxy	2	600	13	0	27.78	33.14	30.46	2.68
A	Epoxy	2	600	13	200	30.73	36.84	33.78	3.06
B	Vinyl Ester	2	600	13	200	21.62	28.05	24.83	3.22
C	Epoxy	2	600	13	200	38.13	46.23	42.18	4.05
A	Epoxy	2	600	13	20000	70.56	74.83	72.70	2.14
B	Vinyl Ester	2	600	13	20000	47.16	52.72	49.94	2.78
C	Epoxy	2	600	13	20000	82.62	88.25	85.44	2.82
A	Epoxy	2	600	13	SeaWater	82.81	94.04	88.42	5.61
B	Vinyl Ester	2	600	13	SeaWater	56.17	65.04	60.60	4.44
C	Epoxy	2	600	13	SeaWater	96.04	111.00	103.52	7.48

Table 8.29: Iron Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Iron			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	600	4	0	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	600	4	0	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	600	4	200	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	600	4	200	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	600	4	20000	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	600	4	20000	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	600	4	SeaWater	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	600	4	SeaWater	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	600	7	0	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	600	7	0	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	600	7	200	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	600	7	200	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	600	7	20000	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	600	7	20000	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	600	7	SeaWater	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	600	7	SeaWater	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	600	10	0	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	600	10	0	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	600	10	200	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	600	10	200	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	600	10	20000	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	600	10	20000	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	600	10	SeaWater	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	600	10	SeaWater	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	600	13	0	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	600	13	0	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	600	13	200	Below 0.05	Below 0.05	Below 0.05	0.0

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Table 8.29: Iron Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Iron			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	600	13	200	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	600	13	20000	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	600	13	20000	Below 0.05	Below 0.05	Below 0.05	0.0
A	Epoxy	600	13	SeaWater	Below 0.05	Below 0.05	Below 0.05	0.0
B	Vinyl Ester	600	13	SeaWater	Below 0.05	Below 0.05	Below 0.05	0.0

Table 8.30: Iron Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Iron			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	∧ ppm	∨ ppm	μ ppm	σ ppm
A	Sized	600	4	0	6.27	10.31	8.29	2.02
B	Sized	600	4	0	3.28	6.18	4.73	1.45
C	Sized	600	4	0	11.92	13.97	12.94	1.02
A	Sized	600	4	200	6.73	10.91	8.82	2.09
B	Sized	600	4	200	3.35	6.37	4.86	1.51
C	Sized	600	4	200	12.43	14.64	13.54	1.10
A	Sized	600	4	20000	18.16	22.54	20.35	2.19
B	Sized	600	4	20000	14.50	17.68	16.09	1.59
C	Sized	600	4	20000	24.04	26.46	25.25	1.21
A	Sized	600	4	SeaWater	20.86	26.50	23.68	2.82
B	Sized	600	4	SeaWater	14.42	18.64	16.53	2.11
C	Sized	600	4	SeaWater	27.06	30.90	28.98	1.92
A	Unsized	600	4	0	4.75	7.06	5.90	1.15
B	Unsized	600	4	0	3.27	5.47	4.37	1.10
A	Unsized	600	4	200	5.18	7.66	6.42	1.24
B	Unsized	600	4	200	3.34	5.67	4.51	1.17
A	Unsized	600	4	20000	16.54	19.25	17.89	1.35
B	Unsized	600	4	20000	14.47	16.98	15.73	1.26
A	Unsized	600	4	SeaWater	19.04	23.23	21.13	2.10
B	Unsized	600	4	SeaWater	14.38	18.03	16.20	1.83
A	Sized	600	7	0	6.26	10.38	8.32	2.06
B	Sized	600	7	0	3.27	6.23	4.75	1.48
C	Sized	600	7	0	11.91	14.04	12.98	1.06
A	Sized	600	7	200	6.78	11.02	8.90	2.12
B	Sized	600	7	200	3.46	6.52	4.99	1.53
C	Sized	600	7	200	12.50	14.76	13.63	1.13
A	Sized	600	7	20000	18.65	23.59	21.12	2.47
B	Sized	600	7	20000	14.96	18.60	16.78	1.82
C	Sized	600	7	20000	24.59	27.64	26.11	1.52
A	Sized	600	7	SeaWater	21.93	26.77	24.35	2.42
B	Sized	600	7	SeaWater	15.54	19.10	17.32	1.78
C	Sized	600	7	SeaWater	28.26	31.20	29.73	1.47
A	Unsized	600	7	0	4.74	7.13	5.94	1.20
B	Unsized	600	7	0	3.26	5.52	4.39	1.13
A	Unsized	600	7	200	5.23	7.76	6.50	1.27
B	Unsized	600	7	200	3.45	5.82	4.63	1.19
A	Unsized	600	7	20000	16.96	20.32	18.64	1.68
B	Unsized	600	7	20000	14.93	17.95	16.44	1.51
A	Unsized	600	7	SeaWater	20.17	23.42	21.80	1.63
B	Unsized	600	7	SeaWater	15.53	18.46	17.00	1.46
A	Sized	600	10	0	6.42	10.48	8.45	2.03

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Table 8.30: Iron Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Iron			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Sized	600	10	0	3.35	6.27	4.81	1.46
C	Sized	600	10	0	12.09	14.16	13.12	1.04
A	Sized	600	10	200	7.10	11.36	9.23	2.13
B	Sized	600	10	200	3.68	6.76	5.22	1.54
C	Sized	600	10	200	12.85	15.14	14.00	1.15
A	Sized	600	10	20000	19.02	24.12	21.57	2.55
B	Sized	600	10	20000	15.11	18.89	17.00	1.89
C	Sized	600	10	20000	25.00	28.24	26.62	1.62
A	Sized	600	10	SeaWater	21.78	28.24	25.01	3.23
B	Sized	600	10	SeaWater	15.76	20.66	18.21	2.45
C	Sized	600	10	SeaWater	28.09	32.85	30.47	2.38
A	Unsized	600	10	0	4.89	7.23	6.06	1.17
B	Unsized	600	10	0	3.34	5.56	4.45	1.11
A	Unsized	600	10	200	5.53	8.10	6.81	1.28
B	Unsized	600	10	200	3.66	6.06	4.86	1.20
A	Unsized	600	10	20000	17.30	20.86	19.08	1.78
B	Unsized	600	10	20000	15.07	18.24	16.66	1.59
A	Unsized	600	10	SeaWater	19.84	25.01	22.43	2.58
B	Unsized	600	10	SeaWater	15.69	20.09	17.89	2.20
A	Sized	600	13	0	6.45	10.95	8.70	2.25
B	Sized	600	13	0	3.40	6.68	5.04	1.64
C	Sized	600	13	0	12.12	14.68	13.40	1.28
A	Sized	600	13	200	7.52	12.50	10.01	2.49
B	Sized	600	13	200	4.03	7.71	5.87	1.84
C	Sized	600	13	200	13.32	16.42	14.87	1.55
A	Sized	600	13	20000	20.95	25.51	23.23	2.28
B	Sized	600	13	20000	16.43	19.75	18.09	1.66
C	Sized	600	13	20000	27.17	29.78	28.48	1.31
A	Sized	600	13	SeaWater	22.99	29.19	26.09	3.10
B	Sized	600	13	SeaWater	17.31	21.99	19.65	2.34
C	Sized	600	13	SeaWater	29.45	33.91	31.68	2.23
A	Unsized	600	13	0	4.87	7.72	6.30	1.43
B	Unsized	600	13	0	3.36	5.98	4.67	1.31
A	Unsized	600	13	200	5.85	9.27	7.56	1.71
B	Unsized	600	13	200	3.97	7.03	5.50	1.53
A	Unsized	600	13	20000	19.23	22.14	20.69	1.45
B	Unsized	600	13	20000	16.41	19.08	17.74	1.33
A	Unsized	600	13	SeaWater	21.06	25.91	23.49	2.43
B	Unsized	600	13	SeaWater	17.20	21.36	19.28	2.08

For a better understanding, change in the Iron content of the environments was plotted in graphs in Figure 8.28, 8.29, and 8.30. It can be seen that the Iron content of all environments has increased except for

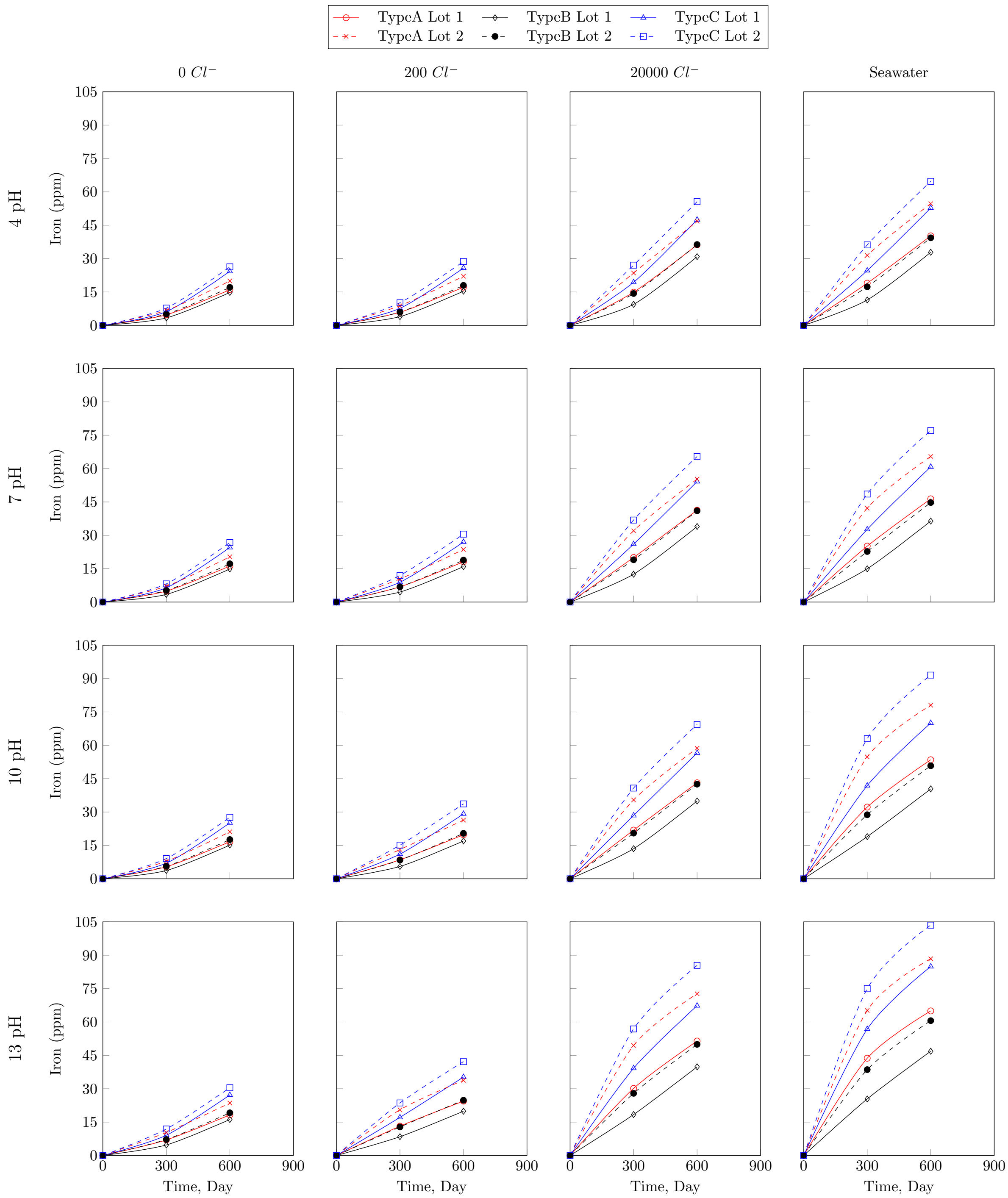

Figure 8.28: Iron concentration of all environments after exposure of rebars

the environments in which resin samples were exposed.

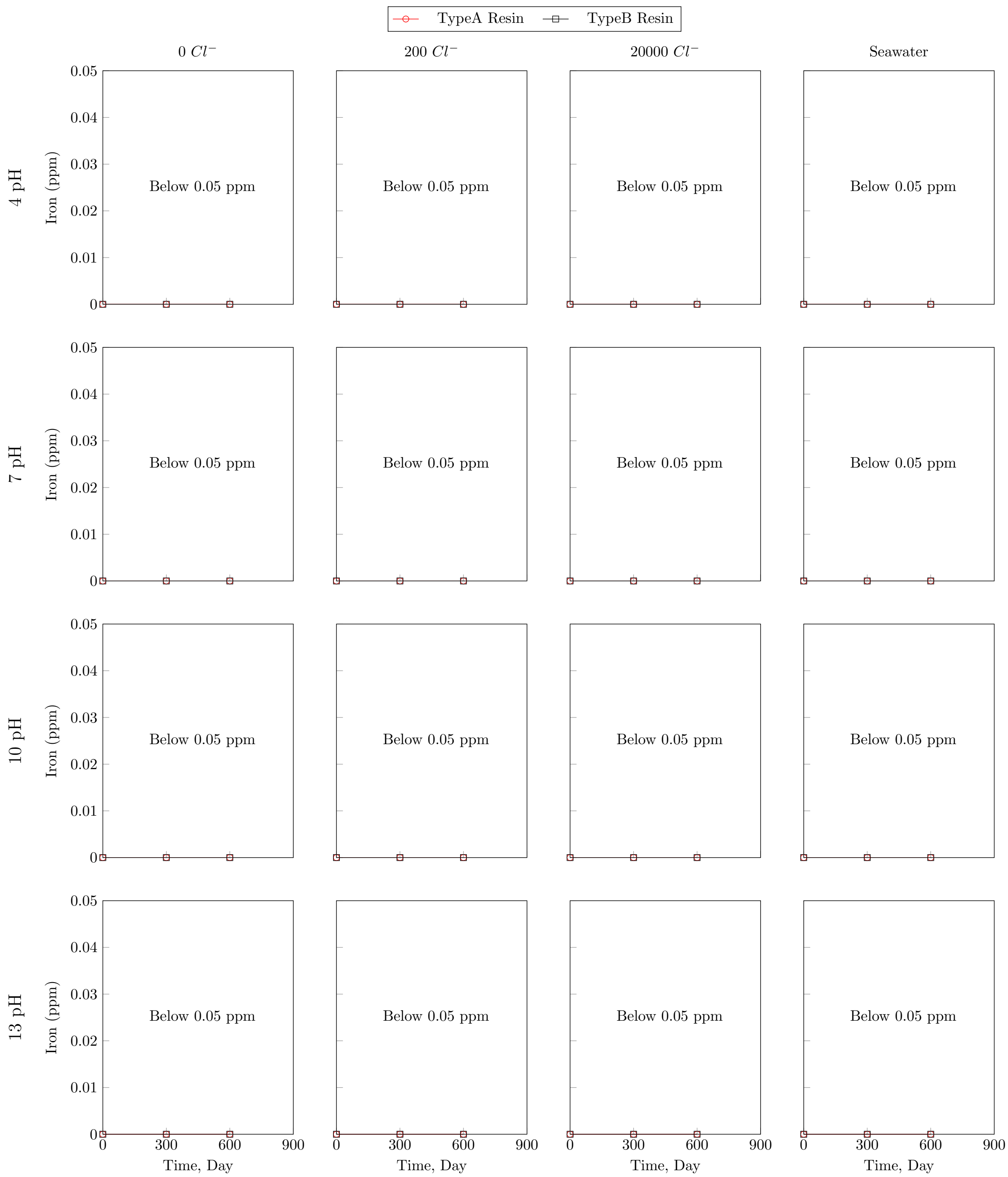

Figure 8.29: Iron concentration of all environments after exposure of resins

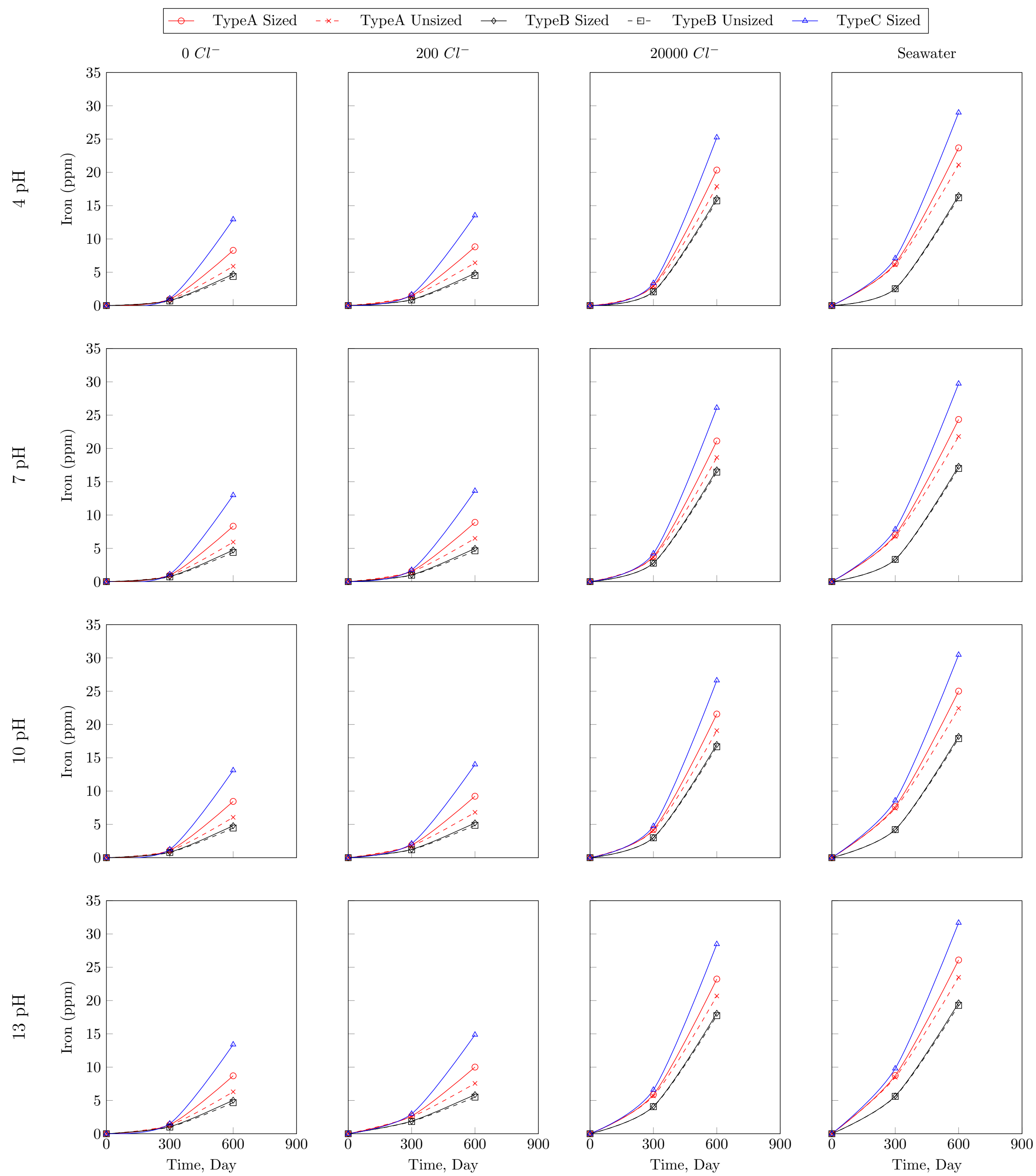

Figure 8.30: Iron concentration of all environments after exposure of sized and unsized fibers

Magnesium

Magnesium content of the chemical environments was measured after 600 days of exposure. Tables 8.31, 8.32, and 8.33 below shows the pH data of environments in which rebars, resins, and fibers were exposed.

Table 8.31: Magnesium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Magnesium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	1	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	1	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	1	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	1	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	1	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	1	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	1	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	1	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	1	600	4	SeaWater	1018.24	1038.46	1028.35	10.11
B	Vinyl Ester	1	600	4	SeaWater	1110.99	1128.05	1119.52	8.53
C	Epoxy	1	600	4	SeaWater	1091.41	1117.46	1104.44	13.02
A	Epoxy	2	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	2	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	2	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	2	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	2	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	2	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	2	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	2	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	2	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	2	600	4	SeaWater	1054.56	1076.76	1065.66	11.10
B	Vinyl Ester	2	600	4	SeaWater	1080.93	1106.75	1093.84	12.91
C	Epoxy	2	600	4	SeaWater	1074.13	1102.24	1088.19	14.05
A	Epoxy	1	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	1	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	1	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.00

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Table 8.31: Magnesium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Magnesium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	1	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	1	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	1	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	1	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	1	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	1	600	7	SeaWater	1006.68	1025.58	1016.13	9.45
B	Vinyl Ester	1	600	7	SeaWater	1095.28	1121.08	1108.18	12.90
C	Epoxy	1	600	7	SeaWater	1079.80	1104.38	1092.09	12.29
A	Epoxy	2	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	2	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	2	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	2	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	2	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	2	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	2	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	2	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	2	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	2	600	7	SeaWater	1042.89	1064.81	1053.85	10.96
B	Vinyl Ester	2	600	7	SeaWater	1073.71	1097.29	1085.50	11.79
C	Epoxy	2	600	7	SeaWater	1062.43	1090.15	1076.29	13.86
A	Epoxy	1	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	1	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	1	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	1	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	1	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	1	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.00

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Table 8.31: Magnesium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Magnesium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	1	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	1	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	1	600	10	SeaWater	994.93	1018.91	1006.92	11.99
B	Vinyl Ester	1	600	10	SeaWater	1087.96	1107.26	1097.61	9.65
C	Epoxy	1	600	10	SeaWater	1067.68	1097.90	1082.79	15.11
A	Epoxy	2	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	2	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	2	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	2	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	2	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	2	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	2	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	2	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	2	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	2	600	10	SeaWater	1035.46	1059.00	1047.23	11.77
B	Vinyl Ester	2	600	10	SeaWater	1058.04	1087.82	1072.93	14.89
C	Epoxy	2	600	10	SeaWater	1054.67	1084.58	1069.63	14.96
A	Epoxy	1	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	1	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	1	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	1	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	1	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	1	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	1	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	1	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	1	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00

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Table 8.31: Magnesium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Magnesium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	13	SeaWater	993.79	1010.69	1002.24	8.45
B	Vinyl Ester	1	600	13	SeaWater	1079.01	1100.81	1089.91	10.90
C	Epoxy	1	600	13	SeaWater	1066.89	1089.25	1078.07	11.18
A	Epoxy	2	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	2	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	2	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	2	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	2	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	2	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	2	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Vinyl Ester	2	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00
C	Epoxy	2	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Epoxy	2	600	13	SeaWater	1024.68	1050.20	1037.44	12.76
B	Vinyl Ester	2	600	13	SeaWater	1050.10	1082.36	1066.23	16.13
C	Epoxy	2	600	13	SeaWater	1043.48	1076.07	1059.78	16.29

Table 8.32: Magnesium Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Magnesium			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	600	4	0	0.0204	0.0234	0.0219	0.00
B	Vinyl Ester	600	4	0	0.0199	0.0237	0.0218	0.00
A	Epoxy	600	4	200	0.0195	0.0227	0.0211	0.00
B	Vinyl Ester	600	4	200	0.0191	0.0229	0.0210	0.00
A	Epoxy	600	4	20000	0.0207	0.0233	0.0220	0.00
B	Vinyl Ester	600	4	20000	0.0199	0.0239	0.0219	0.00
A	Epoxy	600	4	SeaWater	1450.92	1475.38	1463.15	12.23
B	Vinyl Ester	600	4	SeaWater	1450.48	1470.46	1460.47	9.99
A	Epoxy	600	7	0	0.0209	0.0239	0.0224	0.00
B	Vinyl Ester	600	7	0	0.0205	0.0241	0.0223	0.00
A	Epoxy	600	7	200	0.0194	0.0228	0.0211	0.00
B	Vinyl Ester	600	7	200	0.0190	0.0230	0.0210	0.00
A	Epoxy	600	7	20000	0.0203	0.0231	0.0217	0.00
B	Vinyl Ester	600	7	20000	0.0195	0.0237	0.0216	0.00
A	Epoxy	600	7	SeaWater	1472.42	1494.22	1483.32	10.90
B	Vinyl Ester	600	7	SeaWater	1465.75	1495.53	1480.64	14.89
A	Epoxy	600	10	0	0.0198	0.0230	0.0214	0.00
B	Vinyl Ester	600	10	0	0.0195	0.0231	0.0213	0.00
A	Epoxy	600	10	200	0.0189	0.0225	0.0207	0.00
B	Vinyl Ester	600	10	200	0.0188	0.0224	0.0206	0.00
A	Epoxy	600	10	20000	0.0195	0.0223	0.0209	0.00
B	Vinyl Ester	600	10	20000	0.0186	0.0230	0.0208	0.00
A	Epoxy	600	10	SeaWater	1467.06	1494.42	1480.74	13.68
B	Vinyl Ester	600	10	SeaWater	1466.16	1489.96	1478.06	11.90
A	Epoxy	600	13	0	0.0203	0.0231	0.0217	0.00
B	Vinyl Ester	600	13	0	0.0195	0.0237	0.0216	0.00
A	Epoxy	600	13	200	0.0202	0.0228	0.0215	0.00
B	Vinyl Ester	600	13	200	0.0196	0.0232	0.0214	0.00
A	Epoxy	600	13	20000	0.0197	0.0225	0.0211	0.00
B	Vinyl Ester	600	13	20000	0.0190	0.0230	0.0210	0.00
A	Epoxy	600	13	SeaWater	1489.83	1510.05	1499.94	10.11
B	Vinyl Ester	600	13	SeaWater	1485.82	1513.60	1499.71	13.89

Table 8.33: Magnesium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Magnesium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Sized	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Sized	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
C	Sized	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Sized	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Sized	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
C	Sized	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Sized	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Sized	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
C	Sized	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Sized	600	4	SeaWater	1194.39	1221.97	1208.18	13.79
B	Sized	600	4	SeaWater	1226.09	1258.79	1242.44	16.35
C	Sized	600	4	SeaWater	1224.61	1247.59	1236.10	11.49
A	Unsized	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Unsized	600	4	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Unsized	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Unsized	600	4	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Unsized	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Unsized	600	4	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Unsized	600	4	SeaWater	1218.20	1245.56	1231.88	13.68
B	Unsized	600	4	SeaWater	1236.90	1270.38	1253.64	16.74
A	Sized	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Sized	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.00
C	Sized	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Sized	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Sized	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
C	Sized	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Sized	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00

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Table 8.33: Magnesium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Magnesium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Sized	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00
C	Sized	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Sized	600	7	SeaWater	1185.88	1218.14	1202.01	16.13
B	Sized	600	7	SeaWater	1219.49	1249.11	1234.30	14.81
C	Sized	600	7	SeaWater	1215.98	1243.73	1229.85	13.87
A	Unsized	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Unsized	600	7	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Unsized	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Unsized	600	7	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Unsized	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Unsized	600	7	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Unsized	600	7	SeaWater	1208.61	1243.53	1226.07	17.46
B	Unsized	600	7	SeaWater	1233.85	1258.41	1246.13	12.28
A	Sized	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Sized	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.00
C	Sized	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Sized	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Sized	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.00
C	Sized	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Sized	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Sized	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
C	Sized	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Sized	600	10	SeaWater	1179.99	1208.01	1194.00	14.01
B	Sized	600	10	SeaWater	1205.07	1241.19	1223.13	18.06
C	Sized	600	10	SeaWater	1210.03	1233.46	1221.74	11.71
A	Unsized	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Unsized	600	10	0	Below 0.01	Below 0.01	Below 0.01	0.00

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Table 8.33: Magnesium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Magnesium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Unsized	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Unsized	600	10	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Unsized	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Unsized	600	10	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Unsized	600	10	SeaWater	1196.98	1233.92	1215.45	18.47
B	Unsized	600	10	SeaWater	1217.77	1246.65	1232.21	14.44
A	Sized	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Sized	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
C	Sized	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Sized	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Sized	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.00
C	Sized	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Sized	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Sized	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00
C	Sized	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Sized	600	13	SeaWater	1169.14	1195.20	1182.17	13.03
B	Sized	600	13	SeaWater	1195.40	1230.06	1212.73	17.33
C	Sized	600	13	SeaWater	1199.06	1220.48	1209.77	10.71
A	Unsized	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
B	Unsized	600	13	0	Below 0.01	Below 0.01	Below 0.01	0.00
A	Unsized	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.00
B	Unsized	600	13	200	Below 0.01	Below 0.01	Below 0.01	0.00
A	Unsized	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00
B	Unsized	600	13	20000	Below 0.01	Below 0.01	Below 0.01	0.00
A	Unsized	600	13	SeaWater	1191.65	1223.01	1207.33	15.68
B	Unsized	600	13	SeaWater	1208.36	1237.58	1222.97	14.61

For a better understanding, change in the Magnesium content of the environments was plotted in graphs in Figure 8.31, 8.32, and 8.33. It can be seen that the Magnesium concentration in all environments has

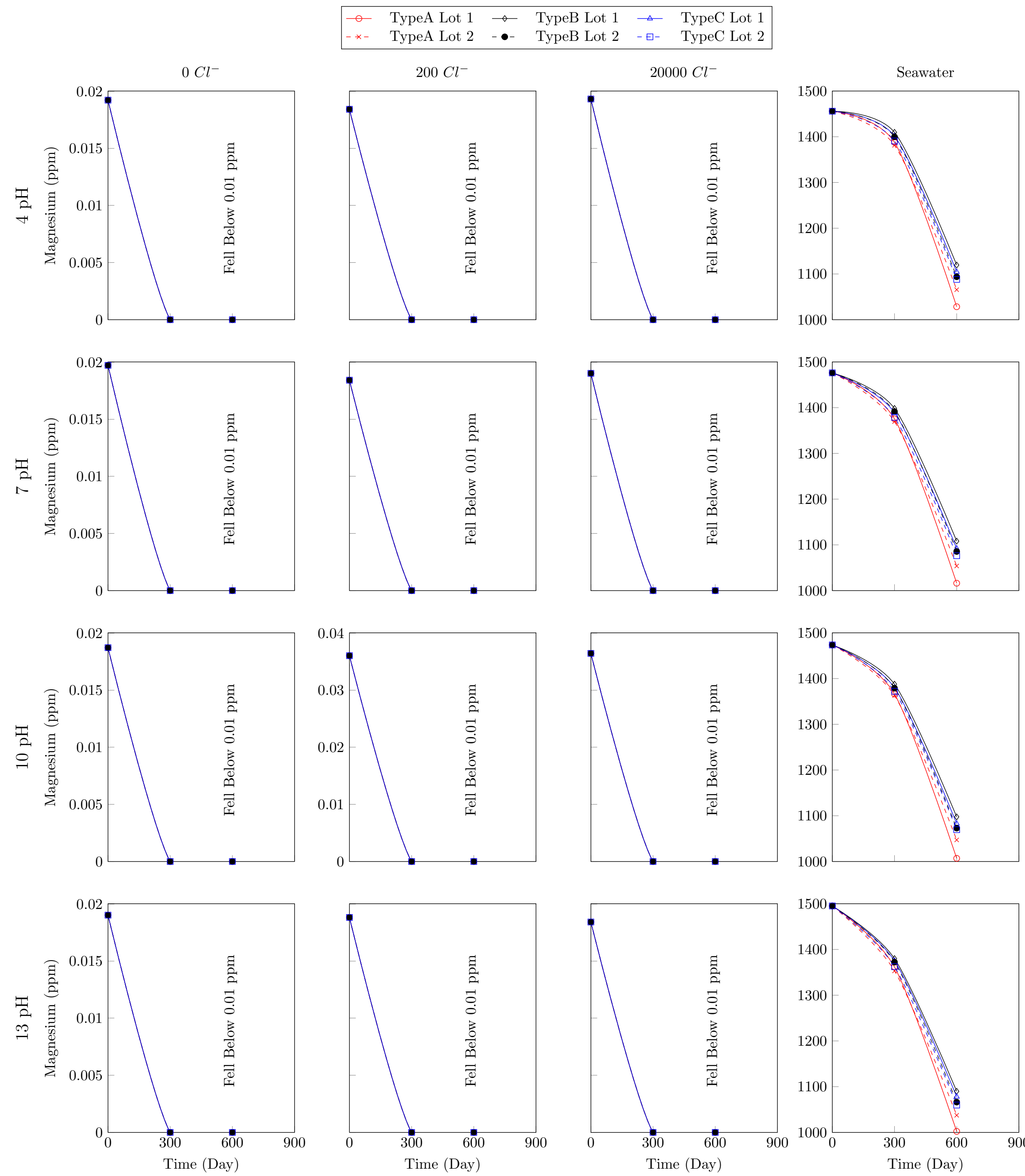

Figure 8.31: Magnesium concentration of all environments after exposure of rebars

decreased except for the environments in which resin samples were exposed.

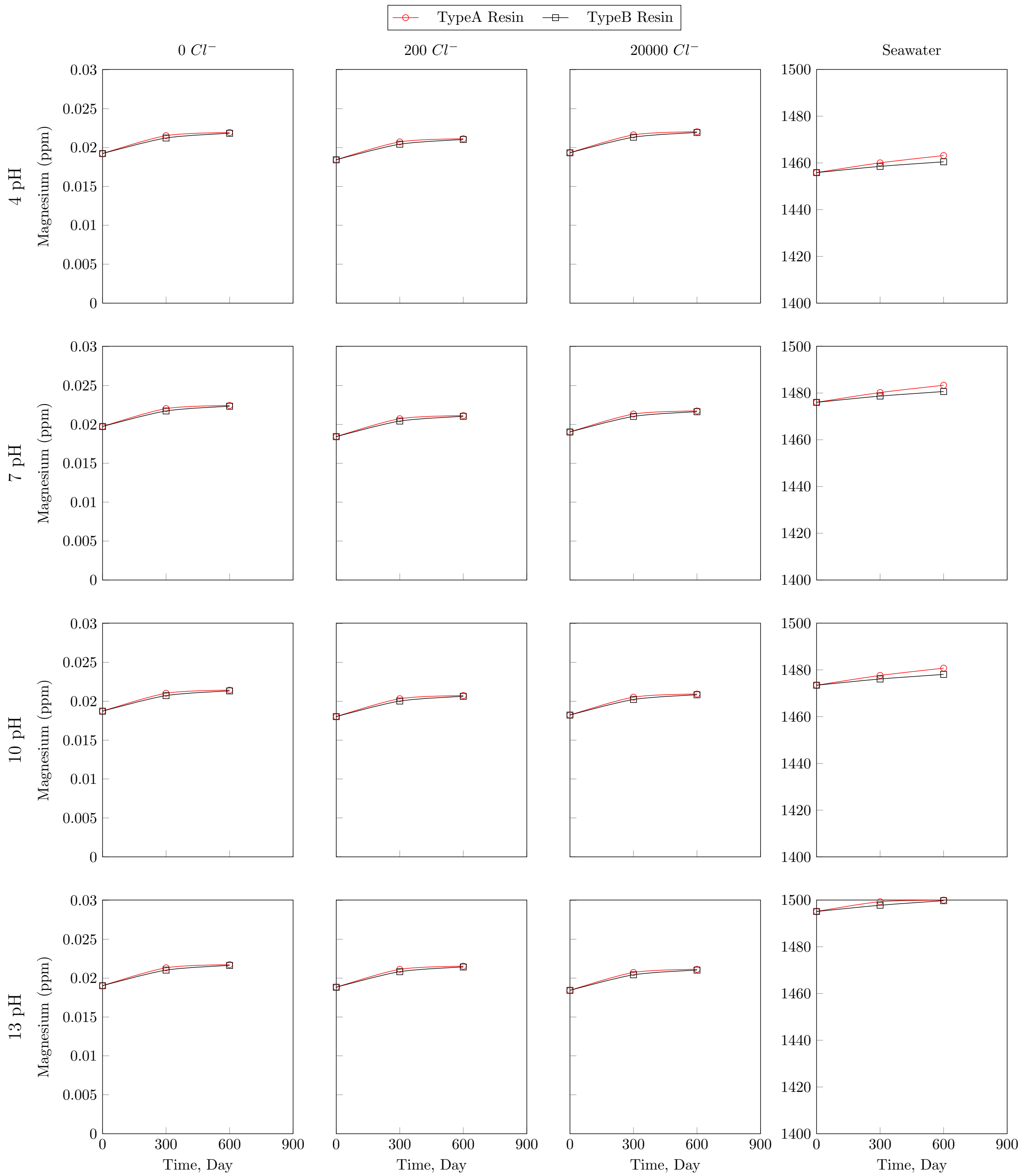

Figure 8.32: Magnesium concentration of all environments after exposure of resins

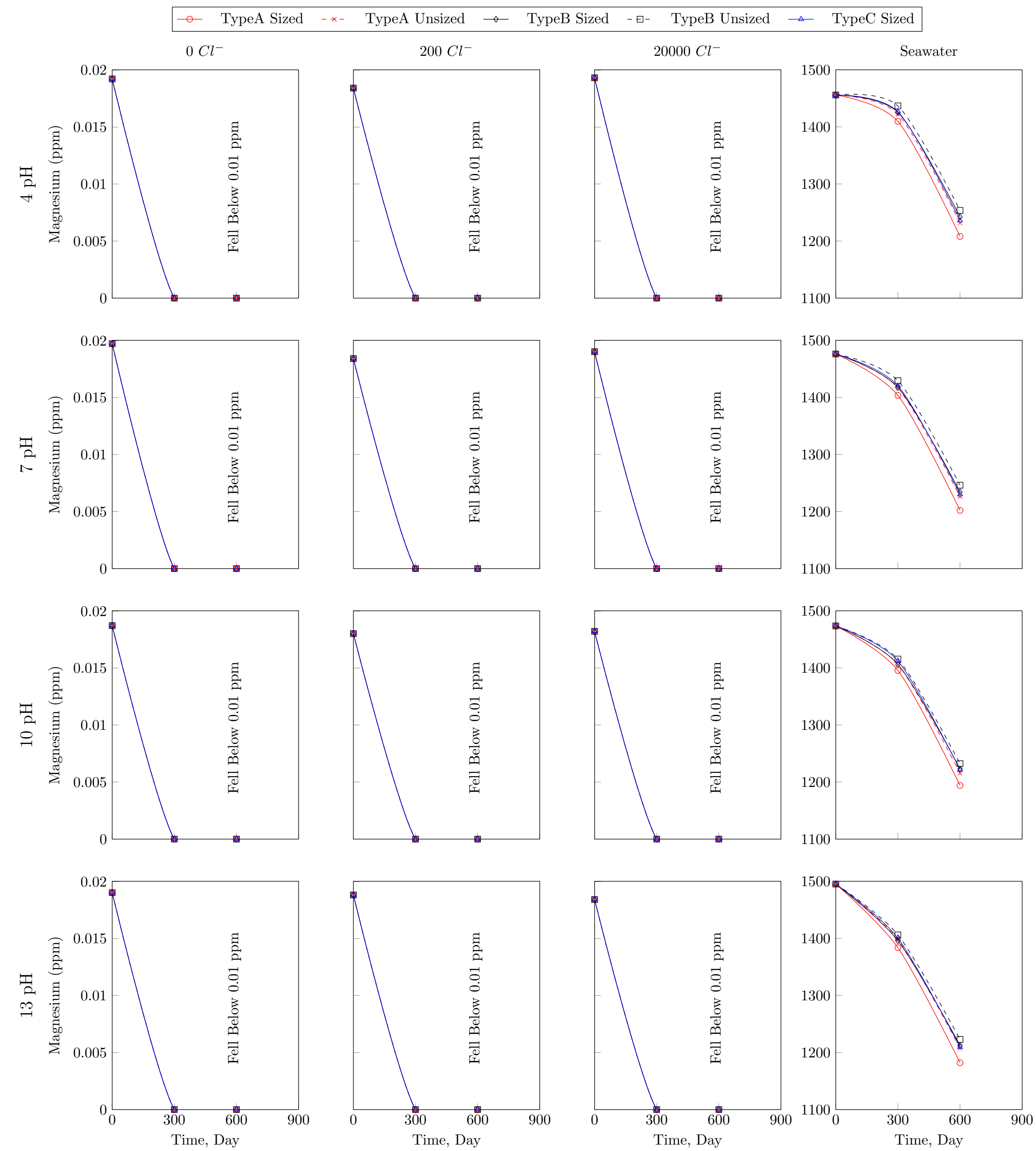

Figure 8.33: Magnesium concentration of all environments after exposure of sized and unsized fibers

Potassium

Potassium content of the chemical environments was measured after 600 days of exposure. Tables 8.34, 8.35, and 8.36 below shows the pH data of environments in which rebars, resins, and fibers were exposed.

Table 8.34: Potassium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Potassium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	4	0	0.17	0.17	0.17	0.00
B	Vinyl Ester	1	600	4	0	0.13	0.13	0.13	0.00
C	Epoxy	1	600	4	0	0.19	0.20	0.19	0.00
A	Epoxy	1	600	4	200	0.18	0.18	0.18	0.00
B	Vinyl Ester	1	600	4	200	0.14	0.14	0.14	0.00
C	Epoxy	1	600	4	200	0.20	0.21	0.21	0.00
A	Epoxy	1	600	4	20000	0.19	0.20	0.19	0.00
B	Vinyl Ester	1	600	4	20000	0.15	0.15	0.15	0.00
C	Epoxy	1	600	4	20000	0.22	0.22	0.22	0.00
A	Epoxy	1	600	4	SeaWater	435.27	453.25	444.26	8.99
B	Vinyl Ester	1	600	4	SeaWater	428.83	445.47	437.15	8.32
C	Epoxy	1	600	4	SeaWater	464.35	484.71	474.53	10.18
A	Epoxy	2	600	4	0	0.29	0.29	0.29	0.00
B	Vinyl Ester	2	600	4	0	0.16	0.16	0.16	0.00
C	Epoxy	2	600	4	0	0.33	0.33	0.33	0.00
A	Epoxy	2	600	4	200	0.30	0.31	0.30	0.00
B	Vinyl Ester	2	600	4	200	0.17	0.17	0.17	0.00
C	Epoxy	2	600	4	200	0.35	0.35	0.35	0.00
A	Epoxy	2	600	4	20000	0.32	0.32	0.32	0.00
B	Vinyl Ester	2	600	4	20000	0.18	0.18	0.18	0.00
C	Epoxy	2	600	4	20000	0.36	0.37	0.37	0.00
A	Epoxy	2	600	4	SeaWater	453.35	476.99	465.17	11.82
B	Vinyl Ester	2	600	4	SeaWater	429.48	455.76	442.62	13.14
C	Epoxy	2	600	4	SeaWater	474.51	501.90	488.20	13.69
A	Epoxy	1	600	7	0	0.17	0.18	0.18	0.00
B	Vinyl Ester	1	600	7	0	0.13	0.14	0.14	0.00
C	Epoxy	1	600	7	0	0.20	0.20	0.20	0.00
A	Epoxy	1	600	7	200	0.19	0.19	0.19	0.00
B	Vinyl Ester	1	600	7	200	0.14	0.15	0.15	0.00
C	Epoxy	1	600	7	200	0.21	0.21	0.21	0.00
A	Epoxy	1	600	7	20000	0.20	0.20	0.20	0.00
B	Vinyl Ester	1	600	7	20000	0.15	0.16	0.15	0.00
C	Epoxy	1	600	7	20000	0.22	0.23	0.22	0.00
A	Epoxy	1	600	7	SeaWater	443.06	462.36	452.71	9.65
B	Vinyl Ester	1	600	7	SeaWater	435.66	454.38	445.02	9.36
C	Epoxy	1	600	7	SeaWater	472.46	494.35	483.40	10.94
A	Epoxy	2	600	7	0	0.29	0.30	0.29	0.00

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Table 8.34: Potassium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Potassium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	2	600	7	0	0.16	0.16	0.16	0.00
C	Epoxy	2	600	7	0	0.33	0.34	0.33	0.00
A	Epoxy	2	600	7	200	0.31	0.31	0.31	0.00
B	Vinyl Ester	2	600	7	200	0.17	0.17	0.17	0.00
C	Epoxy	2	600	7	200	0.35	0.35	0.35	0.00
A	Epoxy	2	600	7	20000	0.32	0.32	0.32	0.00
B	Vinyl Ester	2	600	7	20000	0.18	0.18	0.18	0.00
C	Epoxy	2	600	7	20000	0.37	0.38	0.37	0.00
A	Epoxy	2	600	7	SeaWater	467.66	487.78	477.72	10.06
B	Vinyl Ester	2	600	7	SeaWater	434.87	465.13	450.00	15.13
C	Epoxy	2	600	7	SeaWater	489.91	512.48	501.19	11.28
A	Epoxy	1	600	10	0	0.18	0.18	0.18	0.00
B	Vinyl Ester	1	600	10	0	0.14	0.14	0.14	0.00
C	Epoxy	1	600	10	0	0.20	0.20	0.20	0.00
A	Epoxy	1	600	10	200	0.19	0.19	0.19	0.00
B	Vinyl Ester	1	600	10	200	0.15	0.15	0.15	0.00
C	Epoxy	1	600	10	200	0.21	0.22	0.21	0.00
A	Epoxy	1	600	10	20000	0.20	0.20	0.20	0.00
B	Vinyl Ester	1	600	10	20000	0.15	0.16	0.16	0.00
C	Epoxy	1	600	10	20000	0.22	0.23	0.22	0.00
A	Epoxy	1	600	10	SeaWater	449.82	473.98	461.90	12.08
B	Vinyl Ester	1	600	10	SeaWater	439.73	457.25	448.49	8.76
C	Epoxy	1	600	10	SeaWater	479.30	506.82	493.06	13.76
A	Epoxy	2	600	10	0	0.29	0.30	0.30	0.00
B	Vinyl Ester	2	600	10	0	0.16	0.16	0.16	0.00
C	Epoxy	2	600	10	0	0.33	0.34	0.34	0.00
A	Epoxy	2	600	10	200	0.31	0.31	0.31	0.00
B	Vinyl Ester	2	600	10	200	0.17	0.18	0.17	0.00
C	Epoxy	2	600	10	200	0.35	0.36	0.36	0.00
A	Epoxy	2	600	10	20000	0.32	0.33	0.32	0.00
B	Vinyl Ester	2	600	10	20000	0.18	0.18	0.18	0.00
C	Epoxy	2	600	10	20000	0.37	0.38	0.38	0.00
A	Epoxy	2	600	10	SeaWater	471.06	491.14	481.10	10.04
B	Vinyl Ester	2	600	10	SeaWater	441.97	470.67	456.32	14.35
C	Epoxy	2	600	10	SeaWater	493.44	515.96	504.70	11.26
A	Epoxy	1	600	13	0	0.18	0.18	0.18	0.00
B	Vinyl Ester	1	600	13	0	0.14	0.14	0.14	0.00
C	Epoxy	1	600	13	0	0.20	0.21	0.20	0.00
A	Epoxy	1	600	13	200	0.19	0.19	0.19	0.00
B	Vinyl Ester	1	600	13	200	0.15	0.15	0.15	0.00
C	Epoxy	1	600	13	200	0.21	0.22	0.22	0.00
A	Epoxy	1	600	13	20000	0.20	0.20	0.20	0.00

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Table 8.34: Potassium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Potassium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	1	600	13	20000	0.16	0.16	0.16	0.00
C	Epoxy	1	600	13	20000	0.22	0.23	0.23	0.00
A	Epoxy	1	600	13	SeaWater	456.00	478.04	467.02	11.02
B	Vinyl Ester	1	600	13	SeaWater	442.28	465.60	453.94	11.66
C	Epoxy	1	600	13	SeaWater	485.90	510.97	498.43	12.53
A	Epoxy	2	600	13	0	0.30	0.31	0.30	0.00
B	Vinyl Ester	2	600	13	0	0.16	0.17	0.17	0.00
C	Epoxy	2	600	13	0	0.34	0.35	0.35	0.00
A	Epoxy	2	600	13	200	0.31	0.32	0.31	0.00
B	Vinyl Ester	2	600	13	200	0.17	0.18	0.18	0.00
C	Epoxy	2	600	13	200	0.36	0.37	0.36	0.00
A	Epoxy	2	600	13	20000	0.32	0.33	0.33	0.00
B	Vinyl Ester	2	600	13	20000	0.18	0.19	0.18	0.00
C	Epoxy	2	600	13	20000	0.37	0.38	0.38	0.00
A	Epoxy	2	600	13	SeaWater	476.10	503.98	490.04	13.94
B	Vinyl Ester	2	600	13	SeaWater	451.51	473.99	462.75	11.24
C	Epoxy	2	600	13	SeaWater	497.35	530.55	513.95	16.60

Table 8.35: Potassium Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Potassium			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	600	4	0	0.0070	0.0076	0.0073	0.00
B	Vinyl Ester	600	4	0	0.0069	0.0073	0.0071	0.00
A	Epoxy	600	4	200	0.0069	0.0077	0.0073	0.00
B	Vinyl Ester	600	4	200	0.0070	0.0073	0.0072	0.00
A	Epoxy	600	4	20000	0.0071	0.0076	0.0074	0.00
B	Vinyl Ester	600	4	20000	0.0069	0.0075	0.0072	0.00
A	Epoxy	600	4	SeaWater	374.55	392.35	383.45	8.90
B	Vinyl Ester	600	4	SeaWater	377.62	387.84	382.73	5.11
A	Epoxy	600	7	0	0.0067	0.0079	0.0073	0.00
B	Vinyl Ester	600	7	0	0.0068	0.0075	0.0072	0.00
A	Epoxy	600	7	200	0.0070	0.0077	0.0073	0.00
B	Vinyl Ester	600	7	200	0.0070	0.0074	0.0072	0.00
A	Epoxy	600	7	20000	0.0071	0.0076	0.0074	0.00
B	Vinyl Ester	600	7	20000	0.0069	0.0075	0.0072	0.00

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Table 8.35: Potassium Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Potassium			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	600	7	SeaWater	386.27	403.17	394.72	8.45
B	Vinyl Ester	600	7	SeaWater	386.44	401.56	394.00	7.56
A	Epoxy	600	10	0	0.0070	0.0074	0.0072	0.00
B	Vinyl Ester	600	10	0	0.0067	0.0073	0.0070	0.00
A	Epoxy	600	10	200	0.0070	0.0076	0.0073	0.00
B	Vinyl Ester	600	10	200	0.0067	0.0076	0.0071	0.00
A	Epoxy	600	10	20000	0.0069	0.0077	0.0073	0.00
B	Vinyl Ester	600	10	20000	0.0070	0.0073	0.0071	0.00
A	Epoxy	600	10	SeaWater	382.83	396.83	389.83	7.00
B	Vinyl Ester	600	10	SeaWater	380.44	397.78	389.11	8.67
A	Epoxy	600	13	0	0.0072	0.0076	0.0074	0.00
B	Vinyl Ester	600	13	0	0.0070	0.0074	0.0072	0.00
A	Epoxy	600	13	200	0.0069	0.0078	0.0074	0.00
B	Vinyl Ester	600	13	200	0.0068	0.0076	0.0072	0.00
A	Epoxy	600	13	20000	0.0067	0.0078	0.0072	0.00
B	Vinyl Ester	600	13	20000	0.0065	0.0077	0.0071	0.00
A	Epoxy	600	13	SeaWater	389.94	404.62	397.28	7.34
B	Vinyl Ester	600	13	SeaWater	390.12	403.00	396.56	6.44

Table 8.36: Potassium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Potassium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Sized	600	4	0	0.05	0.05	0.05	0.00
B	Sized	600	4	0	0.03	0.03	0.03	0.00
C	Sized	600	4	0	0.06	0.06	0.06	0.00
A	Sized	600	4	200	0.06	0.06	0.06	0.00
B	Sized	600	4	200	0.04	0.04	0.04	0.00
C	Sized	600	4	200	0.07	0.07	0.07	0.00
A	Sized	600	4	20000	0.07	0.07	0.07	0.00
B	Sized	600	4	20000	0.04	0.05	0.04	0.00
C	Sized	600	4	20000	0.07	0.08	0.08	0.00
A	Sized	600	4	SeaWater	415.76	442.66	429.21	13.45
B	Sized	600	4	SeaWater	407.77	425.77	416.77	9.00
C	Sized	600	4	SeaWater	427.21	453.51	440.36	13.15
A	Unsized	600	4	0	0.04	0.04	0.04	0.00

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Table 8.36: Potassium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Potassium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Unsized	600	4	0	0.02	0.02	0.02	0.00
A	Unsized	600	4	200	0.04	0.05	0.04	0.00
B	Unsized	600	4	200	0.02	0.02	0.02	0.00
A	Unsized	600	4	20000	0.04	0.05	0.05	0.00
B	Unsized	600	4	20000	0.02	0.03	0.02	0.00
A	Unsized	600	4	SeaWater	398.32	416.80	407.56	9.24
B	Unsized	600	4	SeaWater	394.30	405.00	399.65	5.35
A	Sized	600	7	0	0.05	0.06	0.06	0.00
B	Sized	600	7	0	0.03	0.03	0.03	0.00
C	Sized	600	7	0	0.06	0.06	0.06	0.00
A	Sized	600	7	200	0.06	0.06	0.06	0.00
B	Sized	600	7	200	0.04	0.04	0.04	0.00
C	Sized	600	7	200	0.07	0.07	0.07	0.00
A	Sized	600	7	20000	0.07	0.07	0.07	0.00
B	Sized	600	7	20000	0.04	0.05	0.04	0.00
C	Sized	600	7	20000	0.08	0.08	0.08	0.00
A	Sized	600	7	SeaWater	426.89	452.67	439.78	12.89
B	Sized	600	7	SeaWater	413.40	437.36	425.38	11.98
C	Sized	600	7	SeaWater	438.71	463.78	451.24	12.54
A	Unsized	600	7	0	0.04	0.04	0.04	0.00
B	Unsized	600	7	0	0.02	0.02	0.02	0.00
A	Unsized	600	7	200	0.04	0.05	0.04	0.00
B	Unsized	600	7	200	0.02	0.02	0.02	0.00
A	Unsized	600	7	20000	0.05	0.05	0.05	0.00
B	Unsized	600	7	20000	0.02	0.03	0.02	0.00
A	Unsized	600	7	SeaWater	406.56	426.46	416.51	9.95
B	Unsized	600	7	SeaWater	398.02	414.04	406.03	8.01
A	Sized	600	10	0	0.06	0.06	0.06	0.00
B	Sized	600	10	0	0.03	0.04	0.03	0.00
C	Sized	600	10	0	0.06	0.06	0.06	0.00
A	Sized	600	10	200	0.06	0.07	0.07	0.00
B	Sized	600	10	200	0.04	0.04	0.04	0.00
C	Sized	600	10	200	0.07	0.07	0.07	0.00
A	Sized	600	10	20000	0.07	0.08	0.07	0.00
B	Sized	600	10	20000	0.04	0.05	0.05	0.00
C	Sized	600	10	20000	0.08	0.08	0.08	0.00
A	Sized	600	10	SeaWater	432.53	457.87	445.20	12.67
B	Sized	600	10	SeaWater	417.98	444.20	431.09	13.11
C	Sized	600	10	SeaWater	444.53	469.12	456.83	12.29
A	Unsized	600	10	0	0.04	0.04	0.04	0.00
B	Unsized	600	10	0	0.02	0.02	0.02	0.00
A	Unsized	600	10	200	0.04	0.05	0.04	0.00

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Table 8.36: Potassium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Potassium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Unsized	600	10	200	0.02	0.02	0.02	0.00
A	Unsized	600	10	20000	0.05	0.05	0.05	0.00
B	Unsized	600	10	20000	0.02	0.03	0.03	0.00
A	Unsized	600	10	SeaWater	415.07	431.07	423.07	8.00
B	Unsized	600	10	SeaWater	402.01	418.17	410.09	8.08
A	Sized	600	13	0	0.06	0.06	0.06	0.00
B	Sized	600	13	0	0.03	0.04	0.04	0.00
C	Sized	600	13	0	0.06	0.07	0.07	0.00
A	Sized	600	13	200	0.07	0.07	0.07	0.00
B	Sized	600	13	200	0.04	0.04	0.04	0.00
C	Sized	600	13	200	0.07	0.08	0.08	0.00
A	Sized	600	13	20000	0.07	0.08	0.07	0.00
B	Sized	600	13	20000	0.04	0.05	0.05	0.00
C	Sized	600	13	20000	0.08	0.09	0.08	0.00
A	Sized	600	13	SeaWater	437.03	466.11	451.57	14.54
B	Sized	600	13	SeaWater	421.49	448.33	434.91	13.42
C	Sized	600	13	SeaWater	449.05	477.75	463.40	14.35
A	Unsized	600	13	0	0.04	0.05	0.04	0.00
B	Unsized	600	13	0	0.02	0.02	0.02	0.00
A	Unsized	600	13	200	0.04	0.05	0.05	0.00
B	Unsized	600	13	200	0.02	0.02	0.02	0.00
A	Unsized	600	13	20000	0.04	0.05	0.05	0.00
B	Unsized	600	13	20000	0.02	0.03	0.03	0.00
A	Unsized	600	13	SeaWater	419.21	437.01	428.11	8.90
B	Unsized	600	13	SeaWater	405.51	425.73	415.62	10.11

For a better understanding, change in the Potassium content of the environments was plotted in graphs in Figure 8.34, 8.35, and 8.36. It can be seen that the Potassium concentration in all environments has increased except for the environments in which resin samples were exposed.

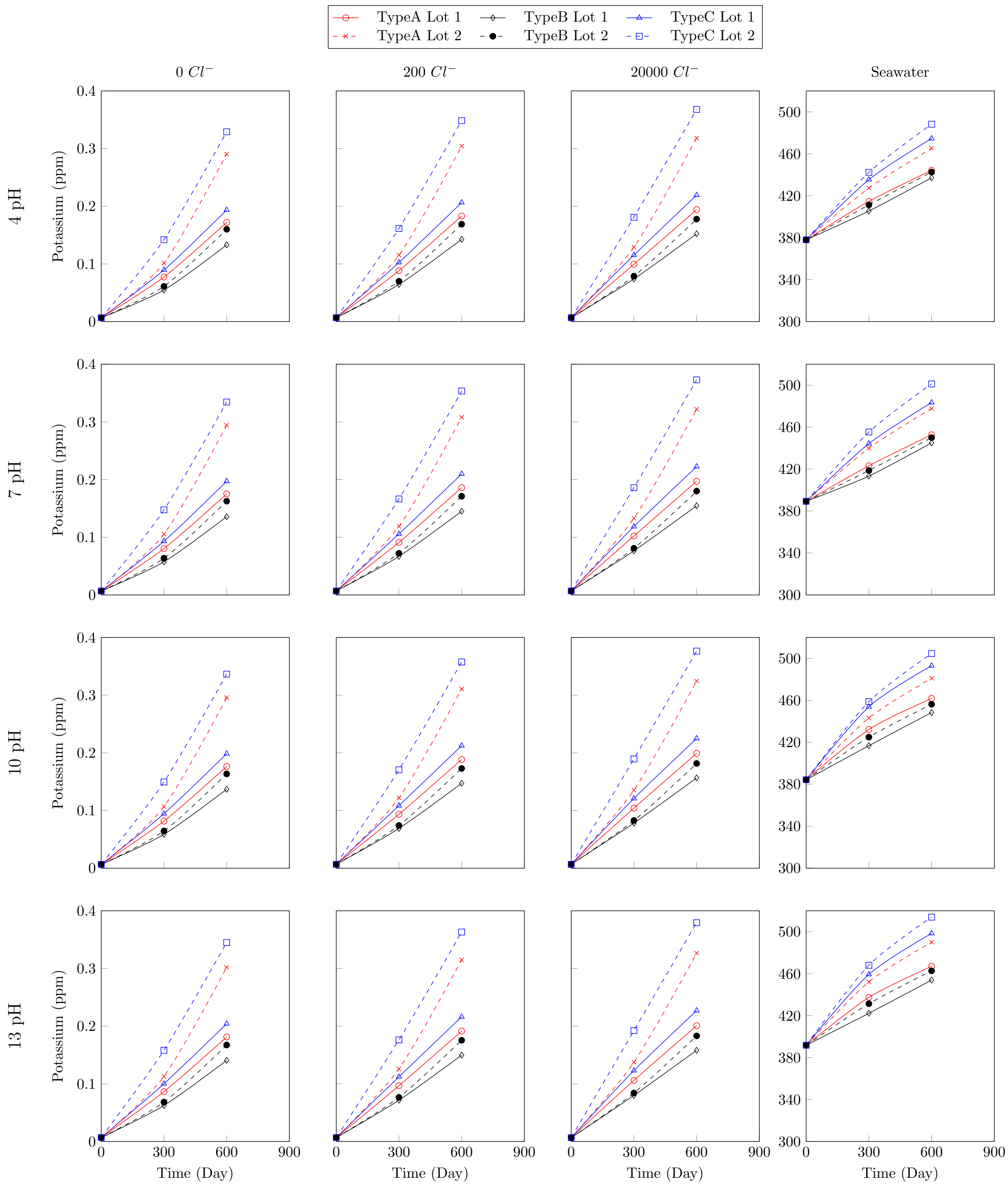

Figure 8.34: Potassium concentration of all environments after exposure of rebars

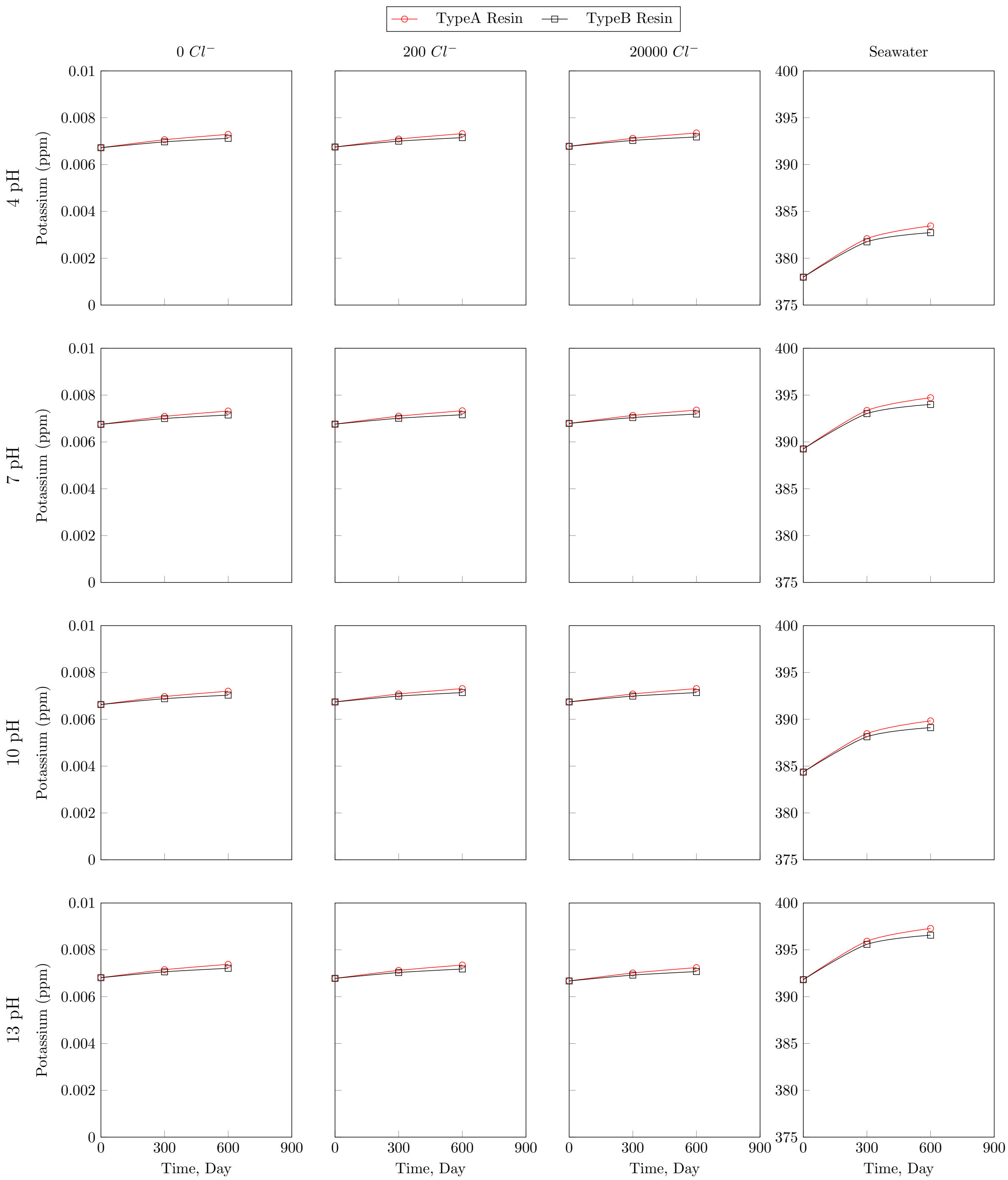

Figure 8.35: Potassium concentration of all environments after exposure of resins

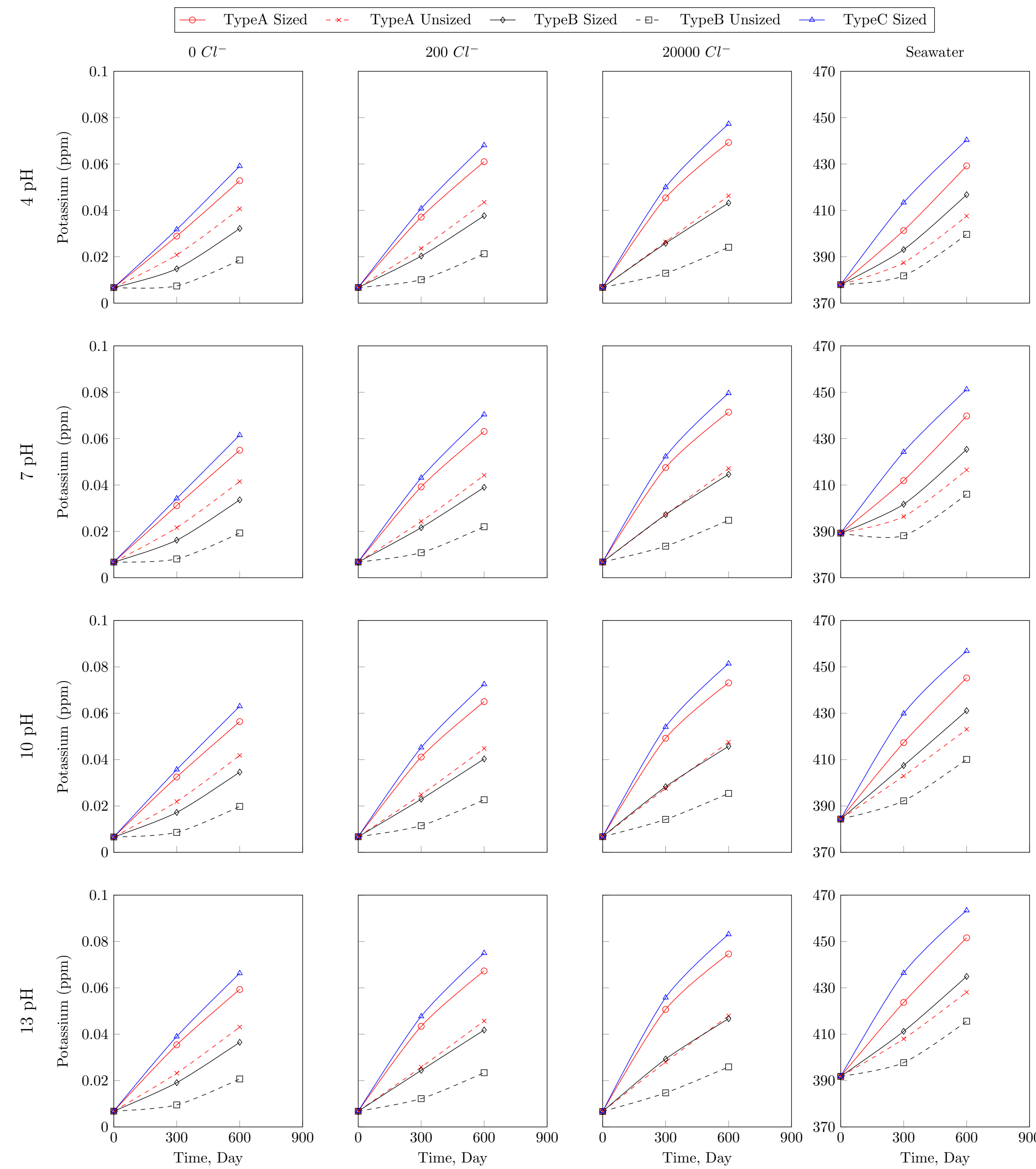

Figure 8.36: Potassium concentration of all environments after exposure of sized and unsized fibers

Silicon

Silicon content of the chemical environments was measured after 600 days of exposure. Tables 8.37, 8.38, and 8.39 below shows the pH data of environments in which rebars, resins, and fibers were exposed.

Table 8.37: Silicon Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Silicon			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	4	0	45.08	50.23	47.66	2.57
B	Vinyl Ester	1	600	4	0	34.35	38.86	36.60	2.25
C	Epoxy	1	600	4	0	53.28	61.62	57.45	4.17
A	Epoxy	1	600	4	200	50.36	57.31	53.84	3.48
B	Vinyl Ester	1	600	4	200	37.20	42.60	39.90	2.70
C	Epoxy	1	600	4	200	60.50	71.10	65.80	5.30
A	Epoxy	1	600	4	20000	57.60	60.85	59.23	1.63
B	Vinyl Ester	1	600	4	20000	40.57	44.14	42.36	1.79
C	Epoxy	1	600	4	20000	70.08	76.06	73.07	2.99
A	Epoxy	1	600	4	SeaWater	1.70	3.41	2.55	0.86
B	Vinyl Ester	1	600	4	SeaWater	2.16	3.55	2.85	0.70
C	Epoxy	1	600	4	SeaWater	2.00	3.58	2.79	0.79
A	Epoxy	2	600	4	0	59.67	64.85	62.26	2.59
B	Vinyl Ester	2	600	4	0	39.09	43.32	41.21	2.12
C	Epoxy	2	600	4	0	68.54	76.59	72.56	4.02
A	Epoxy	2	600	4	200	69.79	76.79	73.29	3.50
B	Vinyl Ester	2	600	4	200	44.79	49.99	47.39	2.60
C	Epoxy	2	600	4	200	81.70	92.12	86.91	5.21
A	Epoxy	2	600	4	20000	82.43	85.69	84.06	1.63
B	Vinyl Ester	2	600	4	20000	51.16	54.39	52.78	1.61
C	Epoxy	2	600	4	20000	98.13	103.68	100.90	2.78
A	Epoxy	2	600	4	SeaWater	1.97	3.47	2.72	0.75
B	Vinyl Ester	2	600	4	SeaWater	2.55	3.51	3.03	0.48
C	Epoxy	2	600	4	SeaWater	2.22	3.64	2.93	0.71
A	Epoxy	1	600	7	0	49.44	57.42	53.43	3.99
B	Vinyl Ester	1	600	7	0	37.44	43.36	40.40	2.96
C	Epoxy	1	600	7	0	59.30	71.19	65.25	5.94
A	Epoxy	1	600	7	200	55.18	59.38	57.28	2.10
B	Vinyl Ester	1	600	7	200	39.90	43.94	41.92	2.02
C	Epoxy	1	600	7	200	66.87	74.03	70.45	3.58
A	Epoxy	1	600	7	20000	62.07	67.99	65.03	2.96
B	Vinyl Ester	1	600	7	20000	43.28	48.17	45.72	2.45
C	Epoxy	1	600	7	20000	76.26	85.56	80.91	4.65
A	Epoxy	1	600	7	SeaWater	1.50	4.24	2.87	1.37
B	Vinyl Ester	1	600	7	SeaWater	2.24	4.14	3.19	0.95
C	Epoxy	1	600	7	SeaWater	1.65	4.58	3.12	1.46
A	Epoxy	2	600	7	0	66.99	75.04	71.02	4.02

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Table 8.37: Silicon Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Silicon			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	2	600	7	0	44.11	49.86	46.98	2.87
C	Epoxy	2	600	7	0	78.06	89.83	83.95	5.89
A	Epoxy	2	600	7	200	76.98	81.20	79.09	2.11
B	Vinyl Ester	2	600	7	200	48.97	52.70	50.83	1.87
C	Epoxy	2	600	7	200	91.05	97.85	94.45	3.40
A	Epoxy	2	600	7	20000	91.04	97.00	94.02	2.98
B	Vinyl Ester	2	600	7	20000	56.26	60.91	58.58	2.32
C	Epoxy	2	600	7	20000	109.33	118.39	113.86	4.53
A	Epoxy	2	600	7	SeaWater	1.79	4.33	3.06	1.27
B	Vinyl Ester	2	600	7	SeaWater	2.63	4.15	3.39	0.76
C	Epoxy	2	600	7	SeaWater	1.89	4.66	3.28	1.39
A	Epoxy	1	600	10	0	52.64	62.18	57.41	4.77
B	Vinyl Ester	1	600	10	0	39.52	46.20	42.86	3.34
C	Epoxy	1	600	10	0	63.71	77.53	70.62	6.91
A	Epoxy	1	600	10	200	59.08	66.81	62.94	3.86
B	Vinyl Ester	1	600	10	200	42.43	48.22	45.32	2.89
C	Epoxy	1	600	10	200	72.31	83.87	78.09	5.78
A	Epoxy	1	600	10	20000	67.19	74.05	70.62	3.43
B	Vinyl Ester	1	600	10	20000	46.19	51.55	48.87	2.68
C	Epoxy	1	600	10	20000	83.21	93.70	88.45	5.24
A	Epoxy	1	600	10	SeaWater	1.43	4.77	3.10	1.67
B	Vinyl Ester	1	600	10	SeaWater	2.23	4.43	3.33	1.10
C	Epoxy	1	600	10	SeaWater	1.50	5.20	3.35	1.85
A	Epoxy	2	600	10	0	72.58	82.19	77.38	4.80
B	Vinyl Ester	2	600	10	0	47.68	54.25	50.96	3.29
C	Epoxy	2	600	10	0	85.32	99.13	92.23	6.90
A	Epoxy	2	600	10	200	84.55	92.33	88.44	3.89
B	Vinyl Ester	2	600	10	200	53.69	59.30	56.49	2.81
C	Epoxy	2	600	10	200	100.89	112.32	106.60	5.72
A	Epoxy	2	600	10	20000	100.40	107.32	103.86	3.46
B	Vinyl Ester	2	600	10	20000	61.59	66.75	64.17	2.58
C	Epoxy	2	600	10	20000	121.50	131.80	126.65	5.15
A	Epoxy	2	600	10	SeaWater	1.62	4.78	3.20	1.58
B	Vinyl Ester	2	600	10	SeaWater	2.62	4.46	3.54	0.92
C	Epoxy	2	600	10	SeaWater	1.64	5.20	3.42	1.78
A	Epoxy	1	600	13	0	60.19	64.39	62.29	2.10
B	Vinyl Ester	1	600	13	0	43.84	47.88	45.86	2.02
C	Epoxy	1	600	13	0	73.63	80.78	77.20	3.58
A	Epoxy	1	600	13	200	65.66	70.72	68.19	2.53
B	Vinyl Ester	1	600	13	200	46.14	50.61	48.37	2.23
C	Epoxy	1	600	13	200	81.05	89.28	85.17	4.11
A	Epoxy	1	600	13	20000	69.39	79.61	74.50	5.11

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Table 8.37: Silicon Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Silicon			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	1	600	13	20000	47.39	54.41	50.90	3.51
C	Epoxy	1	600	13	20000	86.35	101.04	93.69	7.34
A	Epoxy	1	600	13	SeaWater	1.39	4.91	3.15	1.76
B	Vinyl Ester	1	600	13	SeaWater	2.28	4.56	3.42	1.14
C	Epoxy	1	600	13	SeaWater	1.43	5.37	3.40	1.97
A	Epoxy	2	600	13	0	83.12	87.34	85.23	2.11
B	Vinyl Ester	2	600	13	0	53.97	57.70	55.84	1.87
C	Epoxy	2	600	13	0	99.03	105.83	102.43	3.40
A	Epoxy	2	600	13	200	94.82	99.91	97.37	2.54
B	Vinyl Ester	2	600	13	200	59.64	63.83	61.74	2.10
C	Epoxy	2	600	13	200	114.24	122.17	118.20	3.96
A	Epoxy	2	600	13	20000	105.97	116.28	111.13	5.15
B	Vinyl Ester	2	600	13	20000	64.58	71.52	68.05	3.47
C	Epoxy	2	600	13	20000	128.74	143.45	136.09	7.35
A	Epoxy	2	600	13	SeaWater	1.66	4.98	3.32	1.66
B	Vinyl Ester	2	600	13	SeaWater	2.61	4.55	3.58	0.97
C	Epoxy	2	600	13	SeaWater	1.65	5.44	3.54	1.89

Table 8.38: Silicon Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Silicon			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	600	4	0	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	600	4	0	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	600	4	200	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	600	4	200	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	600	4	20000	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	600	4	20000	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	600	4	SeaWater	2.94	5.18	4.06	1.12
B	Vinyl Ester	600	4	SeaWater	2.81	5.09	3.95	1.14
A	Epoxy	600	7	0	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	600	7	0	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	600	7	200	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	600	7	200	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	600	7	20000	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	600	7	20000	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	600	7	SeaWater	3.22	5.20	4.21	0.99
B	Vinyl Ester	600	7	SeaWater	2.57	5.65	4.11	1.54
A	Epoxy	600	10	0	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	600	10	0	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	600	10	200	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	600	10	200	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	600	10	20000	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	600	10	20000	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	600	10	SeaWater	3.09	5.73	4.41	1.32
B	Vinyl Ester	600	10	SeaWater	2.56	6.08	4.32	1.76
A	Epoxy	600	13	0	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	600	13	0	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	600	13	200	Below 0.05	Below 0.05	Below 0.05	0.00

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Table 8.38: Silicon Test Statistical values for All Resin Sample Groups

| Sample Group | | | | | Statistical Values | | | |
					Silicon			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Vinyl Ester	600	13	200	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	600	13	20000	Below 0.05	Below 0.05	Below 0.05	0.00
B	Vinyl Ester	600	13	20000	Below 0.05	Below 0.05	Below 0.05	0.00
A	Epoxy	600	13	SeaWater	2.91	6.03	4.47	1.56
B	Vinyl Ester	600	13	SeaWater	3.04	5.72	4.38	1.34

Table 8.39: Silicon Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Silicon			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Sized	600	4	0	21.55	25.59	23.57	2.02
B	Sized	600	4	0	14.17	17.95	16.06	1.89
C	Sized	600	4	0	24.52	28.92	26.72	2.20
A	Sized	600	4	200	22.33	26.80	24.57	2.24
B	Sized	600	4	200	14.69	18.89	16.79	2.10
C	Sized	600	4	200	25.41	30.31	27.86	2.45
A	Sized	600	4	20000	23.54	27.13	25.33	1.79
B	Sized	600	4	20000	15.66	19.00	17.33	1.67
C	Sized	600	4	20000	26.79	30.68	28.74	1.94
A	Sized	600	4	SeaWater	1.34	3.14	2.24	0.90
B	Sized	600	4	SeaWater	1.28	3.08	2.18	0.90
C	Sized	600	4	SeaWater	1.56	2.92	2.24	0.68
A	Unsized	600	4	0	18.07	21.50	19.78	1.71
B	Unsized	600	4	0	11.05	14.18	12.61	1.56
A	Unsized	600	4	200	18.73	22.64	20.68	1.95
B	Unsized	600	4	200	11.46	15.10	13.28	1.82
A	Unsized	600	4	20000	19.94	22.85	21.40	1.46
B	Unsized	600	4	20000	12.50	15.09	13.80	1.30
A	Unsized	600	4	SeaWater	1.04	2.66	1.85	0.81
B	Unsized	600	4	SeaWater	1.31	2.28	1.79	0.49
A	Sized	600	7	0	22.34	27.06	24.70	2.36
B	Sized	600	7	0	14.69	19.13	16.91	2.22
C	Sized	600	7	0	25.43	30.60	28.02	2.59
A	Sized	600	7	200	23.27	27.08	25.18	1.91
B	Sized	600	7	200	15.46	19.02	17.24	1.78
C	Sized	600	7	200	26.49	30.63	28.56	2.07
A	Sized	600	7	20000	24.24	28.46	26.35	2.11
B	Sized	600	7	20000	16.10	20.06	18.08	1.98
C	Sized	600	7	20000	27.59	32.20	29.89	2.30
A	Sized	600	7	SeaWater	1.79	3.84	2.81	1.03
B	Sized	600	7	SeaWater	1.72	3.76	2.74	1.02
C	Sized	600	7	SeaWater	2.01	3.65	2.83	0.82
A	Unsized	600	7	0	18.66	22.84	20.75	2.09
B	Unsized	600	7	0	11.38	15.32	13.35	1.97
A	Unsized	600	7	200	19.63	22.80	21.21	1.59
B	Unsized	600	7	200	12.25	15.11	13.68	1.43
A	Unsized	600	7	20000	20.46	24.10	22.28	1.82
B	Unsized	600	7	20000	12.79	16.14	14.46	1.67
A	Unsized	600	7	SeaWater	1.44	3.33	2.38	0.95
B	Unsized	600	7	SeaWater	1.65	2.91	2.28	0.63
A	Sized	600	10	0	22.88	27.98	25.43	2.55

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Table 8.39: Silicon Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Silicon			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Sized	600	10	0	15.06	19.86	17.46	2.40
C	Sized	600	10	0	26.05	31.64	28.85	2.80
A	Sized	600	10	200	23.87	28.53	26.20	2.33
B	Sized	600	10	200	15.81	20.19	18.00	2.19
C	Sized	600	10	200	27.17	32.28	29.72	2.55
A	Sized	600	10	20000	25.08	29.53	27.30	2.23
B	Sized	600	10	20000	16.69	20.87	18.78	2.09
C	Sized	600	10	20000	28.55	33.41	30.98	2.43
A	Sized	600	10	SeaWater	1.98	4.17	3.07	1.10
B	Sized	600	10	SeaWater	1.90	4.08	2.99	1.09
C	Sized	600	10	SeaWater	2.20	4.00	3.10	0.90
A	Unsized	600	10	0	19.07	23.68	21.37	2.30
B	Unsized	600	10	0	11.64	16.02	13.83	2.19
A	Unsized	600	10	200	20.04	24.15	22.10	2.06
B	Unsized	600	10	200	12.42	16.28	14.35	1.93
A	Unsized	600	10	20000	21.17	25.06	23.11	1.94
B	Unsized	600	10	20000	13.28	16.89	15.09	1.81
A	Unsized	600	10	SeaWater	1.60	3.66	2.63	1.03
B	Unsized	600	10	SeaWater	1.78	3.22	2.50	0.72
A	Sized	600	13	0	24.42	28.24	26.33	1.91
B	Sized	600	13	0	16.35	19.91	18.13	1.78
C	Sized	600	13	0	27.80	31.94	29.87	2.07
A	Sized	600	13	200	25.11	29.13	27.12	2.01
B	Sized	600	13	200	16.80	20.56	18.68	1.88
C	Sized	600	13	200	28.59	32.96	30.77	2.19
A	Sized	600	13	20000	25.29	30.55	27.92	2.63
B	Sized	600	13	20000	16.75	21.71	19.23	2.48
C	Sized	600	13	20000	28.79	34.58	31.69	2.89
A	Sized	600	13	SeaWater	2.04	4.28	3.16	1.12
B	Sized	600	13	SeaWater	1.96	4.18	3.07	1.11
C	Sized	600	13	SeaWater	2.26	4.11	3.19	0.92
A	Unsized	600	13	0	20.56	23.74	22.15	1.59
B	Unsized	600	13	0	12.99	15.85	14.42	1.43
A	Unsized	600	13	200	21.20	24.60	22.90	1.70
B	Unsized	600	13	200	13.40	16.50	14.95	1.55
A	Unsized	600	13	20000	21.27	26.06	23.66	2.39
B	Unsized	600	13	20000	13.21	17.78	15.49	2.28
A	Unsized	600	13	SeaWater	1.93	4.03	2.98	1.05
B	Unsized	600	13	SeaWater	1.83	3.32	2.58	0.74

For a better understanding, change in the Silicon content of the environments was plotted in graphs in

Figure 8.37, 8.38, and 8.39. It can be seen that the silicon concentration has increased in al exposure

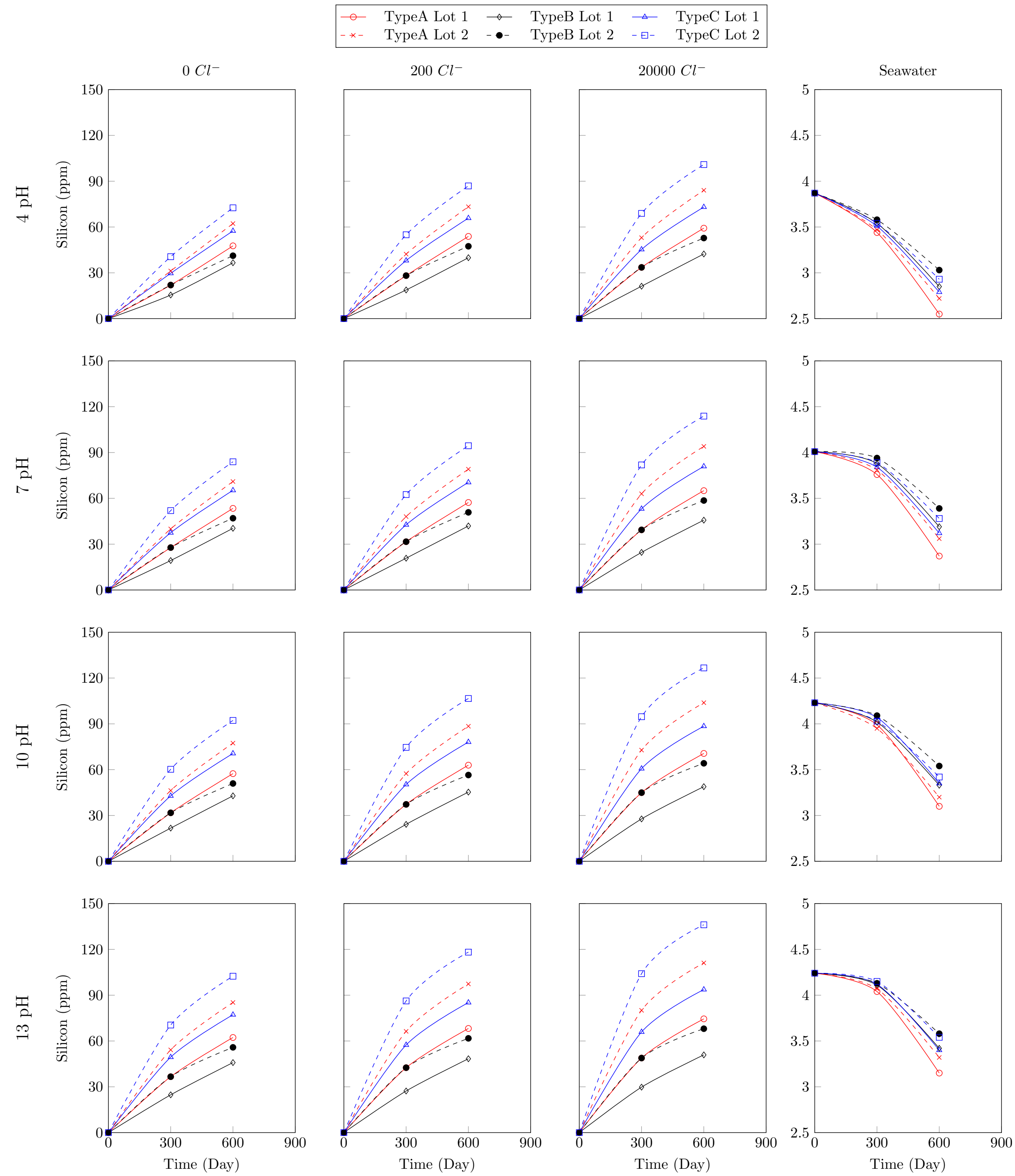

Figure 8.37: Silicon concentration of all environments after exposure of rebars

environments except the sea water environments and the exposure environments with resin samples.

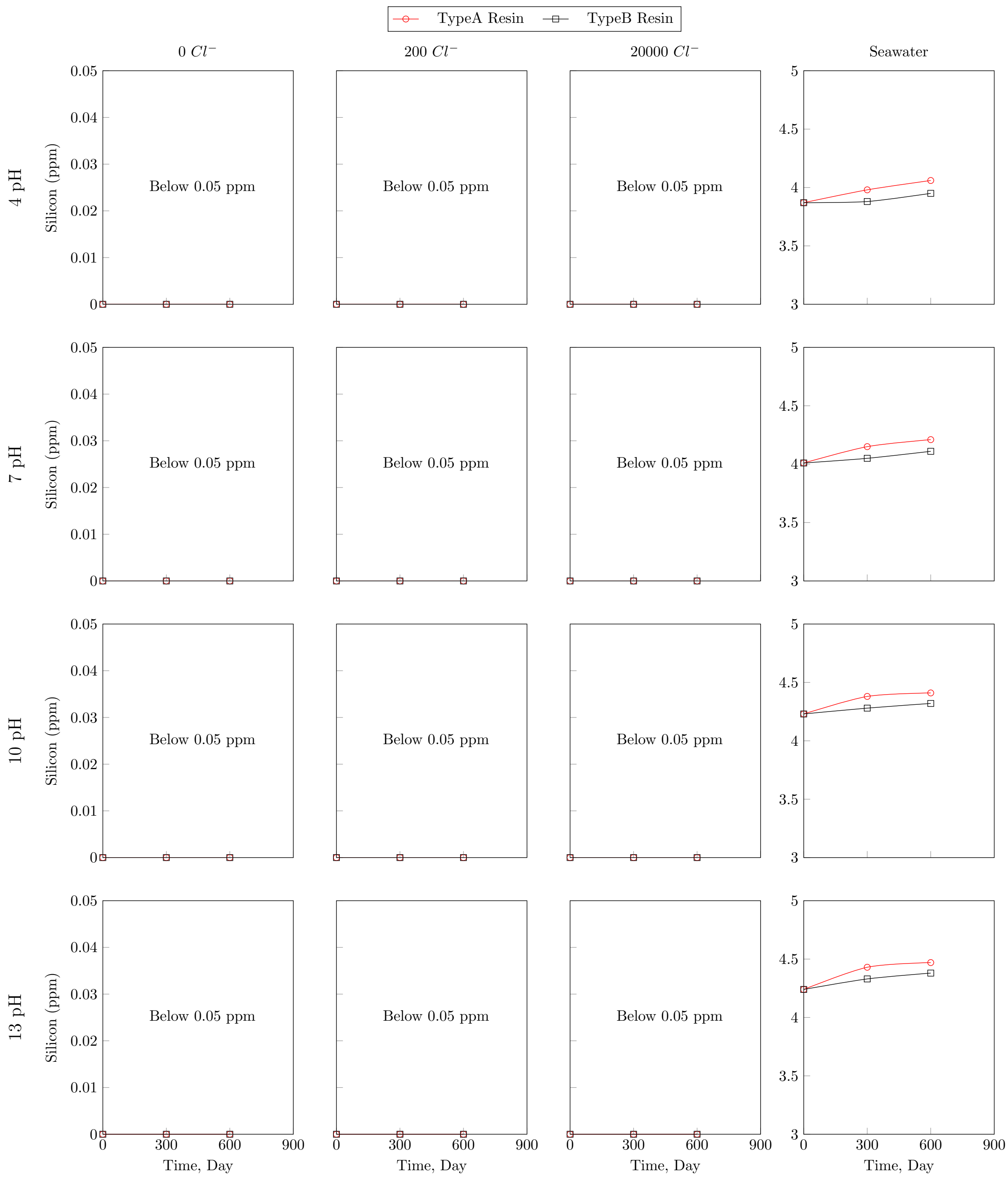

Figure 8.38: Silicon concentration of all environments after exposure of resins

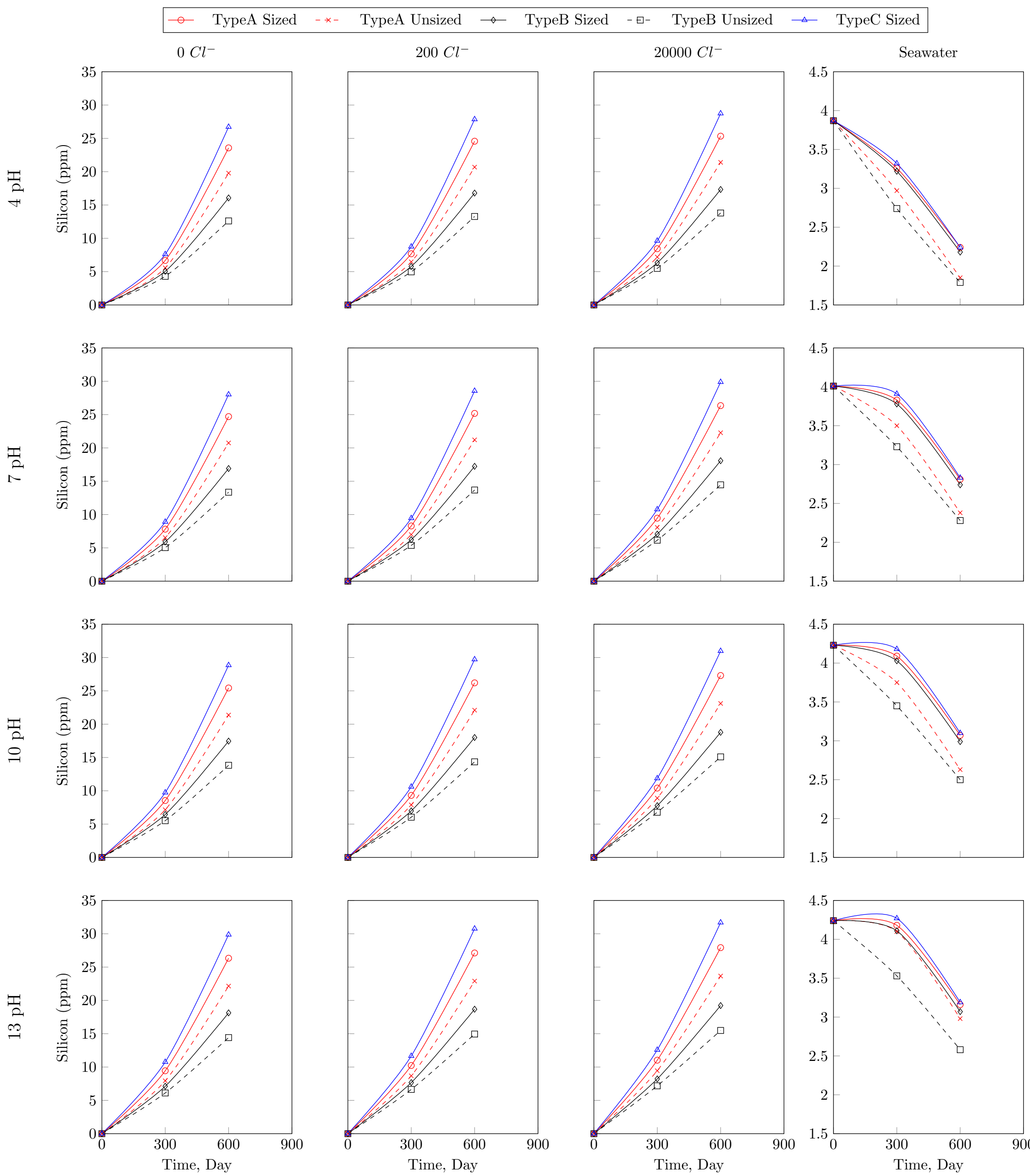

Figure 8.39: Silicon concentration of all environments after exposure of sized and unsized fibers

Sodium

Sodium content of the chemical environments was measured after 600 days of exposure. Tables 8.40, 8.41, and 8.42 below shows the pH data of environments in which rebars, resins, and fibers were exposed.

Table 8.40: Sodium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Sodium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	4	0	0.03	0.09	0.06	0.03
B	Vinyl Ester	1	600	4	0	0.04	0.08	0.06	0.02
C	Epoxy	1	600	4	0	0.02	0.08	0.05	0.03
A	Epoxy	1	600	4	200	90.18	100.42	95.30	5.12
B	Vinyl Ester	1	600	4	200	105.16	113.40	109.28	4.12
C	Epoxy	1	600	4	200	85.18	89.42	87.30	2.12
A	Epoxy	1	600	4	20000	12 900.20	12 968.44	12 934.32	34.12
B	Vinyl Ester	1	600	4	20000	12 924.57	12 993.03	12 958.80	34.23
C	Epoxy	1	600	4	20000	12 884.66	12 949.78	12 917.22	32.56
A	Epoxy	1	600	4	SeaWater	11 182.70	11 256.28	11 219.49	36.79
B	Vinyl Ester	1	600	4	SeaWater	11 201.78	11 284.46	11 243.12	41.34
C	Epoxy	1	600	4	SeaWater	11 171.32	11 236.22	11 203.77	32.45
A	Epoxy	2	600	4	0	0.04	0.08	0.06	0.02
B	Vinyl Ester	2	600	4	0	0.04	0.08	0.06	0.02
C	Epoxy	2	600	4	0	0.05	0.07	0.06	0.01
A	Epoxy	2	600	4	200	73.19	82.31	77.75	4.56
B	Vinyl Ester	2	600	4	200	87.98	98.88	93.43	5.45
C	Epoxy	2	600	4	200	67.13	74.03	70.58	3.45
A	Epoxy	2	600	4	20000	12 864.57	12 938.39	12 901.48	36.91
B	Vinyl Ester	2	600	4	20000	12 894.82	12 959.06	12 926.94	32.12
C	Epoxy	2	600	4	20000	12 857.41	12 925.87	12 891.64	34.23
A	Epoxy	2	600	4	SeaWater	11 154.25	11 222.49	11 188.37	34.12
B	Vinyl Ester	2	600	4	SeaWater	11 179.52	11 246.42	11 212.97	33.45
C	Epoxy	2	600	4	SeaWater	11 134.59	11 225.21	11 179.90	45.31
A	Epoxy	1	600	7	0	0.03	0.09	0.06	0.03
B	Vinyl Ester	1	600	7	0	0.03	0.09	0.06	0.03
C	Epoxy	1	600	7	0	0.04	0.08	0.06	0.02

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Table 8.40: Sodium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Sodium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	7	200	91.32	102.66	96.99	5.67
B	Vinyl Ester	1	600	7	200	104.28	117.84	111.06	6.78
C	Epoxy	1	600	7	200	87.33	90.45	88.89	1.56
A	Epoxy	1	600	7	20000	12 954.79	13 057.03	13 005.91	51.12
B	Vinyl Ester	1	600	7	20000	12 984.76	13 076.10	13 030.43	45.67
C	Epoxy	1	600	7	20000	12 964.19	13 013.31	12 988.75	24.56
A	Epoxy	1	600	7	SeaWater	11 185.12	11 269.58	11 227.35	42.23
B	Vinyl Ester	1	600	7	SeaWater	11 218.09	11 283.87	11 250.98	32.89
C	Epoxy	1	600	7	SeaWater	11 173.73	11 249.51	11 211.62	37.89
A	Epoxy	2	600	7	0	0.06	0.08	0.07	0.01
B	Vinyl Ester	2	600	7	0	0.04	0.08	0.06	0.02
C	Epoxy	2	600	7	0	0.02	0.10	0.06	0.04
A	Epoxy	2	600	7	200	70.49	88.05	79.27	8.78
B	Vinyl Ester	2	600	7	200	89.37	100.71	95.04	5.67
C	Epoxy	2	600	7	200	65.23	78.79	72.01	6.78
A	Epoxy	2	600	7	20000	12 935.19	13 010.81	12 973.00	37.81
B	Vinyl Ester	2	600	7	20000	12 973.94	13 023.06	12 998.50	24.56
C	Epoxy	2	600	7	20000	12 928.87	12 997.33	12 963.10	34.23
A	Epoxy	2	600	7	SeaWater	11 156.52	11 235.94	11 196.23	39.71
B	Vinyl Ester	2	600	7	SeaWater	11 188.93	11 252.73	11 220.83	31.90
C	Epoxy	2	600	7	SeaWater	11 143.84	11 231.64	11 187.74	43.90
A	Epoxy	1	600	10	0	0.55	2.29	1.42	0.87
B	Vinyl Ester	1	600	10	0	0.93	2.71	1.82	0.89
C	Epoxy	1	600	10	0	1.18	1.86	1.52	0.34
A	Epoxy	1	600	10	200	93.51	111.71	102.61	9.10
B	Vinyl Ester	1	600	10	200	109.19	124.75	116.97	7.78
C	Epoxy	1	600	10	200	89.93	98.39	94.16	4.23

Continued on next page . . .

Table 8.40: Sodium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Sodium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	10	20000	12 987.77	13 052.67	13 020.22	32.45
B	Vinyl Ester	1	600	10	20000	13 013.41	13 076.09	13 044.75	31.34
C	Epoxy	1	600	10	20000	12 972.14	13 033.98	13 003.06	30.92
A	Epoxy	1	600	10	SeaWater	11 203.34	11 286.46	11 244.90	41.56
B	Vinyl Ester	1	600	10	SeaWater	11 235.09	11 301.99	11 268.54	33.45
C	Epoxy	1	600	10	SeaWater	11 186.81	11 271.49	11 229.15	42.34
A	Epoxy	2	600	10	0	0.59	1.77	1.18	0.59
B	Vinyl Ester	2	600	10	0	1.09	2.21	1.65	0.56
C	Epoxy	2	600	10	0	1.14	1.82	1.48	0.34
A	Epoxy	2	600	10	200	78.65	89.99	84.32	5.67
B	Vinyl Ester	2	600	10	200	91.24	109.48	100.36	9.12
C	Epoxy	2	600	10	200	71.52	81.98	76.75	5.23
A	Epoxy	2	600	10	20000	12 954.54	13 020.06	12 987.30	32.76
B	Vinyl Ester	2	600	10	20000	12 989.68	13 035.92	13 012.80	23.12
C	Epoxy	2	600	10	20000	12 931.72	13 023.06	12 977.39	45.67
A	Epoxy	2	600	10	SeaWater	11 172.52	11 254.98	11 213.75	41.23
B	Vinyl Ester	2	600	10	SeaWater	11 195.25	11 281.49	11 238.37	43.12
C	Epoxy	2	600	10	SeaWater	11 181.81	11 228.71	11 205.26	23.45
A	Epoxy	1	600	13	0	2215.28	2235.06	2225.17	9.89
B	Vinyl Ester	1	600	13	0	2232.61	2253.07	2242.84	10.23
C	Epoxy	1	600	13	0	2211.13	2219.23	2215.18	4.05
A	Epoxy	1	600	13	200	2422.87	2447.55	2435.21	12.34
B	Vinyl Ester	1	600	13	200	2441.04	2461.72	2451.38	10.34
C	Epoxy	1	600	13	200	2394.70	2419.60	2407.15	12.45
A	Epoxy	1	600	13	20000	14 954.27	15 042.73	14 998.50	44.23
B	Vinyl Ester	1	600	13	20000	14 976.57	15 071.47	15 024.02	47.45
C	Epoxy	1	600	13	20000	14 944.08	15 015.42	14 979.75	35.67

Continued on next page ...

Table 8.40: Sodium Test Statistical values for All Rebar Sample Groups

Sample Group						Statistical Values			
						Sodium			
Manuf. Type	Resin Type	Lot No.	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	1	600	13	SeaWater	13 562.29	13 629.63	13 595.96	33.67
B	Vinyl Ester	1	600	13	SeaWater	13 587.88	13 653.68	13 620.78	32.90
C	Epoxy	1	600	13	SeaWater	13 546.21	13 610.45	13 578.33	32.12
A	Epoxy	2	600	13	0	2185.00	2209.24	2197.12	12.12
B	Vinyl Ester	2	600	13	0	2216.08	2224.76	2220.42	4.34
C	Epoxy	2	600	13	0	2172.50	2197.18	2184.84	12.34
A	Epoxy	2	600	13	200	2396.45	2418.23	2407.34	10.89
B	Vinyl Ester	2	600	13	200	2378.68	2465.14	2421.91	43.23
C	Epoxy	2	600	13	200	2368.08	2388.76	2378.42	10.34
A	Epoxy	2	600	13	20000	14 922.69	15 004.51	14 963.60	40.91
B	Vinyl Ester	2	600	13	20000	14 951.19	15 028.99	14 990.09	38.90
C	Epoxy	2	600	13	20000	14 928.66	14 975.56	14 952.11	23.45
A	Epoxy	2	600	13	SeaWater	13 528.13	13 596.81	13 562.47	34.34
B	Vinyl Ester	2	600	13	SeaWater	13 545.13	13 631.37	13 588.25	43.12
C	Epoxy	2	600	13	SeaWater	13 515.31	13 588.87	13 552.09	36.78

Table 8.41: Sodium Test Statistical values for All Resin Sample Groups

Sample Group					Statistical Values			
					Sodium			
Manuf. Type	Resin Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Epoxy	600	4	0	0.07	0.11	0.09	0.02
B	Vinyl Ester	600	4	0	0.08	0.11	0.09	0.02
A	Epoxy	600	4	200	139.67	151.01	145.34	5.67
B	Vinyl Ester	600	4	200	138.50	154.04	146.27	7.77
A	Epoxy	600	4	20000	13 186.80	13 257.88	13 222.34	35.54
B	Vinyl Ester	600	4	20000	13 186.55	13 255.67	13 221.11	34.56
A	Epoxy	600	4	SeaWater	11 481.55	11 528.45	11 505.00	23.45
B	Vinyl Ester	600	4	SeaWater	11 479.26	11 519.94	11 499.60	20.34
A	Epoxy	600	7	0	0.08	0.10	0.09	0.01
B	Vinyl Ester	600	7	0	0.06	0.12	0.09	0.03
A	Epoxy	600	7	200	139.54	157.36	148.45	8.91
B	Vinyl Ester	600	7	200	141.15	155.11	148.13	6.98
A	Epoxy	600	7	20000	13 266.15	13 324.11	13 295.13	28.98
B	Vinyl Ester	600	7	20000	13 265.90	13 316.58	13 291.24	25.34
A	Epoxy	600	7	SeaWater	11 476.57	11 545.91	11 511.24	34.67
B	Vinyl Ester	600	7	SeaWater	11 484.84	11 533.52	11 509.18	24.34
A	Epoxy	600	10	0	2.22	2.68	2.45	0.23
B	Vinyl Ester	600	10	0	2.27	2.69	2.48	0.21
A	Epoxy	600	10	200	144.31	164.35	154.33	10.02
B	Vinyl Ester	600	10	200	142.88	165.56	154.22	11.34
A	Epoxy	600	10	20000	13 283.33	13 332.89	13 308.11	24.78
B	Vinyl Ester	600	10	20000	13 269.20	13 345.16	13 307.18	37.98
A	Epoxy	600	10	SeaWater	11 497.36	11 560.48	11 528.92	31.56
B	Vinyl Ester	600	10	SeaWater	11 496.43	11 559.11	11 527.77	31.34
A	Epoxy	600	13	0	2317.52	2339.48	2328.50	10.98
B	Vinyl Ester	600	13	0	2315.69	2336.78	2326.23	10.55
A	Epoxy	600	13	200	2498.41	2526.25	2512.33	13.92
B	Vinyl Ester	600	13	200	2500.28	2524.56	2512.42	12.14
A	Epoxy	600	13	20000	15 250.90	15 333.58	15 292.24	41.34
B	Vinyl Ester	600	13	20000	15 244.06	15 334.74	15 289.40	45.34
A	Epoxy	600	13	SeaWater	13 843.84	13 932.62	13 888.23	44.39
B	Vinyl Ester	600	13	SeaWater	13 828.48	13 942.04	13 885.26	56.78

Table 8.42: Sodium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Sodium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
A	Sized	600	4	0	0.03	0.09	0.06	0.03
B	Sized	600	4	0	0.04	0.10	0.07	0.03
C	Sized	600	4	0	0.06	0.08	0.07	0.01
A	Sized	600	4	200	111.72	119.96	115.84	4.12
B	Sized	600	4	200	122.82	133.06	127.94	5.12
C	Sized	600	4	200	119.16	121.80	120.48	1.32
A	Sized	600	4	20000	12 958.73	13 054.97	13 006.85	48.12
B	Sized	600	4	20000	12 998.89	13 068.01	13 033.45	34.56
C	Sized	600	4	20000	12 997.63	13 066.97	13 032.30	34.67
A	Sized	600	4	SeaWater	11 255.42	11 325.20	11 290.31	34.89
B	Sized	600	4	SeaWater	11 259.72	11 372.38	11 316.05	56.33
C	Sized	600	4	SeaWater	11 275.01	11 359.25	11 317.13	42.12
A	Unsized	600	4	0	0.04	0.08	0.06	0.02
B	Unsized	600	4	0	0.03	0.09	0.06	0.03
A	Unsized	600	4	200	114.13	125.69	119.91	5.78
B	Unsized	600	4	200	126.31	137.65	131.98	5.67
A	Unsized	600	4	20000	12 981.92	13 068.34	13 025.13	43.21
B	Unsized	600	4	20000	12 997.76	13 095.72	13 046.74	48.98
A	Unsized	600	4	SeaWater	11 263.67	11 352.13	11 307.90	44.23
B	Unsized	600	4	SeaWater	11 297.29	11 360.01	11 328.65	31.36
A	Sized	600	7	0	0.05	0.07	0.06	0.01
B	Sized	600	7	0	0.06	0.10	0.08	0.02
C	Sized	600	7	0	0.05	0.09	0.07	0.02
A	Sized	600	7	200	114.59	126.83	120.71	6.12
B	Sized	600	7	200	124.47	135.37	129.92	5.45
C	Sized	600	7	200	116.62	127.96	122.29	5.67
A	Sized	600	7	20000	13 046.18	13 110.86	13 078.52	32.34
B	Sized	600	7	20000	13 072.48	13 137.82	13 105.15	32.67
C	Sized	600	7	20000	13 060.67	13 147.13	13 103.90	43.23
A	Sized	600	7	SeaWater	11 265.86	11 330.50	11 298.18	32.32
B	Sized	600	7	SeaWater	11 280.37	11 367.49	11 323.93	43.56
C	Sized	600	7	SeaWater	11 288.87	11 361.11	11 324.99	36.12
A	Unsized	600	7	0	0.05	0.07	0.06	0.01
B	Unsized	600	7	0	0.05	0.09	0.07	0.02
A	Unsized	600	7	200	112.69	130.93	121.81	9.12
B	Unsized	600	7	200	123.75	144.21	133.98	10.23
A	Unsized	600	7	20000	13 064.48	13 129.16	13 096.82	32.34
B	Unsized	600	7	20000	13 076.34	13 160.58	13 118.46	42.12
A	Unsized	600	7	SeaWater	11 288.99	11 342.55	11 315.77	26.78
B	Unsized	600	7	SeaWater	11 312.96	11 360.08	11 336.52	23.56
A	Sized	600	10	0	1.07	1.75	1.41	0.34

Continued on next page ...

Table 8.42: Sodium Test Statistical values for All Fiber Sample Groups

Sample Group					Statistical Values			
					Sodium			
Manuf. Type	Fiber Type	Exposure Period Days	pH	Cl^- ppm	$\wedge$ ppm	$\vee$ ppm	μ ppm	σ ppm
B	Sized	600	10	0	1.18	2.52	1.85	0.67
C	Sized	600	10	0	1.30	1.98	1.64	0.34
A	Sized	600	10	200	122.16	132.40	127.28	5.12
B	Sized	600	10	200	129.60	143.38	136.49	6.89
C	Sized	600	10	200	120.38	136.16	128.27	7.89
A	Sized	600	10	20000	13 046.72	13 138.96	13 092.84	46.12
B	Sized	600	10	20000	13 082.71	13 156.27	13 119.49	36.78
C	Sized	600	10	20000	13 086.10	13 150.34	13 118.22	32.12
A	Sized	600	10	SeaWater	11 284.84	11 346.64	11 315.74	30.90
B	Sized	600	10	SeaWater	11 308.61	11 374.39	11 341.50	32.89
C	Sized	600	10	SeaWater	11 303.53	11 381.55	11 342.54	39.01
A	Unsized	600	10	0	1.18	2.30	1.74	0.56
B	Unsized	600	10	0	1.48	2.60	2.04	0.56
A	Unsized	600	10	200	123.77	132.45	128.11	4.34
B	Unsized	600	10	200	134.94	146.28	140.61	5.67
A	Unsized	600	10	20000	13 071.27	13 151.05	13 111.16	39.89
B	Unsized	600	10	20000	13 092.90	13 172.70	13 132.80	39.90
A	Unsized	600	10	SeaWater	11 294.22	11 372.46	11 333.34	39.12
B	Unsized	600	10	SeaWater	11 332.54	11 375.66	11 354.10	21.56
A	Sized	600	13	0	2233.77	2242.23	2238.00	4.23
B	Sized	600	13	0	2267.48	2277.04	2272.26	4.78
C	Sized	600	13	0	2237.77	2262.67	2250.22	12.45
A	Sized	600	13	200	2435.30	2457.76	2446.53	11.23
B	Sized	600	13	200	2464.27	2486.23	2475.25	10.98
C	Sized	600	13	200	2438.20	2458.66	2448.43	10.23
A	Sized	600	13	20000	15 040.98	15 105.22	15 073.10	32.12
B	Sized	600	13	20000	15 059.39	15 142.07	15 100.73	41.34
C	Sized	600	13	20000	15 062.00	15 131.78	15 096.89	34.89
A	Sized	600	13	SeaWater	13 624.93	13 713.39	13 669.16	44.23
B	Sized	600	13	SeaWater	13 664.86	13 727.32	13 696.09	31.23
C	Sized	600	13	SeaWater	13 661.51	13 726.63	13 694.07	32.56
A	Unsized	600	13	0	2259.24	2265.70	2262.47	3.23
B	Unsized	600	13	0	2278.89	2288.01	2283.45	4.56
A	Unsized	600	13	200	2451.47	2482.37	2466.92	15.45
B	Unsized	600	13	200	2463.87	2504.11	2483.99	20.12
A	Unsized	600	13	20000	15 059.75	15 124.65	15 092.20	32.45
B	Unsized	600	13	20000	15 079.06	15 150.62	15 114.84	35.78
A	Unsized	600	13	SeaWater	13 647.30	13 728.10	13 687.70	40.40
B	Unsized	600	13	SeaWater	13 669.44	13 749.84	13 709.64	40.20

For a better understanding, change in the Sodium content of the environments was plotted in graphs in

Figure 8.40, 8.41, and 8.42. It can be seen that the Sodium concentration of exposure environments has

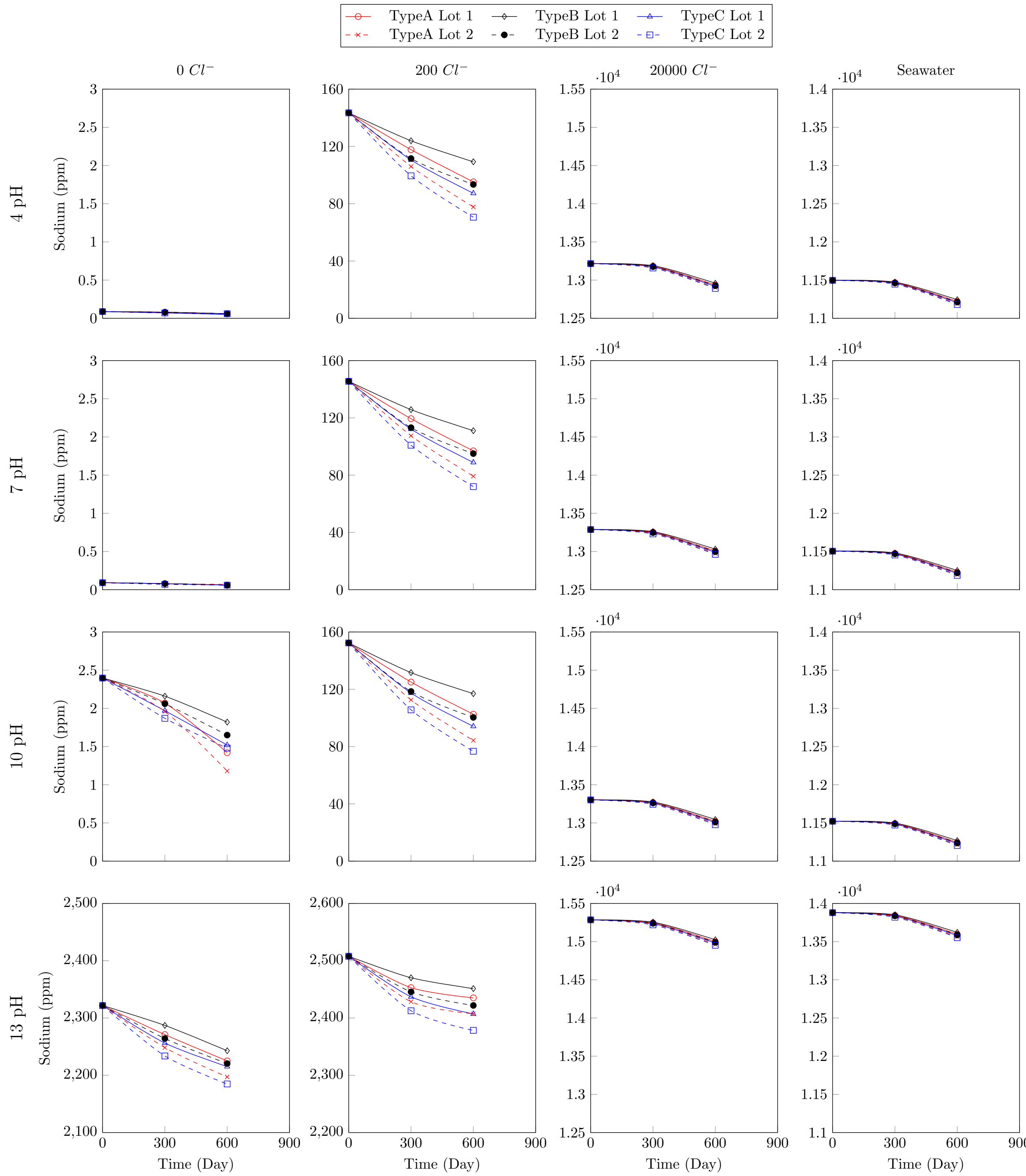

Figure 8.40: Sodium concentration of all environments after exposure of rebars

decreased except in the environments with resin samples.

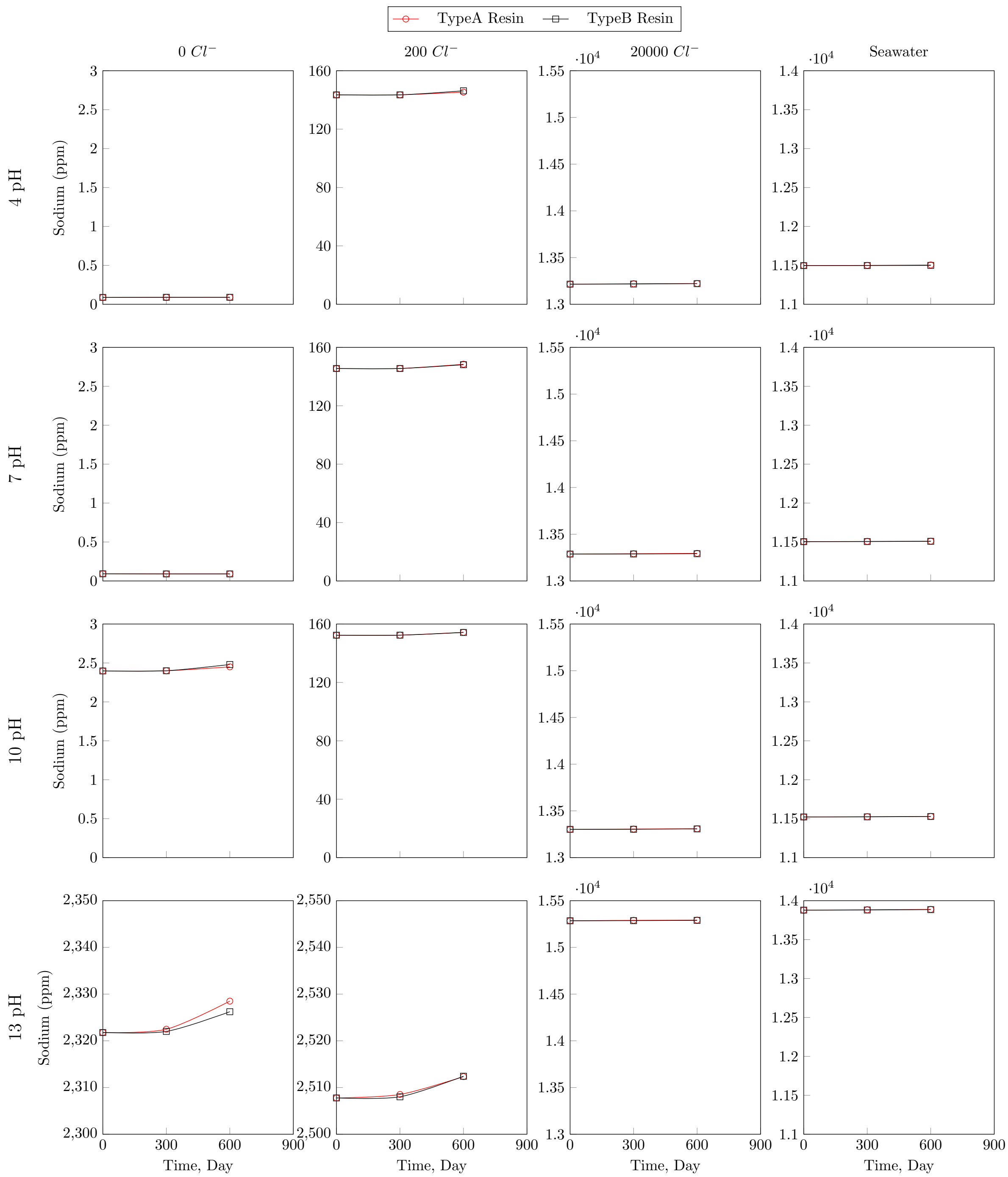

Figure 8.41: Sodium concentration of all environments after exposure of resins

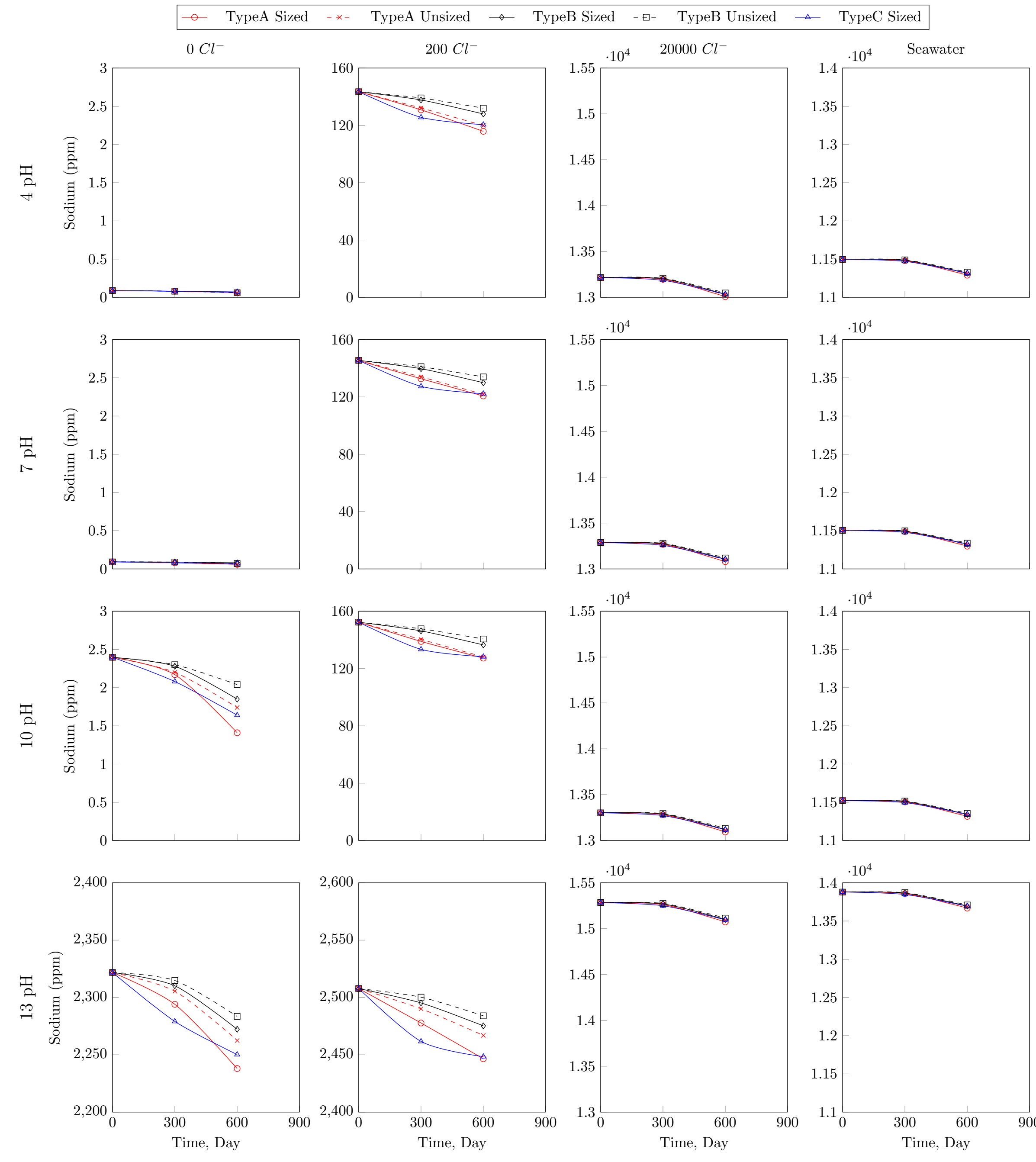

Figure 8.42: Sodium concentration of all environments after exposure of sized and unsized fibers

8.3 Corrosion Behavior of Solid Samples after 600 Day Exposure under SEM

In this section, the scanning electron microscopic (SEM) images has been analyzed for each type of rebar, fiber and resin samples.

8.3.1 Type A Lot 1 Rebars at day 600

The SEM image analysis of the Type A Lot 1 rebars under 16 different environments for day 600 at 200x, 1000x, 2000x and 5000x magnifications were as the following Figures 8.43, 8.44, 8.45, and 8.46.

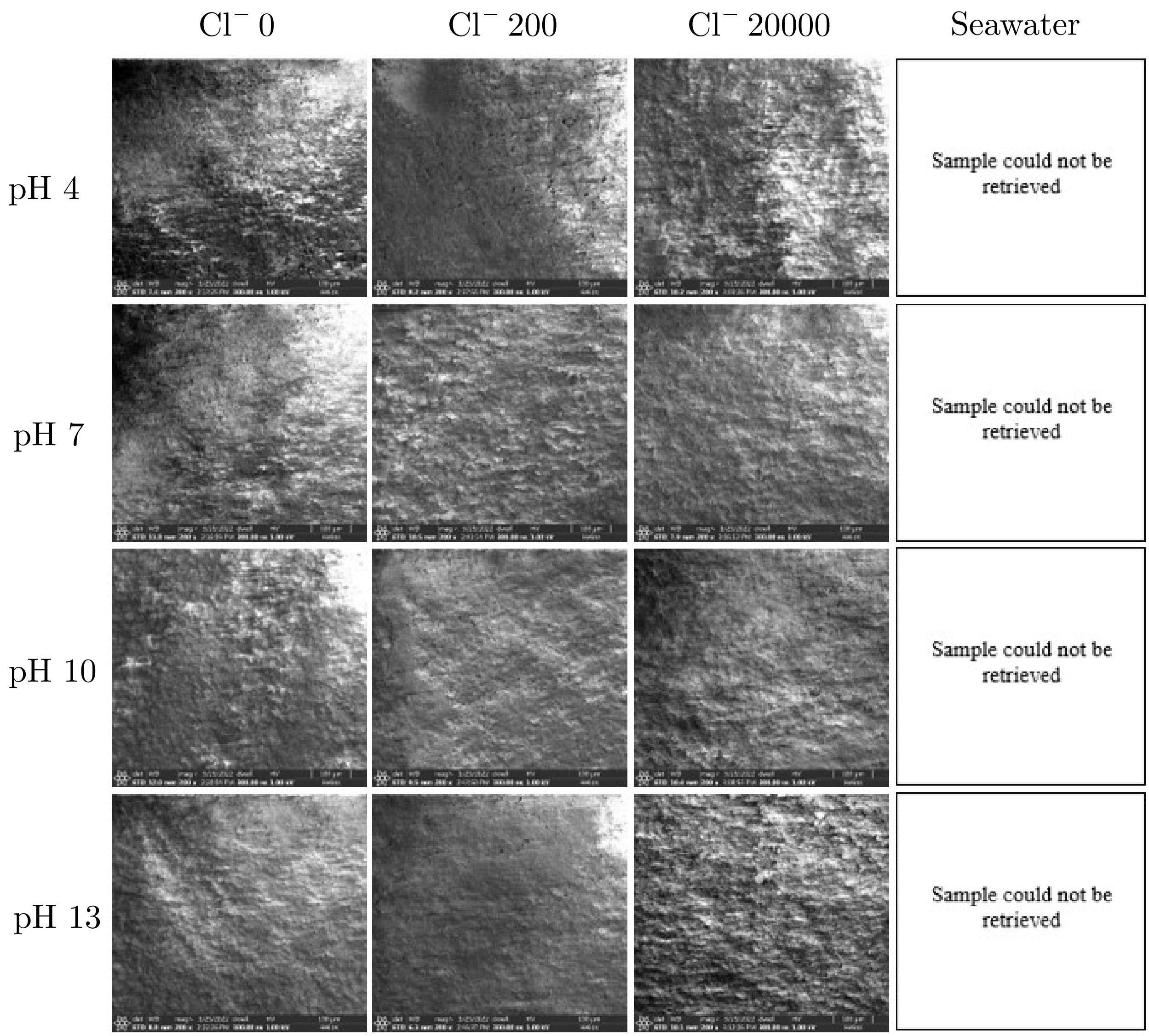

Figure 8.43: Type A Lot 1 rebars at day 600 under 200x magnification

From the figures above it can be assessed that the more the Type A rebars approached higher pH and higher salinity environments, the corrosive layers became more prominent and dense. 13 pH, seawater environment comparatively had more degrading effect.

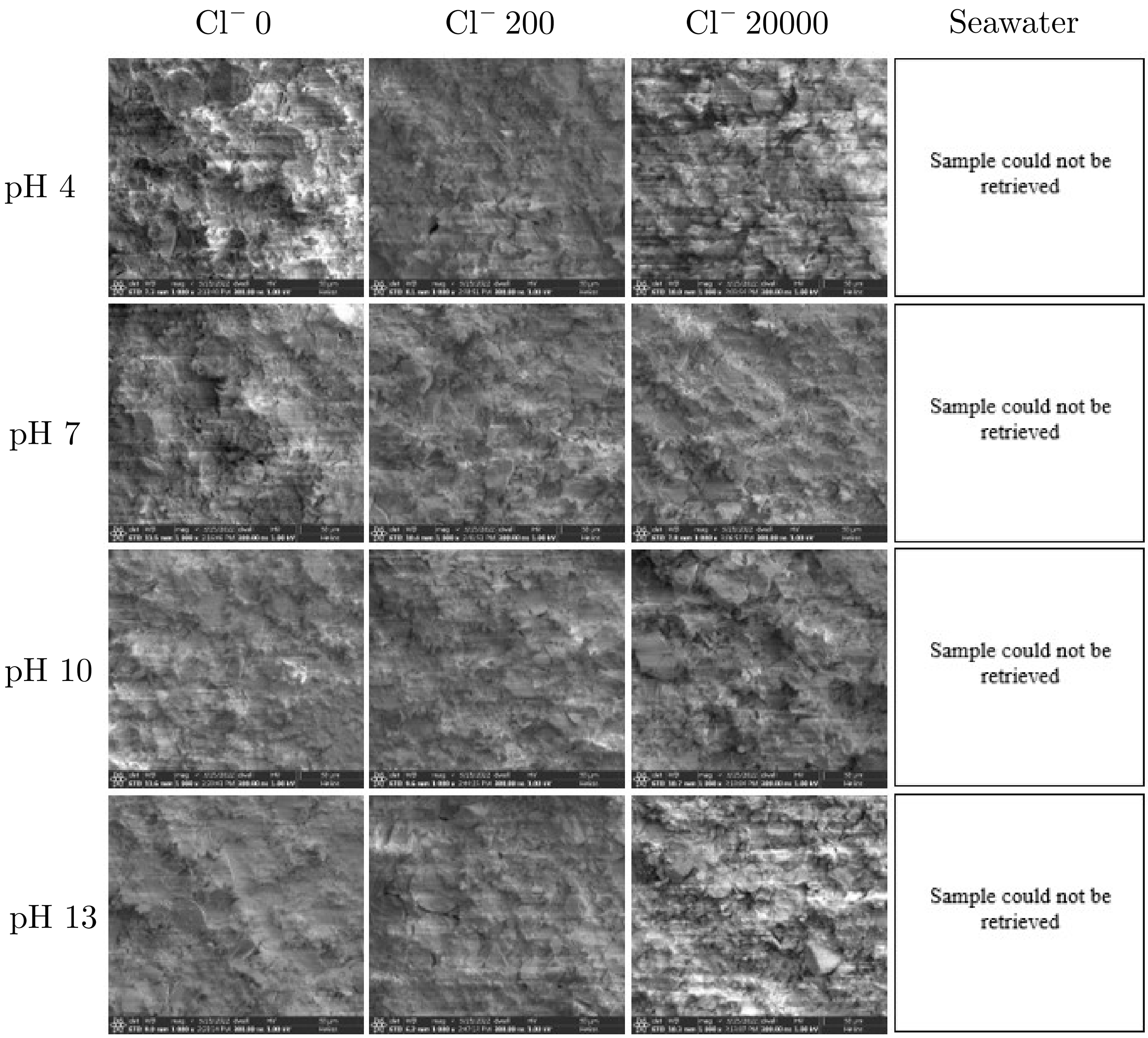

Figure 8.44: Type A Lot 1 rebars at day 600 under 1000x magnification

8.3.2 Type B Lot 1 Rebars at day 600

The SEM image analysis of the Type B Lot 1 rebars under 16 different environments for day 600 at 200x, 1000x, 2000x and 5000x magnifications were as the following Figures 8.47, 8.48, 8.49, and 8.50.

From the figures, it can be assessed that the more the Type B rebars approached higher pH and higher salinity environments, the corrosive layers became more prominent and dense. 13 pH, seawater environment comparatively had more degrading effect.

8.3.3 Type C Lot 1 Rebars at day 600

The SEM image analysis of the Type C Lot 1 rebars under 16 different environments for day 600 at 200x, 1000x, 2000x and 5000x magnifications were as the following Figures 8.51, 8.52, 8.53, and 8.54.

From the figures, it can be assessed that the more the Type C rebars approached higher pH and higher salinity environments, the corrosive layers became more prominent and dense. 13 pH, seawater environment comparatively had more degrading effect.

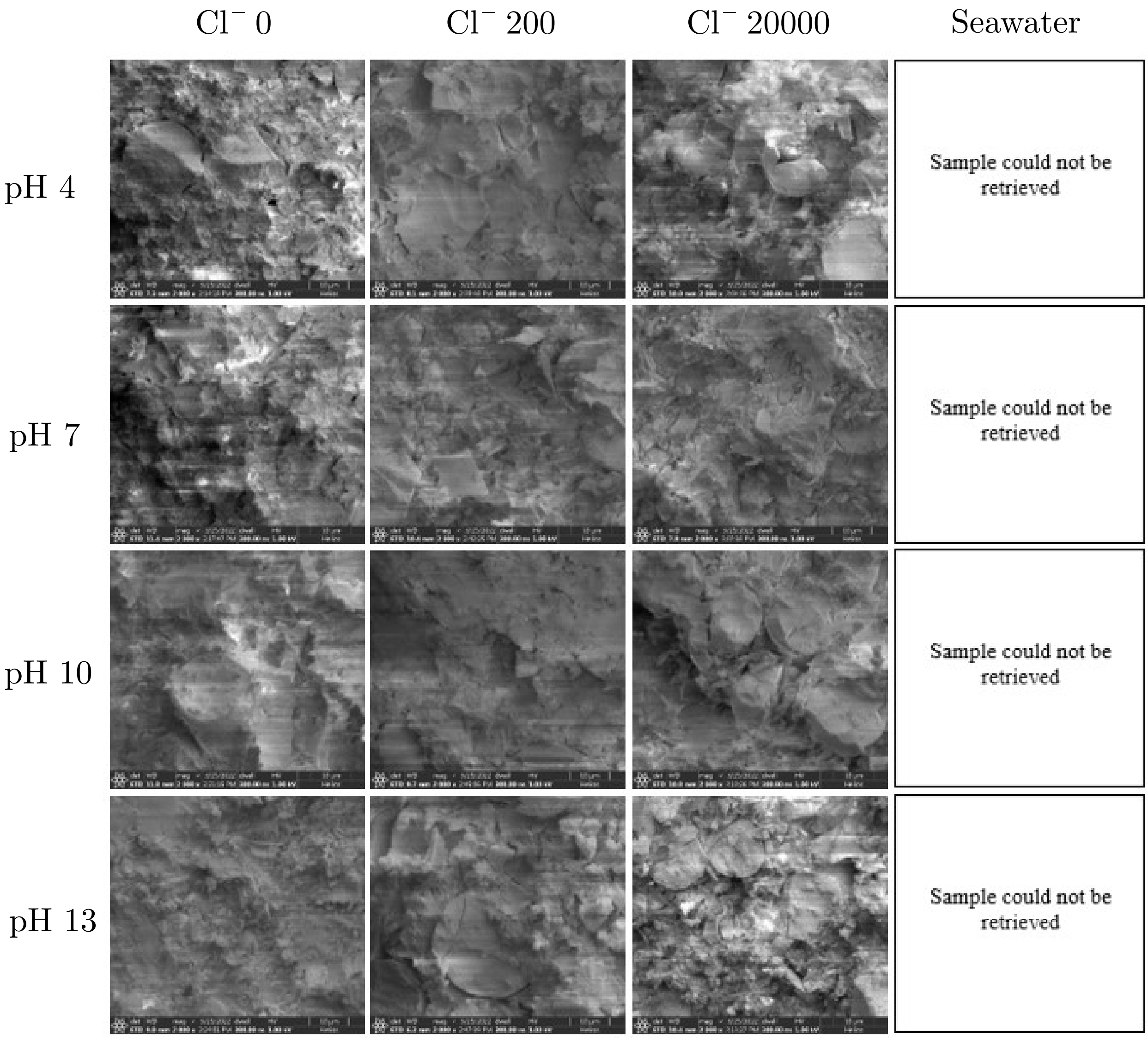

Figure 8.45: Type A Lot 1 rebars at day 600 under 2000x magnification

8.3.4 Type A Sized Fibers at day 600

The SEM image analysis of the Type A sized fibers under 16 different environments for day 600 at 200x, 2000x and 5000x magnifications are represented in Figures 8.55, 8.56, and 8.57.

8.3.5 Type A Unsized Fibers at day 600

The SEM image analysis of the Type A unsized fibers under 16 different environments for day 600 at 200x, 2000x and 5000x magnifications are illustrated in Figures 8.58, 8.59, and 8.60. From the figures, it can be assessed that the corrosive layers for the Sized Type A fibers became more prominent and denser, as the environment solutions approached higher pH and higher salinity values. From the figures, it can be assessed that the corrosive layers for the Type A unsized fibers became more prominent and denser, as the environment solutions approached higher pH and higher salinity values. However, more corrosion layers could be seen to have formed over the unsized fibers than the sized ones, which meant the sizing protected the fibers to some extent from degradation. 13 pH, seawater environment comparatively had more degrading effect for both the

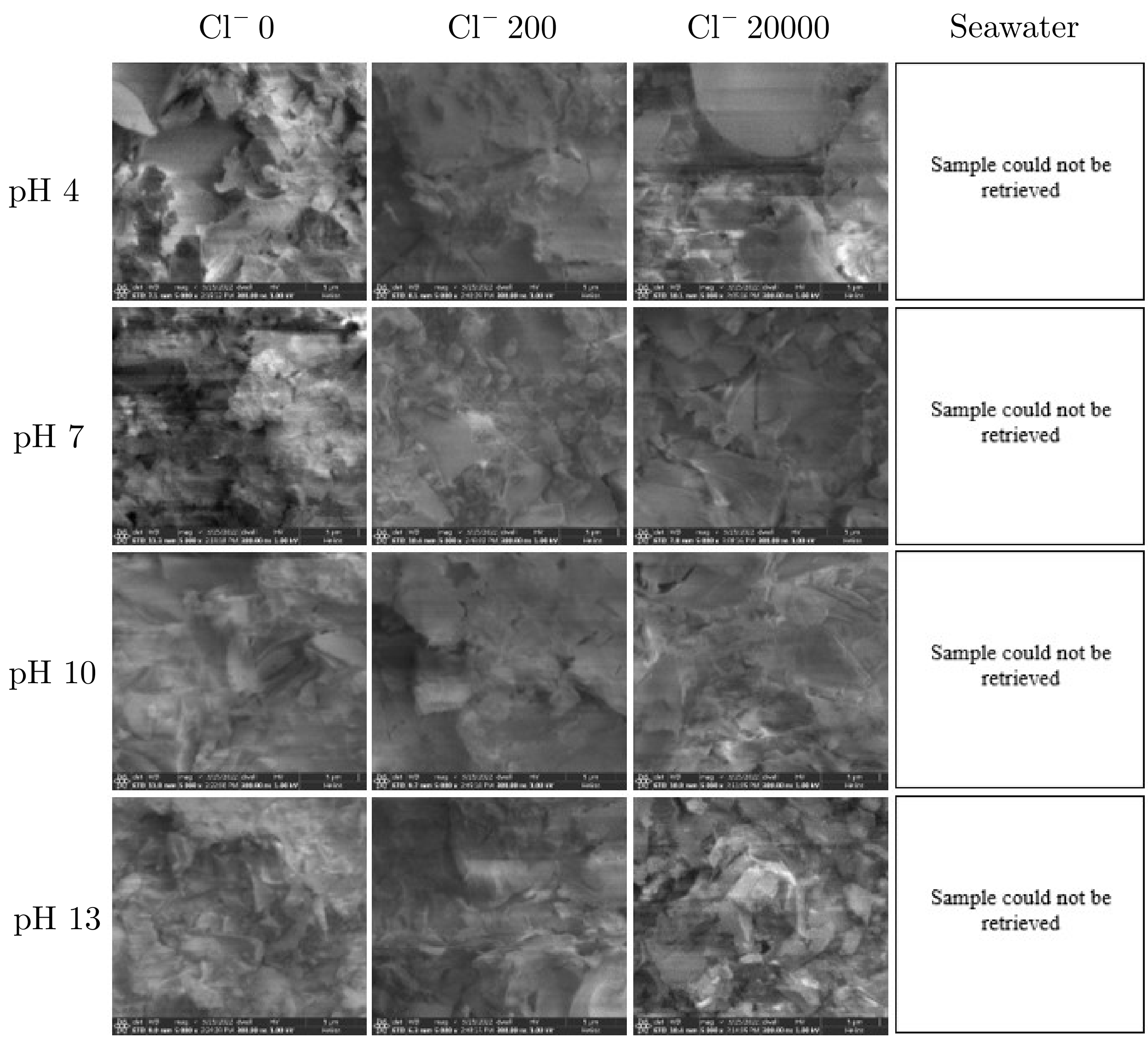

Figure 8.46: Type A Lot 1 rebars at day 600 under 5000x magnification

sized and unsized fibers.

8.3.6 Type B Sized Fibers at day 600

The SEM image analysis of the Type B sized fibers under 16 different environments for day 600 at 200x, 2000x and 5000x magnifications were as the following Figures 8.61, 8.62, and 8.63.

8.3.7 Type B Unsized Fibers at day 600

The SEM image analysis of the Type B unsized fibers under 16 different environments for day 600 at 200x, 2000x and 5000x magnifications are represented in Figures 8.64, 8.65, and 8.66. According to the figures, as the Type B unsized fibers approached higher pH and higher salinity environments, the corrosive layers became more prominent and dense. It appears that the 13 pH-seawater environment had the most degrading effect. According to the figures, as the Type B sized fibers approached higher pH and higher salinity environments, the corrosive layers became more prominent and dense. In addition, more corrosion layers had

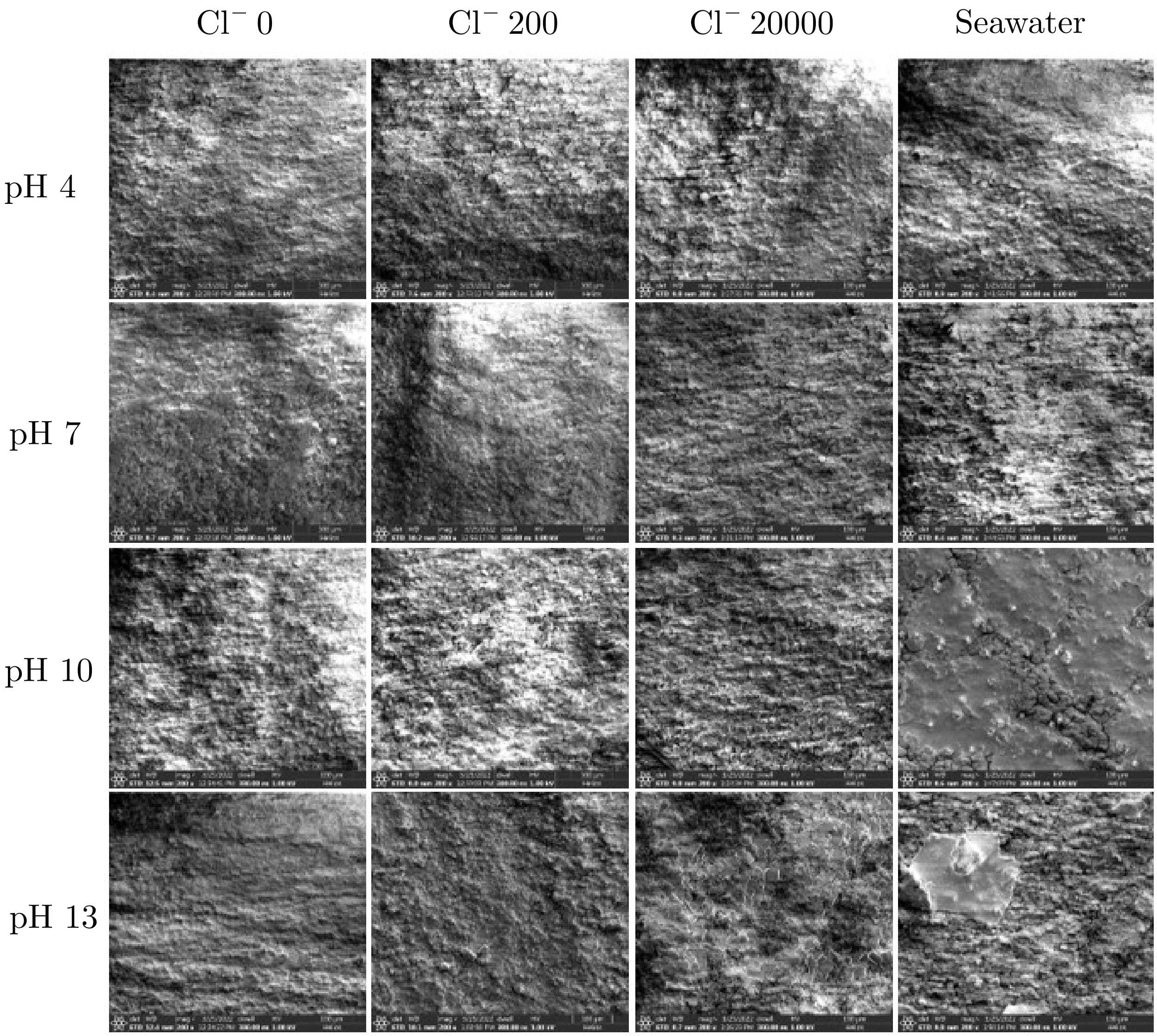

Figure 8.47: Type B Lot 1 rebars at day 600 under 200x magnification

formed over the unsized fibers than the sized ones, which meant the sizing protected the fiber to some extent from degradation. In this comparison, 13 pH, seawater environment had the most degrading effect for both the sized and unsized fibers.

8.3.8 Type C Sized Fibers at day 600

The SEM image analysis of the Type C sized fibers under 16 different environments for day 600 at 200x, 2000x and 5000x magnifications were as the following Figures 8.67, 8.68, and 8.69. From the figures, it can be assessed that the more the Type C fibers approached higher pH and higher salinity environments, the corrosive layers became more prominent and dense. After day 600, the sizing material completely came off of the sized fibers. 13 pH, seawater environment comparatively had more degrading effect.

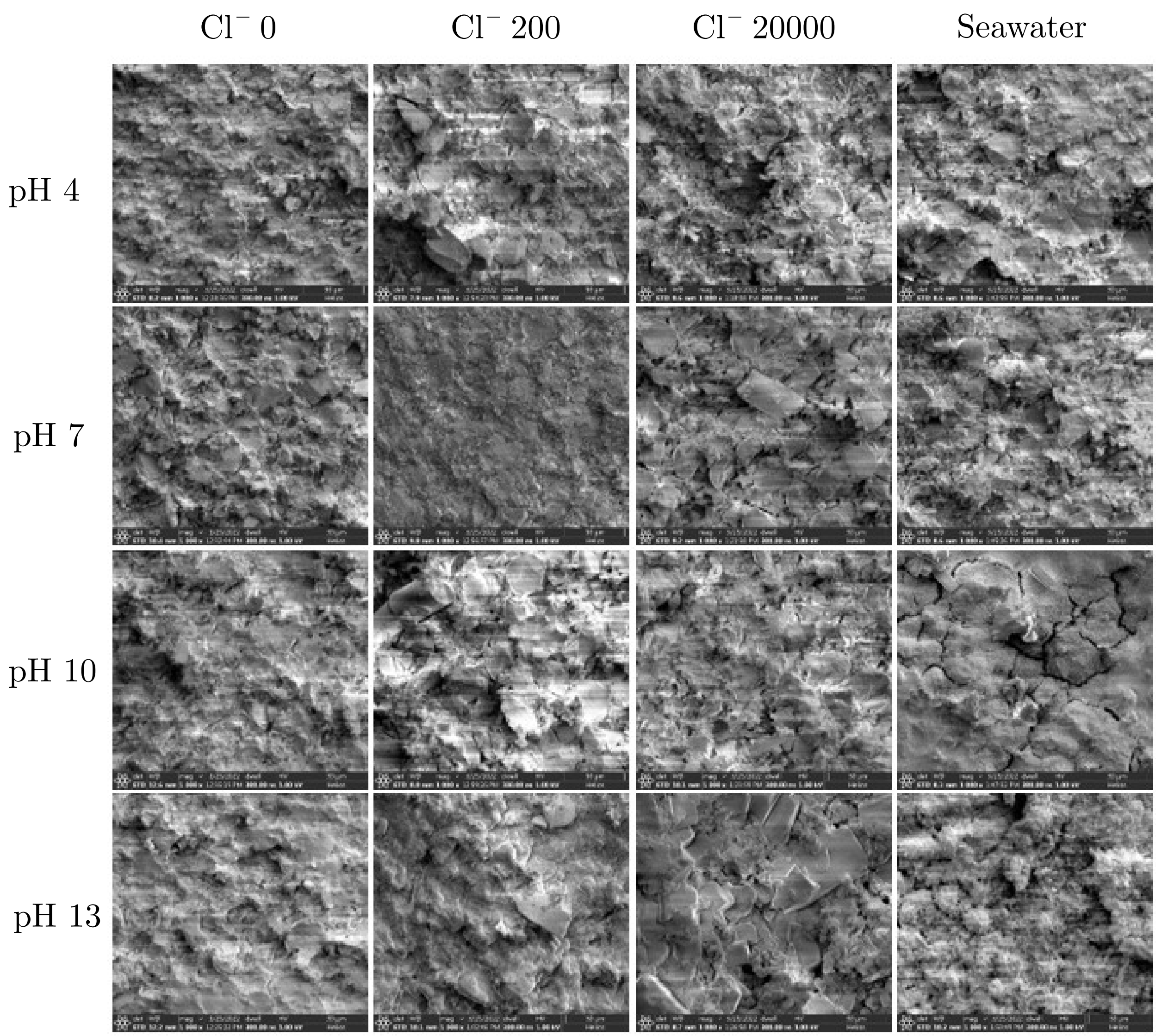

Figure 8.48: Type B Lot 1 rebars at day 600 under 1000x magnification

8.3.9 Type A Resins at day 600

The SEM image analysis of the Type A resins under 16 different environments for day 600 at 150x, 500x and 1500x magnifications were as the following Figures 8.70, 8.71, and 8.72. From the figures, it can be assessed that the more the Type A resins approached higher pH and higher salinity environments, the corrosive layers became more prominent and dense. 13 pH, seawater environment comparatively had more degrading effect.

8.3.10 Type B Resins at day 600

The SEM image analysis of the Type B resins under 16 different environments for day 600 at 150x, 500x and 1500x magnifications were as the following Figures 8.73, 8.74, and 8.75. From the figures, it can be assessed that the more the Type B resins approached higher pH and higher salinity environments, the corrosive layers became more prominent and dense. 13 pH, seawater environment comparatively had more degrading effect.

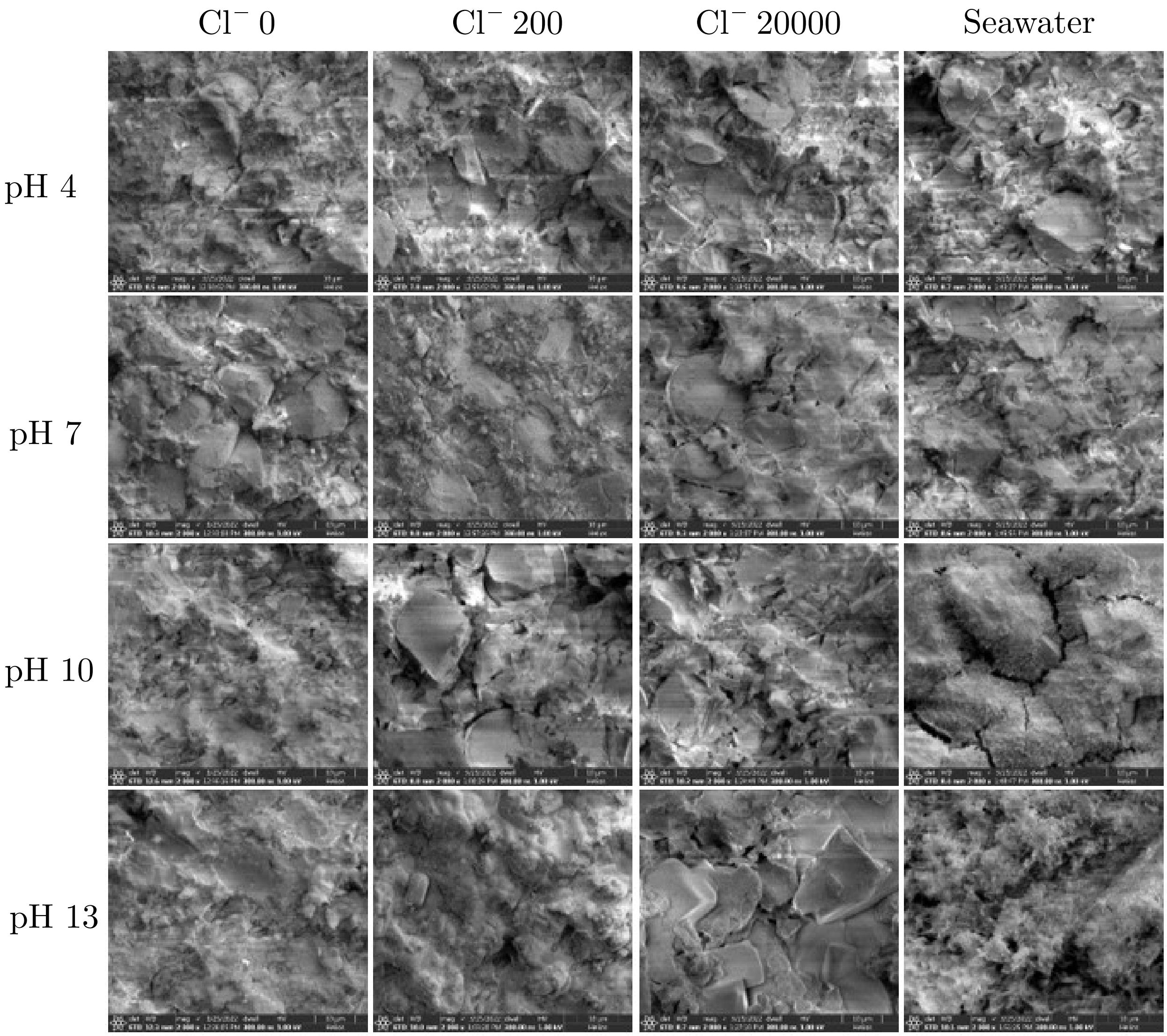

Figure 8.49: Type B Lot 1 rebars at day 600 under 2000x magnification

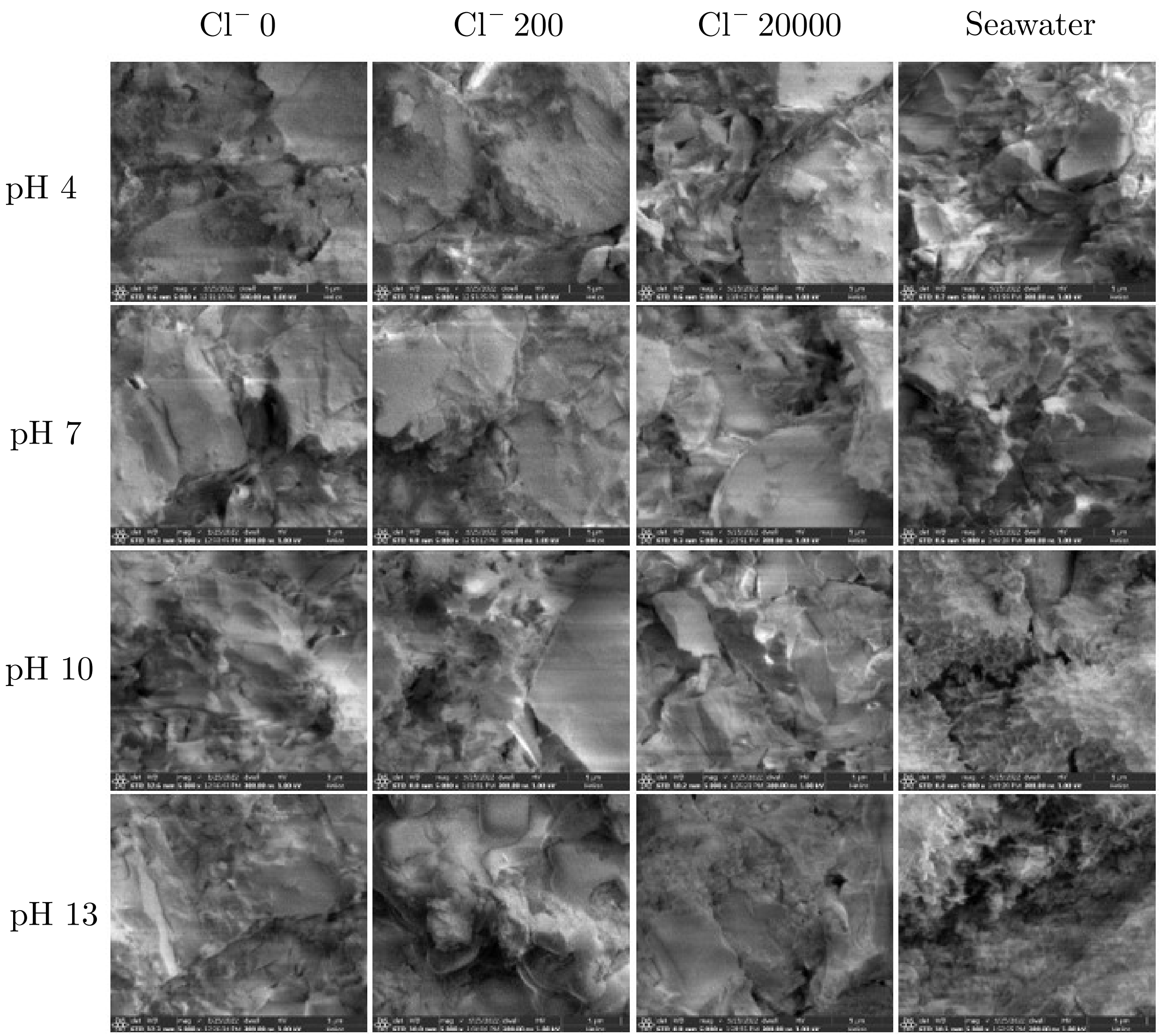

Figure 8.50: Type B Lot 1 rebars at day 600 under 5000x magnification

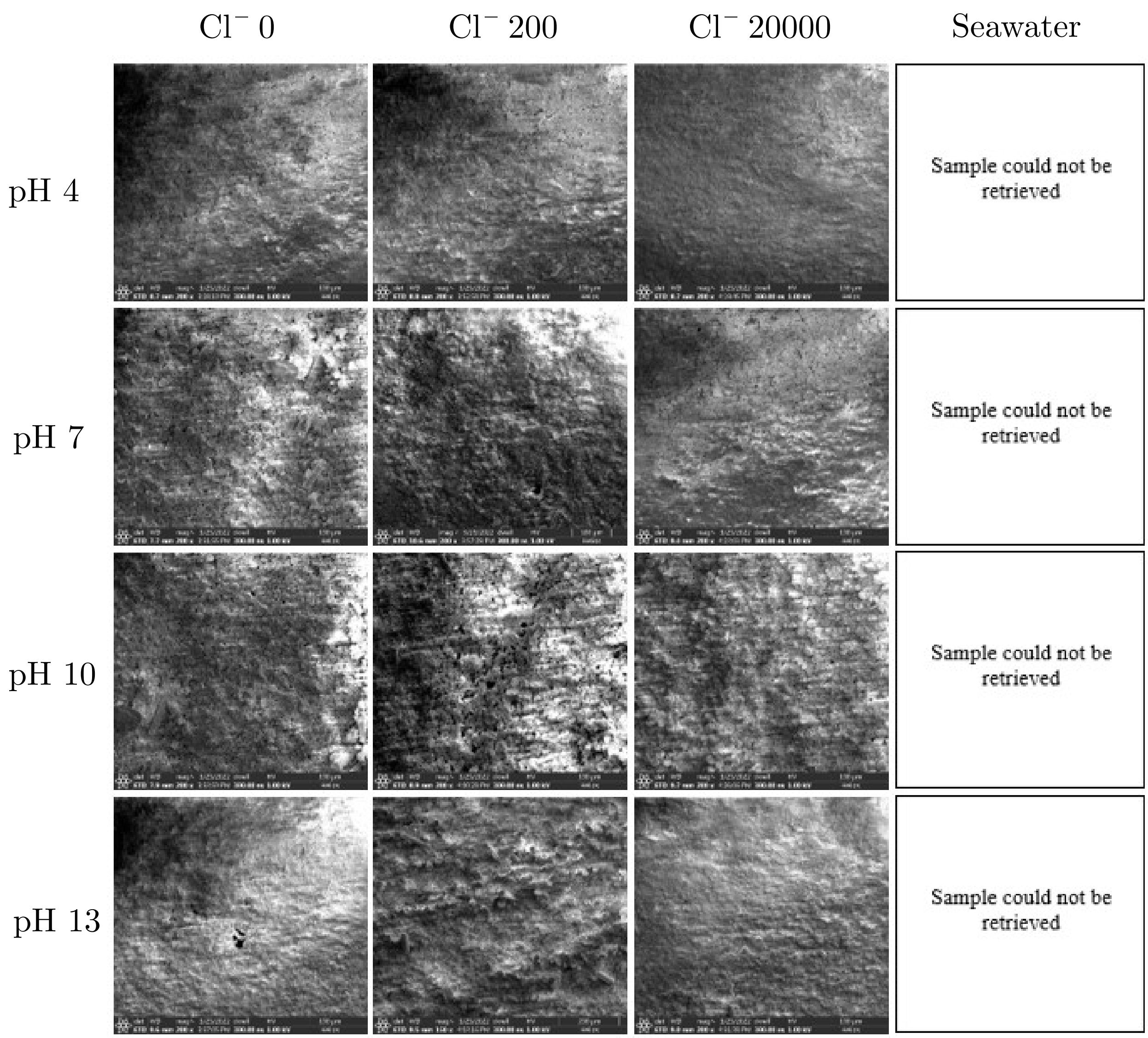

Figure 8.51: Type C Lot 1 rebars at day 600 under 200x magnification

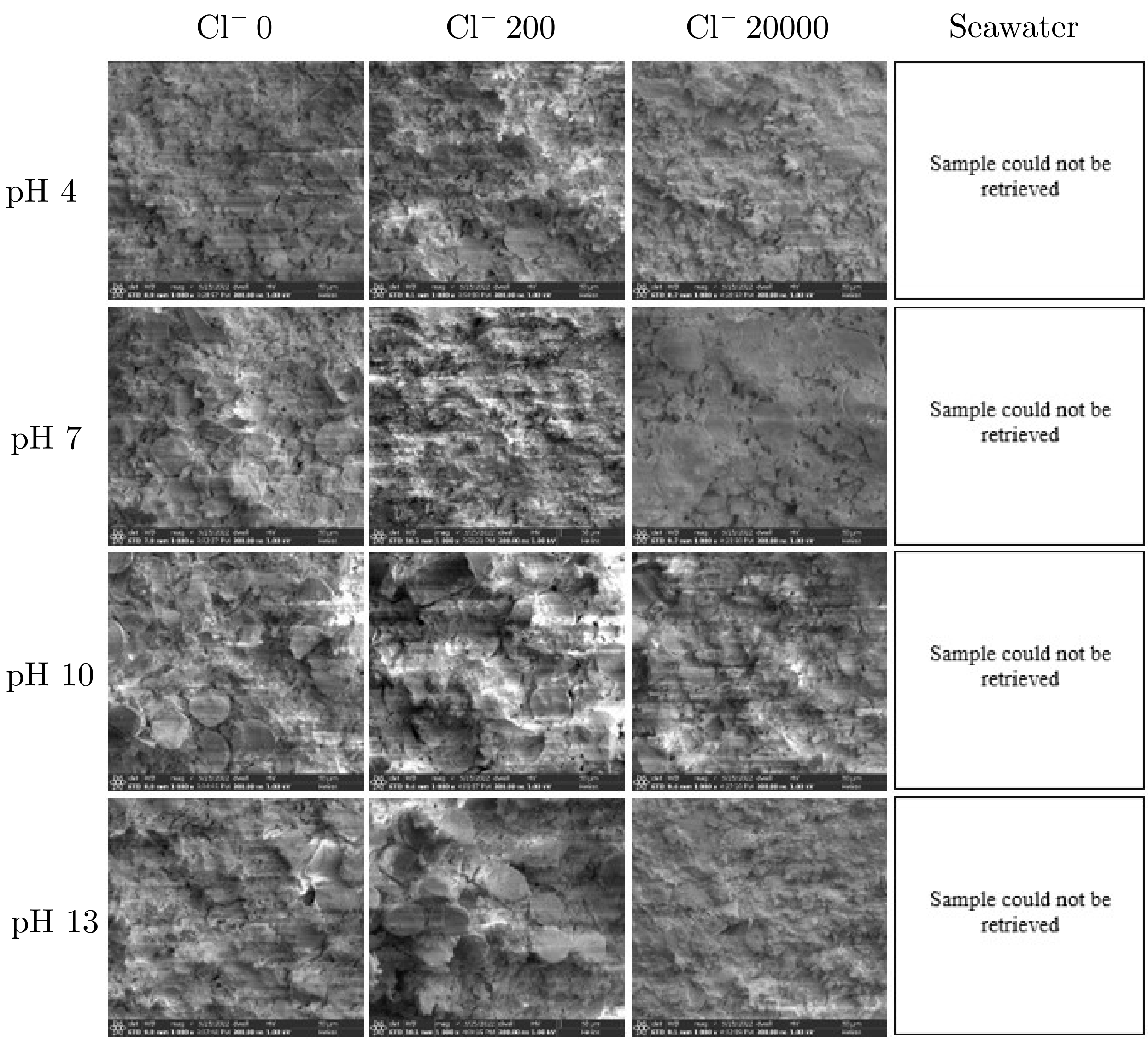

Figure 8.52: Type C Lot 1 rebars at day 600 under 1000x magnification

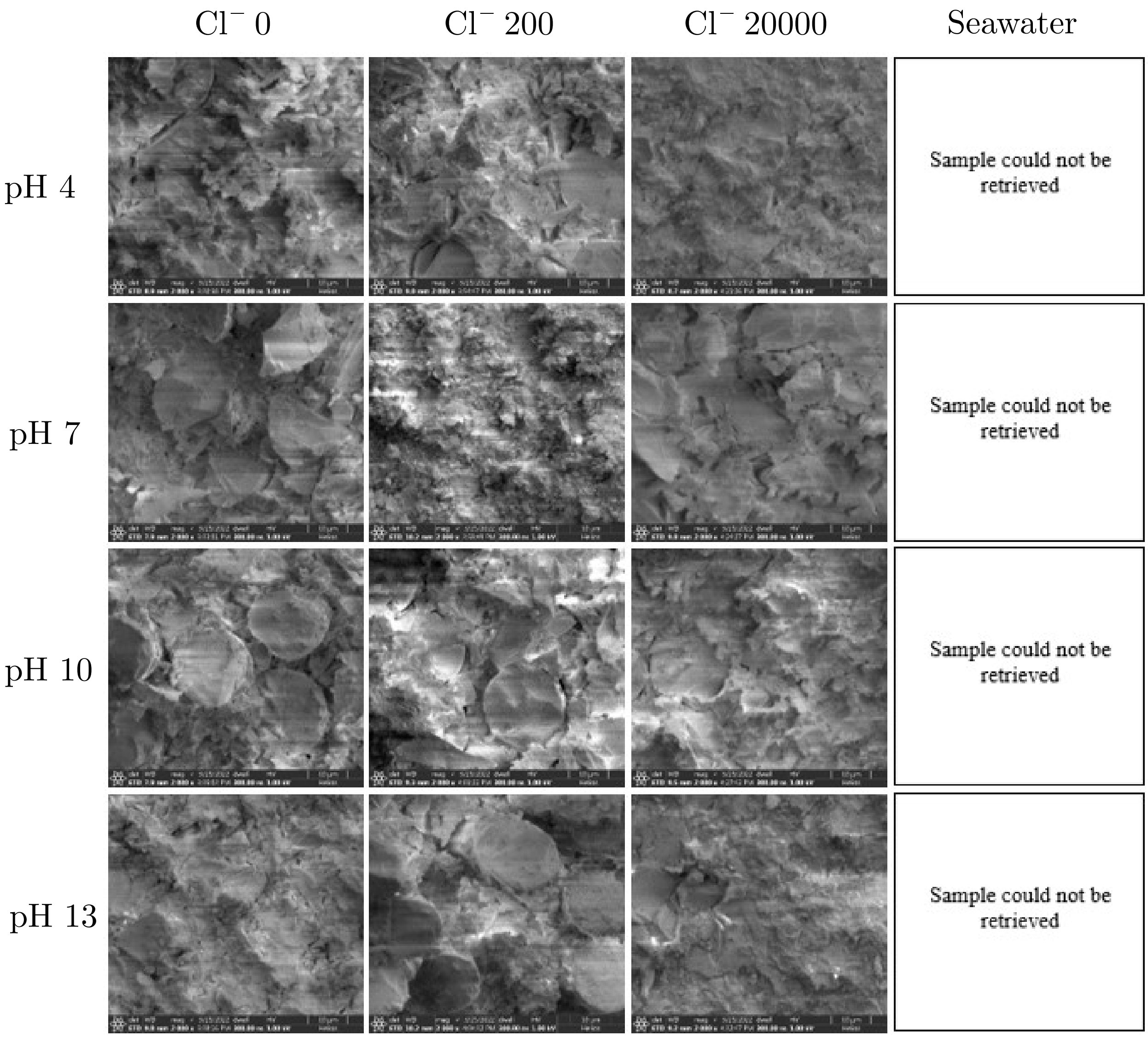

Figure 8.53: Type C Lot 1 rebars at day 600 under 2000x magnification

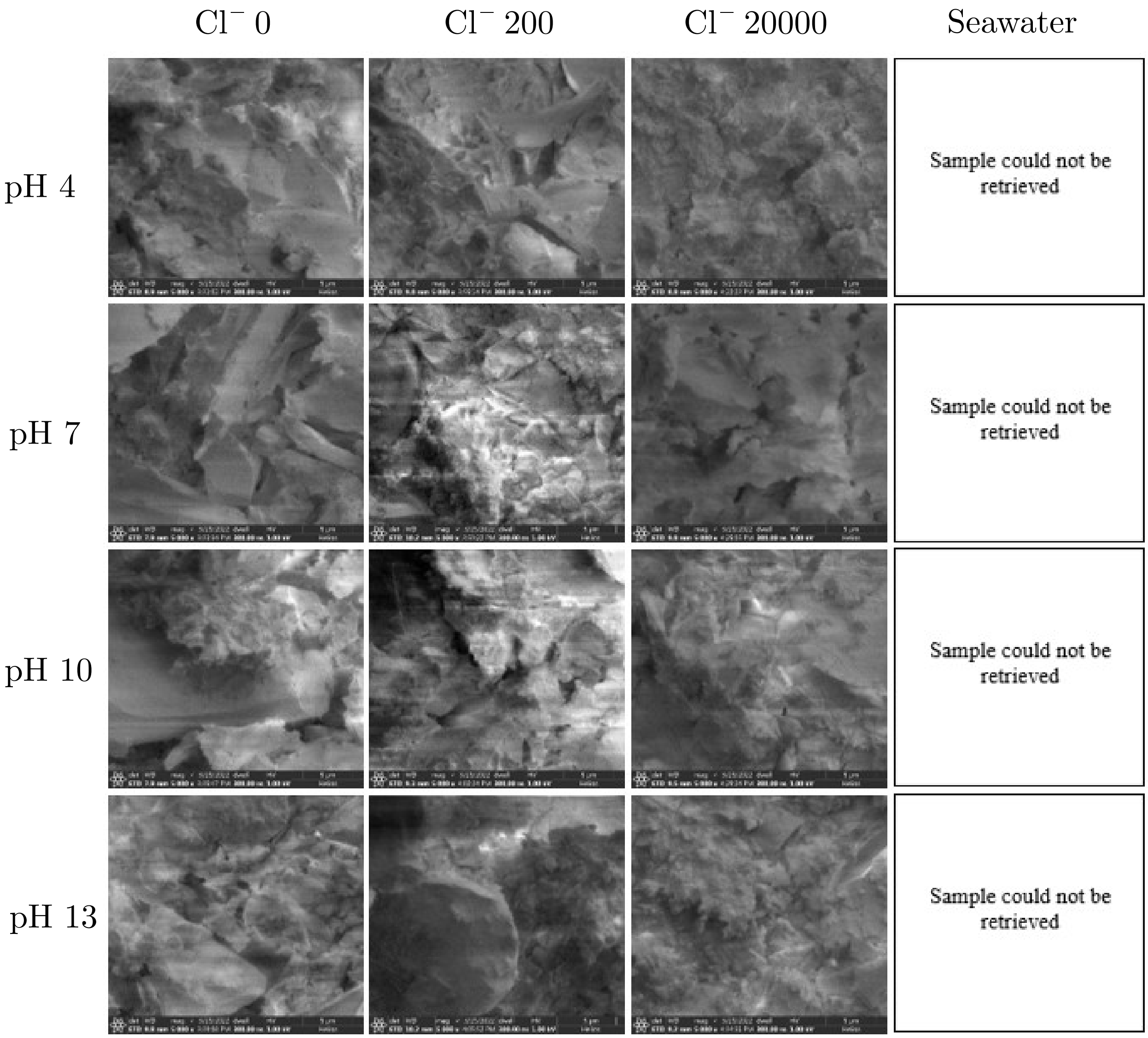

Figure 8.54: Type C Lot 1 rebars at day 600 under 5000x magnification

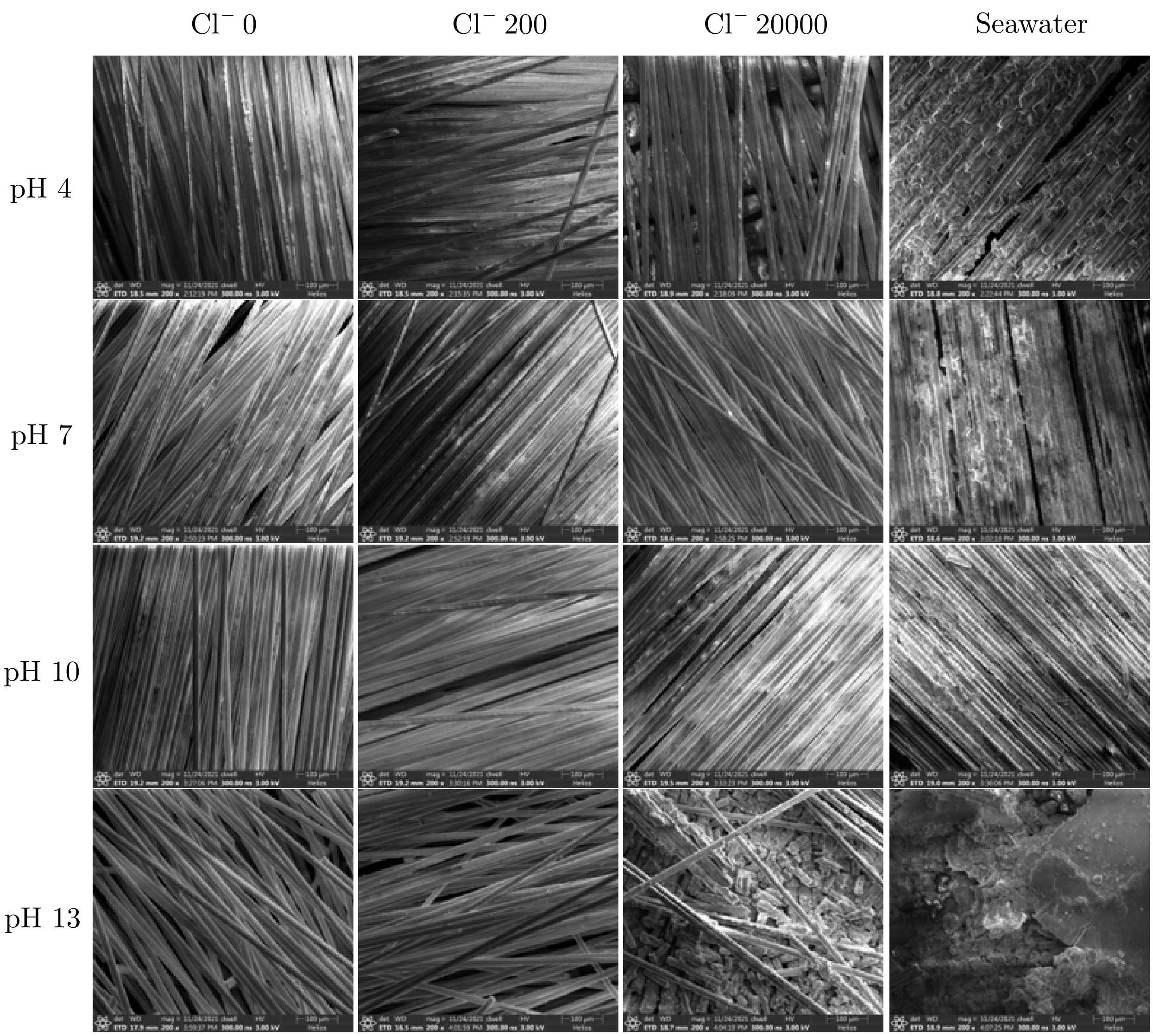

Figure 8.55: Type A sized fibers at day 600 under 200x magnification

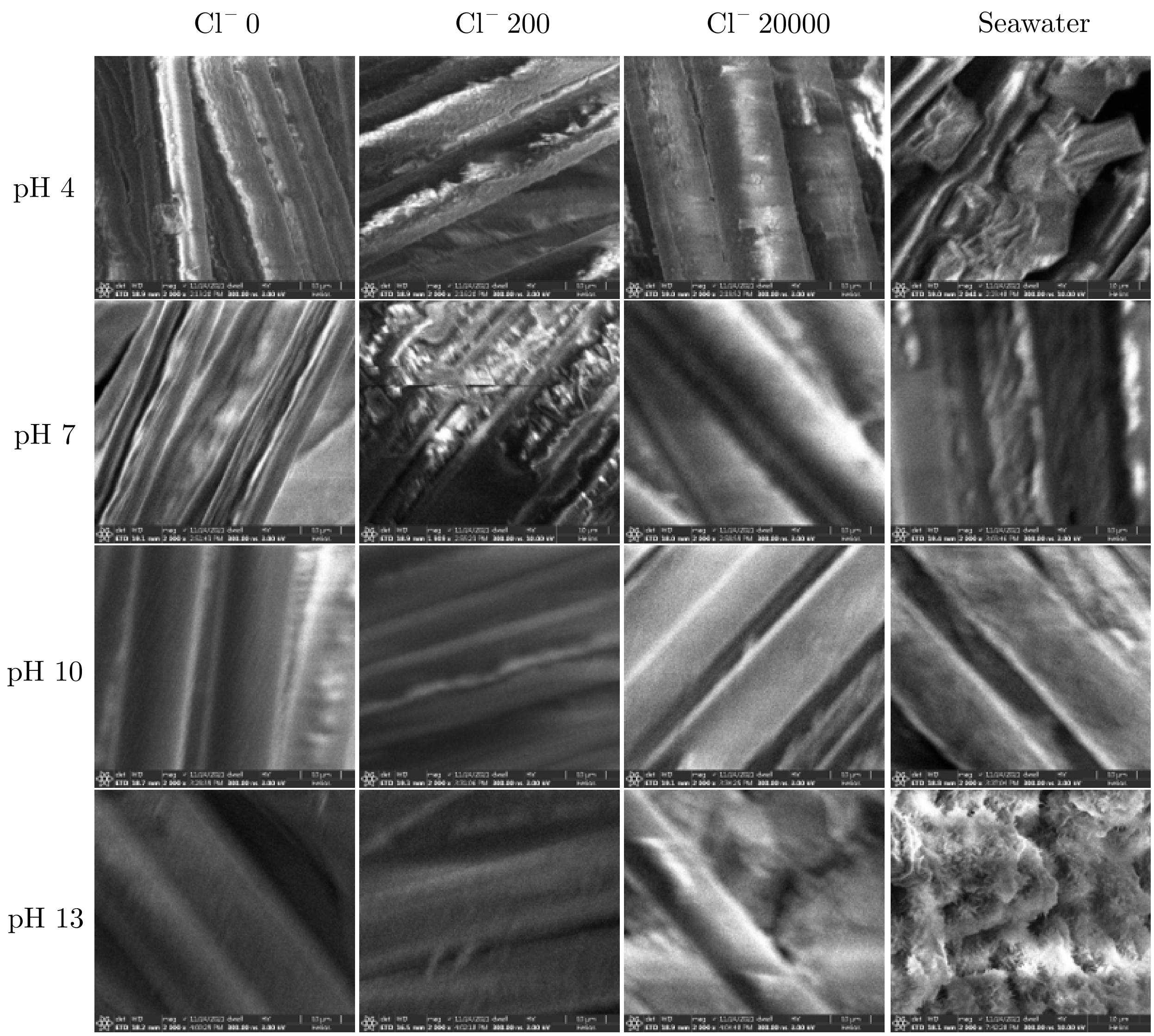

Figure 8.56: Type A sized fibers at day 600 under 2000x magnification

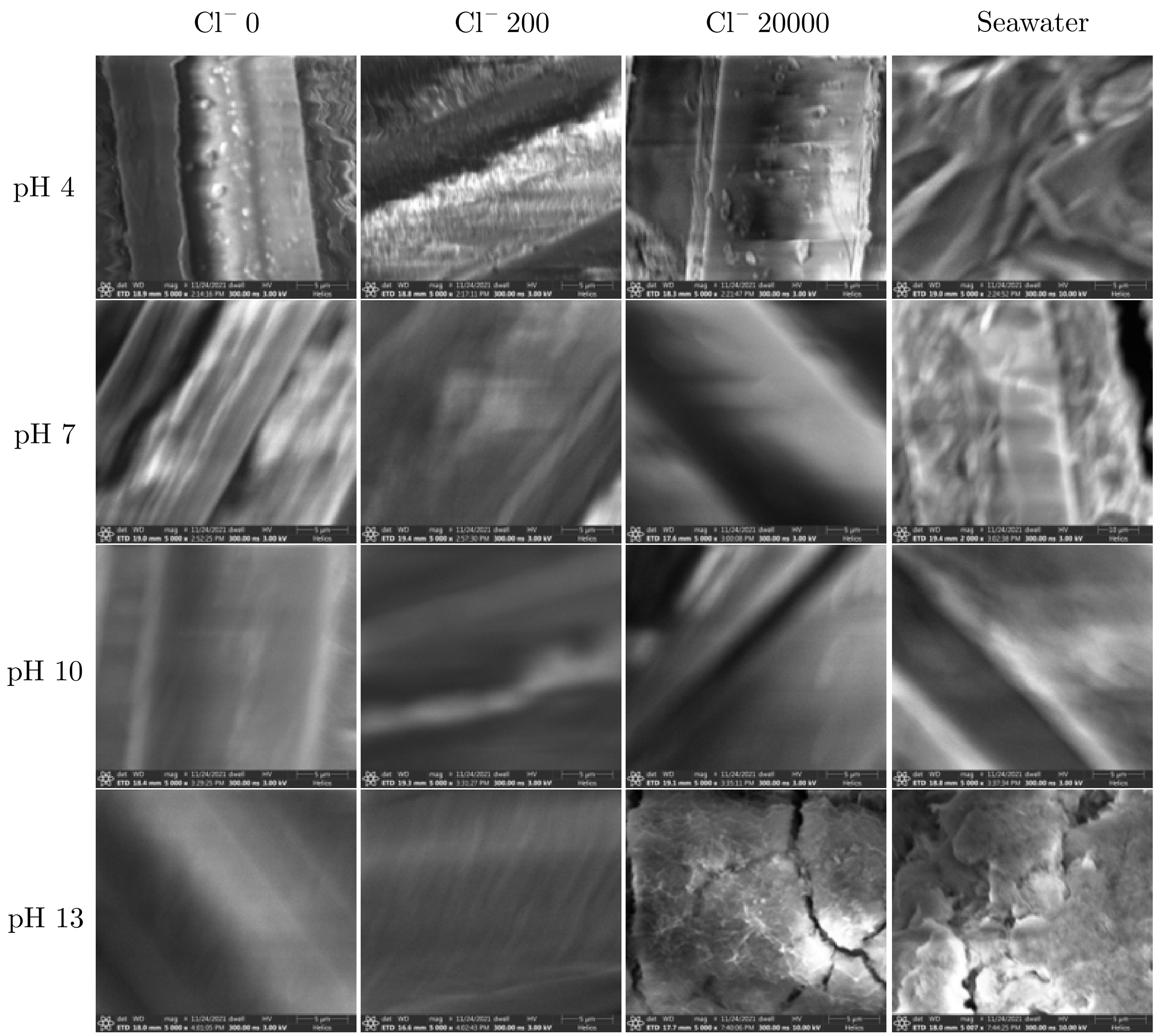

Figure 8.57: Type A sized fibers at day 600 under 5000x magnification

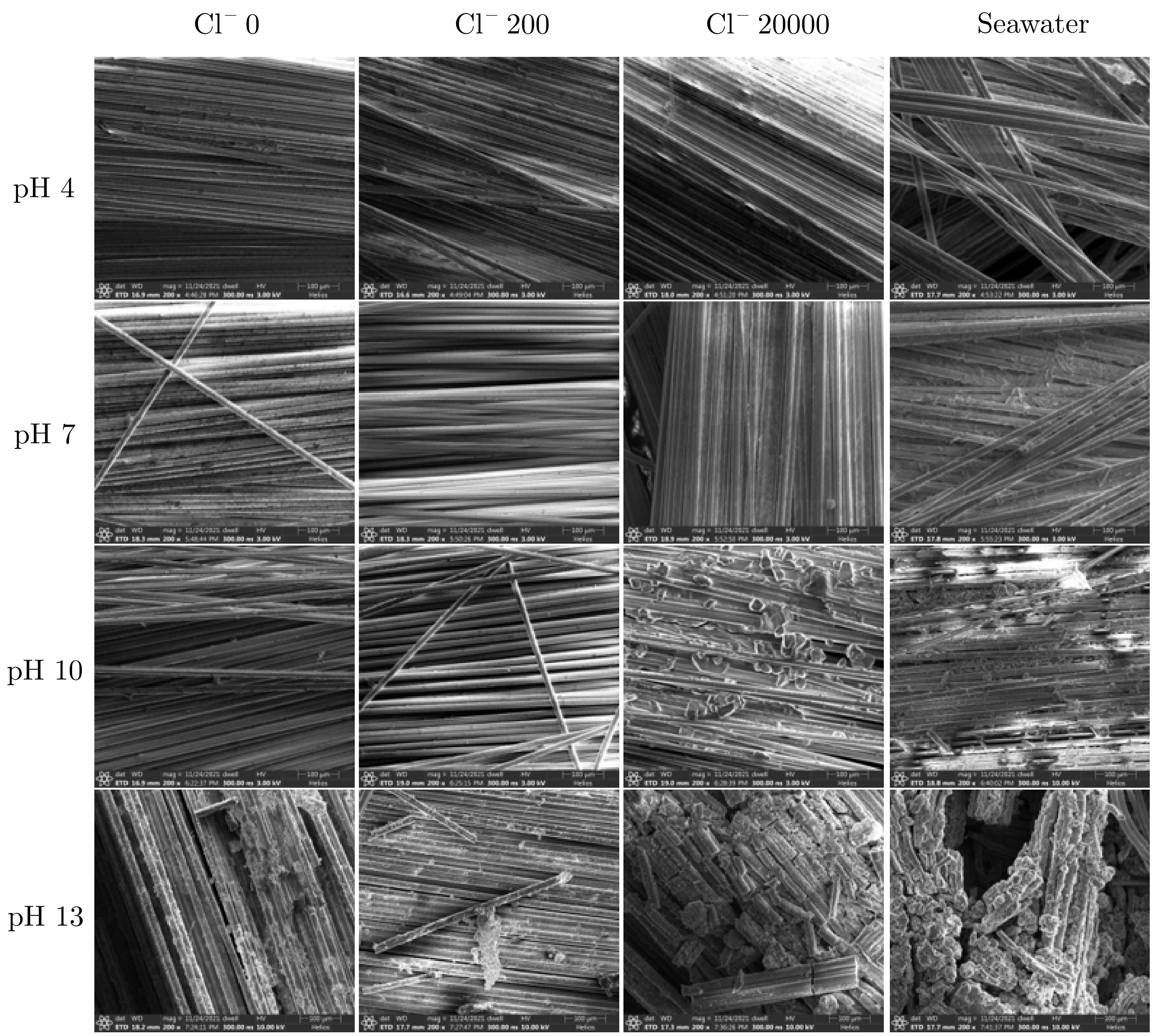

Figure 8.58: Type A unsized fibers at day 600 under 200x magnification

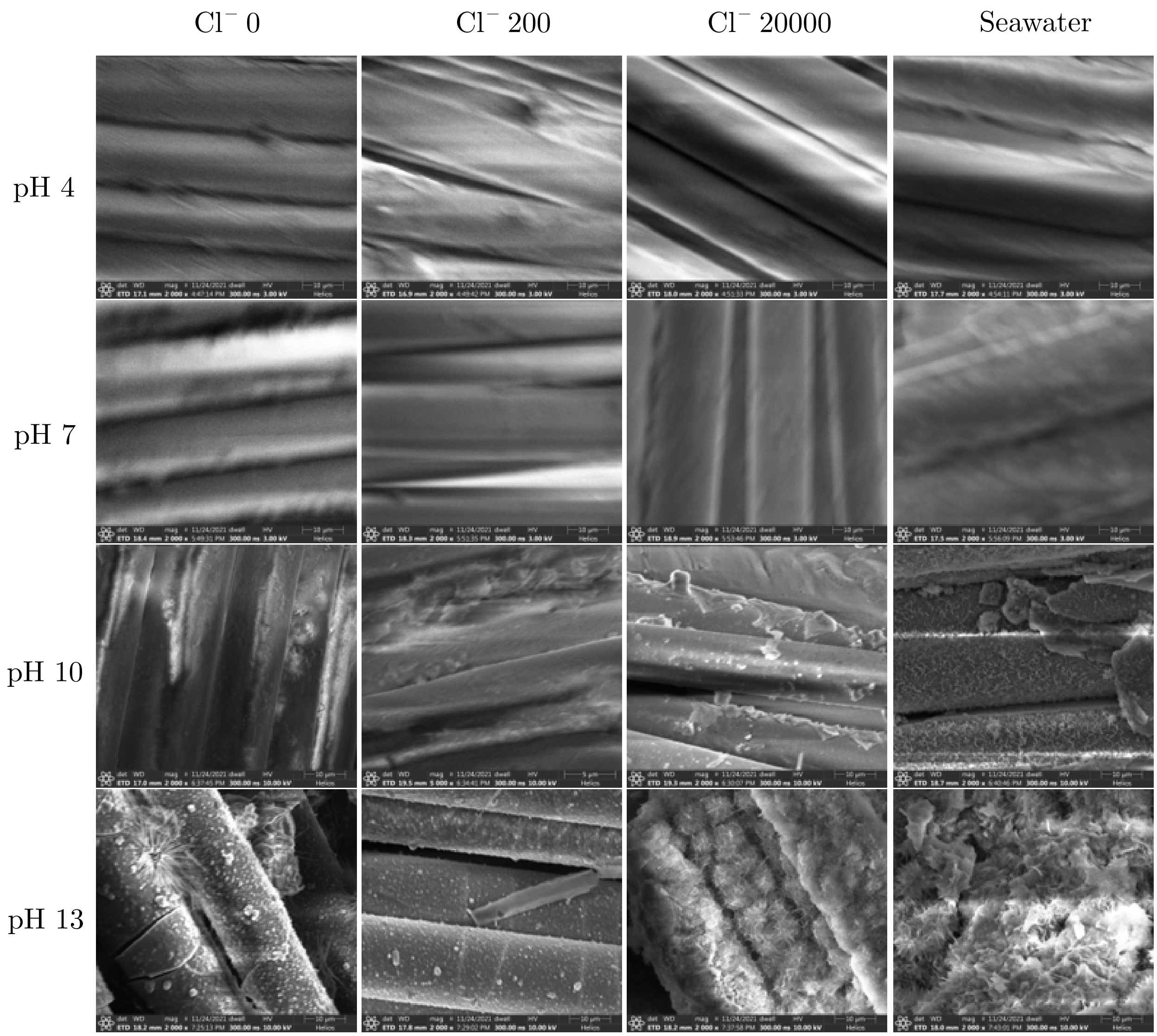

Figure 8.59: Type A unsized fibers at day 600 under 2000x magnification

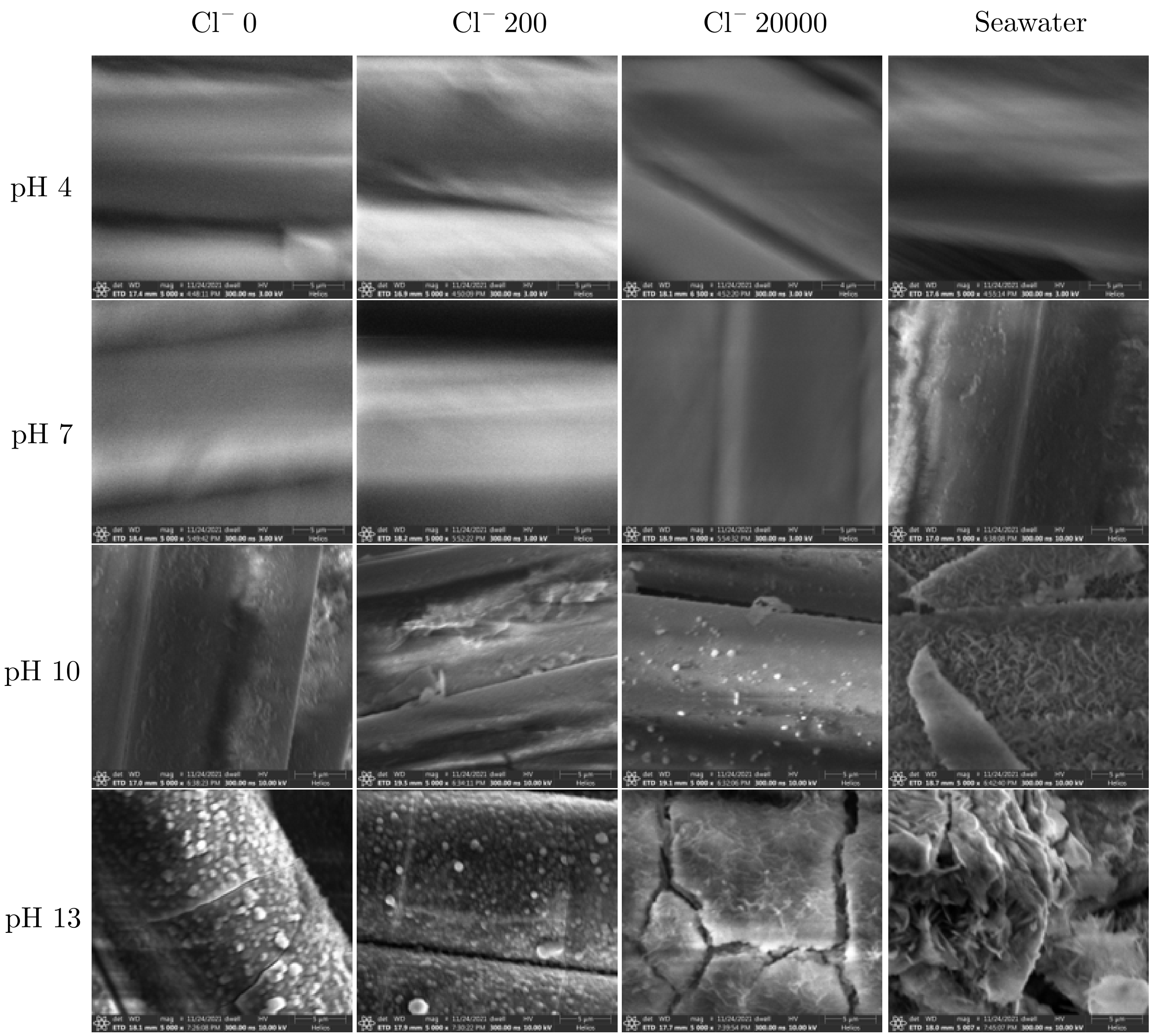

Figure 8.60: Type A unsized fibers at day 600 under 5000x magnification

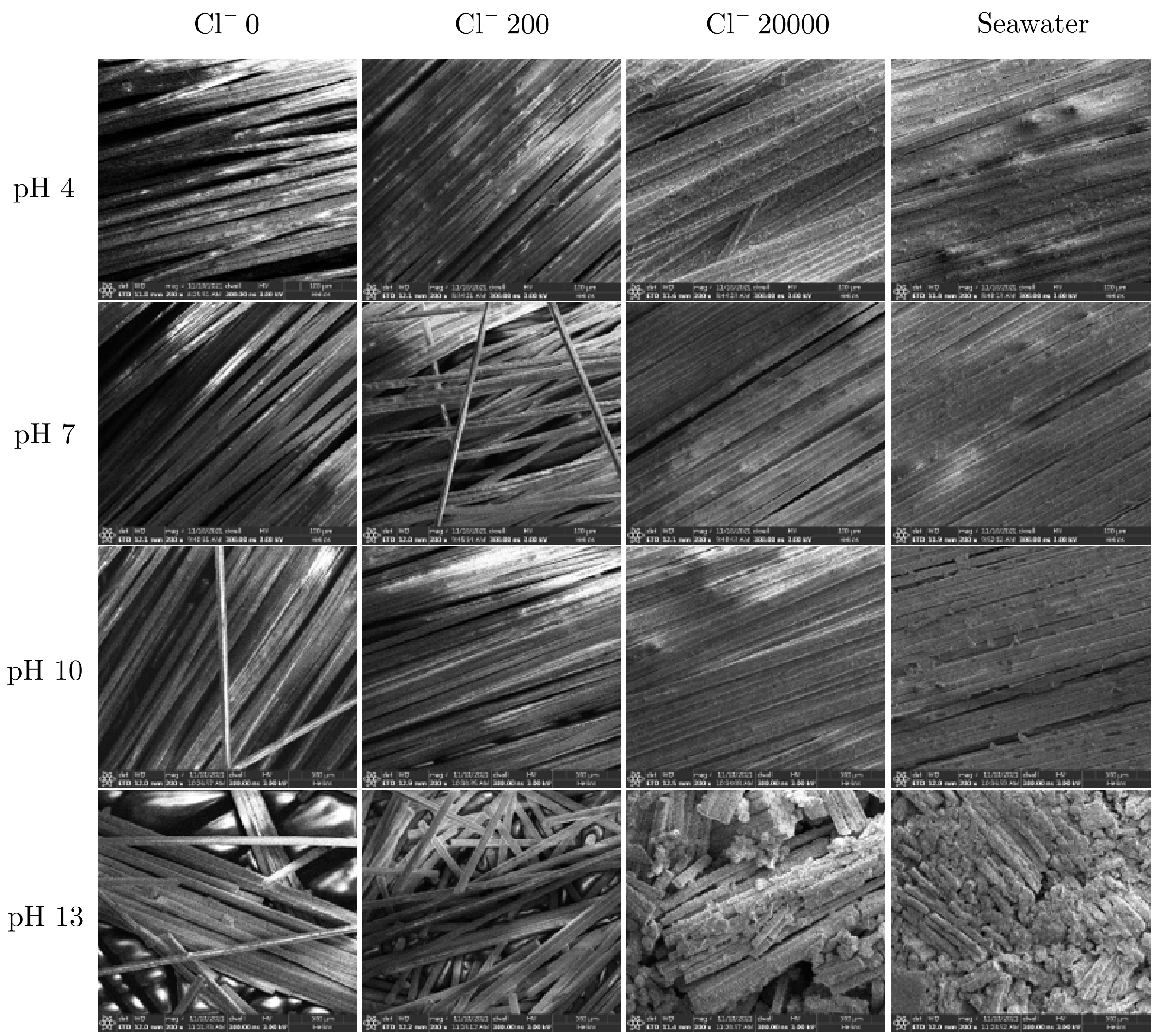

Figure 8.61: Type B sized fibers at day 600 under 200x magnification

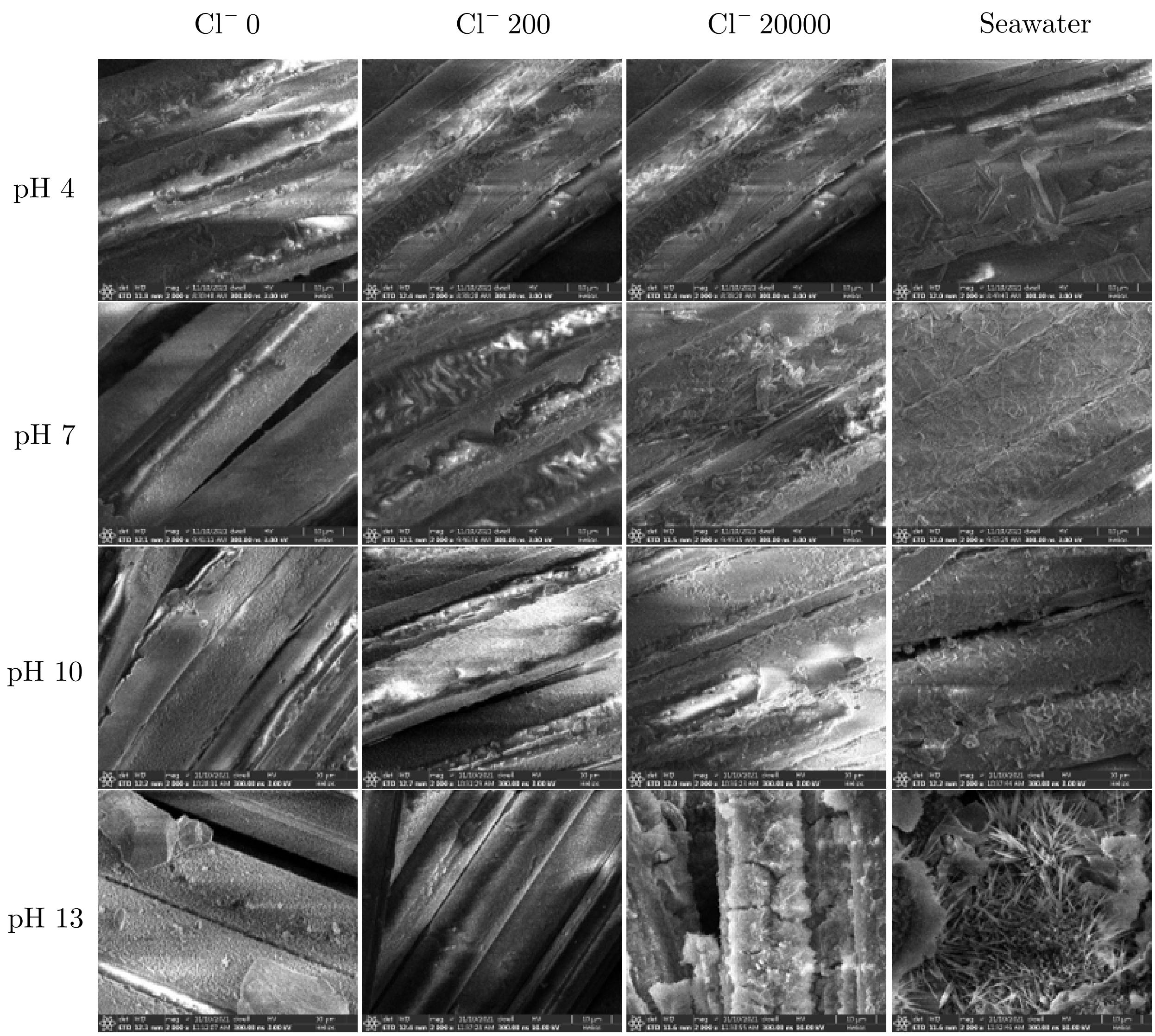

Figure 8.62: Type B sized fibers at day 600 under 2000x magnification

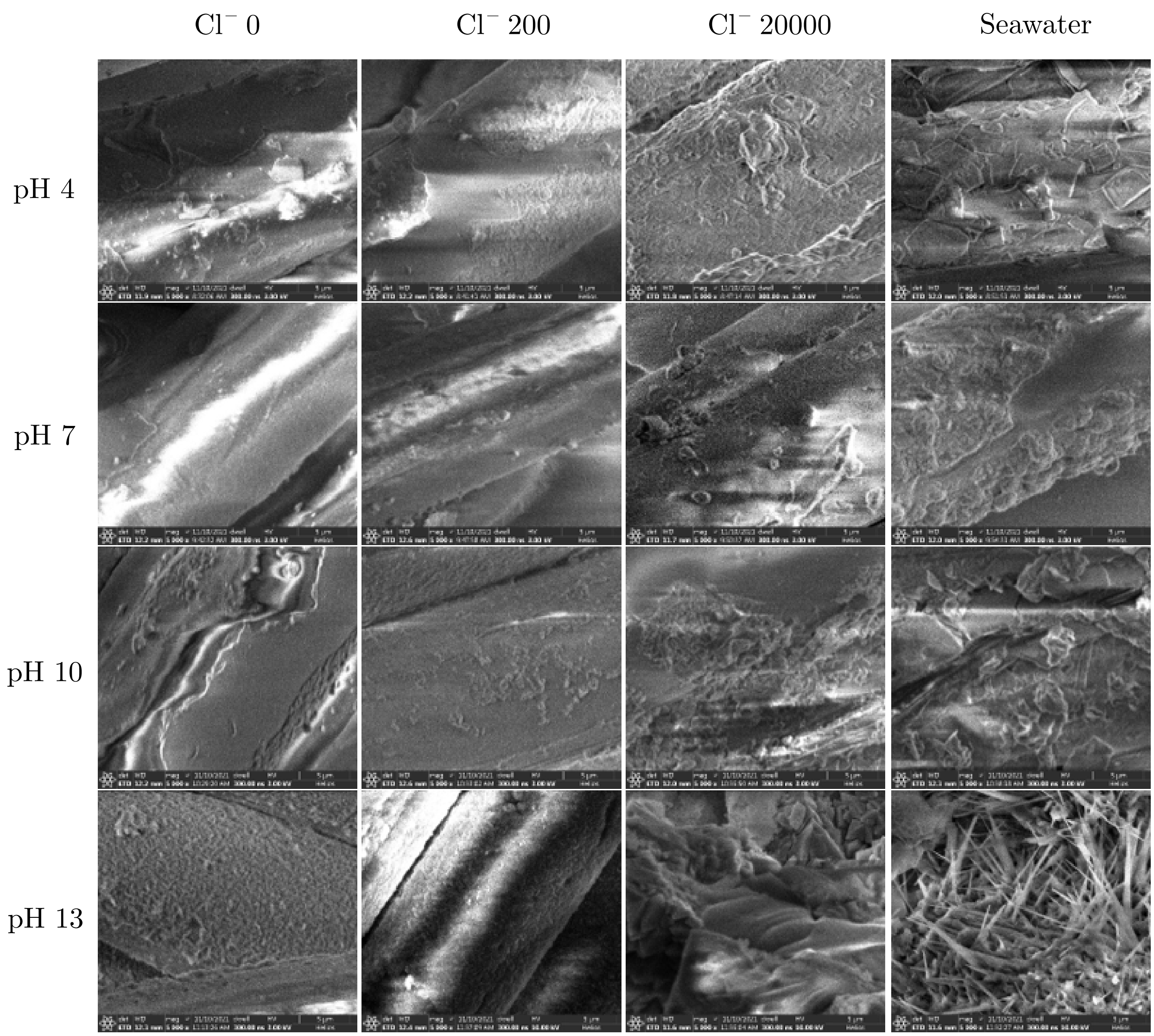

Figure 8.63: Type B sized fibers at day 600 under 5000x magnification

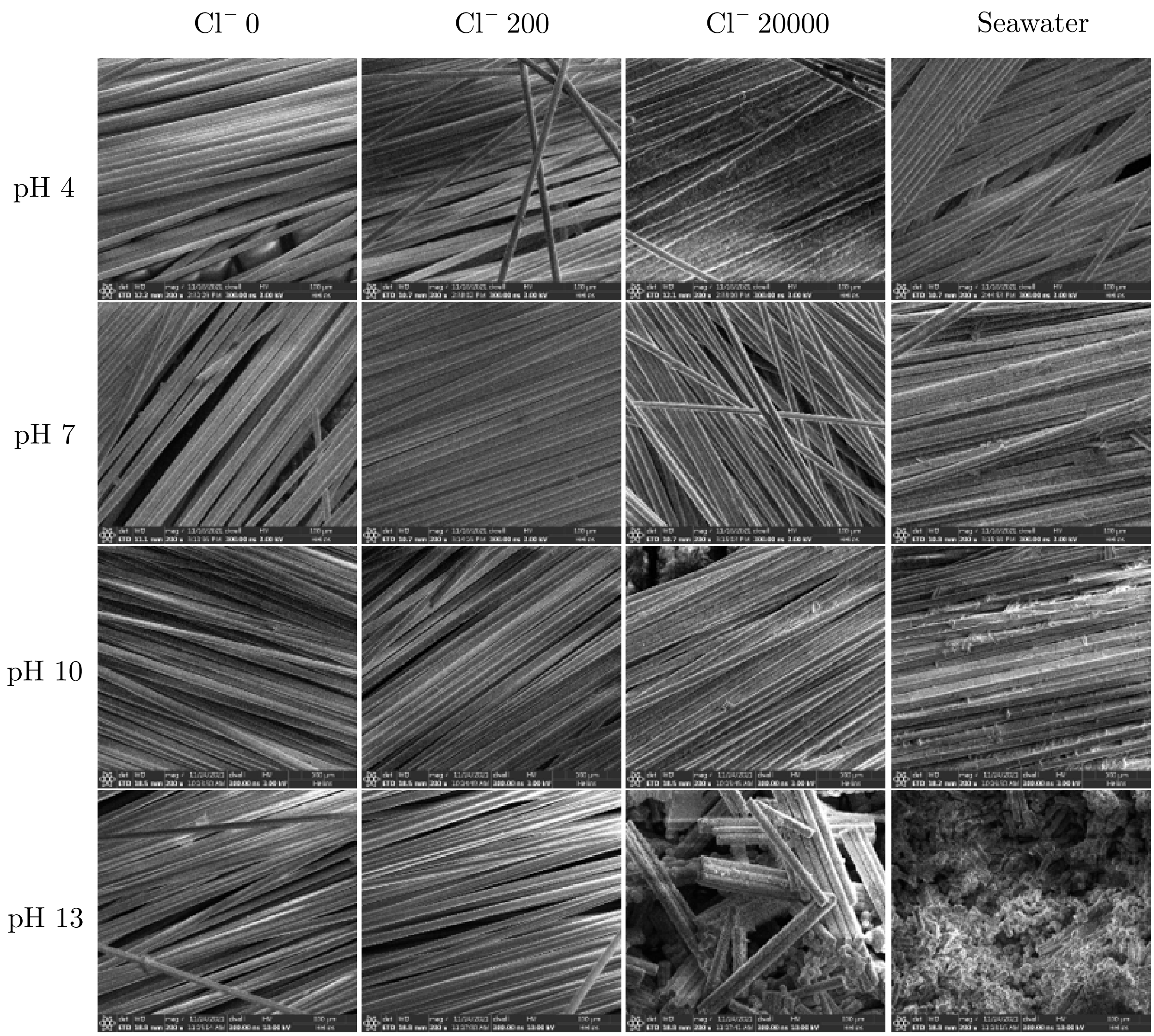

Figure 8.64: Type B unsized fibers at day 600 under 200x magnification

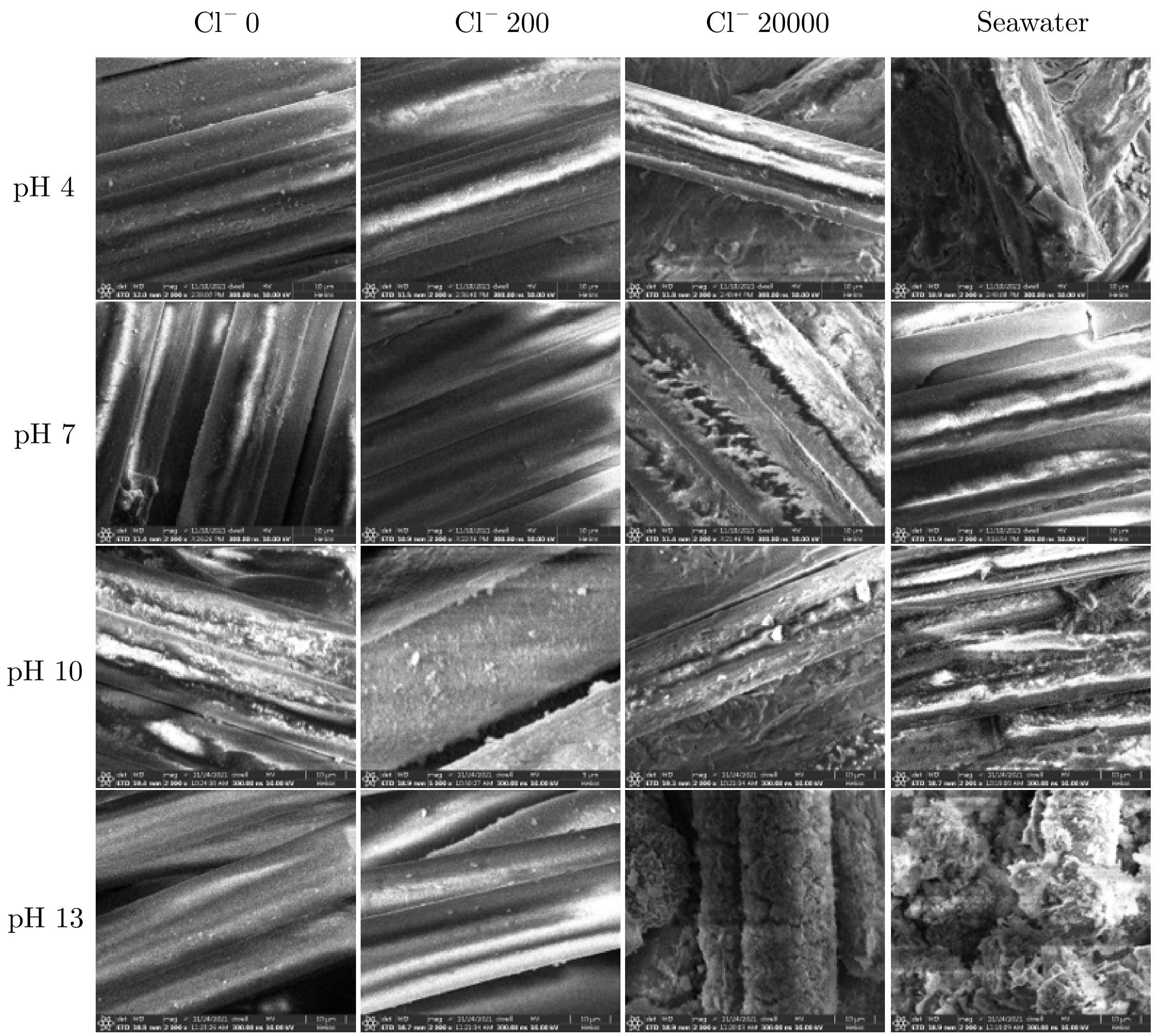

Figure 8.65: Type B unsized fibers at day 600 under 2000x magnification

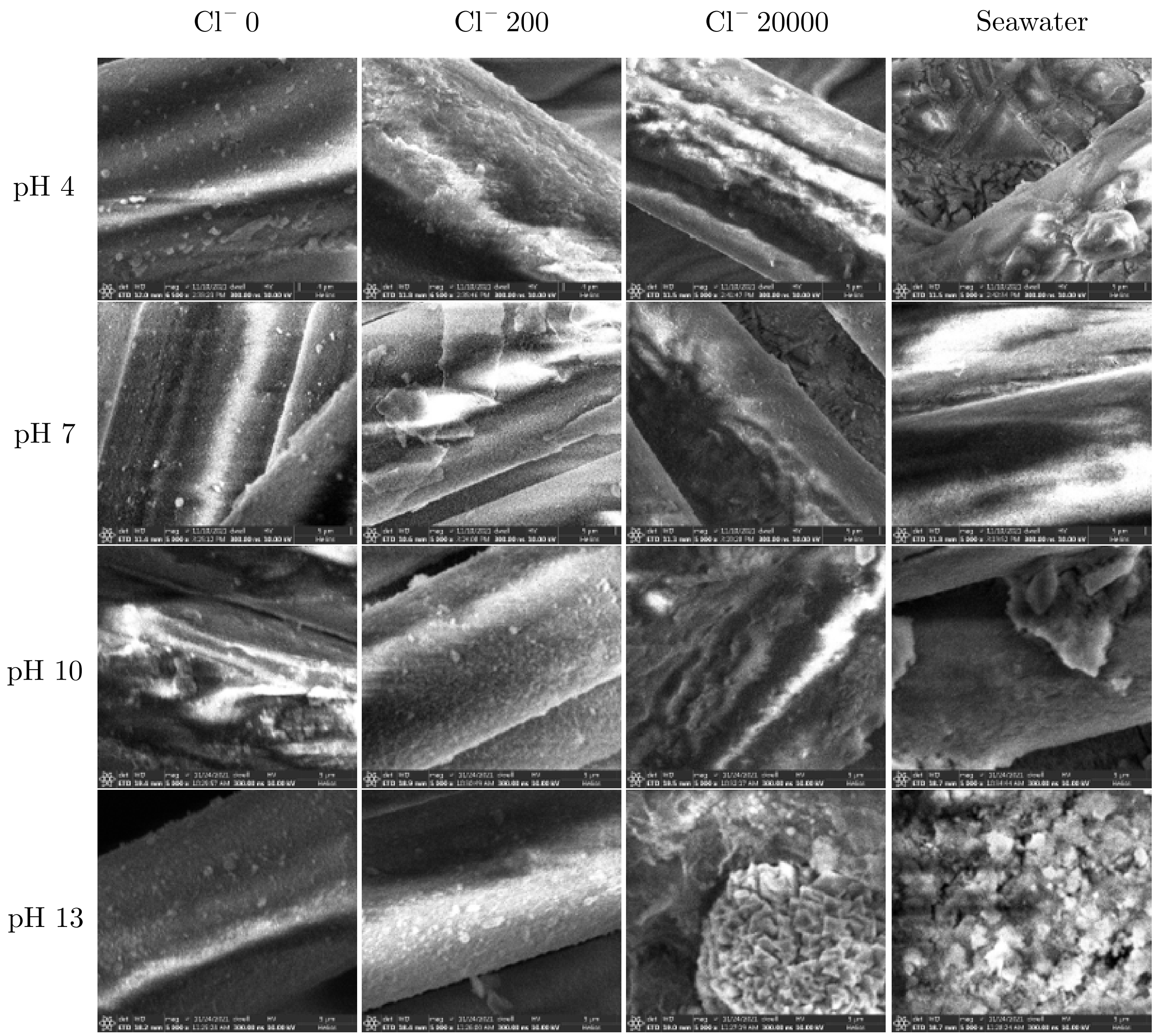

Figure 8.66: Type B unsized fibers at day 600 under 5000x magnification

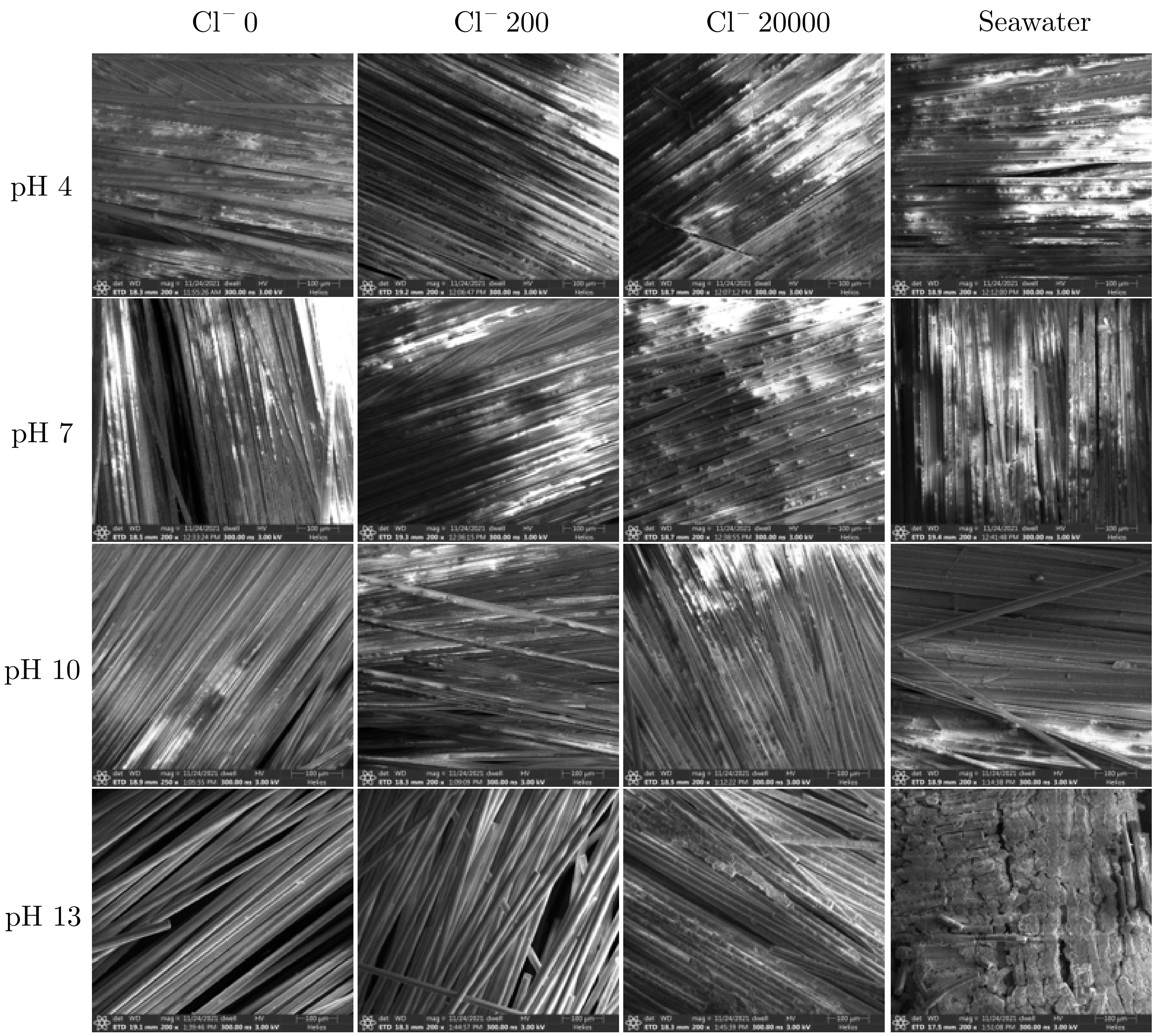

Figure 8.67: Type C sized fibers at day 600 under 200x magnification

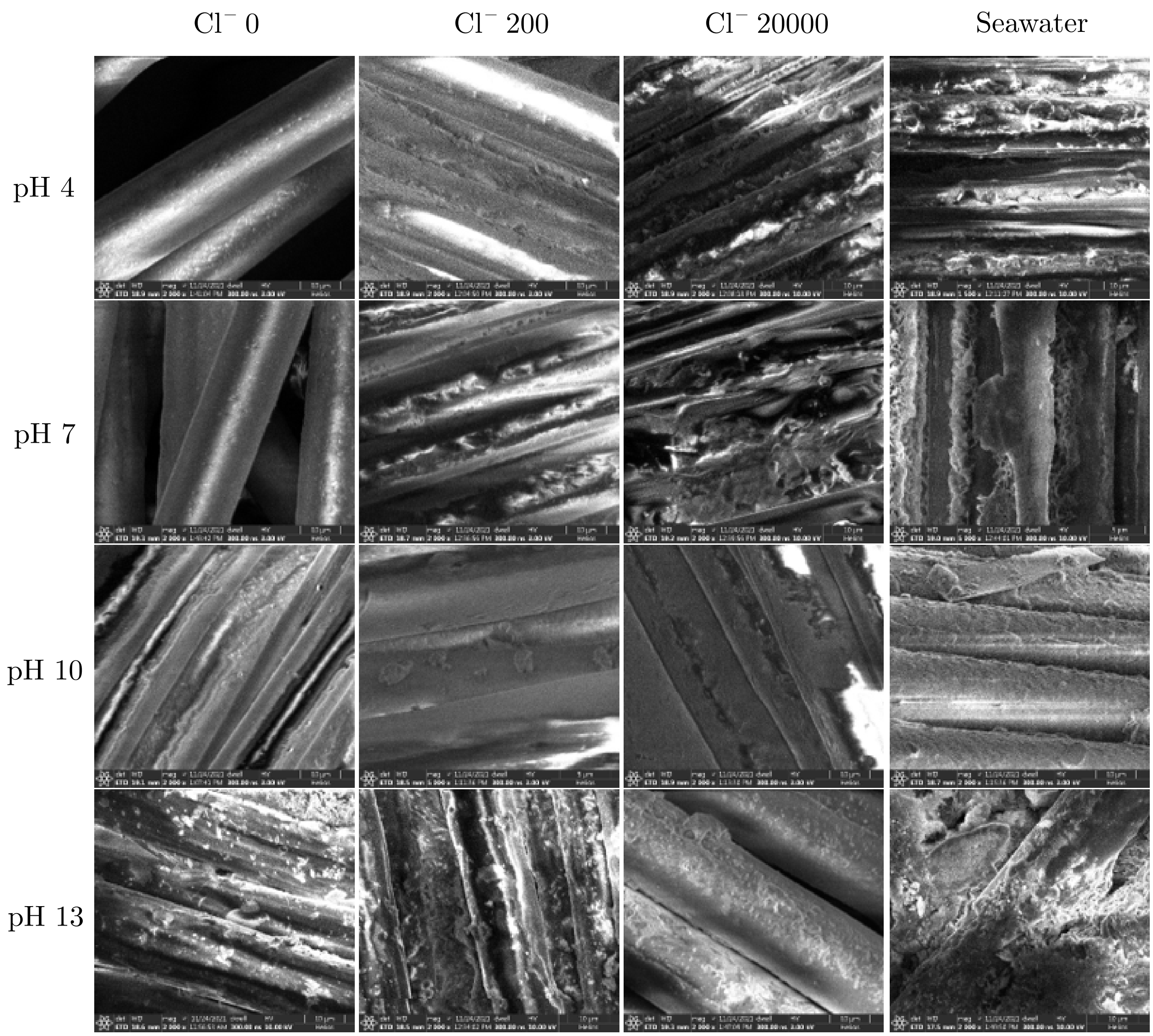

Figure 8.68: Type C sized fibers at day 600 under 2000x magnification

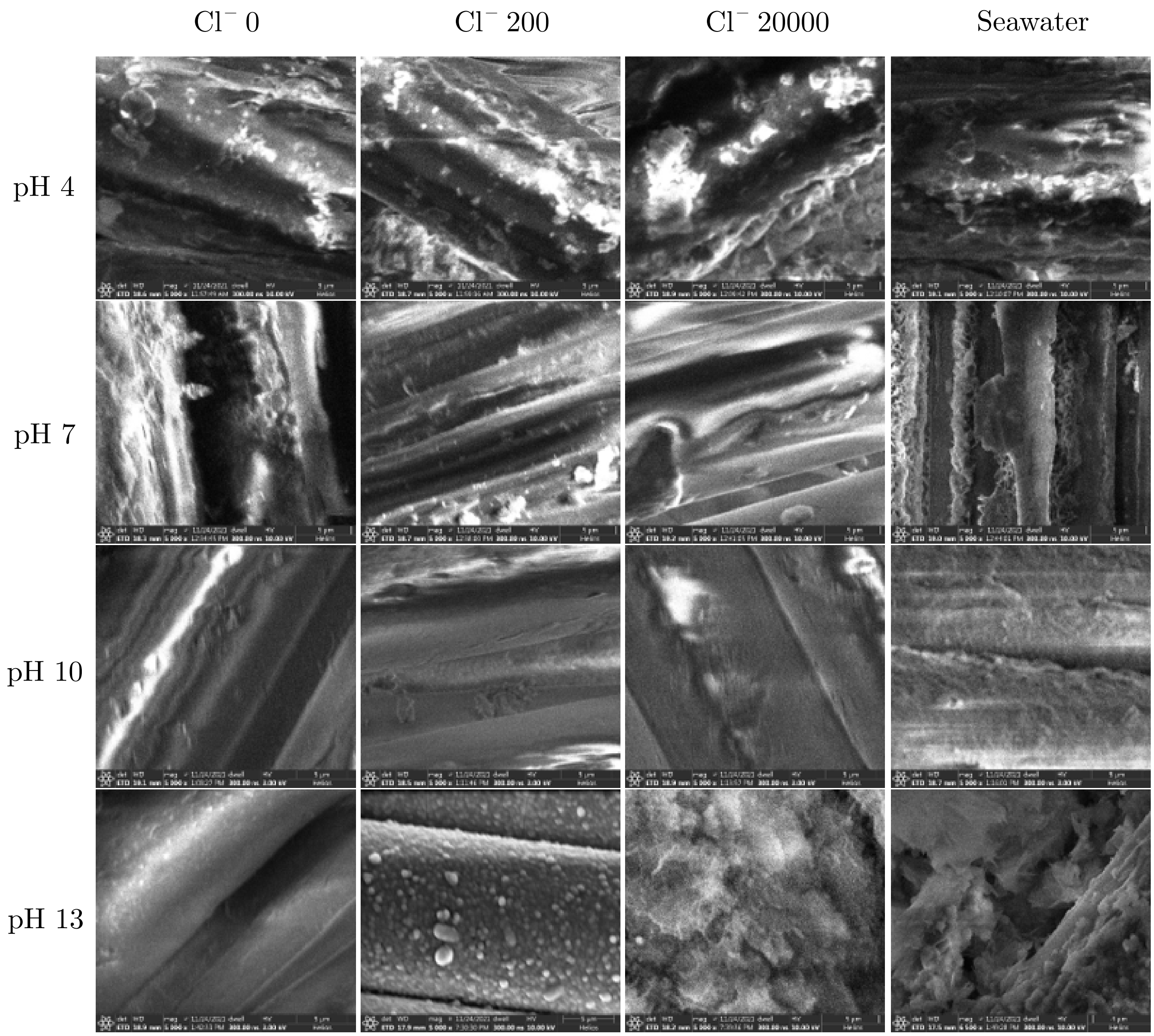

Figure 8.69: Type C sized fibers at day 600 under 5000x magnification

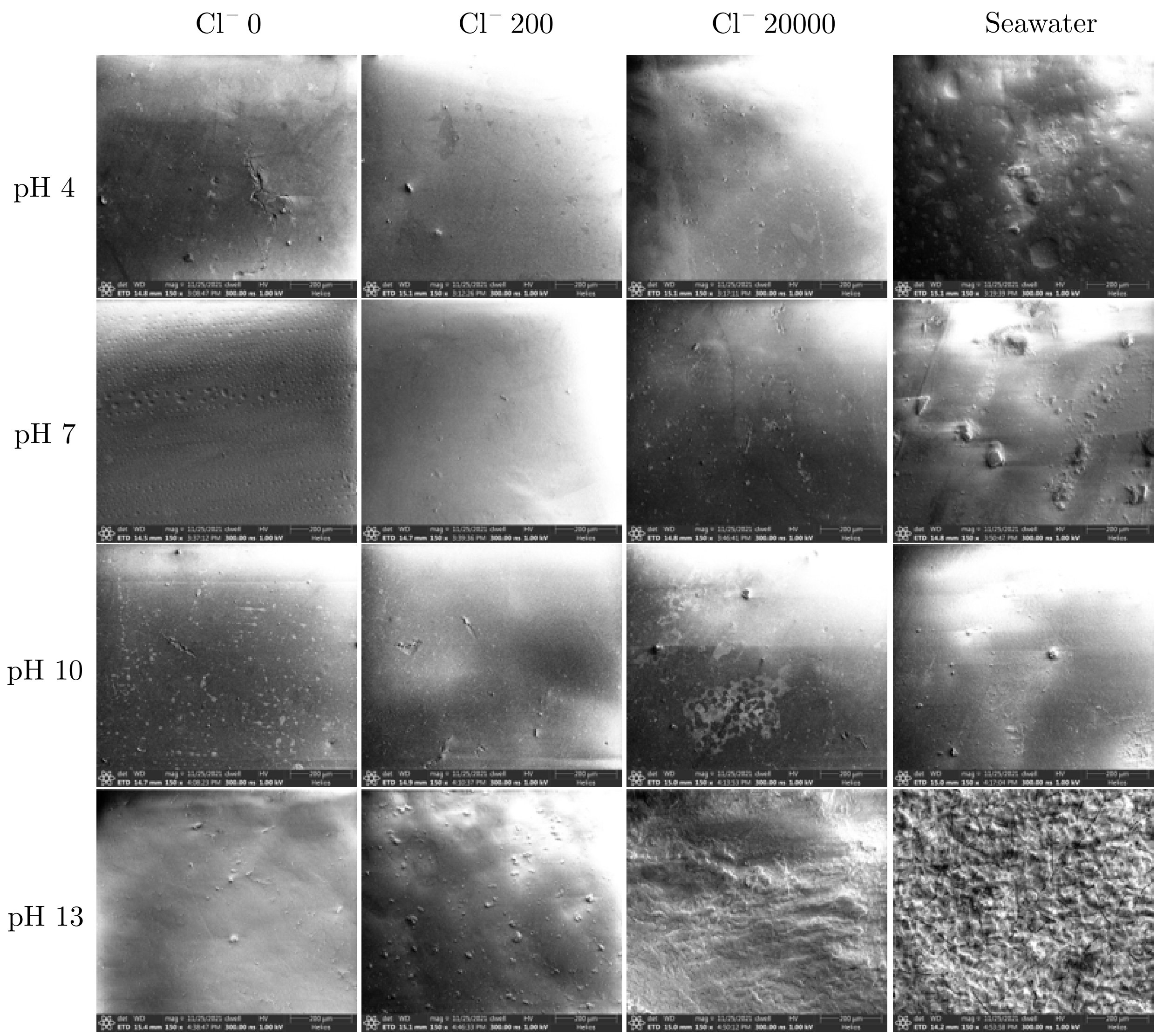

Figure 8.70: Type A resins at day 600 under 150x magnification

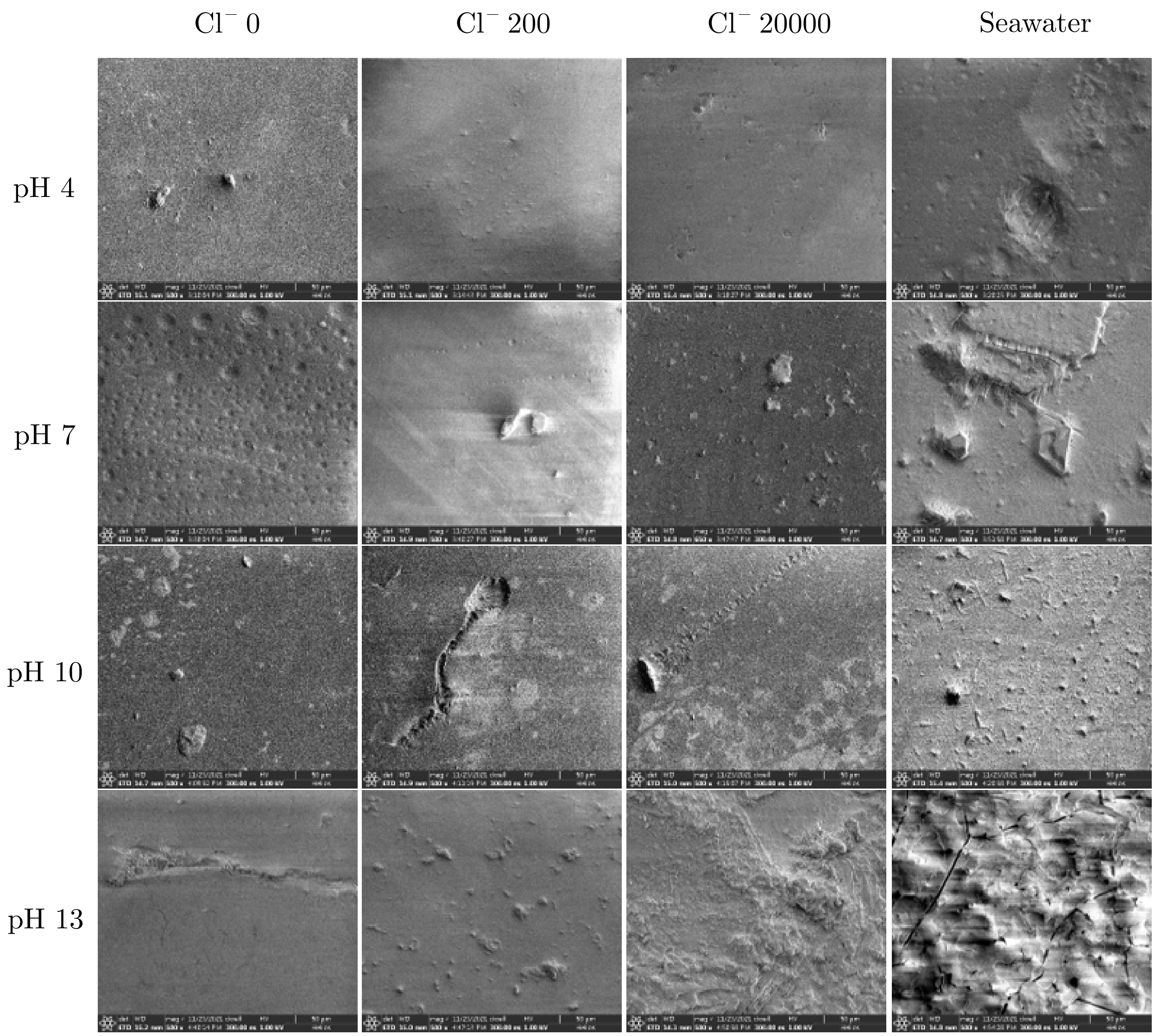

Figure 8.71: Type A resins at day 600 under 500x magnification

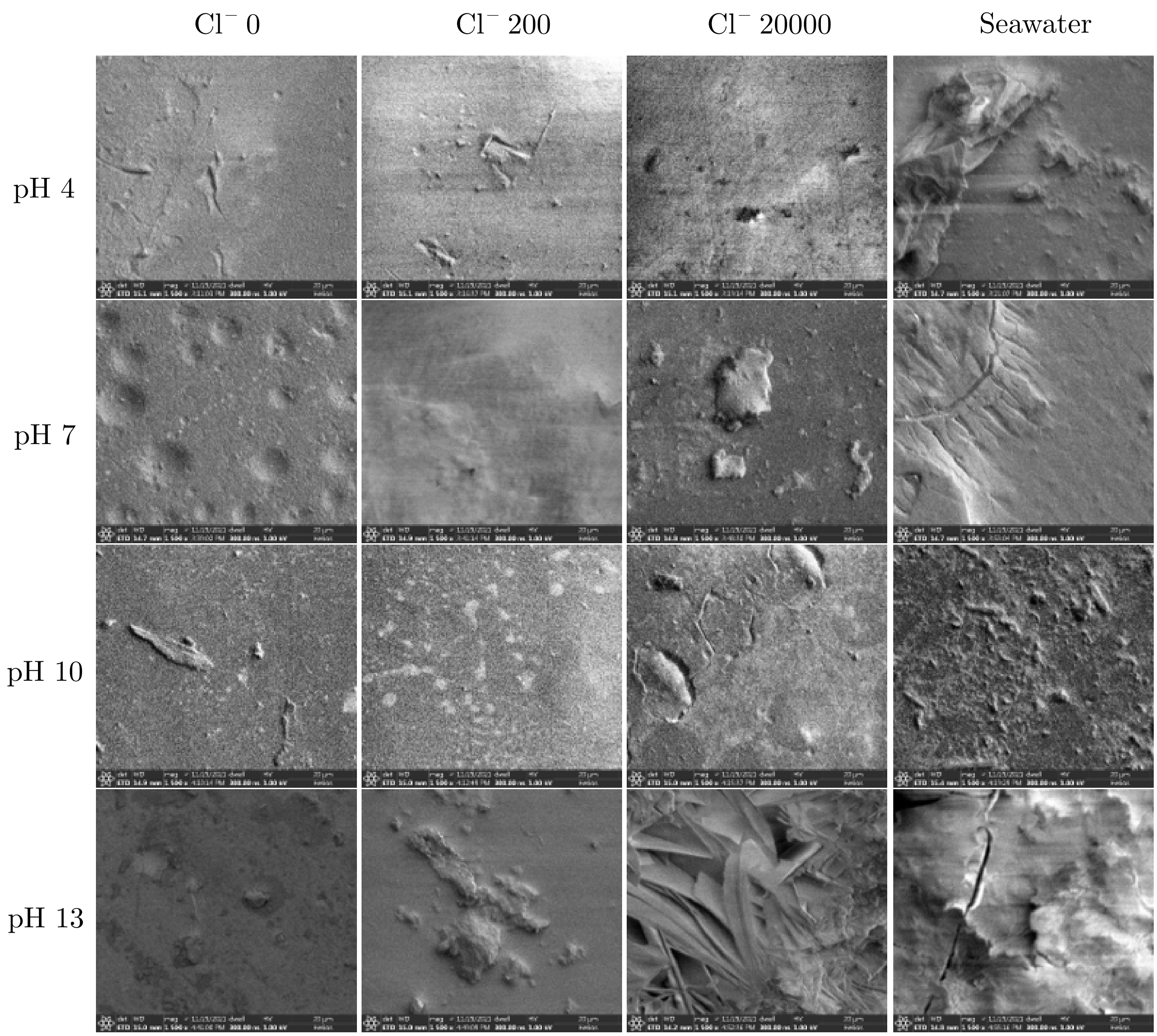

Figure 8.72: Type A resins at day 600 under 1500x magnification

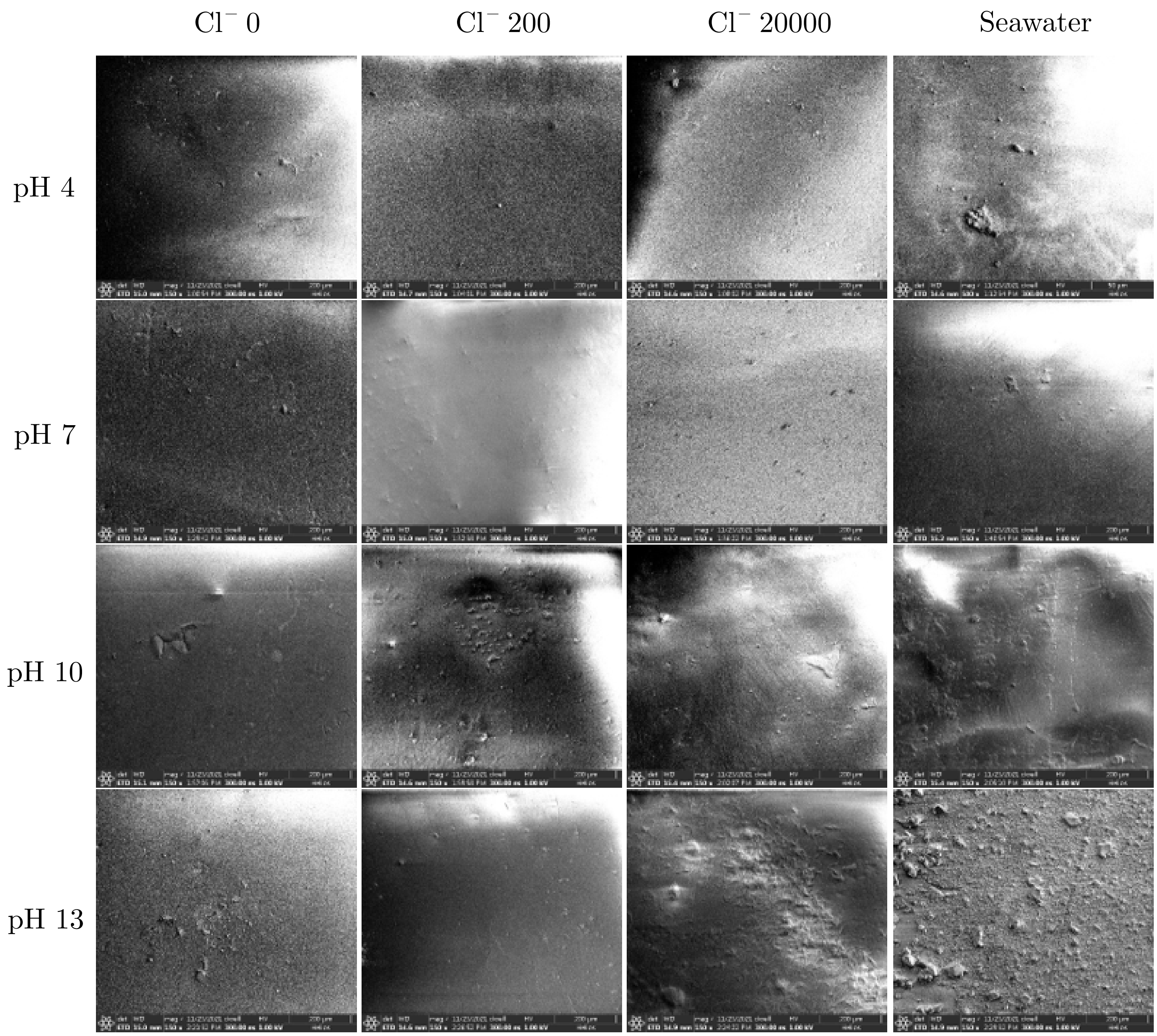

Figure 8.73: Type B resins at day 600 under 150x magnification

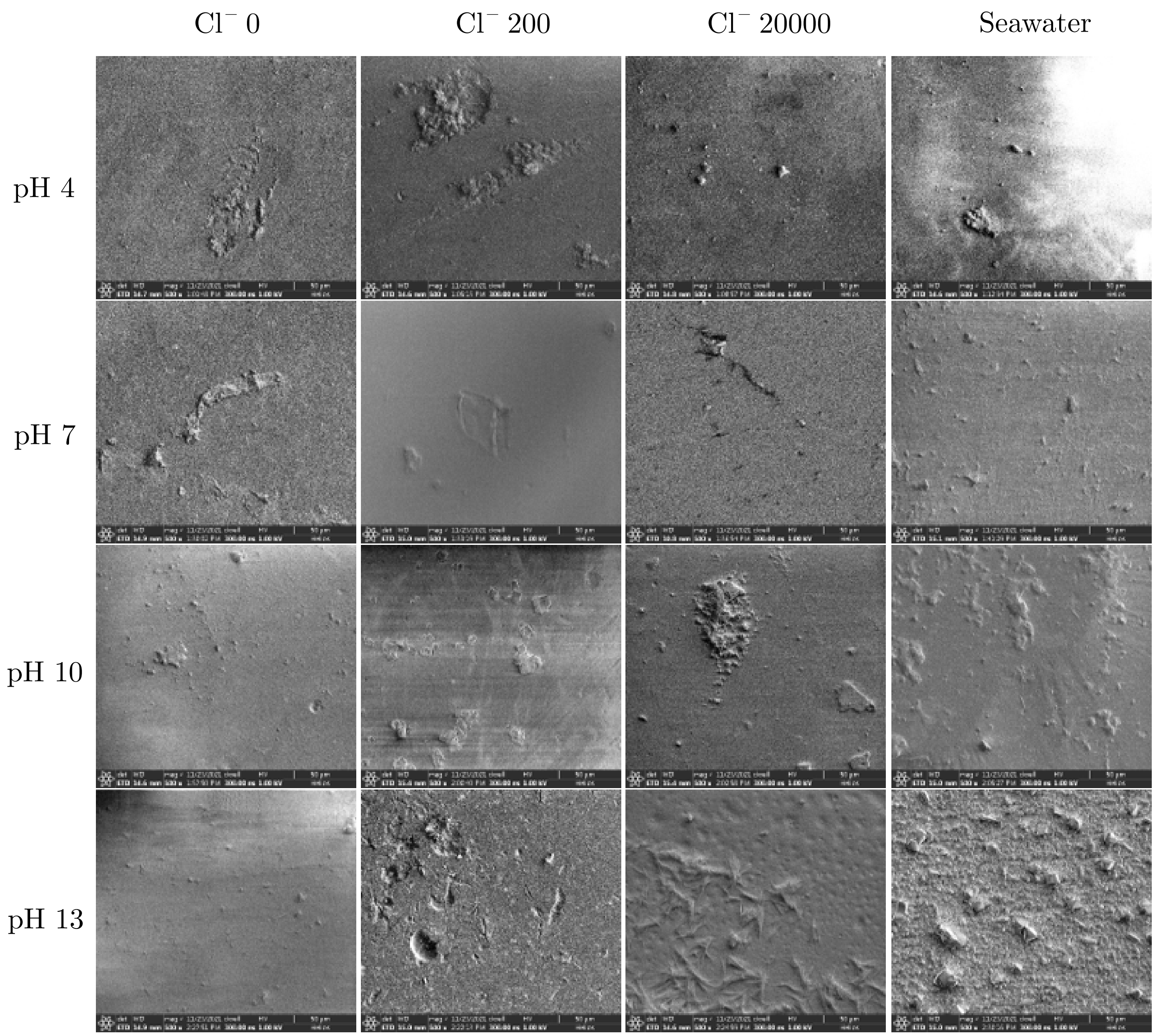

Figure 8.74: Type B resins at day 600 under 500x magnification

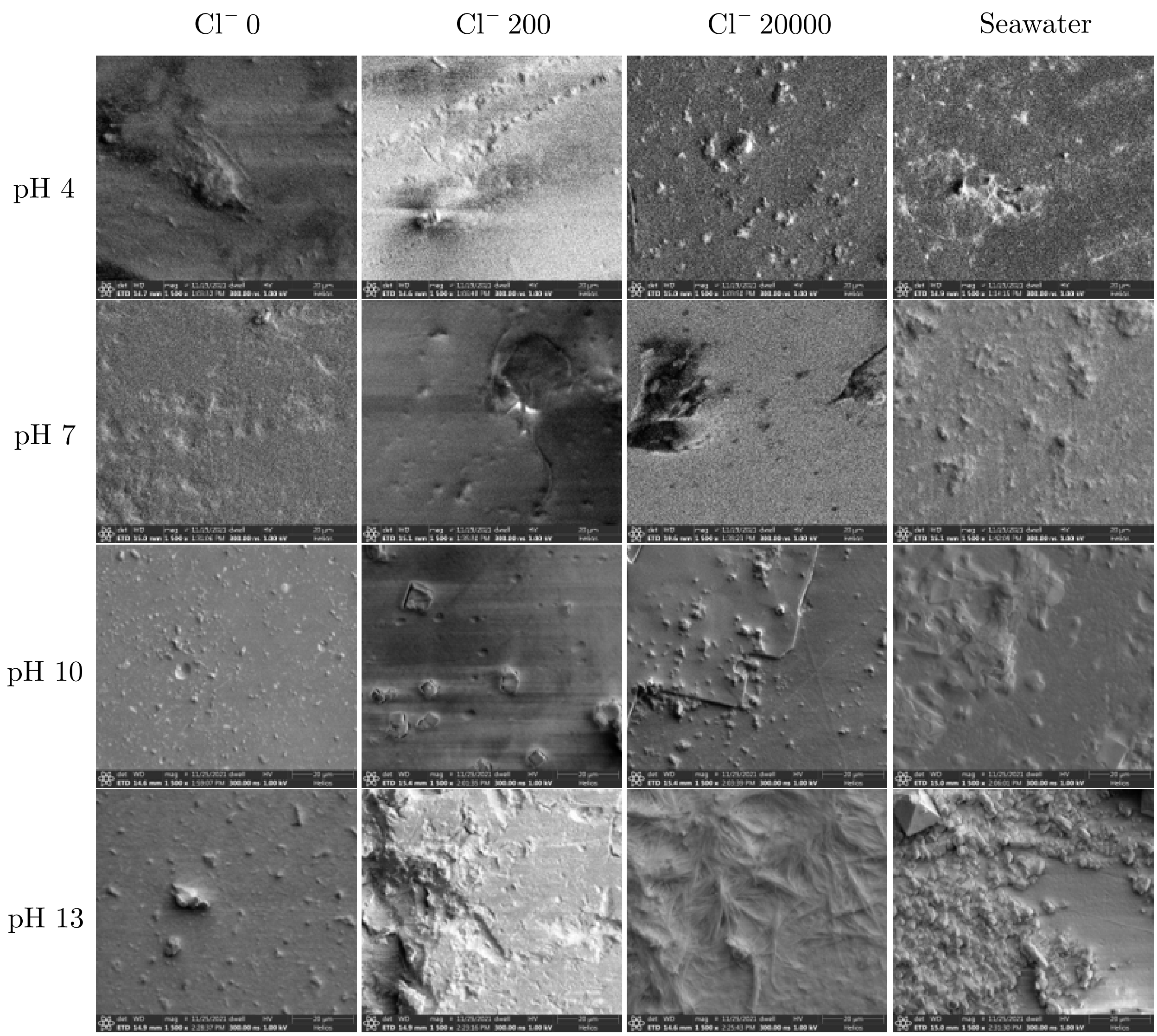

Figure 8.75: Type B resins at day 600 under 1500x magnification

8.4 Mechanical Properties of Components After Exposure to Aggressive Environments

In this section, the mechanical properties such as tensile strength of rebar components is detailed.

8.4.1 Resin Tensile Test

The resins were tested according to the ASTM D 638 (ASTM-International, 2014) to evaluate the tensile properties. The recorded and processed data of the tensile strength test are shown in this section via graphs and table.

Load-Displacement Behavior

To compare the load-displacement behavior of the different resin samples and specimens, the graphs in Figures 8.76 and 8.77 plot the recorded test data. As shown, the x-axis of the graph represents the cross-head extension—which has to be interpreted with care because it includes the elastic deformation of the load frame and the test fixtures—and the y-axis indicates the applied and measured load. Figure 8.76, and 8.77 shows that, although the extension of both resins during the test was similar regardless of the conditioned environments, the peak load was much higher for Type A resin in comparison with Type B resin. All the tested resin specimens failed in similar fashion.

Stress-Strain Behavior

The stress-strain behavior of the failed resins of all types was plotted to quantify and compare the elastic moduli of the tested resins. The data in Figures 8.78 and 8.79 were plotted to compare the stress-strain behavior of the different resin types. Accordingly, the x-axis shows the applied stress while the y-axis represents the outermost surface strain that was measured with an external extensometer. It can be seen in Figure 8.78 and 8.79 that stress-strain behavior of both resins are identical and linear until failure.

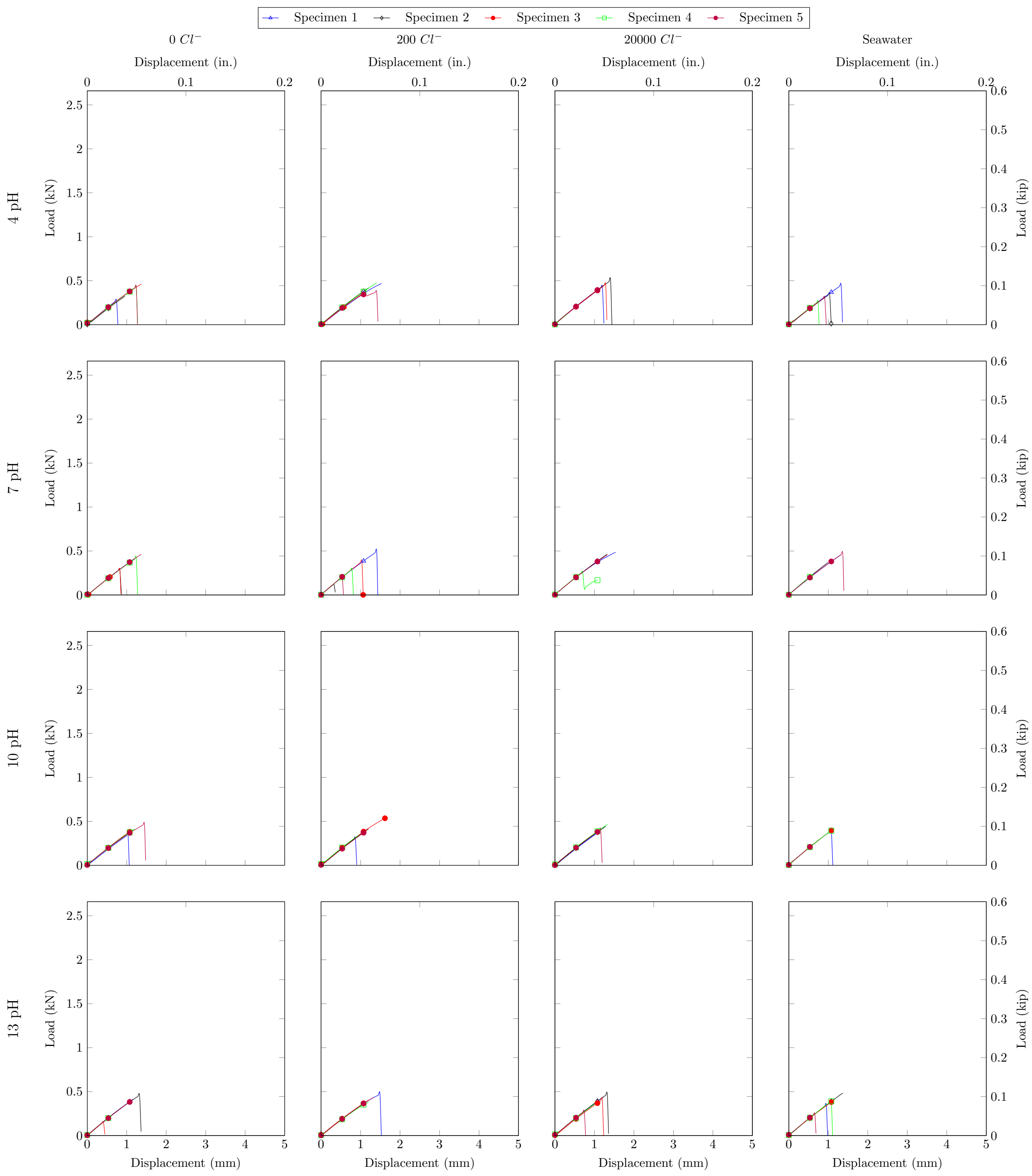

Figure 8.76: 600Day Tensile strength-displacement behavior of Type A Resin

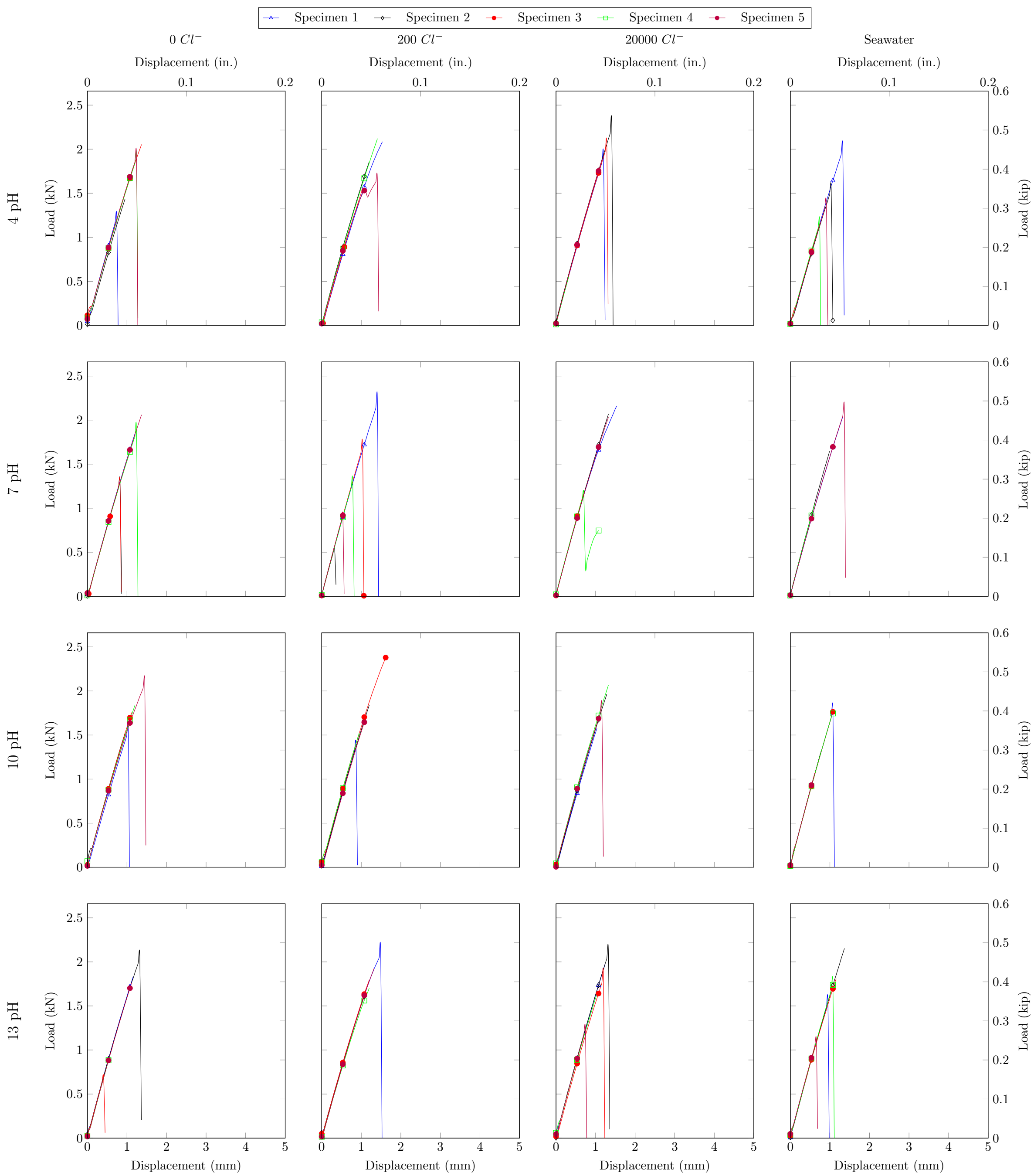

Figure 8.77: 600Day Tensile strength-displacement behavior of Type B Resin

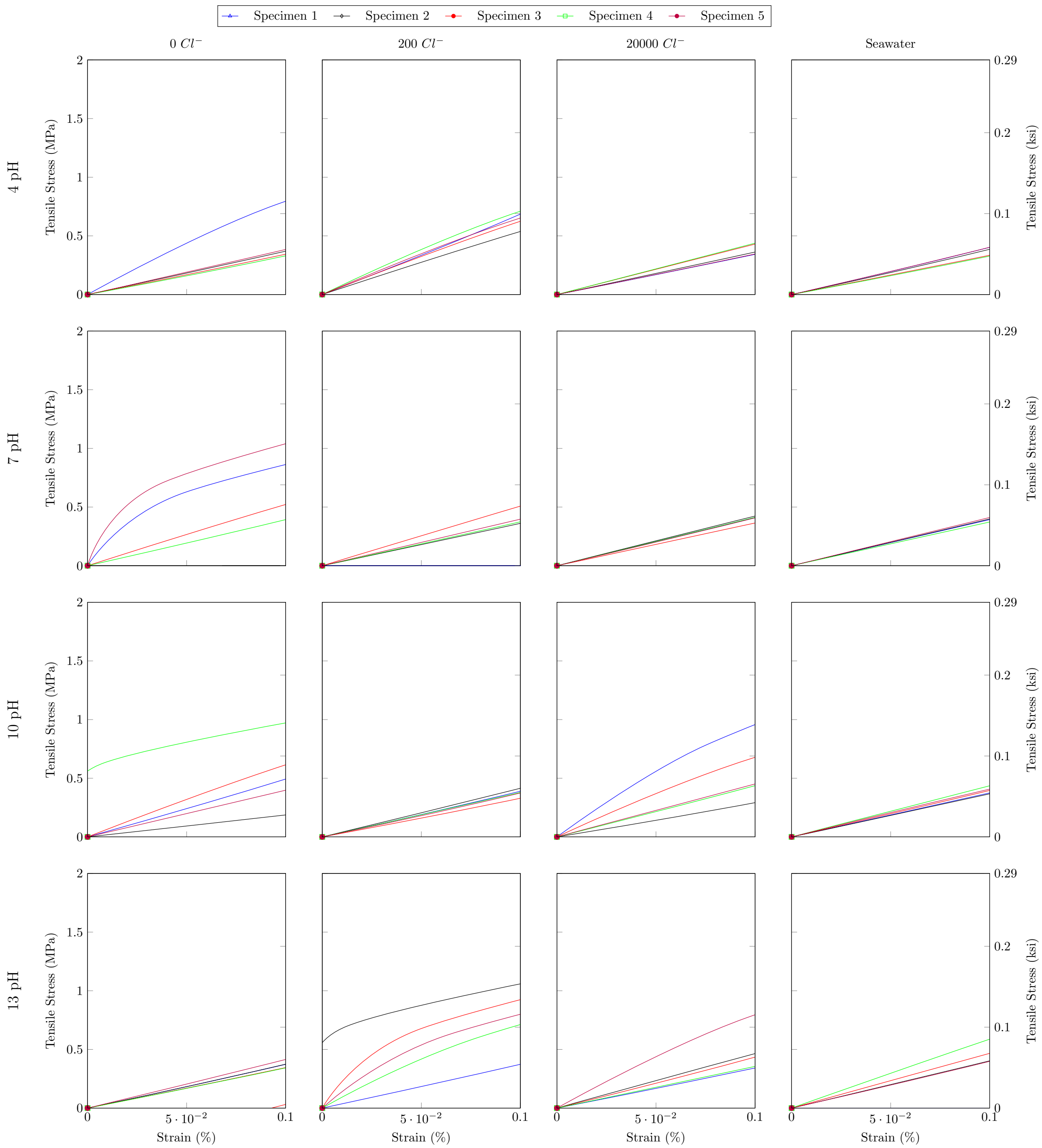

Figure 8.78: 600Day Tensile stress - Strain behavior of rebar Type A Resin

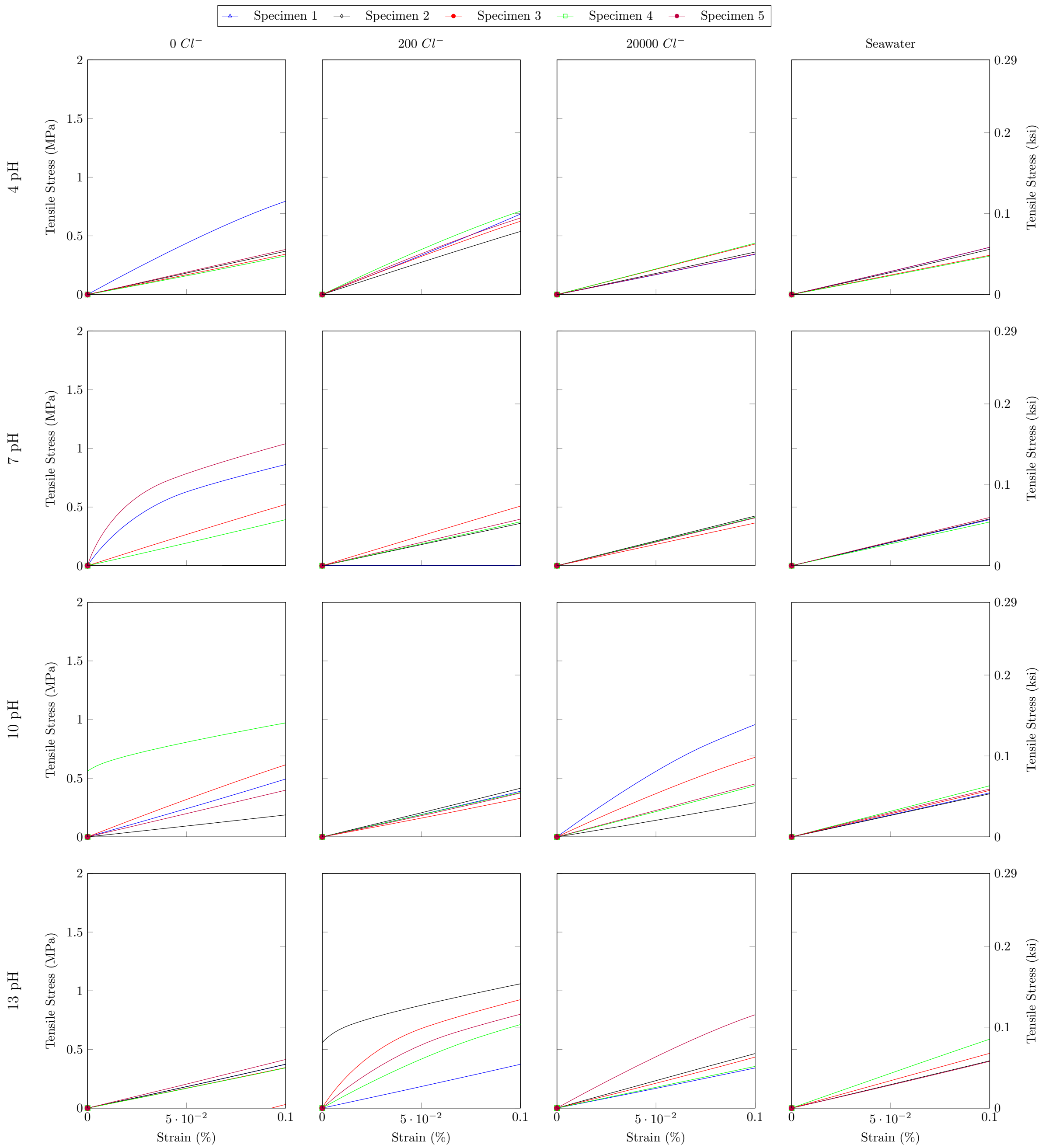

Figure 8.79: 600Day Tensile stress - Strain behavior of rebar Type B Resin

8.5 Rebar Mechanical Properties

8.5.1 Transverse Shear Test

ASTM D 7617 (ASTM-International, 2012b) was used in the process of testing and analyzing the transverse shear strength of the rebars. Tested and processed data are plotted in the following subsections.

Load-Displacement

The graphs plotted in Figures 8.80, 8.81, 8.82, 8.83, 8.84, and 8.85 show the load-displacement behavior recorded during the transverse shear tests of # 3 and # 5 rebars from all rebar types and exposure environments tested in this study. The x-axis of the graph represents the cross-head extension or the relative displacement between the edges of the directly sheared specimen, while the y-axis shows the measured force throughout the load application period.

The Graph in figure 8.80 shows a linear behavior until it reaches the ultimate failure load. It can be seen that # 5 sized rebar sustained higher load in comparison with # 3 rebars. It can be seen that rebars exposed to 4pH and 7pH sustained a consistent load while the displacement of the rebars varied. The graph in Figure 8.81 shows a comparison between the load and the displacement for transverse shear strength of # 3 and # 5 rebars Lot 1 from Type B rebar. It can be seen that the graph had a linear behavior until it reached the ultimate failure load. All the rebars sizes sustained a consistent load with similar displacement. The Graph in Figure 8.82 shows the load - displacement behavior of Type C rebars. Linearity can be seen until it reaches the ultimate failure load. It can be seen that # 5 sized rebar sustained higher load in comparison with # 3 rebars. The graph in Figure 8.83 presents a comparison between the load and the displacement for transverse shear strength of # 3 and # 5 rebars from Type A from Lot 2. The graph shows a linear behavior until it reached approximately 90% of the ultimate failure load. The visualized data in Figure 8.84 show the load-displacement behavior for transverse shear strength of # 3 and # 5 rebars Lot 2 from Type B rebar. It can be seen that the material behaved linearly until approximately 90 % of the ultimate failure load was reached. All the # 3 rebars sustained a consistent load while # 5 rebars sustained same peak load but the displacement of the rebars varied. The graph in Figure 8.85 shows a comparison between the load and the displacement for transverse shear strength of # 3 and # 5 rebars from Lot 2. The graph shows a linear behavior until it reached approximately 90% of the ultimate failure load.

Transverse Stress-Displacement

The results obtained from the transverse test was properly reduced and analyzed. These results are shown via graphs and table. The graphs in Figures 8.86, 8.87, 8.88, 8.89, 8.90, and 8.91 compare the stress-displacement behavior of transverse shear test of # 3 and # 5 rebars from all rebar types that were tested for this research project. The data along the x-axis represents the cross-head extension or the direct shear displacement, while the y-axis signifies the measured shear stress.

The data in Figure 8.86 show that the material behaved nearly linearly until the ultimate failure load was reached. It can be seen in Figure 8.86 that the stress-strain behavior of all rebars was close but not identical—specifically, it varied significantly for rebar number # 5.

The graph in Figure 8.87 presents the stress-displacement behavior of transverse shear test of rebar Type B Lot 1. From the stress-strain behavior of rebar Type B as shown in Figure 8.87, it can be seen that the rebars underwent similar failure behavior. The graph in Figure 8.88 compares the stress - strain behavior of Type C rebar from Lot 1. It shows the linearity of tested rebar until the ultimate failure load was reached. It can be seen in Figure 8.88 that the stress-strain behavior of all rebars was close but not identical—specifically, it varied significantly for rebar number # 5. The graph in Figure 8.89 presents the stress-displacement behavior

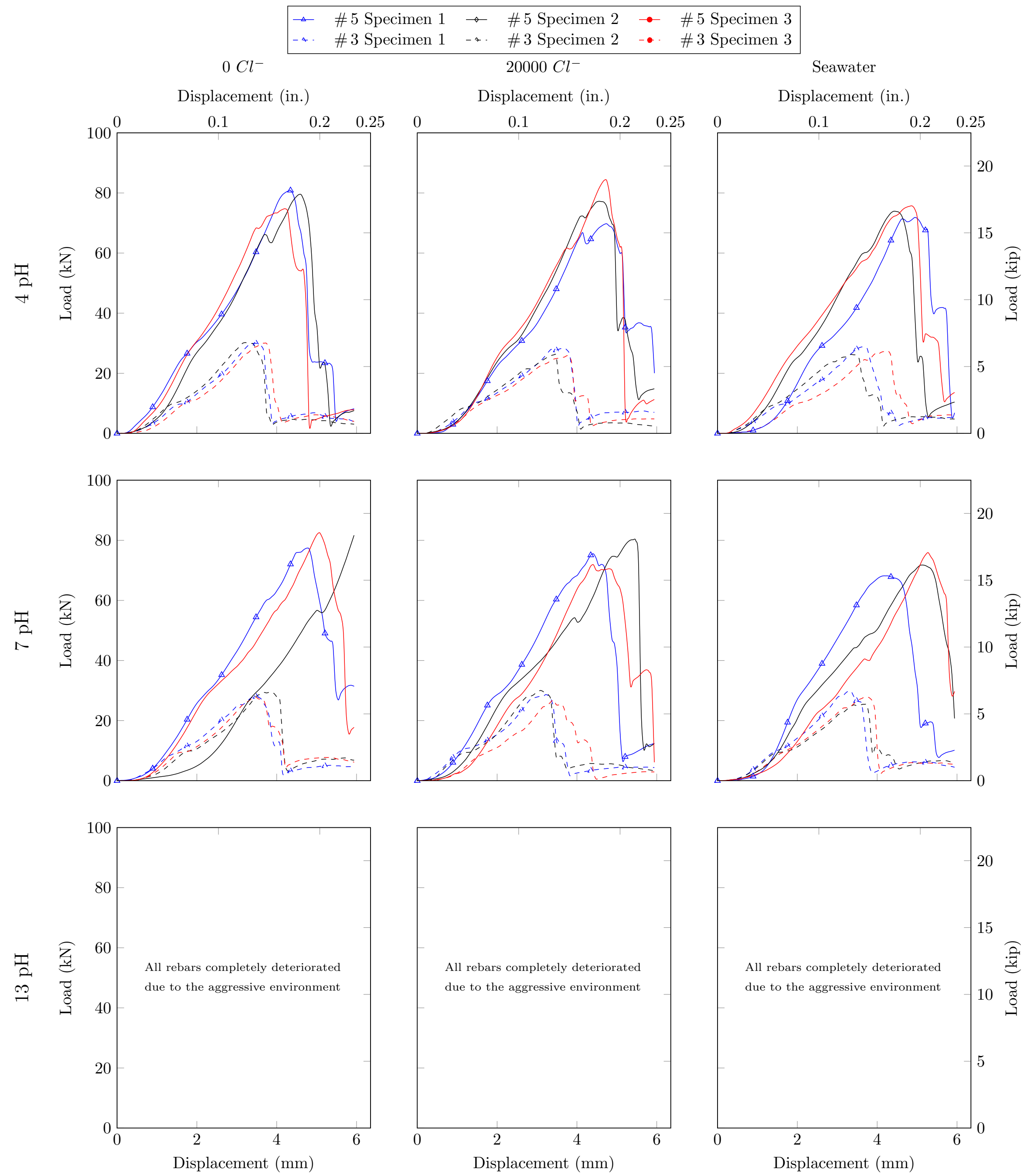

Figure 8.80: 600Day Transverse shear force - displacement behavior of Type A Lot1 tested rebars

of transverse shear test of rebar Type A Lot 2. The graphs display a mostly linear behavior until the ultimate failure load was reached. Figure 8.90 shows the stress-displacement behavior of transverse shear test of rebar Type B Lot 2. It can be seen that the data represented a nearly linear behavior until the ultimate failure load was attained. The stress-displacement behavior of failed rebar specimen from both types from Lot 2 in Figures 8.89 and 8.90 show that, although the ultimate failure capacity of the rebars varied significantly, all the rebar samples failed in a identical manner. The graph in Figure 8.91 presents the stress-displacement behavior of transverse shear test of Lot 2 rebars from Type C manufacturer. From the stress-displacement

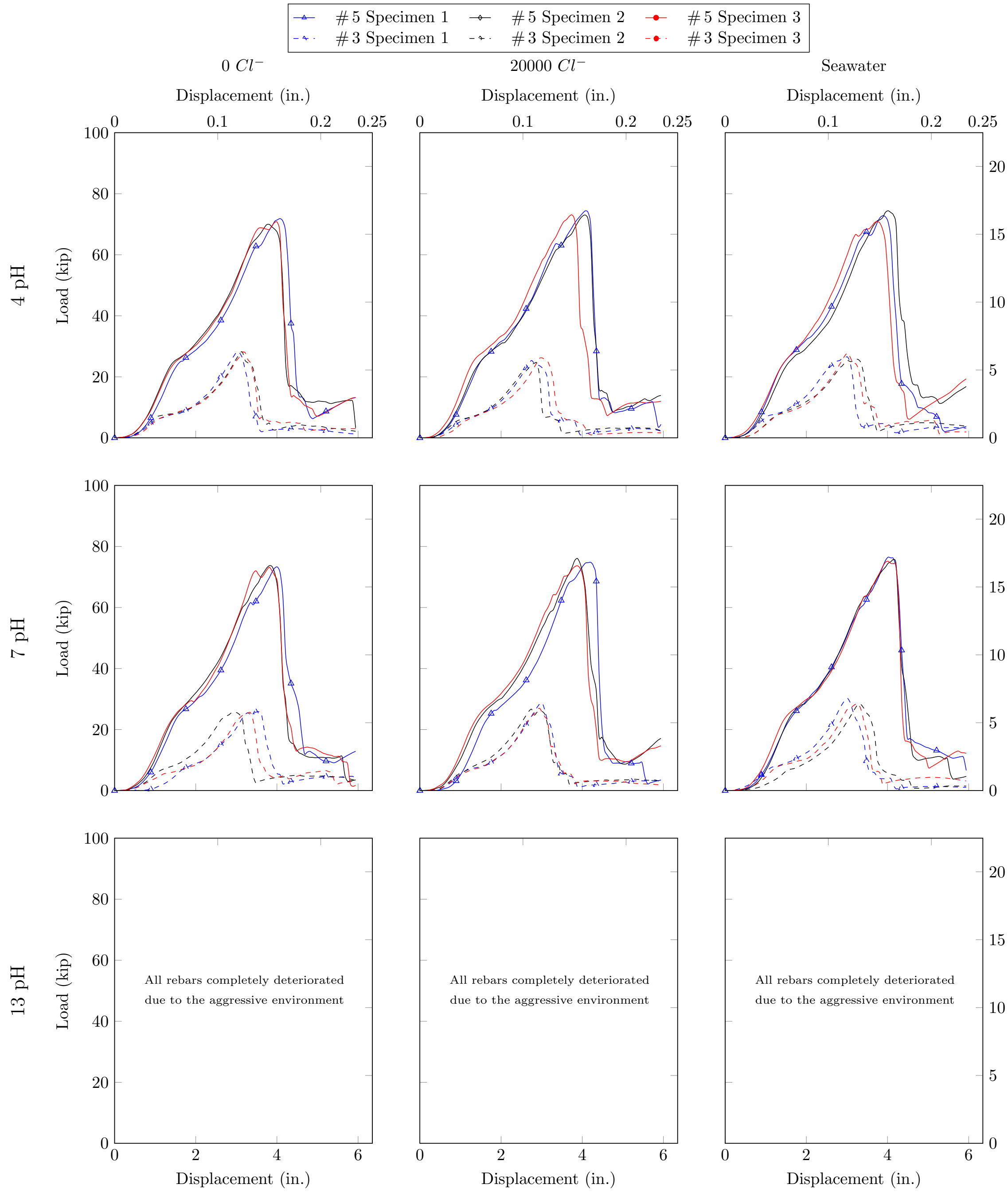

Figure 8.81: 600Day Transverse shear force - displacement behavior of Type B Lot1 tested rebars

behavior of rebar as shown in Figure 8.91, it can be seen that the rebars underwent similar failure behavior.

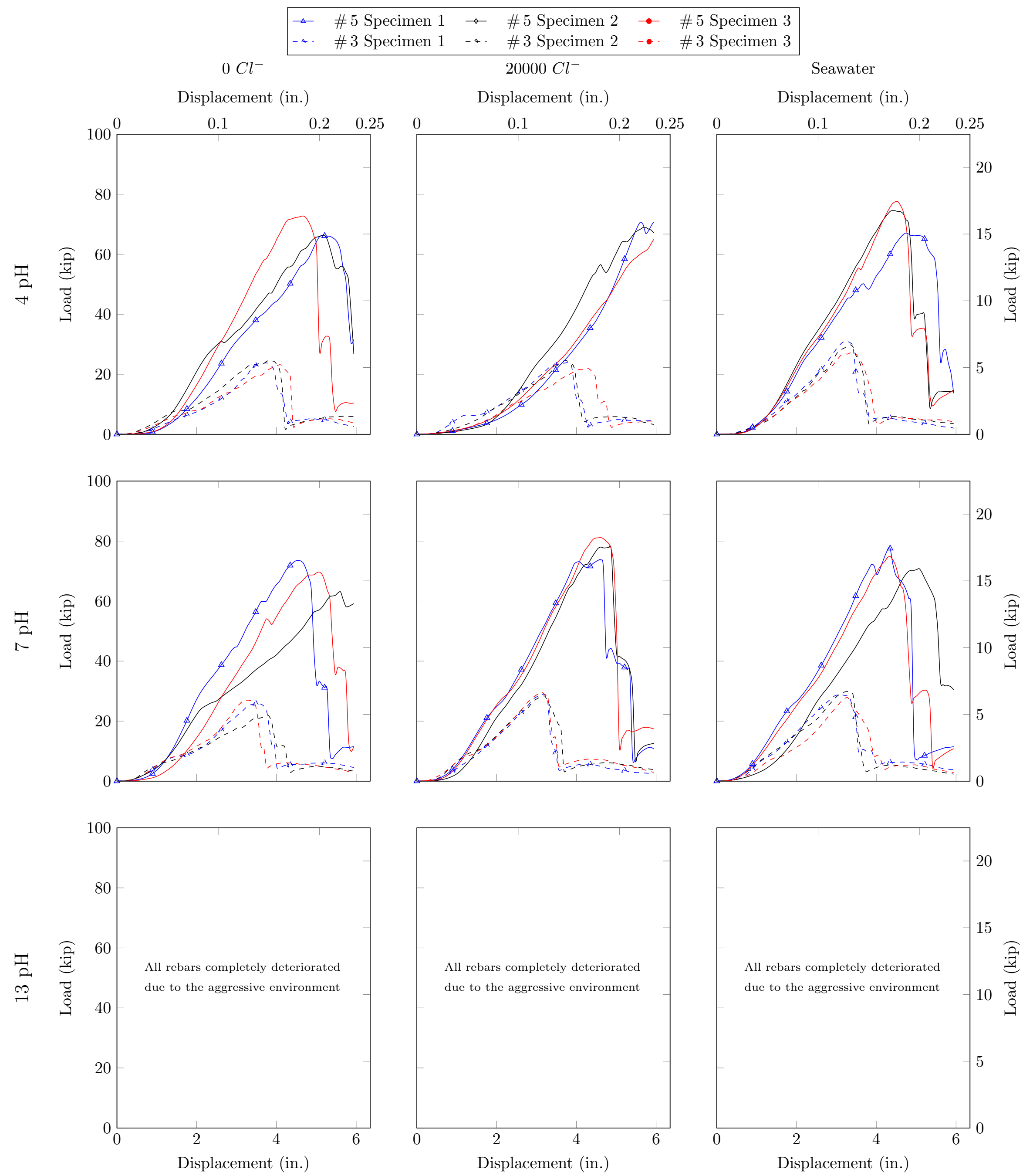

Figure 8.82: 600Day Transverse shear force - displacement behavior of Type C Lot1 tested rebars

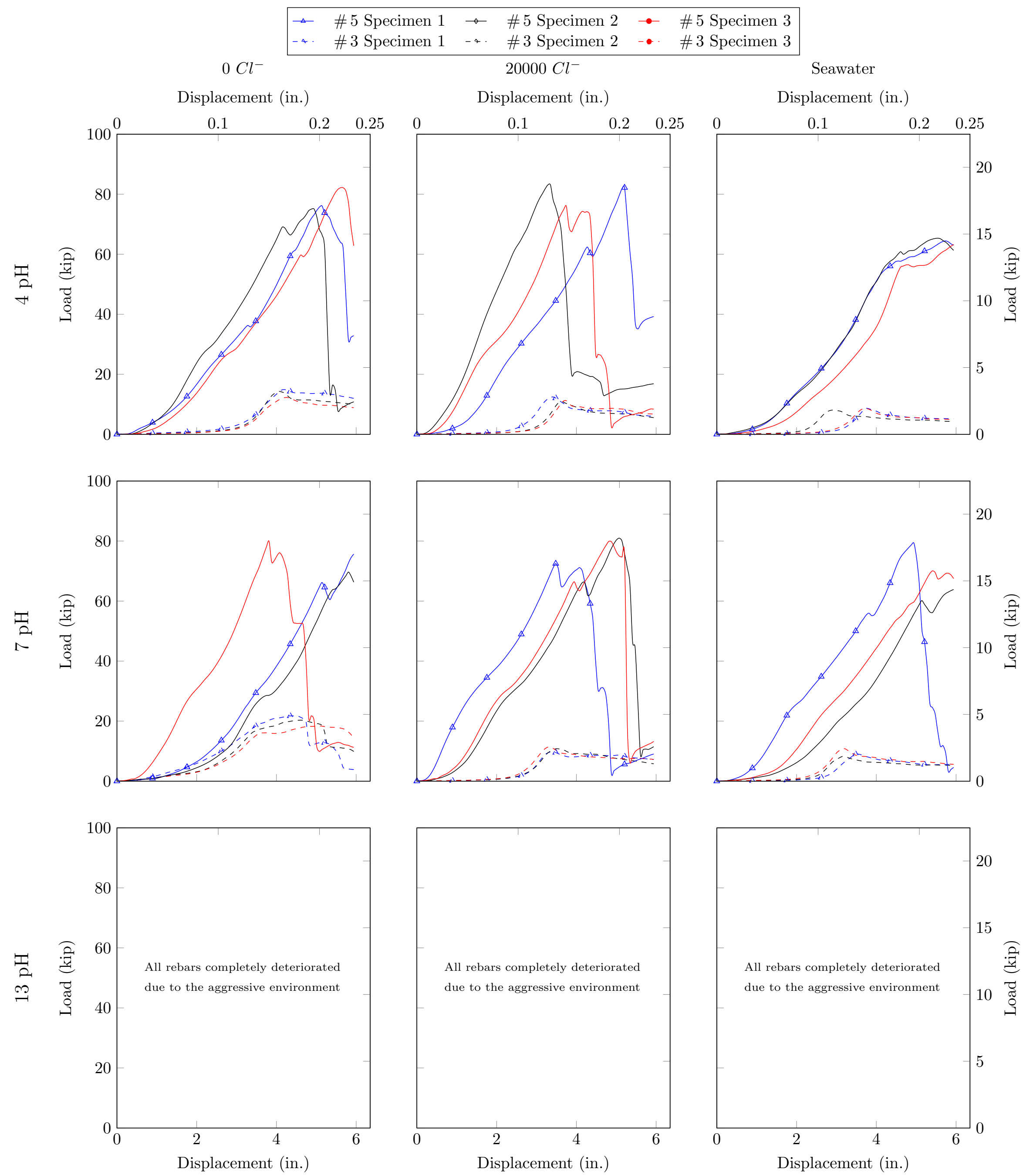

Figure 8.83: 600Day Transverse shear force - displacement behavior of Type A Lot2 tested rebars

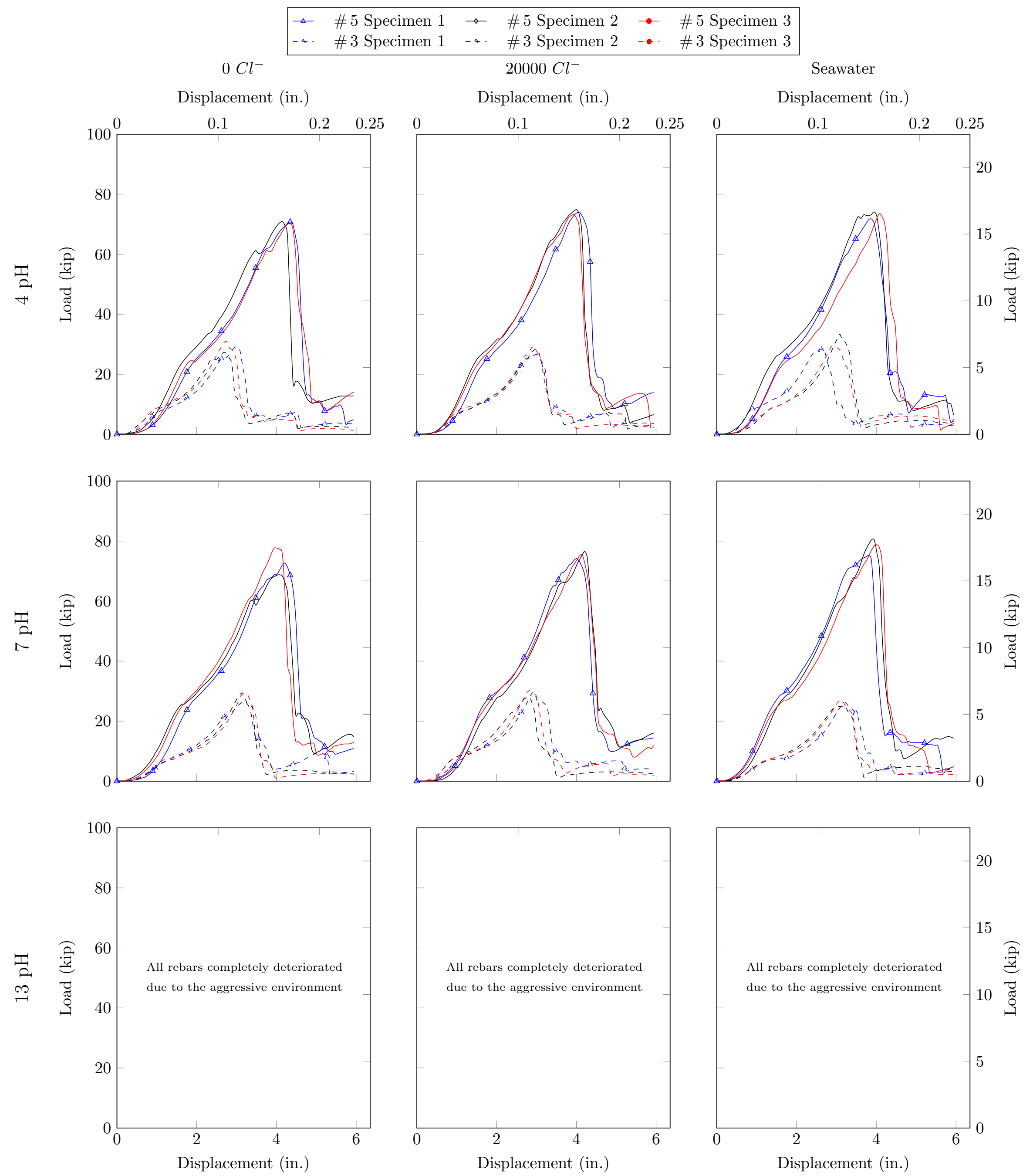

Figure 8.84: 600Day Transverse shear force - displacement behavior of Type B Lot2 tested rebars

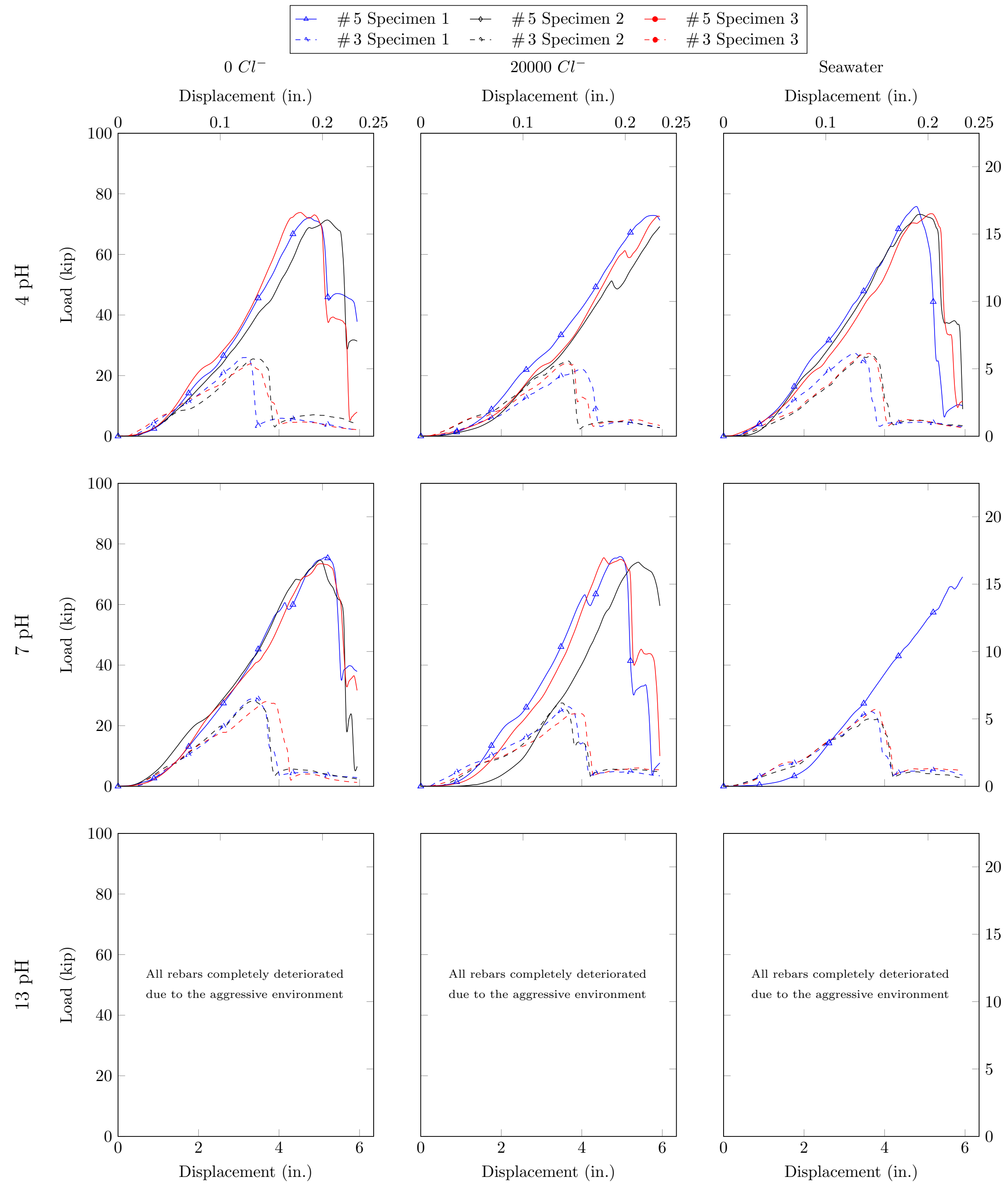

Figure 8.85: 600Day Transverse shear force - displacement behavior of Type C Lot2 tested rebars

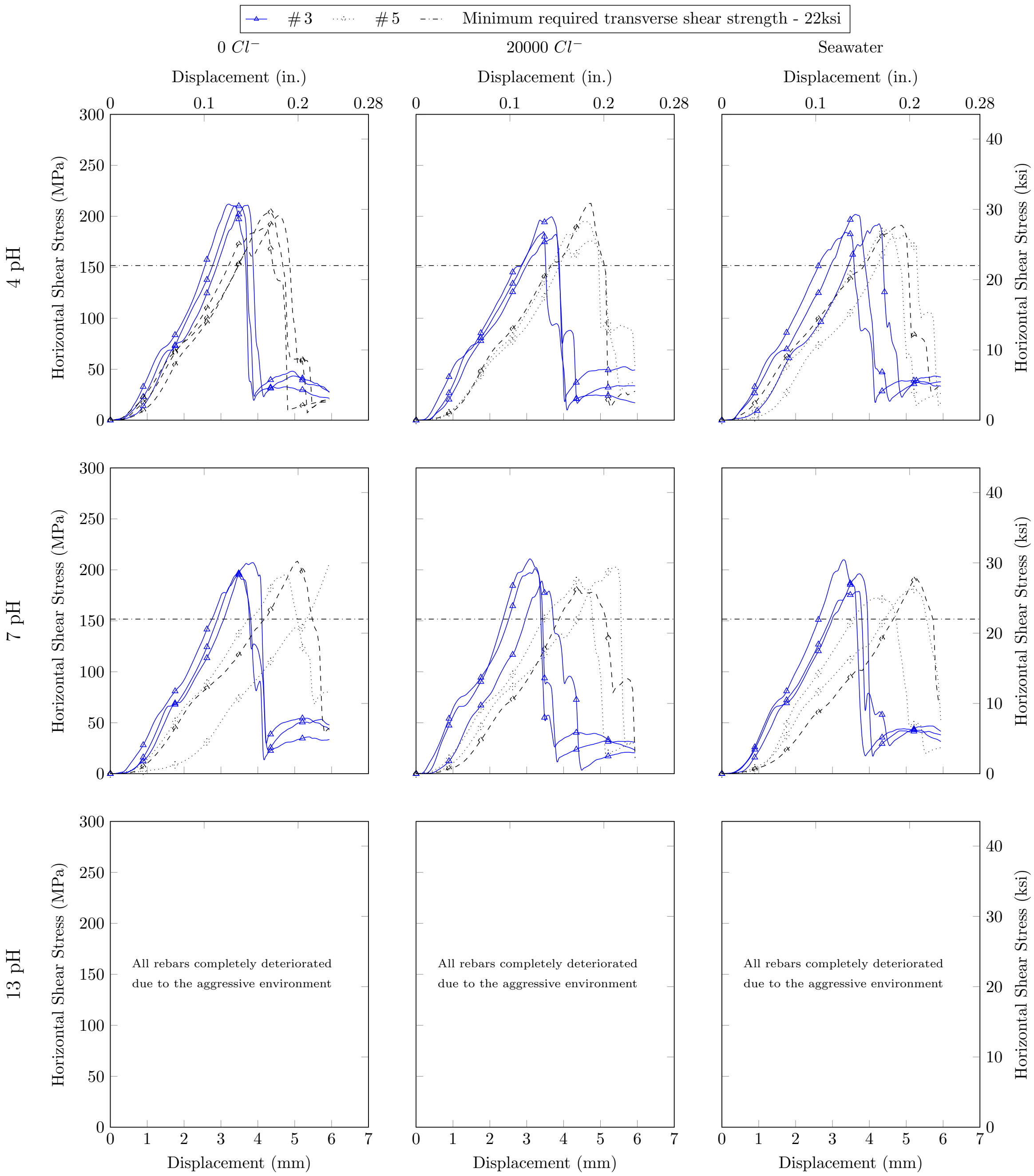

Figure 8.86: 600Day Transverse shear stress - displacement behavior of Type A Lot1 tested rebars

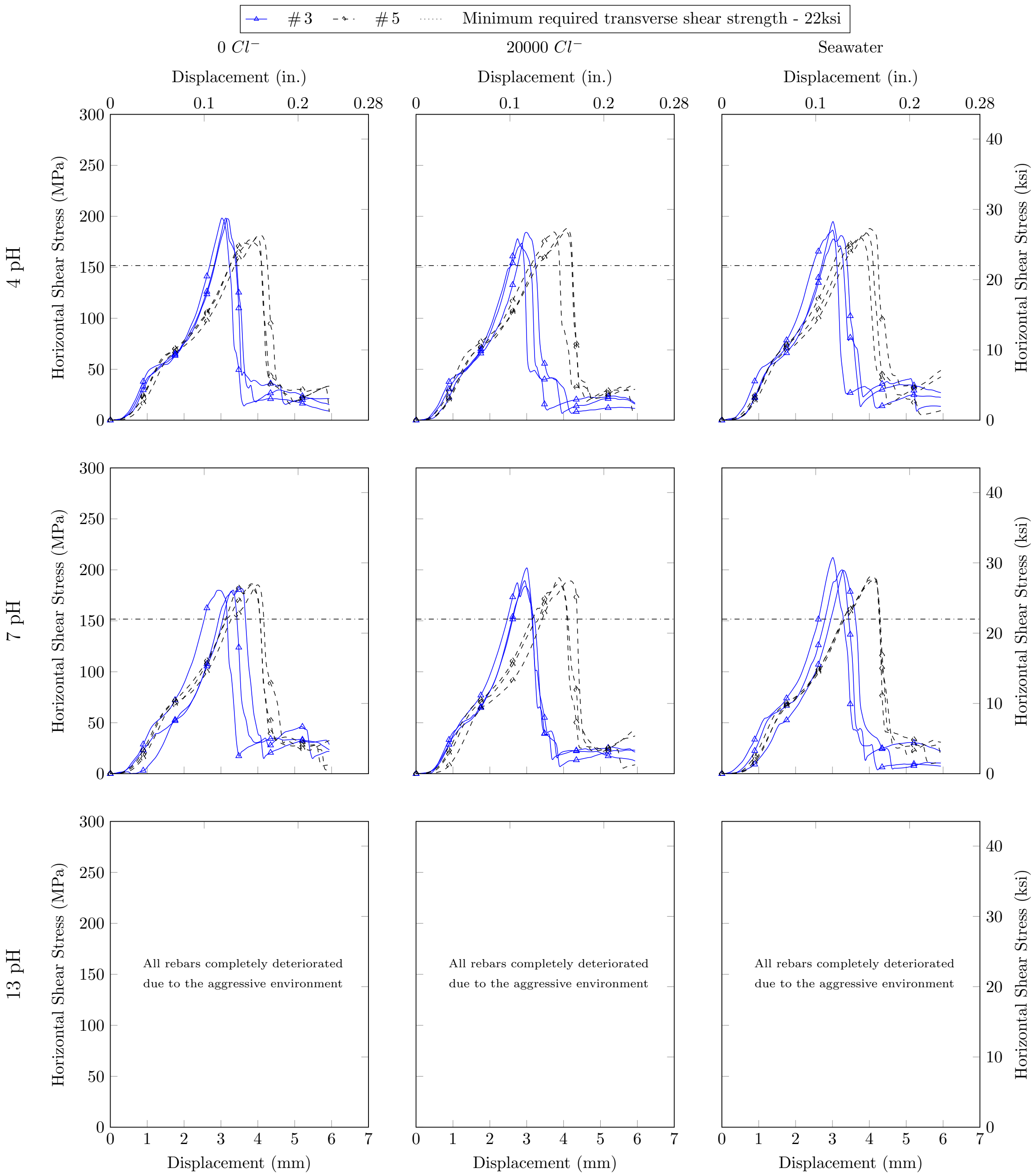

Figure 8.87: 600Day Transverse shear stress - displacement behavior of Type B Lot1 tested rebars

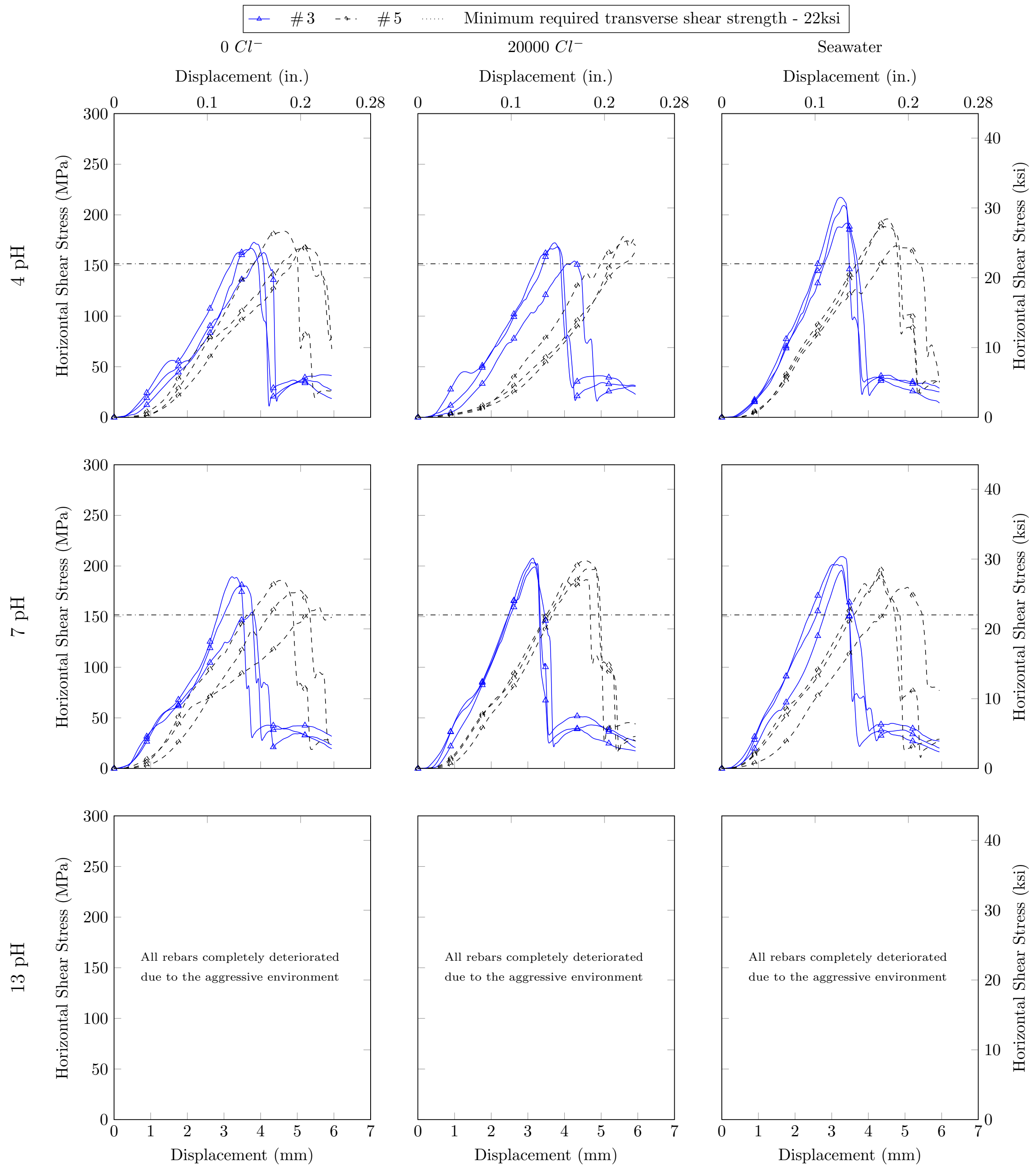

Figure 8.88: 600Day Transverse shear stress - displacement behavior of Type C Lot1 tested rebars

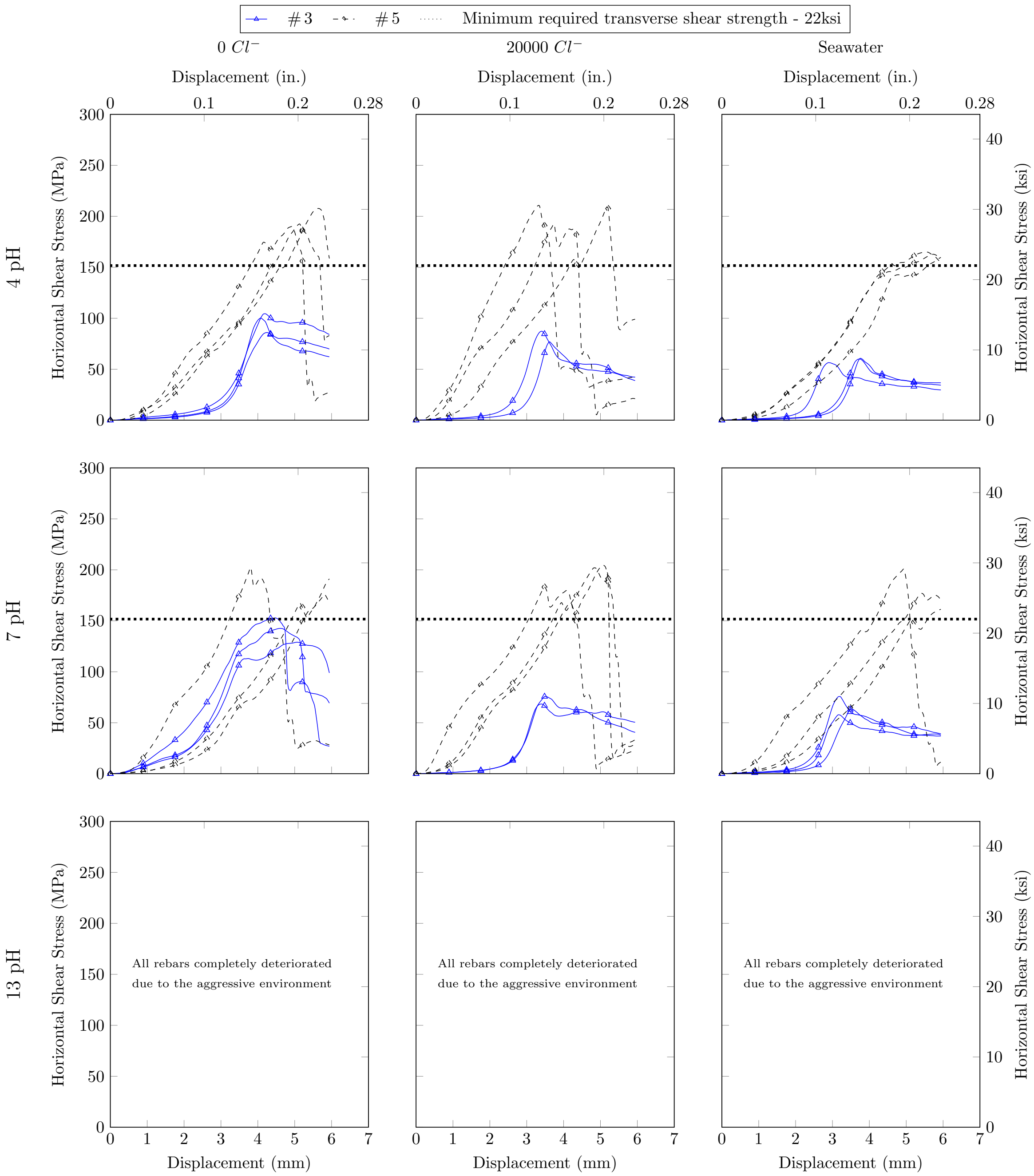

Figure 8.89: 600Day Transverse shear stress - displacement behavior of Type A Lot2 tested rebars

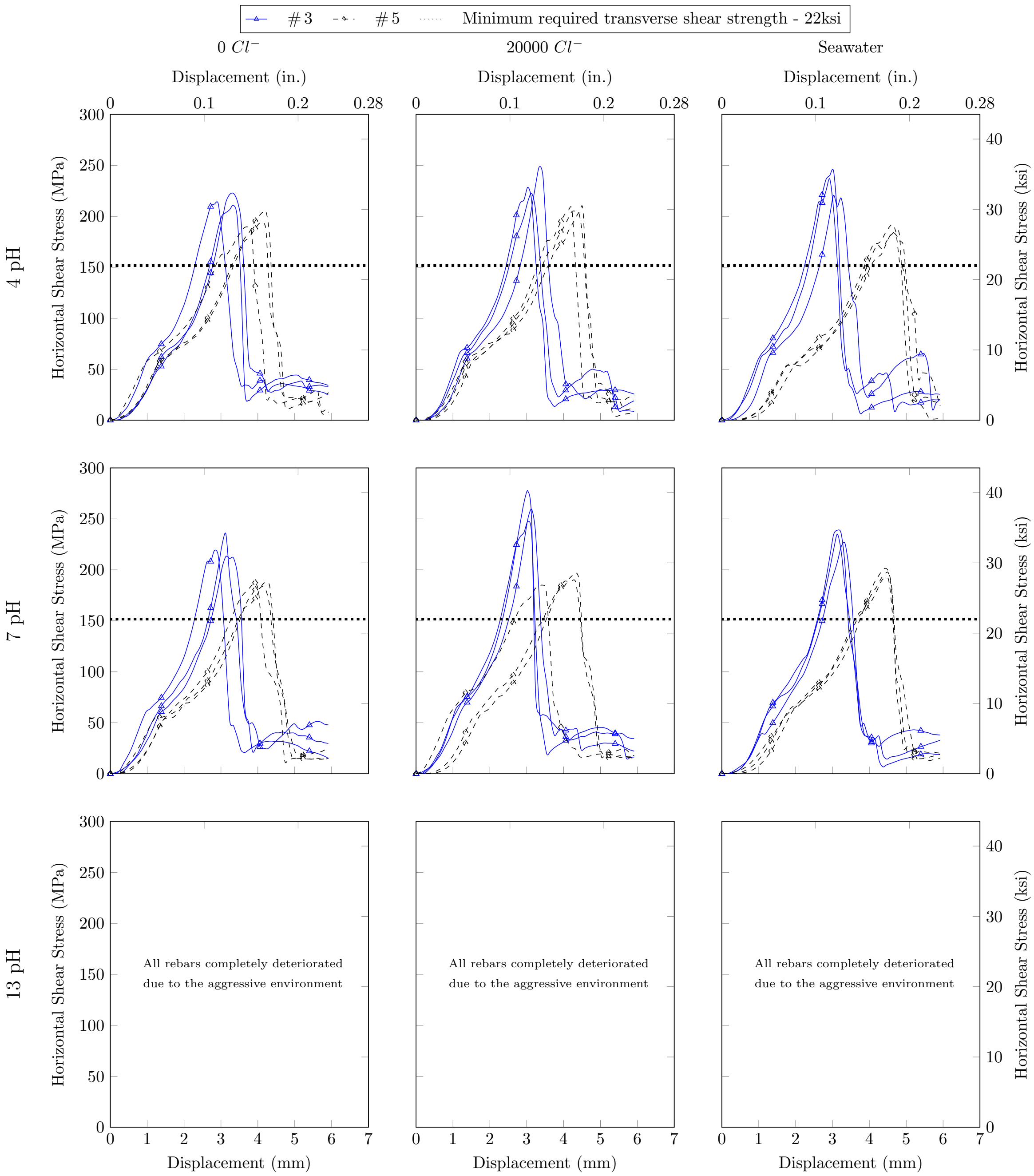

Figure 8.90: 600Day Transverse shear stress - displacement behavior of Type B Lot2 tested rebars

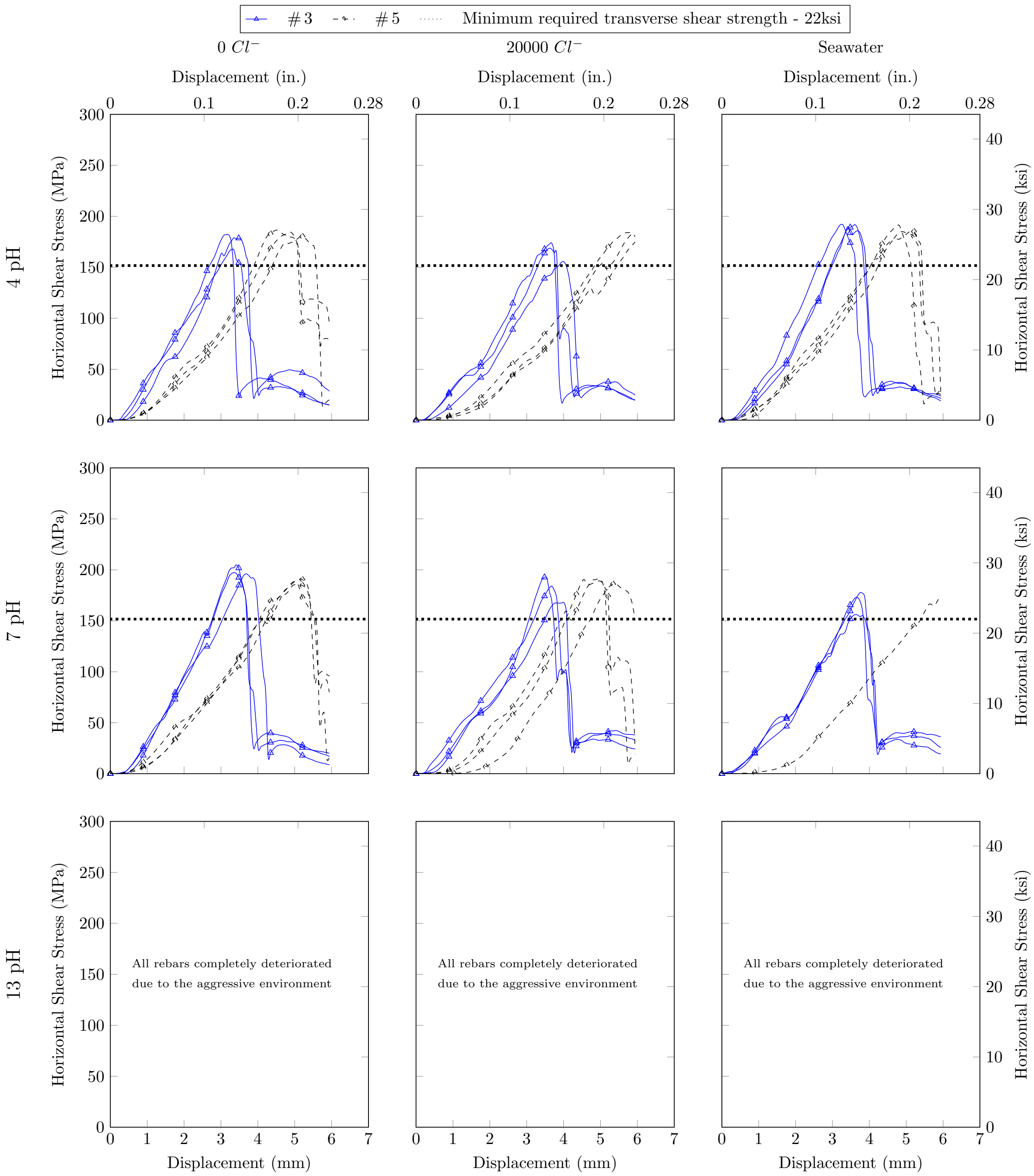

Figure 8.91: 600Day Transverse shear stress - displacement behavior of Type C Lot2 tested rebars

8.5.2 Summary of Transverse Shear Properties

The concentration of the statistical evaluation for the transverse shear strength properties of the tested products are listed in the following Table 8.43. A total of 250 specimen, five for each rebar type, size, lot, and exposure type were tested. The average and all other statistical values were calculated based on a sample size of five specimen, and the corresponding results are shown in the table. For numerical comparison and concluding values, Table 8.43 lists the minimum shear stress ($\wedge$), the maximum shear stress ($\vee$), the average shear stress (μ), the standard deviation (σ), and the coefficient of variation (CV) for each individual test sample.

Table 8.43: 600Day Transverse Shear test statistical values for each sample group (US Customary Units)

Sample Group						Statistical Values				
						Shear Stress				
Manuf. Type	Resin Type	Size #	Lot No.	pH	Cl^-	$\wedge$ ksi	$\vee$ ksi	μ ksi	σ ksi	CV %
TypeA	Epoxy	3	1	4	0	30.6	30.8	30.7	0.1	0.49
TypeA	Epoxy	5	1	4	0	27.4	29.7	28.8	1.2	4.20
TypeB	VinylEster	3	1	4	0	28.9	29.1	29.0	0.1	0.44
TypeB	VinylEster	5	1	4	0	25.7	26.4	26.0	0.3	1.32
TypeC	Epoxy	3	1	4	0	23.8	25.1	24.4	0.7	2.76
TypeC	Epoxy	5	1	4	0	24.3	26.7	25.1	1.3	5.36
TypeA	Epoxy	3	1	4	20000	26.4	29.0	27.4	1.5	5.31
TypeA	Epoxy	5	1	4	20000	25.6	31.0	28.3	2.7	9.51
TypeB	VinylEster	3	1	4	20000	25.1	27.2	26.1	1.1	4.15
TypeB	VinylEster	5	1	4	20000	26.8	27.3	27.0	0.3	1.10
TypeC	Epoxy	3	1	4	20000	22.5	25.1	24.0	1.4	5.74
TypeC	Epoxy	5	1	4	20000	24.3	26.4	25.3	1.0	4.07
TypeA	Epoxy	3	1	4	SeaWater	26.8	29.4	28.1	1.3	4.69
TypeA	Epoxy	5	1	4	SeaWater	26.3	27.8	27.1	0.7	2.63
TypeB	VinylEster	3	1	4	SeaWater	26.4	28.4	27.3	1.0	3.73
TypeB	VinylEster	5	1	4	SeaWater	26.0	27.4	26.7	0.7	2.49
TypeC	Epoxy	3	1	4	SeaWater	28.0	31.6	30.0	1.8	6.08
TypeC	Epoxy	5	1	4	SeaWater	24.6	28.4	26.8	2.0	7.33
TypeA	Epoxy	3	2	4	0	12.5	15.2	14.1	1.4	9.96
TypeA	Epoxy	5	2	4	0	27.5	30.1	28.5	1.4	4.90
TypeB	VinylEster	3	2	4	0	27.8	31.7	29.8	1.9	6.51
TypeB	VinylEster	5	2	4	0	25.8	26.0	25.9	0.1	0.55
TypeC	Epoxy	3	2	4	0	24.4	26.5	25.6	1.1	4.37
TypeC	Epoxy	5	2	4	0	26.2	27.1	26.6	0.5	1.80
TypeA	Epoxy	3	2	4	20000	11.2	12.7	11.8	0.8	6.63
TypeA	Epoxy	5	2	4	20000	28.0	30.7	29.7	1.5	4.91
TypeB	VinylEster	3	2	4	20000	27.3	30.0	28.8	1.4	4.78
TypeB	VinylEster	5	2	4	20000	26.9	27.5	27.2	0.3	1.02
TypeC	Epoxy	3	2	4	20000	22.6	25.3	24.1	1.4	5.81
TypeC	Epoxy	5	2	4	20000	25.6	26.7	26.3	0.6	2.37
TypeA	Epoxy	3	2	4	SeaWater	8.2	8.9	8.6	0.3	3.98
TypeA	Epoxy	5	2	4	SeaWater	23.3	24.0	23.6	0.3	1.32
TypeB	VinylEster	3	2	4	SeaWater	29.0	34.4	31.2	2.8	9.02
TypeB	VinylEster	5	2	4	SeaWater	26.4	27.2	26.9	0.5	1.70
TypeC	Epoxy	3	2	4	SeaWater	27.7	27.9	27.8	0.1	0.39
TypeC	Epoxy	5	2	4	SeaWater	26.9	27.8	27.2	0.5	1.86
TypeA	Epoxy	3	1	7	0	28.4	30.1	29.0	1.0	3.31

Continued on next page ...

Table 8.43: 600Day Transverse Shear test statistical values for each sample group (US Customary Units)

Sample Group						Statistical Values				
						Shear Stress				
Manuf. Type	Resin Type	Size #	Lot No.	pH	Cl^{-}	$\wedge$ ksi	$\vee$ ksi	μ ksi	σ ksi	CV %
TypeA	Epoxy	5	1	7	0	28.4	30.7	29.8	1.2	4.13
TypeB	VinylEster	3	1	7	0	26.0	26.4	26.2	0.2	0.77
TypeB	VinylEster	5	1	7	0	26.9	27.0	27.0	0.1	0.25
TypeC	Epoxy	3	1	7	0	22.5	27.6	25.5	2.7	10.45
TypeC	Epoxy	5	1	7	0	23.2	27.0	25.2	1.9	7.61
TypeA	Epoxy	3	1	7	20000	27.6	30.7	29.2	1.5	5.24
TypeA	Epoxy	5	1	7	20000	26.4	29.4	27.8	1.5	5.40
TypeB	VinylEster	3	1	7	20000	27.3	29.5	28.1	1.2	4.17
TypeB	VinylEster	5	1	7	20000	27.0	27.9	27.5	0.5	1.64
TypeC	Epoxy	3	1	7	20000	29.0	30.3	29.6	0.6	2.15
TypeC	Epoxy	5	1	7	20000	27.1	29.8	28.5	1.4	4.74
TypeA	Epoxy	3	1	7	SeaWater	25.9	30.6	28.4	2.3	8.26
TypeA	Epoxy	5	1	7	SeaWater	25.0	27.9	26.4	1.4	5.41
TypeB	VinylEster	3	1	7	SeaWater	29.1	30.9	29.7	1.0	3.46
TypeB	VinylEster	5	1	7	SeaWater	27.6	28.1	27.8	0.2	0.83
TypeC	Epoxy	3	1	7	SeaWater	28.4	30.4	29.3	1.0	3.48
TypeC	Epoxy	5	1	7	SeaWater	26.0	28.5	27.3	1.3	4.62
TypeA	Epoxy	3	2	7	0	18.7	22.2	20.5	1.7	8.44
TypeA	Epoxy	5	2	7	0	25.6	29.5	27.7	2.0	7.10
TypeB	VinylEster	3	2	7	0	27.1	30.1	29.0	1.7	5.91
TypeB	VinylEster	5	2	7	0	25.2	28.6	26.9	1.7	6.30
TypeC	Epoxy	3	2	7	0	28.5	29.8	29.0	0.7	2.39
TypeC	Epoxy	5	2	7	0	26.9	27.7	27.3	0.4	1.45
TypeA	Epoxy	3	2	7	20000	9.9	11.6	10.9	0.9	7.83
TypeA	Epoxy	5	2	7	20000	26.7	29.7	28.6	1.6	5.66
TypeB	VinylEster	3	2	7	20000	28.7	31.1	30.0	1.2	4.07
TypeB	VinylEster	5	2	7	20000	27.3	28.1	27.7	0.4	1.57
TypeC	Epoxy	3	2	7	20000	24.5	28.0	26.4	1.8	6.75
TypeC	Epoxy	5	2	7	20000	27.1	27.8	27.6	0.4	1.42
TypeA	Epoxy	3	2	7	SeaWater	8.4	11.1	9.6	1.3	14.05
TypeA	Epoxy	5	2	7	SeaWater	23.4	29.1	26.1	2.8	10.91
TypeB	VinylEster	3	2	7	SeaWater	25.7	28.0	26.8	1.1	4.20
TypeB	VinylEster	5	2	7	SeaWater	27.6	29.7	28.7	1.1	3.72
TypeC	Epoxy	3	2	7	SeaWater	22.8	25.8	24.6	1.6	6.63
TypeC	Epoxy	5	2	7	SeaWater	25.7	28.7	27.2	2.1	7.85

8.5.3 Apparent Horizontal Shear Test

The FRP rebar products were tested for horizontal shear properties after exposing them to aggressive environments. The horizontal shear test was conducted according to the ASTM D 4475 (ASTM-International, 2012a) standards.

Load-Displacement

The graphs in Figures 8.92, 8.93, 8.94, 8.95, 8.96, and 8.97 plot the load-displacement behavior of short span 3 point bending. Each rebar type is shown individually—and every specimen within the relevant sample is displayed—to compare # 3 and # 5 from the same type. The x-axis of the graph represents the cross-head frame displacement, and the y-axis represents the applied load.

The graph in Figure 8.92 shows a nearly linear behavior until it reached the ultimate failure load. Following

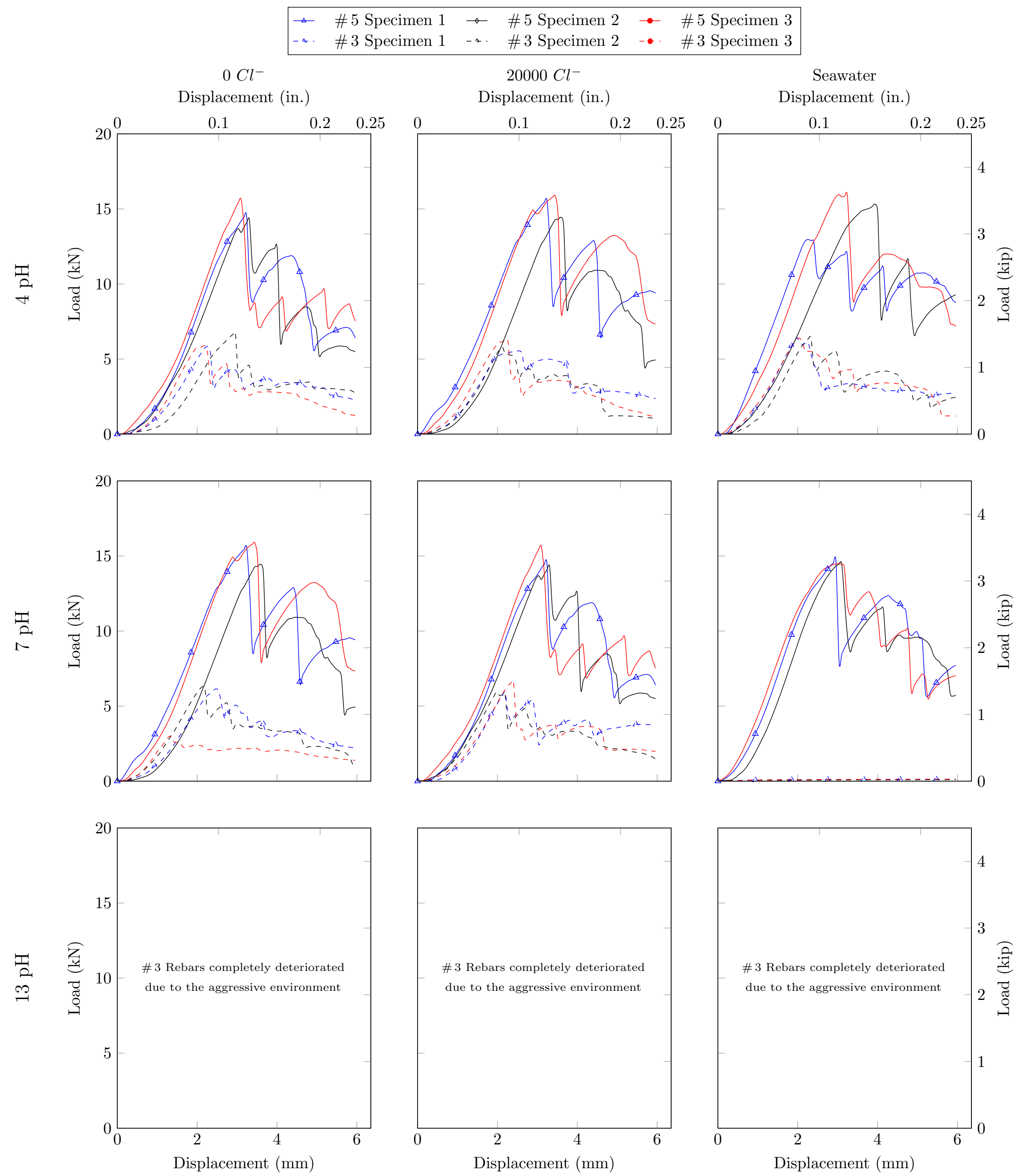

Figure 8.92: 600Day Horizontal shear force - displacement behavior of Type A Lot1 tested rebars

the peak load, a descending branch proceeds with individual local peaks and drops. The peaks and drops represent individual layers of fibers engaged and failing in tension located in the lower part of the specimen experiencing pure tension, while the upper part is in compression. Extension-Horizontal shear behavior of rebar Type B can be seen in the graph in Figure 8.93. Similar to Type A, # 5 Type B rebar sustained

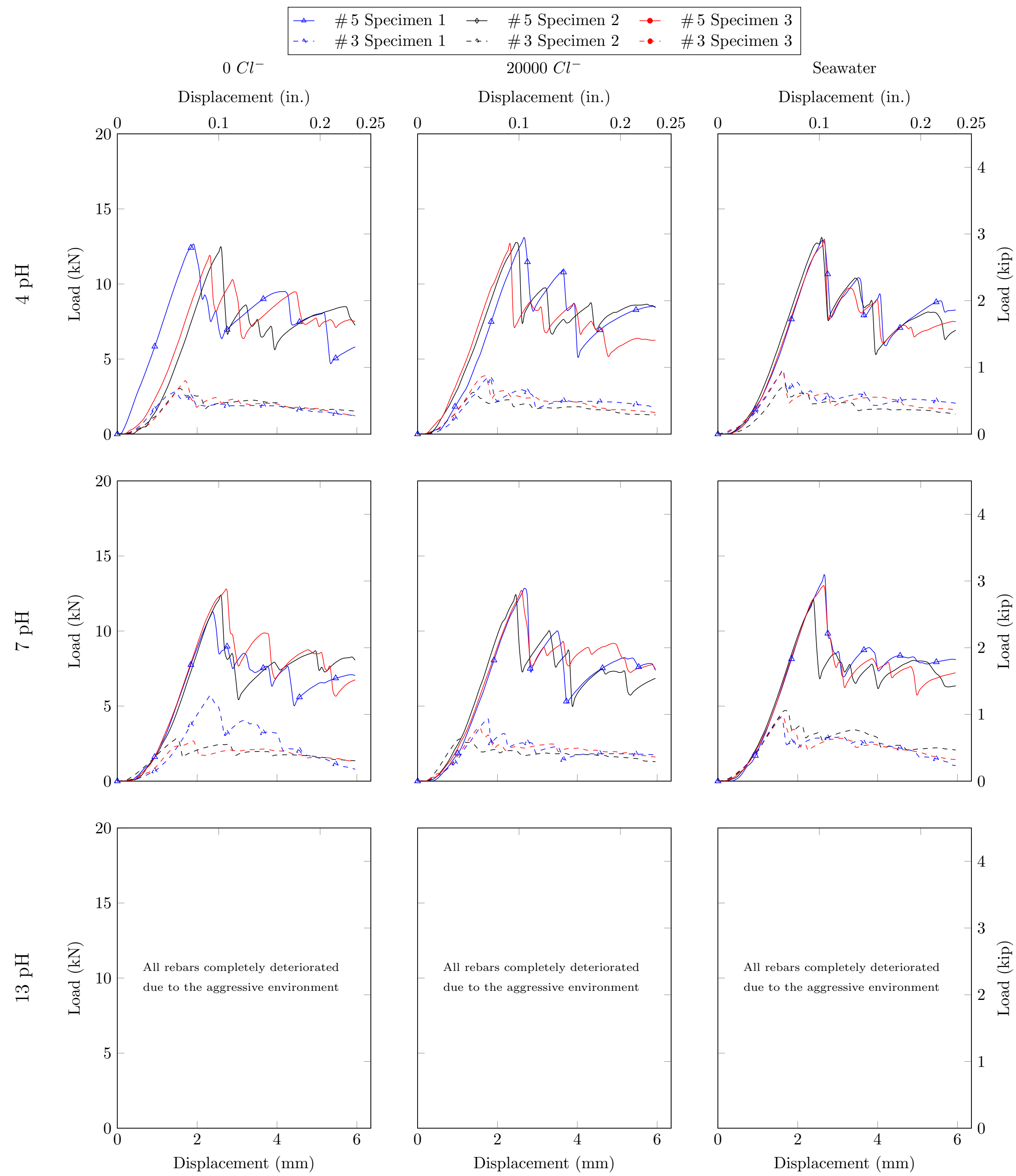

Figure 8.93: 600Day Horizontal shear force - displacement behavior of Type B Lot1 tested rebars

more load in comparison with # 3 rebars. The failure pattern of # 3 and # 5 Type B rebars was similar and identical to Type A rebar failure pattern. The load - displacement graph of Type C rebar in Figure 8.94 shows a nearly linear behavior until it reached the ultimate failure load. Following the peak load, a descending branch proceeds with individual local peaks and drops. The peaks and drops represent individual layers of fibers engaged and failing in tension located in the lower part of the specimen experiencing pure tension,

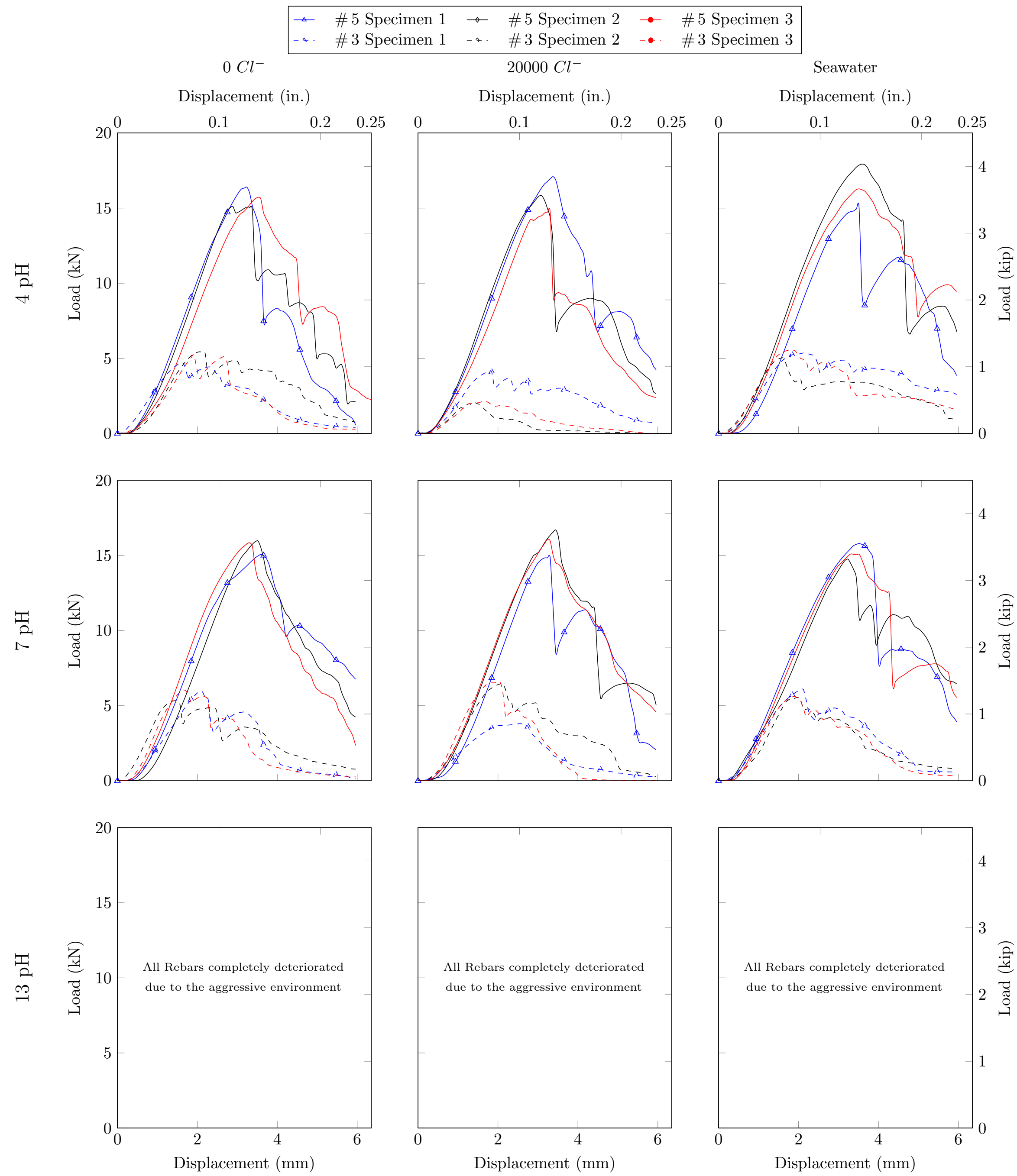

Figure 8.94: 600Day Horizontal shear force - displacement behavior of Type C Lot1 tested rebars

while the upper part is in compression. The graphs shown in Figures 8.95, 8.96, and 8.97 show the load-displacement behavior of Lot 2 Type A, Type B, and Type C rebars. The graphs show a linear behavior until it reached approximately 90 % of the ultimate failure load. It can be seen in Figures 8.95 and 8.96 that the failure behavior of Type A and Type B rebars is identical irrespective of production lot and rebar size. Extension-Horizontal shear behavior of Lot 2 Type C rebars can be seen in the graph in Figure 8.97. Similar to Lot 1, # 5 Lot 2 rebars sustained more load in comparison with # 3 rebars. The failure pattern of

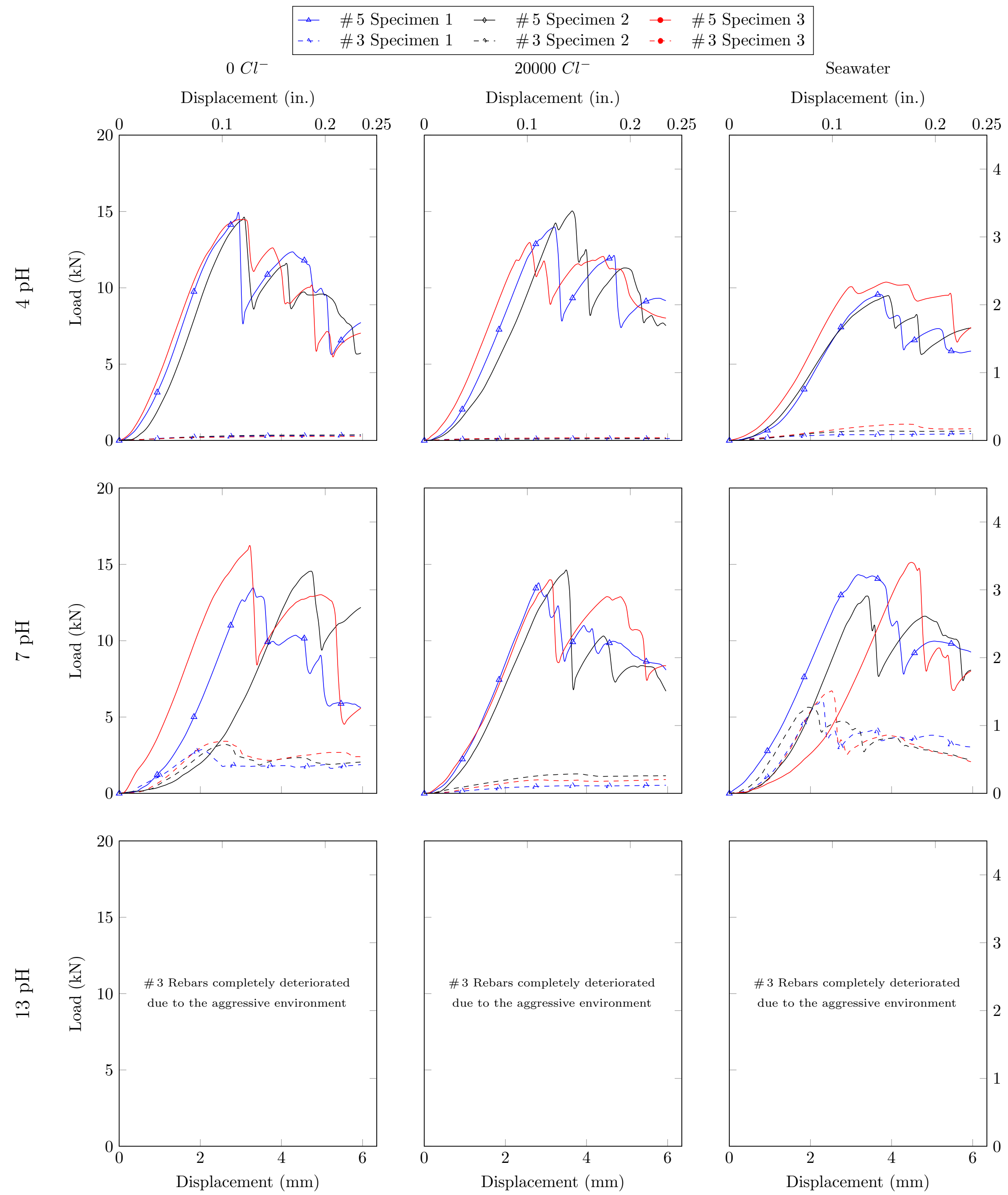

Figure 8.95: 600Day Horizontal shear force - displacement behavior of Type A Lot2 tested rebars

3 and # 5 Lot 2 rebars was similar and identical to the failure pattern of rebars from Lot 1.

Stress-Displacement

To provide clarity and to compare the horizontal shear strength performance of the two rebar sizes, stress-strain behavior of rebar is shown in this section via graphs. The following graphs in Figures 8.98, 8.99, 8.100, 8.101, 8.102, and 8.103 show the comparison of the stress - cross-head behavior for the tested BFRP rebars.

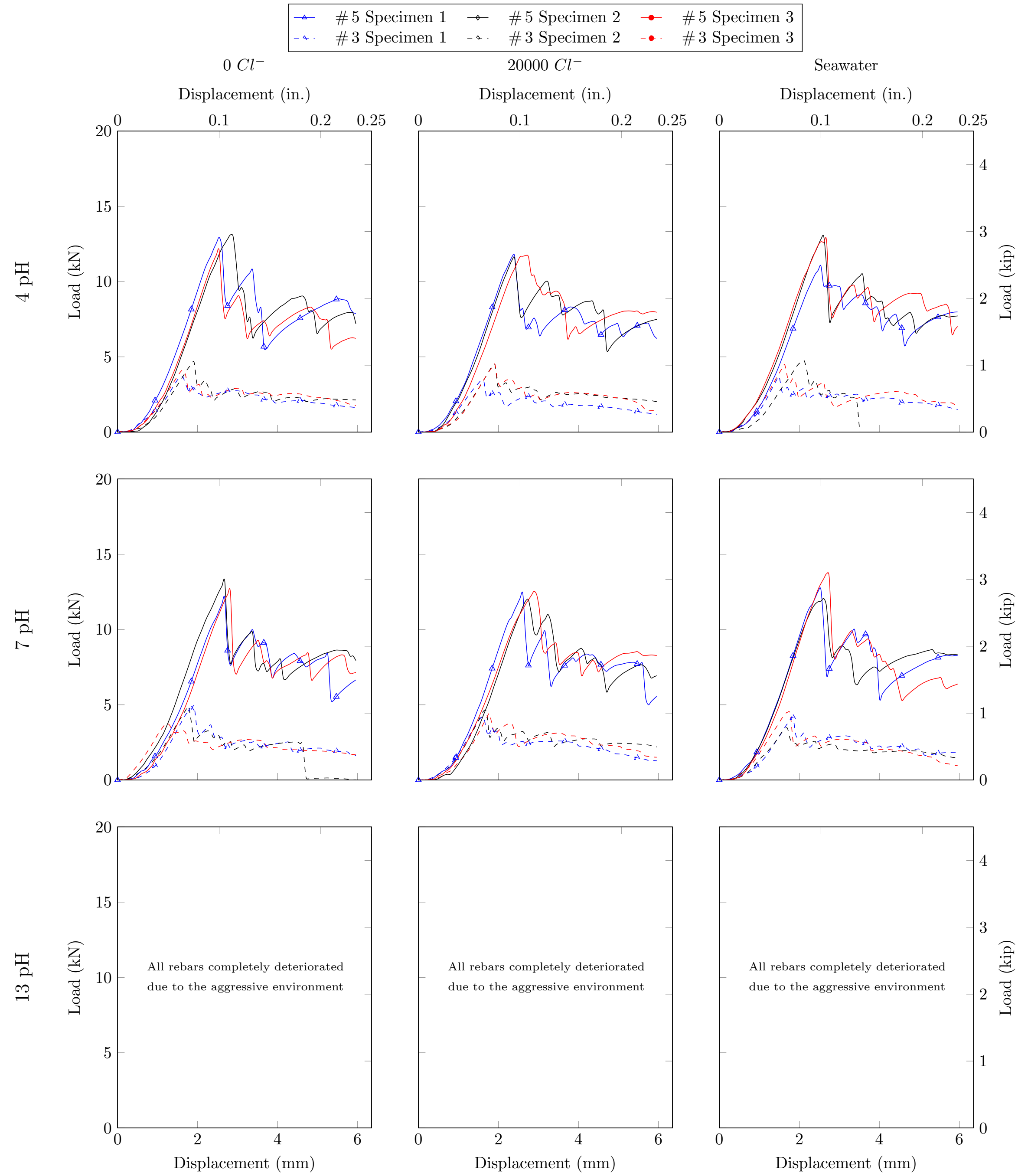

Figure 8.96: 600Day Horizontal shear force - displacement behavior of Type B Lot2 tested rebars

The x-axis of graph represents the cross-head extension, while the y-axis signifies the measured shear stresses.

As expected, a significant difference in peak load between rebar sizes of Type A rebar was observed. Nevertheless, the resultant horizontal shear stress is approximately the same regardless of the rebar size. The stress-displacement behavior of rebar Type B shows that the failure pattern was identical for both the sizes but # 5 rebars sustained more stress in comparison to # 3 rebars. As expected, a significant difference in peak load between rebar sizes of Type C Lot 1 rebar was observed. Nevertheless, the resultant horizontal shear

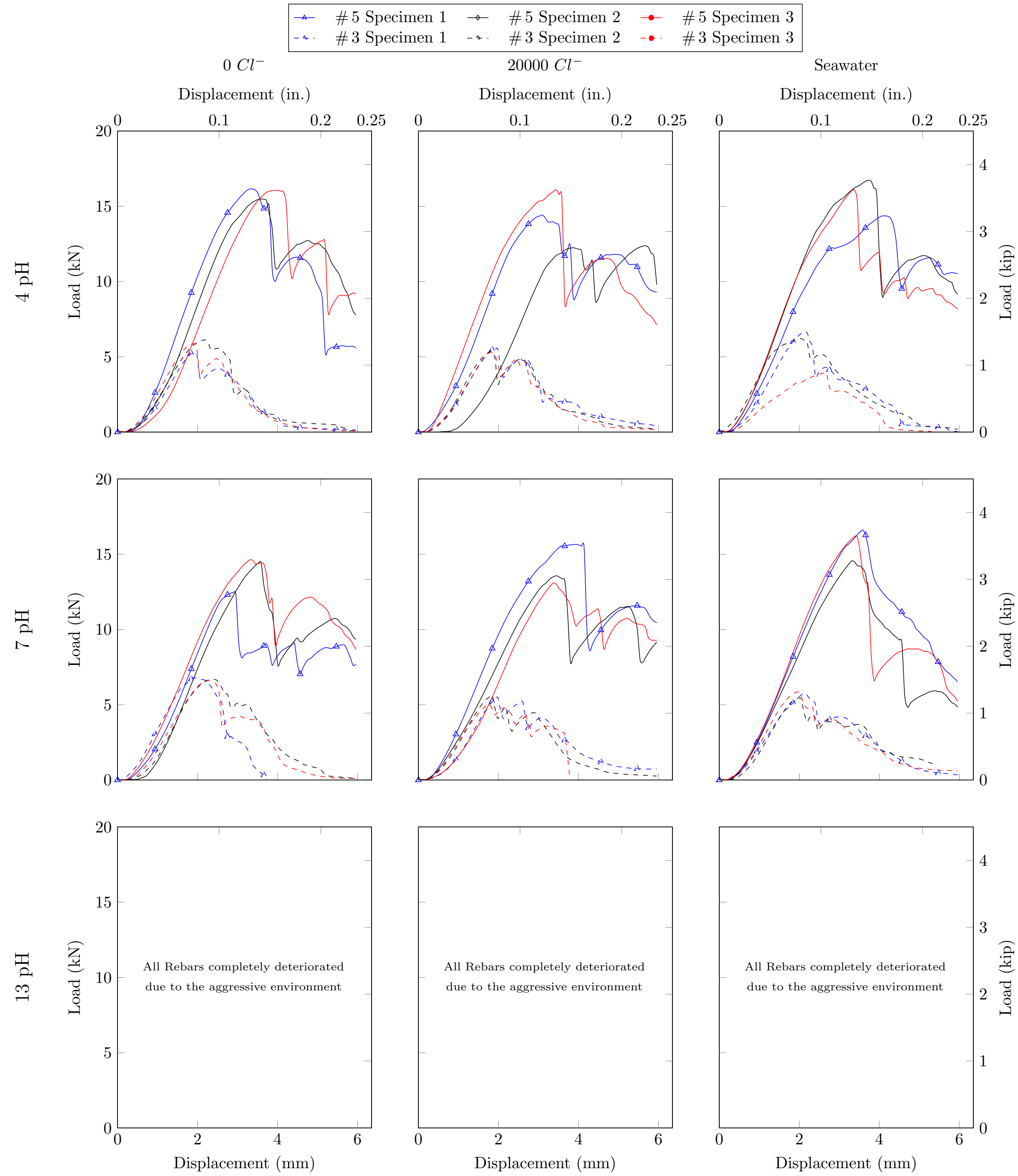

Figure 8.97: 600Day Horizontal shear force - displacement behavior of Type C Lot2 tested rebars

stress is approximately the same regardless of the rebar size. The graphs in Figures 8.101, 8.102, and 8.103 are used to compare the stress-displacement behavior of horizontal shear test of # 3 and # 5 rebars from Type A, Type B, and Type C from Lot 2.

The stress-strain behavior of rebars from Lot 2 show that the failure pattern was identical for both the sizes but # 5 rebars sustained more stress in comparison to # 3 rebars. Figures 8.101 and 8.102 show that all the rebars of Type A and Type B underwent similar stress and strain irrespective of lot and size.

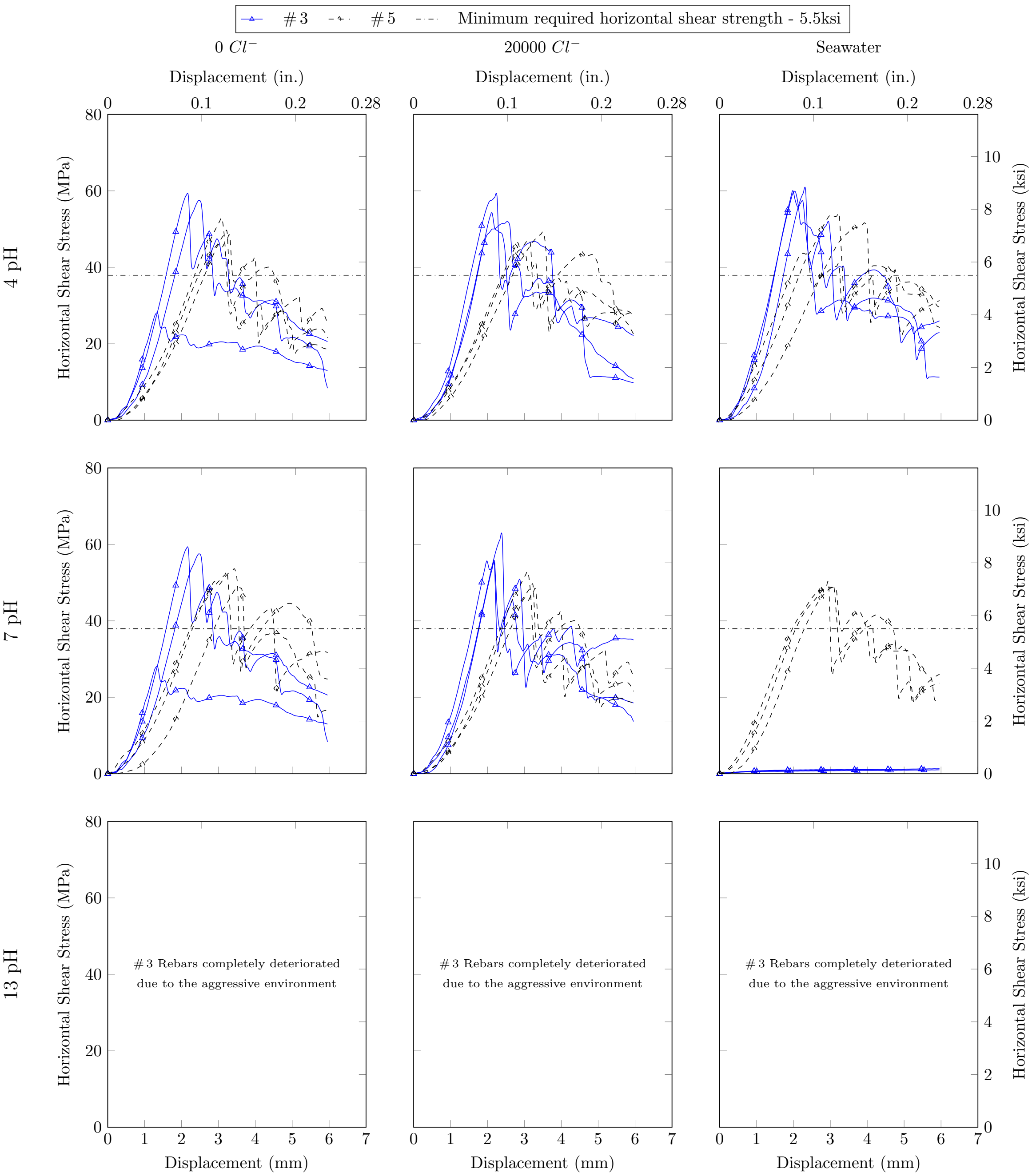

Figure 8.98: 600Day Horizontal shear stress - displacement behavior of Type A Lot1 tested rebars

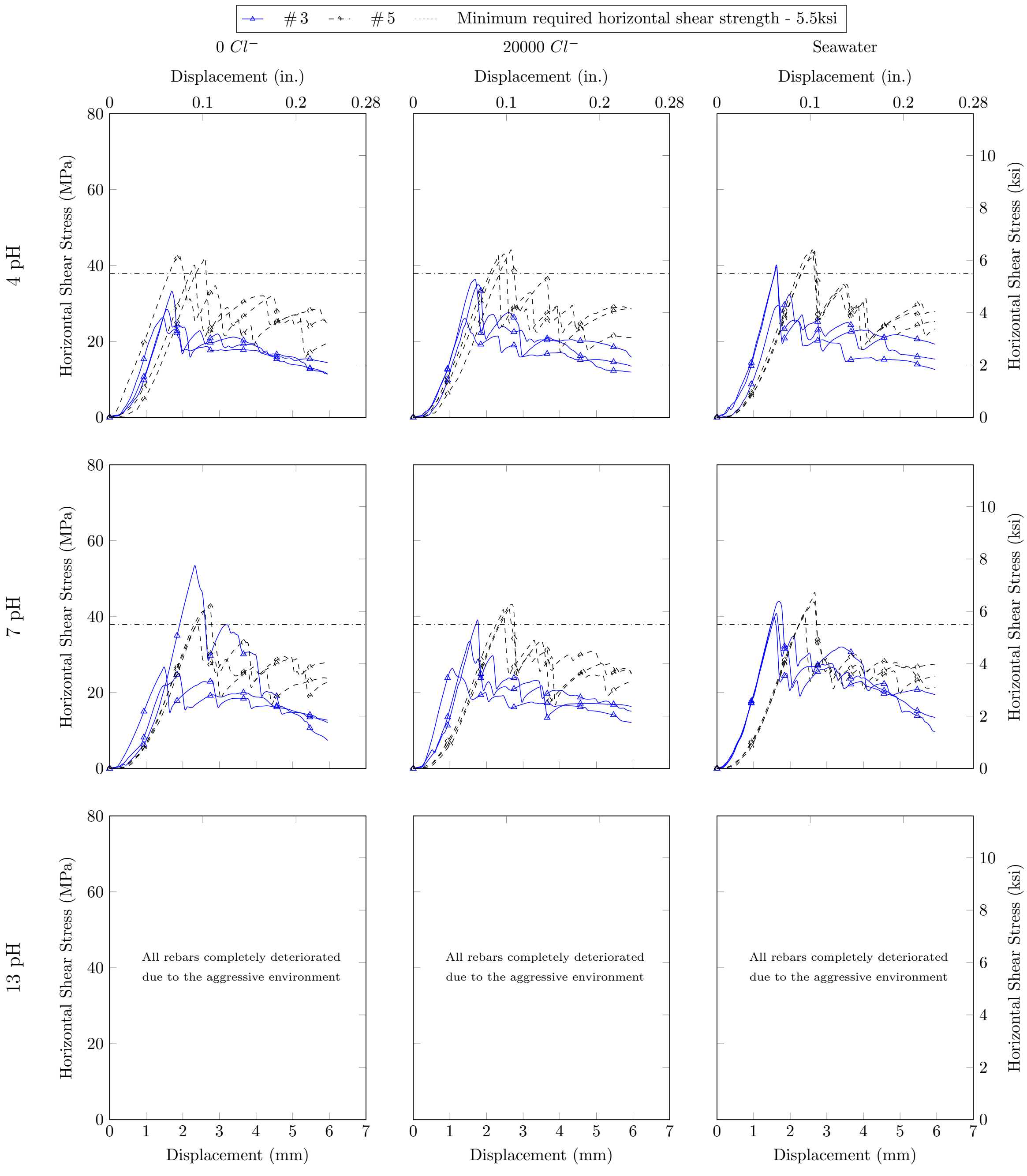

Figure 8.99: 600Day Horizontal shear stress - displacement behavior of Type B Lot1 tested rebars

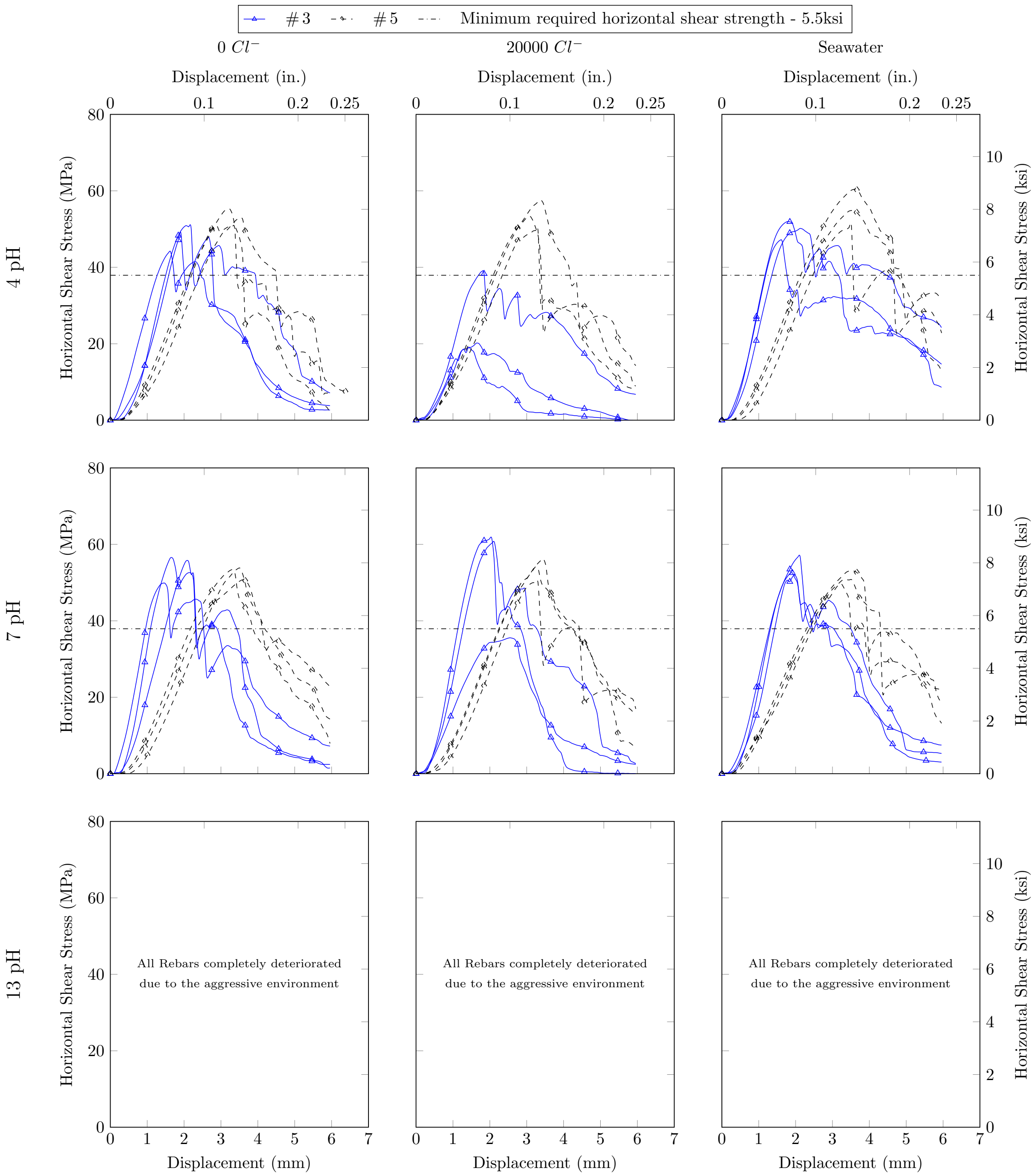

Figure 8.100: 600Day Horizontal shear stress - displacement behavior of Type C Lot1 tested rebars

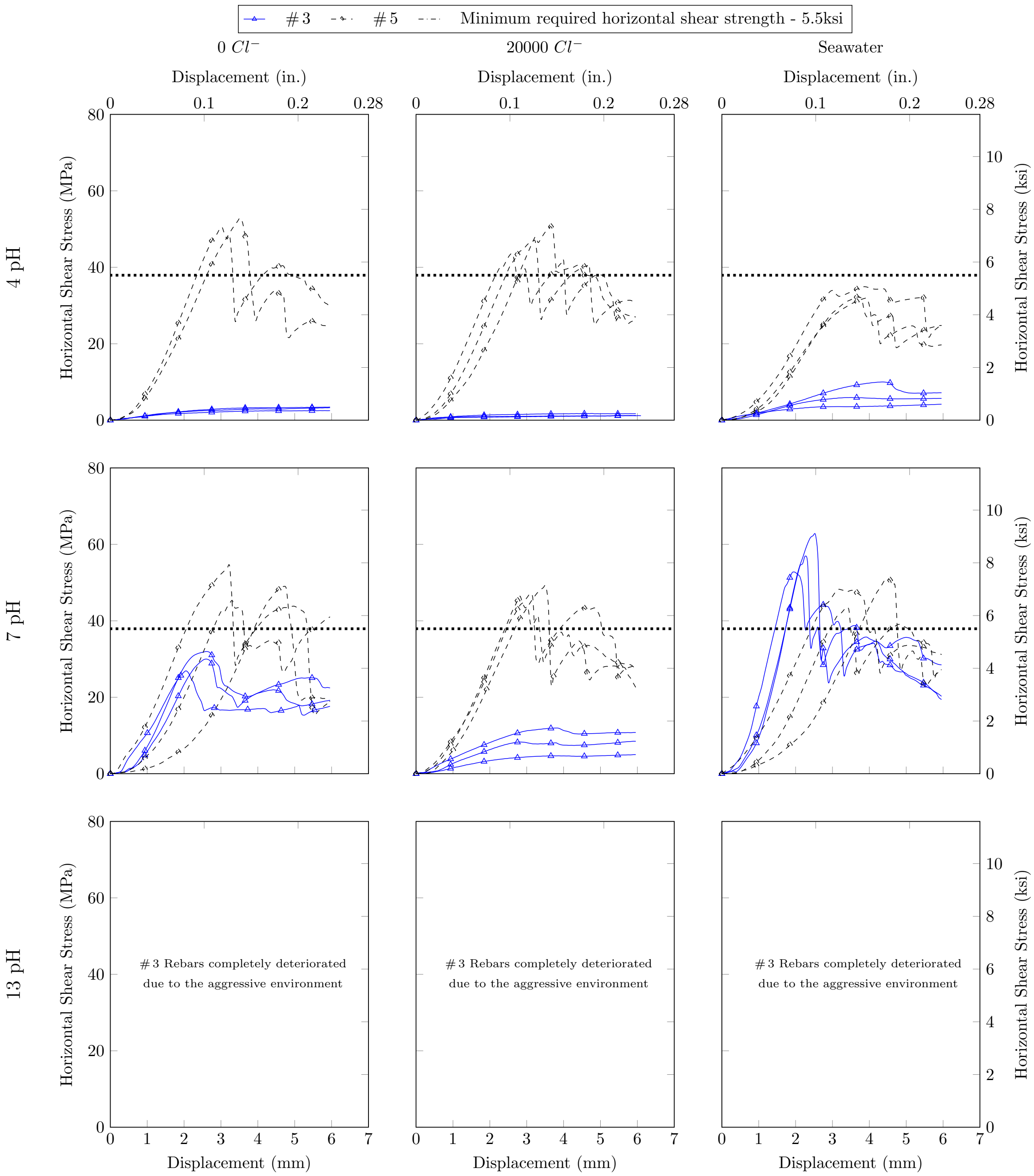

Figure 8.101: 600Day Horizontal shear stress - displacement behavior of Type A Lot2 tested rebars

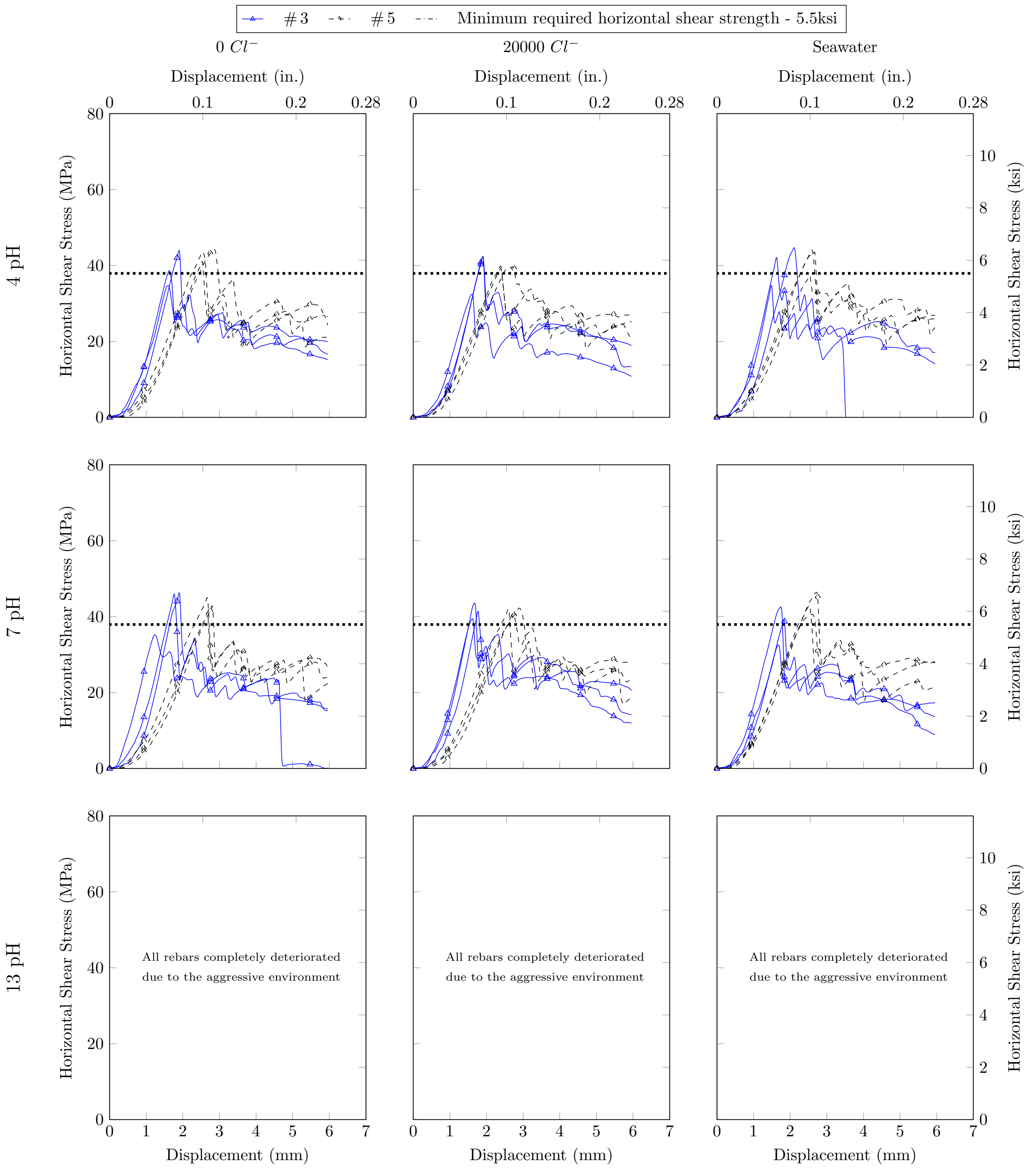

Figure 8.102: 600Day Horizontal shear stress - displacement behavior of Type B Lot2 tested rebars

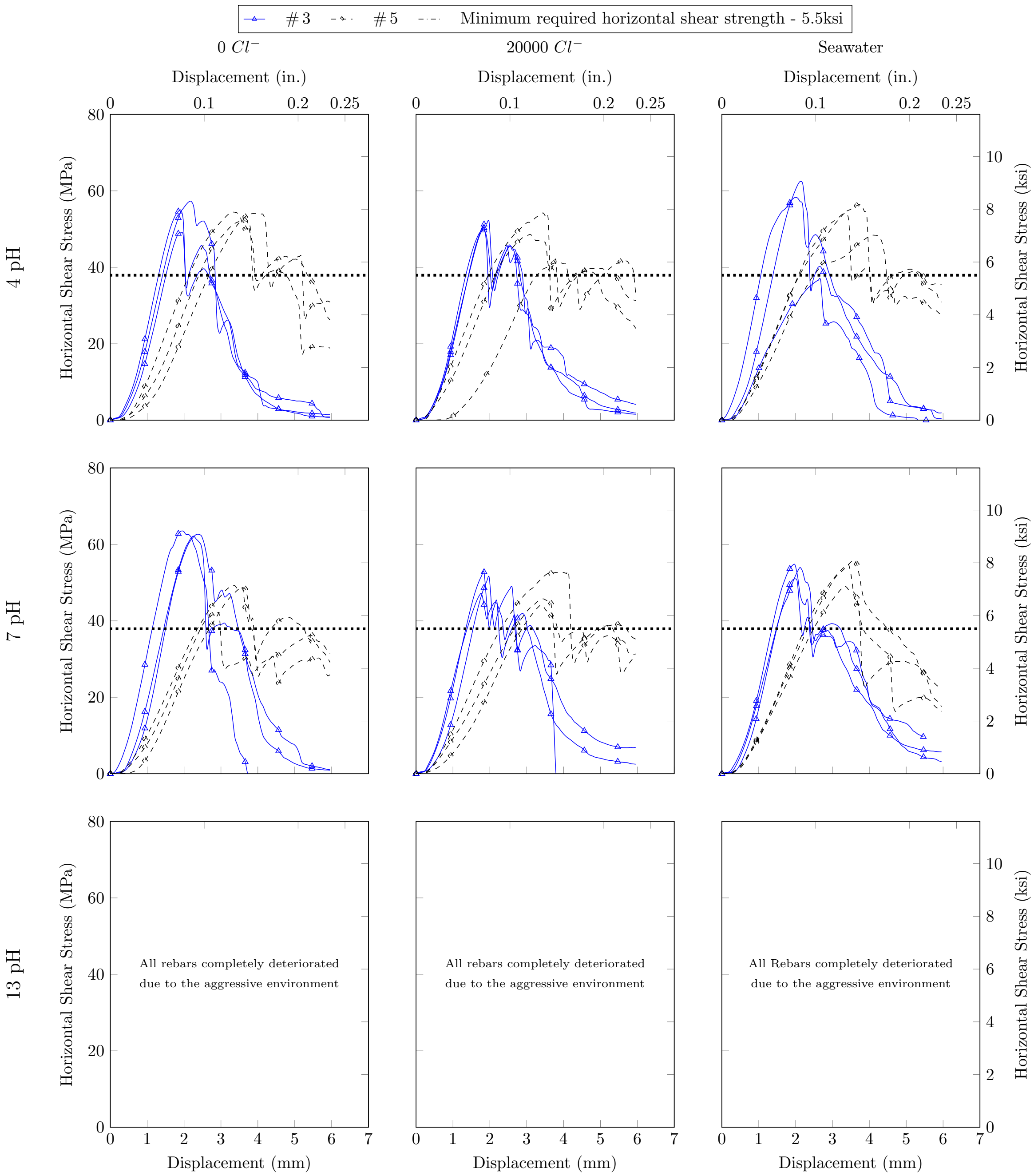

Figure 8.103: 600Day Horizontal shear stress - displacement behavior of Type C Lot2 tested rebars

8.5.4 Summary of Horizontal Shear Strength Properties

The statistical values for the horizontal shear strength properties of the tested products are listed in the following Table 8.44. A total of 250 specimens, five for each type, each size, lot, and exposure type were tested in total. The average of five specimens was assigned to each sample (specimen group) as shown in the table.

Table 8.44: 600Day Horizontal Shear test statistical values for each sample group (US Customary Units)

Sample Group						Statistical Values				
						Shear Stress				
Type	Resin Type	Size #	Lot No.	pH	Cl^-	$\wedge$ ksi	$\vee$ ksi	μ ksi	σ ksi	CV %
TypeA	Epoxy	3	1	4	0	8.0	9.1	8.4	0.7	7.76
TypeA	Epoxy	5	1	4	0	6.4	7.5	6.9	0.6	7.95
TypeB	VinylEster	3	1	4	0	3.8	5.0	4.3	0.6	13.38
TypeB	VinylEster	5	1	4	0	5.8	6.3	6.0	0.2	4.08
TypeC	Epoxy	3	1	4	0	6.4	7.4	7.0	0.5	7.61
TypeC	Epoxy	5	1	4	0	7.4	8.0	7.7	0.3	4.08
TypeA	Epoxy	3	1	4	20000	7.6	8.5	8.0	0.5	5.81
TypeA	Epoxy	5	1	4	20000	7.0	7.4	7.2	0.3	3.55
TypeB	VinylEster	3	1	4	20000	3.8	5.3	4.7	0.8	16.53
TypeB	VinylEster	5	1	4	20000	6.1	6.4	6.3	0.2	2.64
TypeC	Epoxy	3	1	4	20000	2.9	5.7	3.8	1.6	41.57
TypeC	Epoxy	5	1	4	20000	7.2	8.4	7.8	0.6	7.50
TypeA	Epoxy	3	1	4	SeaWater	8.7	8.8	8.8	0.1	0.71
TypeA	Epoxy	5	1	4	SeaWater	6.3	7.8	7.2	0.8	10.94
TypeB	VinylEster	3	1	4	SeaWater	4.3	6.0	5.3	0.9	17.33
TypeB	VinylEster	5	1	4	SeaWater	6.3	6.5	6.4	0.1	2.07
TypeC	Epoxy	3	1	4	SeaWater	6.8	7.6	7.2	0.4	4.99
TypeC	Epoxy	5	1	4	SeaWater	7.3	8.8	8.0	0.7	8.95
TypeA	Epoxy	3	2	4	0	0.4	0.5	0.5	0.1	16.07
TypeA	Epoxy	5	2	4	0	6.6	7.8	7.2	0.6	8.24
TypeB	VinylEster	3	2	4	0	5.1	6.4	5.7	0.7	11.80
TypeB	VinylEster	5	2	4	0	5.9	6.4	6.3	0.3	4.62
TypeC	Epoxy	3	2	4	0	7.1	8.3	7.8	0.6	7.79
TypeC	Epoxy	5	2	4	0	7.6	7.9	7.8	0.2	2.28
TypeA	Epoxy	3	2	4	20000	0.2	0.3	0.2	0.0	21.11
TypeA	Epoxy	5	2	4	20000	6.3	7.4	6.8	0.5	7.43
TypeB	VinylEster	3	2	4	20000	4.9	6.2	5.7	0.8	13.26
TypeB	VinylEster	5	2	4	20000	5.7	5.8	5.8	0.1	1.44
TypeC	Epoxy	3	2	4	20000	7.3	7.6	7.4	0.1	2.01
TypeC	Epoxy	5	2	4	20000	6.1	7.9	7.0	0.9	13.03
TypeA	Epoxy	3	2	4	SeaWater	0.6	1.5	1.0	0.4	44.30
TypeA	Epoxy	5	2	4	SeaWater	4.6	5.1	4.8	0.2	5.03
TypeB	VinylEster	3	2	4	SeaWater	5.1	6.5	6.0	0.8	12.75
TypeB	VinylEster	5	2	4	SeaWater	5.5	6.4	6.0	0.5	8.07
TypeC	Epoxy	3	2	4	SeaWater	5.3	9.1	7.6	2.0	26.48
TypeC	Epoxy	5	2	4	SeaWater	7.0	8.2	7.7	0.6	7.85
TypeA	Epoxy	3	1	7	0	4.1	8.6	7.0	2.5	35.78
TypeA	Epoxy	5	1	7	0	7.1	7.8	7.5	0.4	4.76
TypeB	VinylEster	3	1	7	0	3.7	7.9	5.2	2.3	44.86
TypeB	VinylEster	5	1	7	0	5.5	6.2	5.9	0.3	5.75
TypeC	Epoxy	3	1	7	0	7.2	8.2	7.9	0.5	6.89
TypeC	Epoxy	5	1	7	0	7.4	7.8	7.7	0.2	3.21
TypeA	Epoxy	3	1	7	20000	8.2	9.0	8.4	0.5	5.35
TypeA	Epoxy	5	1	7	20000	7.0	7.7	7.3	0.4	5.27
TypeB	VinylEster	3	1	7	20000	3.9	5.6	4.8	0.9	18.40
TypeB	VinylEster	5	1	7	20000	6.1	6.4	6.2	0.1	2.34
TypeC	Epoxy	3	1	7	20000	5.2	8.9	7.6	2.1	27.96
TypeC	Epoxy	5	1	7	20000	7.3	8.2	7.8	0.5	5.95
TypeA	Epoxy	3	1	7	SeaWater	0.2	0.2	0.2	0.0	13.45
TypeA	Epoxy	5	1	7	SeaWater	7.1	7.1	7.1	0.0	0.43

Continued on next page . . .

Table 8.44: 600Day Horizontal Shear test statistical values for each sample group (US Customary Units)

Sample Group						Statistical Values				
						Shear Stress				
Type	Resin Type	Size #	Lot No.	pH	Cl^-	$\wedge$ ksi	$\vee$ ksi	μ ksi	σ ksi	CV %
TypeB	VinylEster	3	1	7	SeaWater	5.8	6.4	6.1	0.3	5.42
TypeB	VinylEster	5	1	7	SeaWater	5.9	6.7	6.3	0.4	5.83
TypeC	Epoxy	3	1	7	SeaWater	7.6	8.3	7.8	0.4	4.89
TypeC	Epoxy	5	1	7	SeaWater	7.2	7.7	7.4	0.3	3.40
TypeA	Epoxy	3	2	7	0	3.9	4.6	4.3	0.4	8.44
TypeA	Epoxy	5	2	7	0	6.6	7.9	7.2	0.6	8.53
TypeB	VinylEster	3	2	7	0	5.1	6.7	6.2	0.9	14.82
TypeB	VinylEster	5	2	7	0	6.0	6.5	6.2	0.3	4.70
TypeC	Epoxy	3	2	7	0	9.0	9.2	9.1	0.1	1.11
TypeC	Epoxy	5	2	7	0	6.1	7.2	6.8	0.6	8.78
TypeA	Epoxy	3	2	7	20000	0.7	1.7	1.2	0.5	40.62
TypeA	Epoxy	5	2	7	20000	6.8	7.1	6.9	0.2	2.61
TypeB	VinylEster	3	2	7	20000	5.7	6.4	6.1	0.3	5.73
TypeB	VinylEster	5	2	7	20000	5.9	6.2	6.1	0.1	2.44
TypeC	Epoxy	3	2	7	20000	6.9	7.7	7.4	0.4	5.97
TypeC	Epoxy	5	2	7	20000	6.4	7.7	6.9	0.7	9.53
TypeA	Epoxy	3	2	7	SeaWater	7.7	9.1	8.4	0.7	8.43
TypeA	Epoxy	5	2	7	SeaWater	6.3	7.5	6.9	0.6	8.21
TypeB	VinylEster	3	2	7	SeaWater	4.8	6.1	5.5	0.6	11.66
TypeB	VinylEster	5	2	7	SeaWater	5.9	6.8	6.3	0.4	6.84
TypeC	Epoxy	3	2	7	SeaWater	7.4	7.9	7.7	0.3	3.80
TypeC	Epoxy	5	2	7	SeaWater	7.2	8.1	7.7	0.5	6.55

For numerical comparison and concluding values, Table 8.44 lists the minimum shear stress ($\wedge$), the maximum shear stress ($\vee$), the average shear stress (μ), the standard deviation (σ), and the coefficient of variation (CV) for each individual test sample.

8.5.5 Tensile Test

The rebars were tested according to the ASTM D 7205 (ASTM-International, 2015a) to evaluate the tensile properties. The recorded and processed data of the tensile strength test are shown in this section via graphs and table.

Load-Displacement Behavior

To compare the load-displacement behavior of the different rebar samples and specimens, the graphs in Figures 8.104, 8.105, 8.106, 8.107, 8.108, and 8.109 plot the recorded test data. As shown, the x-axis of the graph represents the cross-head extension—which has to be interpreted with care because it includes the elastic deformation of the load frame and the test fixtures—and the y-axis indicates the applied and measured load. Figure 8.104 shows that # 5 rebar Type A sustained higher failure load in comparison with # 3 rebars and the extension of rebar # 5 was almost thrice that of the # 3 rebars extension. Figure 8.105 shows that the extension of # 5 was more than twice in comparison with # 3 rebars and the peak load was much higher. All the rebars failed in similar fashion. The following graph in Figure 8.106 illustrate the test results for the # 3 and # 5 Type C rebars from Lot 1. After comparing Figures 8.107, 8.108, and 8.109 it can be seen that the rebars of the same size from both the lots of all rebar types sustained the same peak load and failed in the same mode. The extension of rebars from lot 2 of both types was similar to rebars from lot 1 for both sizes. The specimens demonstrated a linear characteristic at around 10 kN until the peak load. The common behavior after the maximum load was overcome was a stepwise loss of load with little inclines

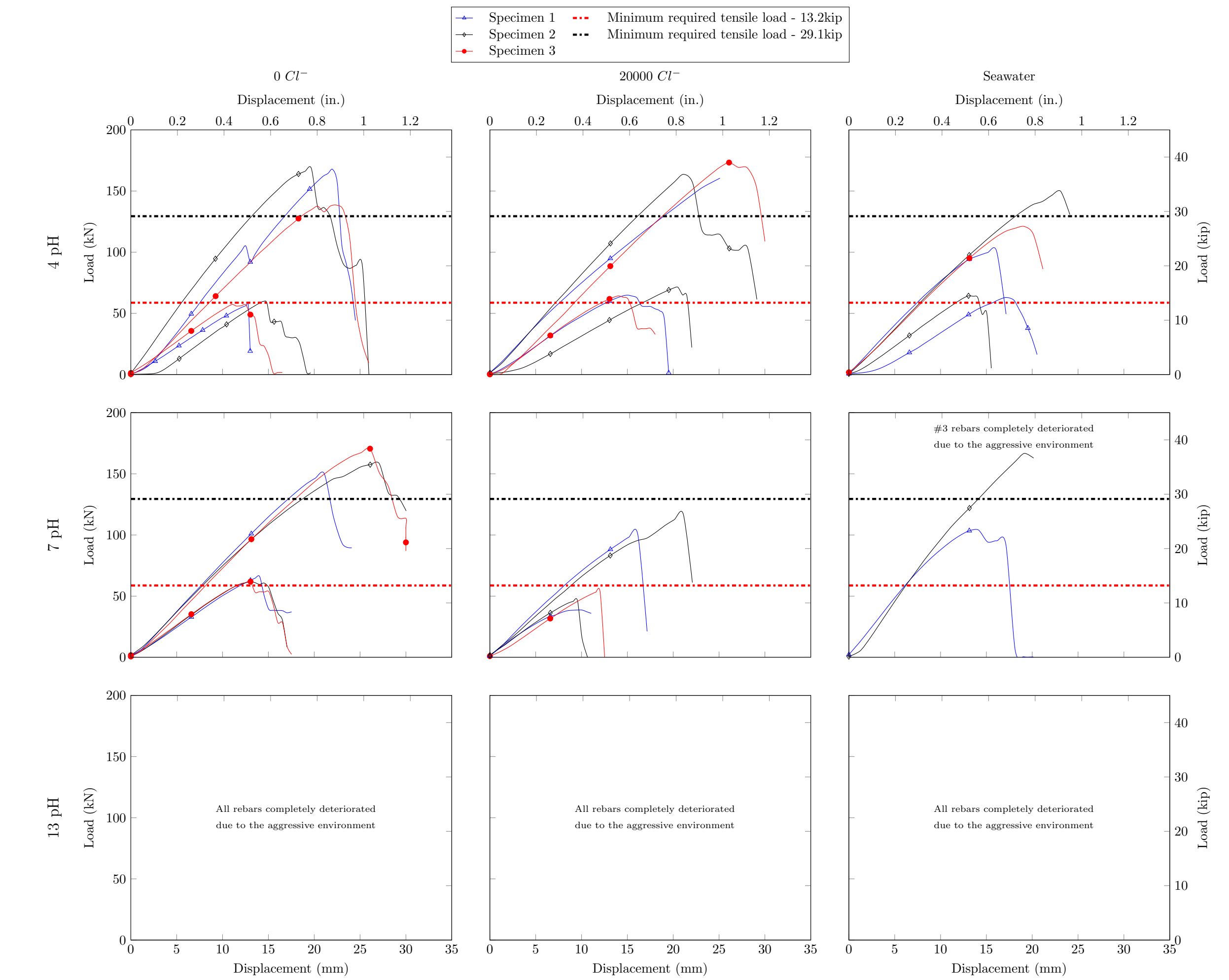

Figure 8.104: 600Day Tensile strength-displacement behavior of rebar Type A Lot 1 size 3 and 5

until the next load loss occurred. With increasing cross-head extension in the post-failure region, the load decreased slightly, but then stagnated or even regained some strength throughout further extension, multiple times, until the specimen failed completely. During testing, it was observed that after the maximum load was reached, the rebars delaminated and flared out more and more, as these load-drops occurred.

Stress-Strain Behavior

The stress-strain behavior of the failed rebars of all types was plotted to quantify and compare the elastic moduli of the tested BFRP rebars. The data in Figures 8.110, 8.111, 8.112, 8.113, 8.114, and 8.115 were plotted to compare the stress-strain behavior of the different rebar types. Accordingly, the x-axis shows the applied stress while the y-axis represents the outermost surface strain that was measured with an external extensometer. The results plotted in the graph in Figure 8.110 show that though the load capacities of the different sized rebars vary widely, the slope of the stress-strain curve was identical for all the rebars. It can be seen in Figure 8.111 that stress-strain behavior of rebar Type B are identical for both the rebar sizes.

The stress-strain behavior of rebars from lot 2 as shown in Figures 8.113, 8.114, and 8.115 show that the slopes of bars from Lot 1 and Lot 2 were identical.

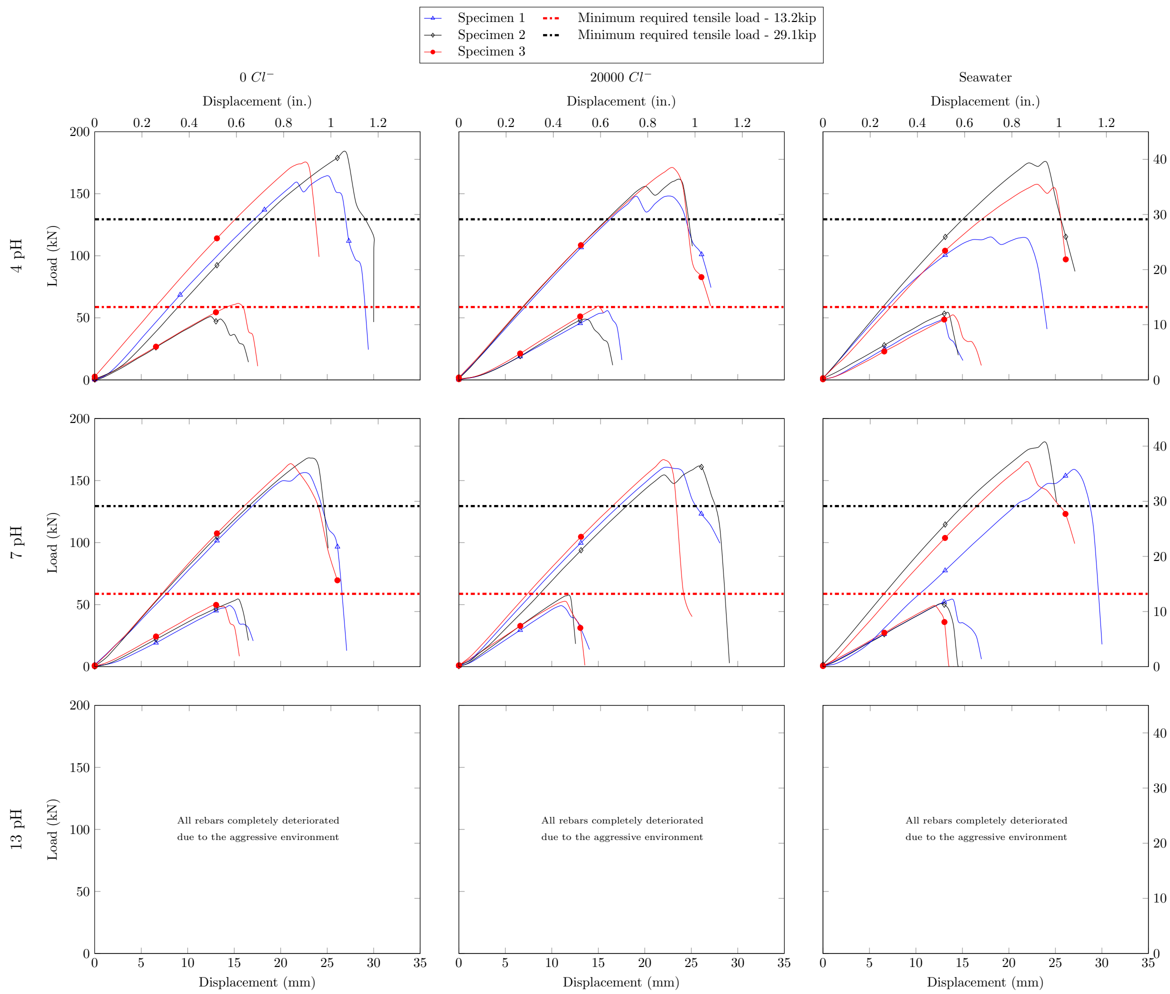

Figure 8.105: 600Day Tensile strength-displacement behavior of rebar Type B Lot 1 size 3 and 5

8.5.6 Summary of Tensile Properties

The concentration of the statistical evaluation for the measured tensile properties of all products along with the elastic modulus property are listed in the following Table 8.45.

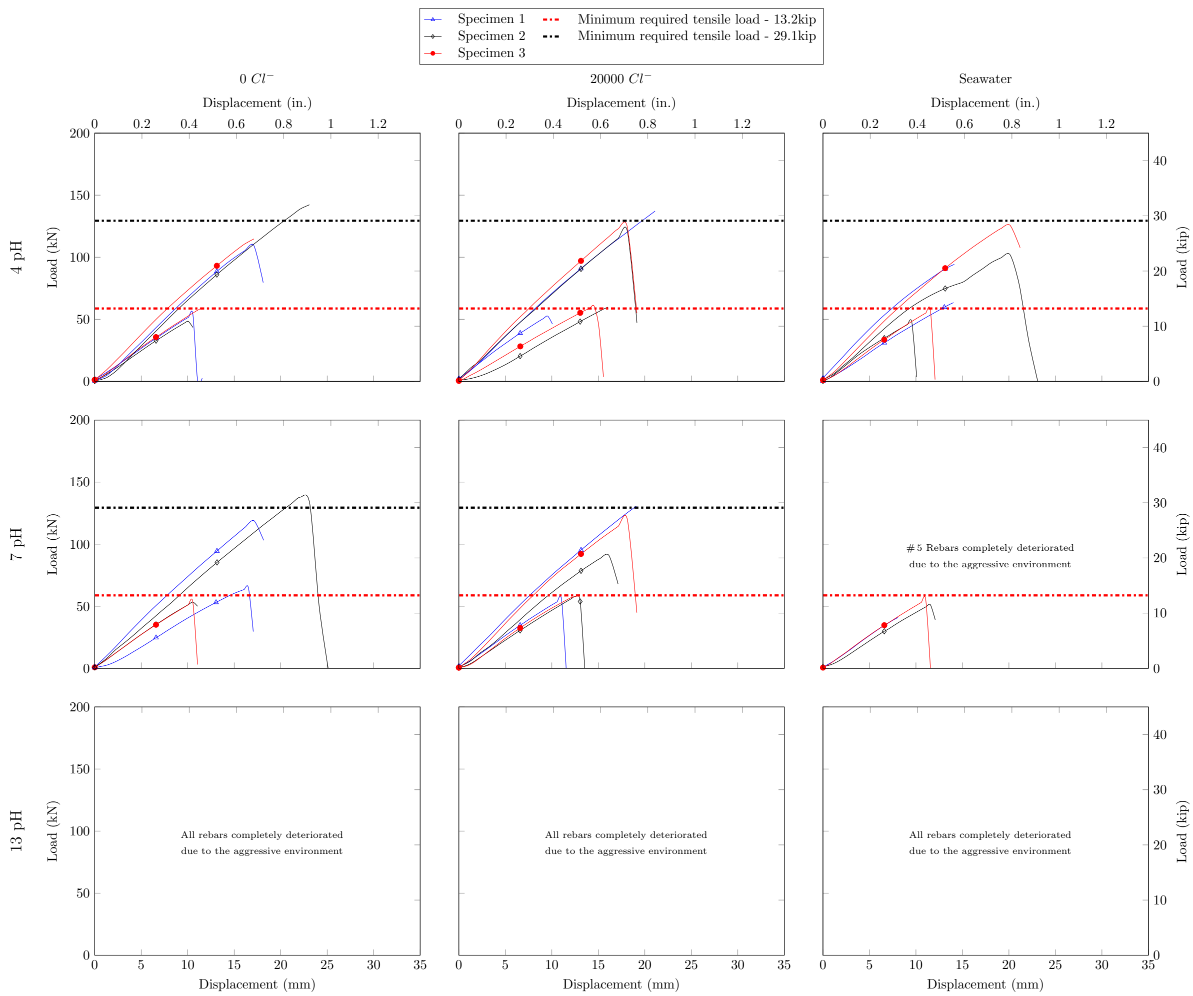

Figure 8.106: 600Day Tensile strength-displacement behavior of rebar Type C Lot 1 size 3 and 5

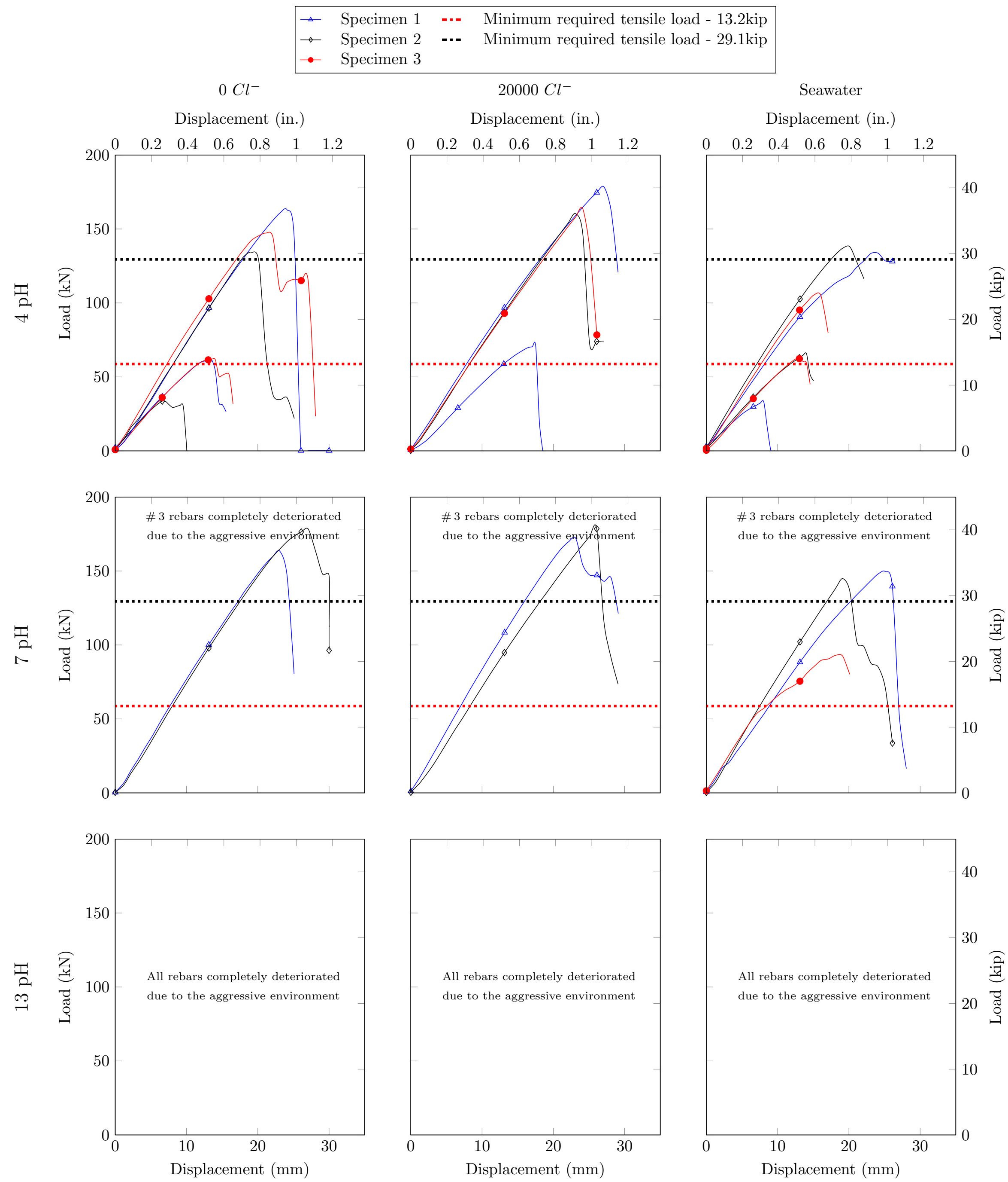

Figure 8.107: 600Day Tensile strength-displacement behavior of rebar Type A Lot 2 size 3 and 5

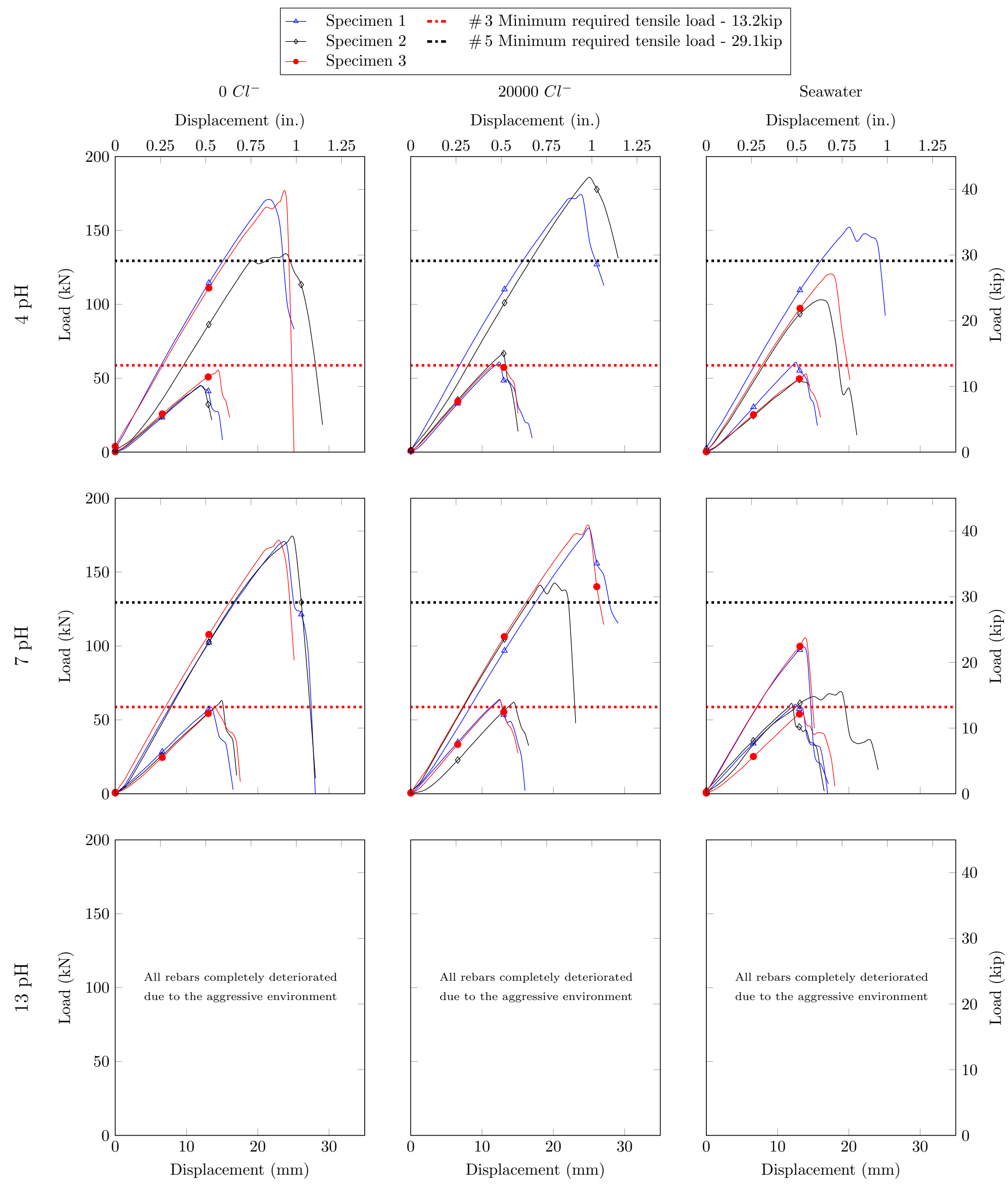

Figure 8.108: 600Day Tensile strength-displacement behavior of rebar Type B Lot 2 size 3 and 5

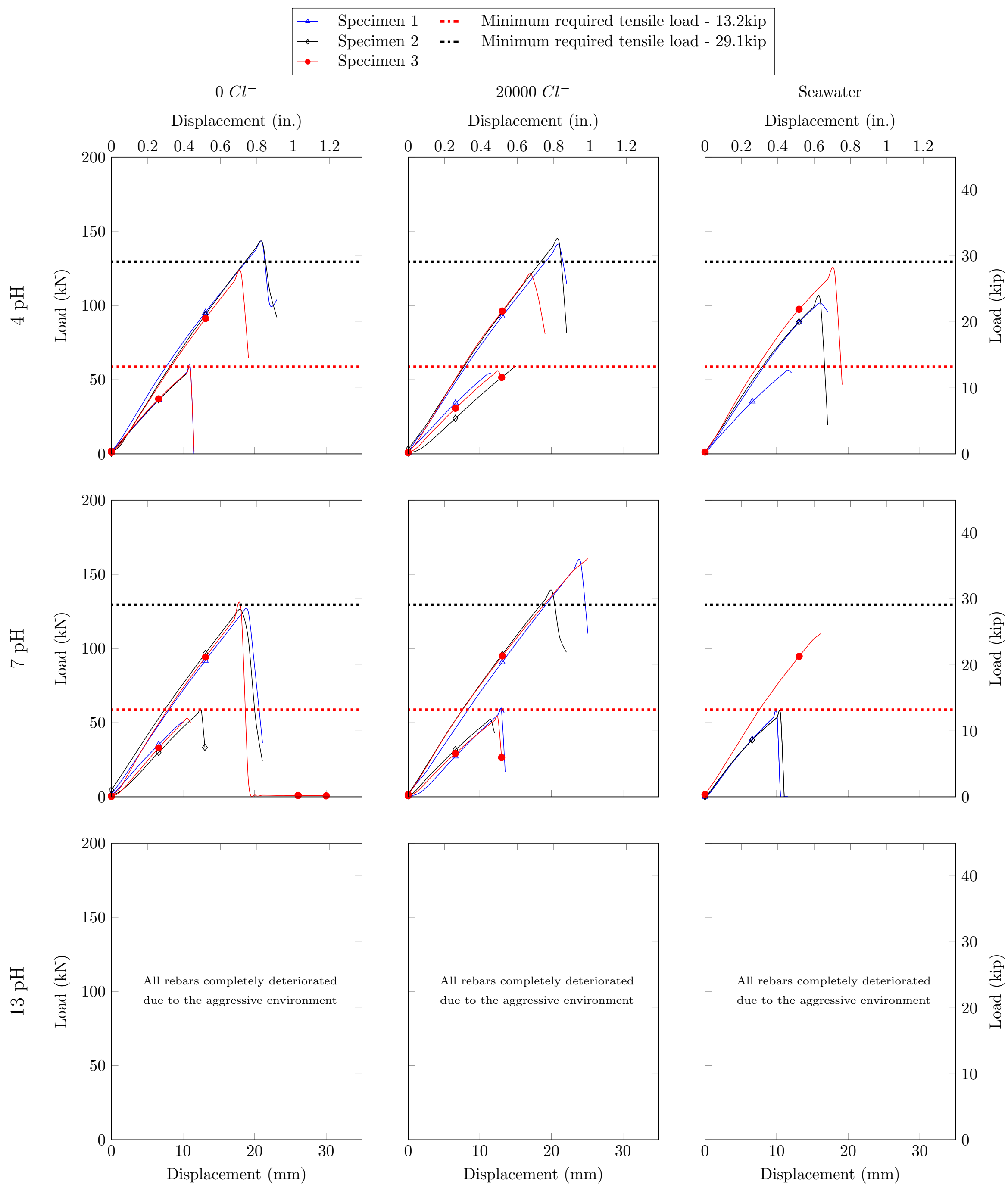

Figure 8.109: 600Day Tensile strength-displacement behavior of rebar Type C Lot 2 size 3 and 5

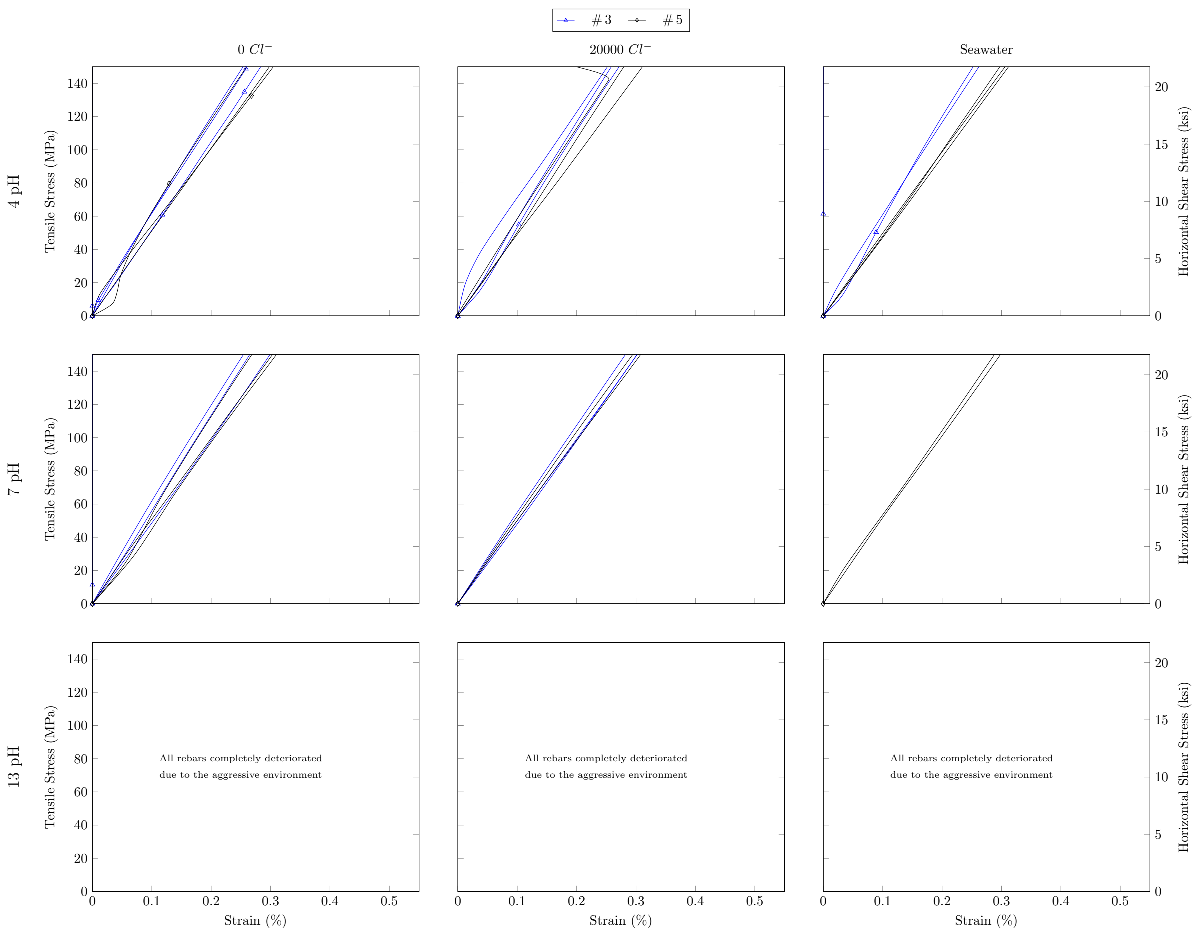

Figure 8.110: 600Day Tensile stress - Strain behavior of rebar Type A Lot 1 size 3 and 5

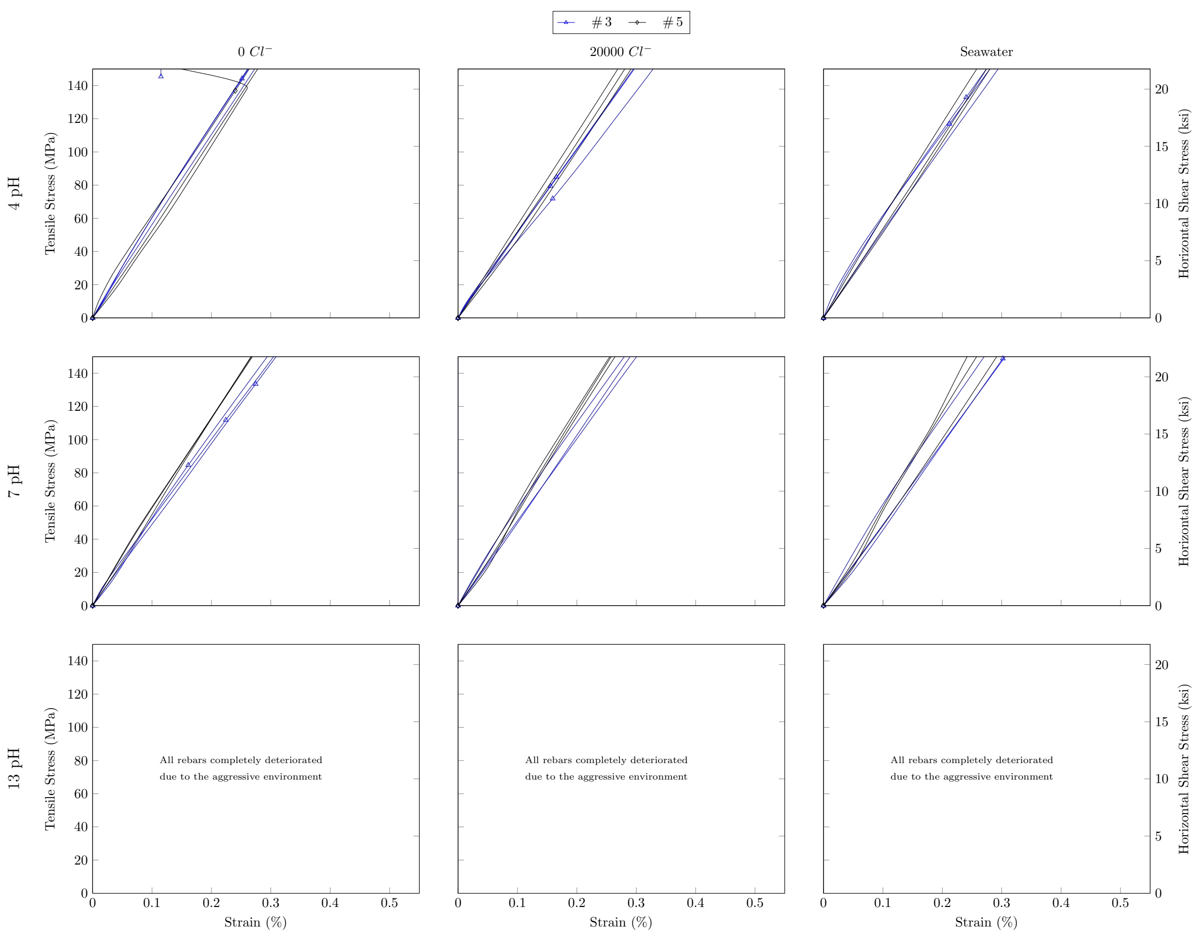

Figure 8.111: 600Day Tensile stress - Strain behavior of rebar Type B Lot 1 size 3 and 5

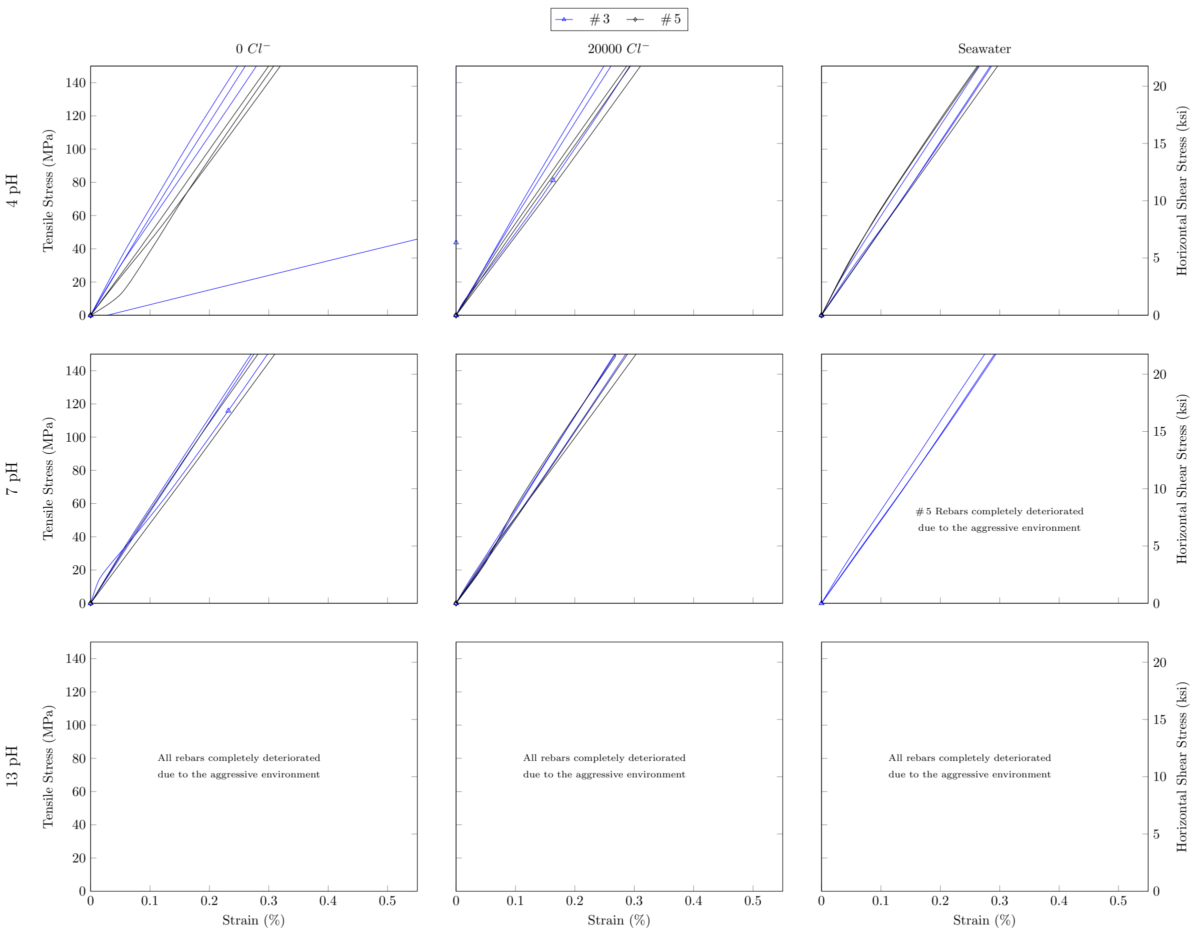

Figure 8.112: 600Day Tensile stress - Strain behavior of rebar Type C Lot 1 size 3 and 5

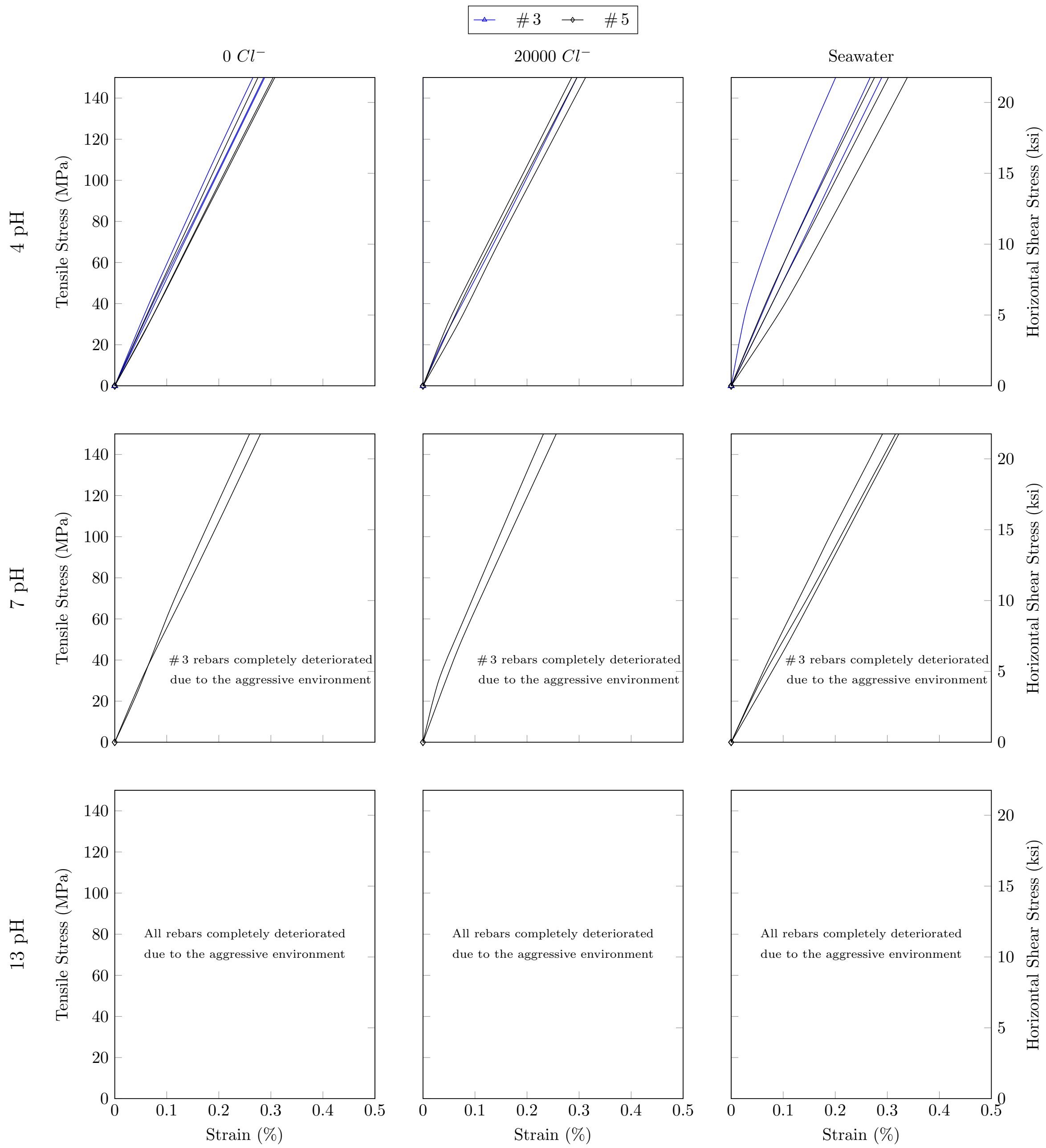

Figure 8.113: 600Day Tensile stress - Strain behavior of rebar Type A Lot 2 size 3 and 5

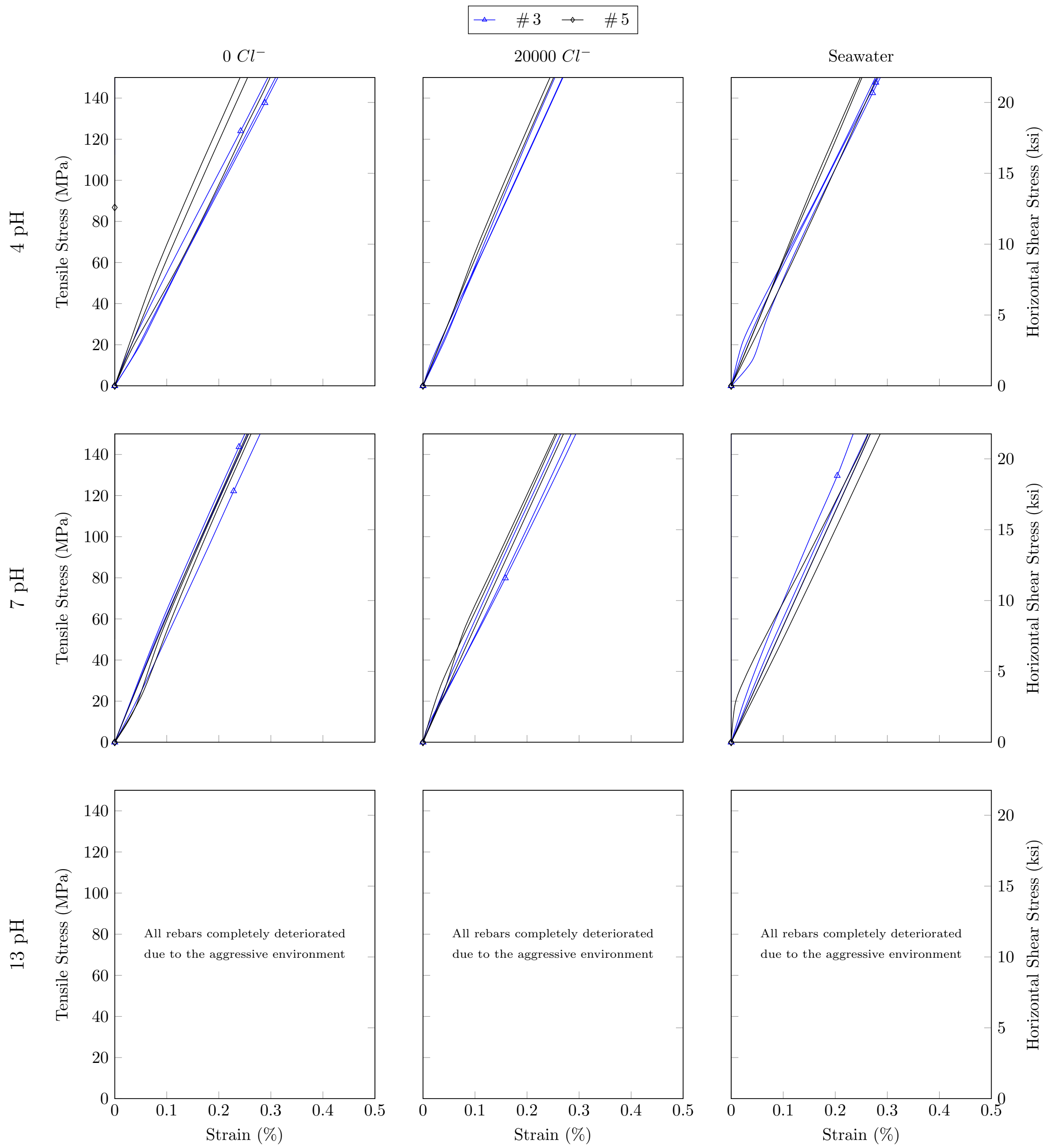

Figure 8.114: 600Day Tensile stress - Strain behavior of rebar Type B Lot 2 size 3 and 5

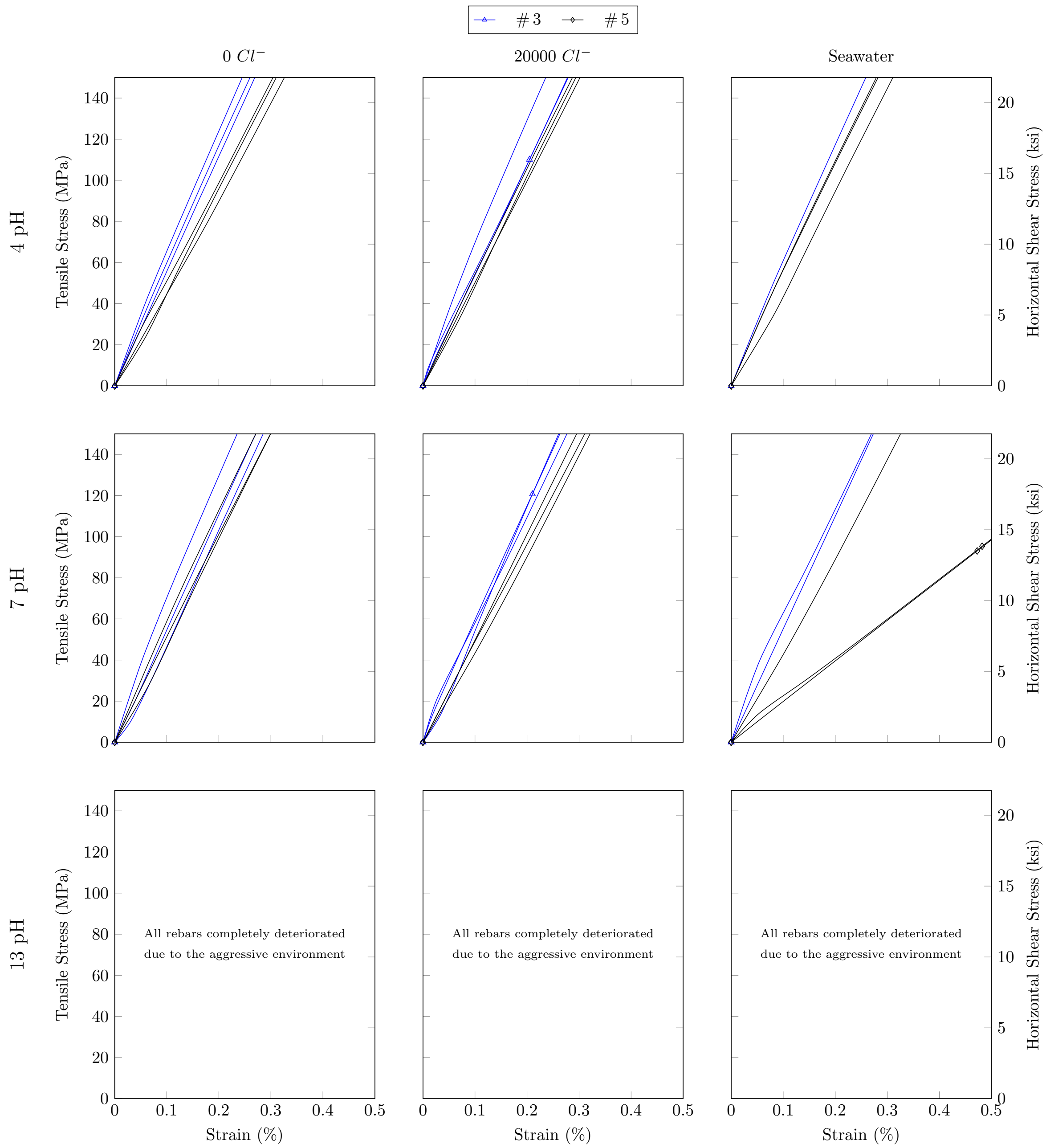

Figure 8.115: 600Day Tensile stress - Strain behavior of rebar Type C Lot 2 size 3 and 5

Table 8.45: 600Day Tensile strength test statistical values for each sample group (US Customary Units)

Sample group						Statistical Values									
						Tensile Strength					Elastic Modulus				
Manuf. Type	Resin Type	Size #	Lot No.	pH	Cl^-	$\wedge$ ksi	$\vee$ ksi	μ ksi	σ ksi	CV %	$\wedge$ ksi	$\vee$ ksi	μ ksi	σ ksi	CV %
A	Epoxy	3	1	4	0	115.4	121.8	117.6	3.6	3.10	7803	8257.4	7993.5	236.0	2.95
A	Epoxy	5	1	4	0	103.3	124.2	117.0	11.8	10.10	6762	7910.1	7309.8	575.8	7.88
A	Epoxy	3	2	4	0	67.1	124.8	104.2	32.2	30.88	7475	7904.9	7643.6	229.5	3.00
A	Epoxy	5	2	4	0	100.2	119.4	109.8	9.6	8.73	7171	7797.1	7406.1	340.8	4.60
B	VinylEster	3	1	4	0	104.3	125.3	115.9	10.7	9.24	7814	8067.0	7957.6	130.2	1.64
B	VinylEster	5	1	4	0	121.1	134.7	128.0	6.8	5.31	7903	8172.0	8020.3	137.7	1.72
B	VinylEster	3	2	4	0	90.9	111.9	98.5	11.6	11.78	7020	7241.5	7110.0	116.5	1.64
B	VinylEster	5	2	4	0	97.8	125.8	115.5	15.3	13.29	7575	8315.9	8026.0	396.2	4.94
C	Epoxy	3	1	4	0	97.6	119.2	108.2	10.8	9.97	7571	8322.3	8014.3	393.6	4.91
C	Epoxy	5	1	4	0	80.4	104.8	89.7	13.2	14.71	6933	7741.8	7330.0	404.5	5.52
C	Epoxy	3	2	4	0	108.9	114.1	111.1	2.7	2.40	8064	8410.8	8225.8	174.6	2.12
C	Epoxy	5	2	4	0	89.9	105.5	99.9	8.7	8.68	6726	7176.2	6983.8	231.8	3.32
A	Epoxy	3	1	4	20000	130.6	144.9	135.7	8.0	5.87	7548	8333.3	7991.7	402.3	5.03
A	Epoxy	5	1	4	20000	117.0	127.8	122.1	5.4	4.45	6973	8002.3	7642.0	580.3	7.59
A	Epoxy	5	2	4	20000	121.3	130.8	124.6	5.4	4.32	7080	7281.8	7156.5	109.5	1.53
B	VinylEster	3	1	4	20000	100.1	122.0	112.4	11.2	10.00	6567	7357.6	7082.6	446.9	6.31
B	VinylEster	5	1	4	20000	111.0	124.2	117.9	6.6	5.61	7793	8150.4	7958.0	180.4	2.27
B	VinylEster	3	2	4	20000	119.7	136.1	125.9	8.9	7.07	7896	8526.0	8146.9	334.0	4.10
B	VinylEster	5	2	4	20000	128.3	135.9	132.1	5.4	4.06	8433	8460.9	8446.8	19.9	0.24
C	Epoxy	3	1	4	20000	105.8	123.8	116.7	9.6	8.22	7630	8613.6	8140.5	492.8	6.05
C	Epoxy	5	1	4	20000	89.9	101.1	94.3	6.0	6.32	7057	7415.3	7269.6	187.9	2.58
C	Epoxy	3	2	4	20000	108.3	120.9	114.8	6.3	5.48	7763	8488.9	8022.6	404.8	5.05
C	Epoxy	5	2	4	20000	91.0	105.5	100.1	7.9	7.89	7178	7524.7	7375.4	178.1	2.41
A	Epoxy	3	1	4	Seawater	127.4	131.5	129.4	2.9	2.21	7962	8681.2	8321.5	508.7	6.11
A	Epoxy	5	1	4	Seawater	73.3	109.9	90.2	18.4	20.43	7088	7468.5	7217.9	217.1	3.01
A	Epoxy	3	2	4	Seawater	61.2	131.1	106.5	39.3	36.89	7594	8381.5	7933.8	404.7	5.10
A	Epoxy	5	2	4	Seawater	77.2	99.5	91.5	12.4	13.57	6760	7473.3	7109.6	356.8	5.02
B	VinylEster	3	1	4	Seawater	99.4	108.5	105.3	5.1	4.89	7096	7371.8	7257.2	143.4	1.98
B	VinylEster	5	1	4	Seawater	85.6	128.4	109.6	21.9	19.97	7976	8198.7	8058.5	122.1	1.51
B	VinylEster	3	2	4	Seawater	102.2	125.3	111.5	12.2	10.96	7222	7604.9	7393.9	194.4	2.63
B	VinylEster	5	2	4	Seawater	75.2	111.4	91.7	18.3	19.94	7973	8572.5	8365.3	339.7	4.06
C	Epoxy	3	1	4	Seawater	97.5	129.2	114.7	16.0	13.96	7668	7928.6	7808.2	131.7	1.69

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Table 8.45: 600Day Tensile strength test statistical values for each sample group (US Customary Units)

Sample group						Statistical Values									
						Tensile Strength					Elastic Modulus				
Manuf. Type	Resin Type	Size #	Lot No.	pH	Cl^-	$\wedge$ ksi	$\vee$ ksi	μ ksi	σ ksi	CV %	$\wedge$ ksi	$\vee$ ksi	μ ksi	σ ksi	CV %
C	Epoxy	5	1	4	Seawater	67.4	92.2	78.0	12.8	16.44	7285	7599.9	7463.5	161.7	2.17
C	Epoxy	3	2	4	Seawater	94.7	117.3	109.1	12.5	11.47	7856	8096.9	7974.1	120.8	1.51
C	Epoxy	5	2	4	Seawater	74.4	89.4	79.6	8.5	10.68	7325	7541.8	7429.4	108.6	1.46
A	Epoxy	5	1	7	0	111.1	125.5	117.6	7.3	6.24	7103	8169.8	7505.8	579.4	7.72
A	Epoxy	5	2	7	0	120.5	131.4	124.3	6.1	4.90	7667	8384.9	8043.3	360.1	4.48
B	VinylEster	3	1	7	0	100.7	111.2	104.8	5.6	5.35	6930	7247.2	7072.1	161.2	2.28
B	VinylEster	5	1	7	0	114.1	123.7	119.5	4.9	4.11	7866	8181.7	7972.8	180.9	2.27
B	VinylEster	3	2	7	0	118.1	126.3	120.9	4.6	3.83	7977	8234.8	8119.1	130.7	1.61
B	VinylEster	5	2	7	0	125.6	126.6	126.2	0.5	0.41	8260	8469.4	8352.0	106.9	1.28
C	Epoxy	3	1	7	0	109.2	131.7	116.8	12.9	11.06	7150	7866.2	7626.3	412.1	5.40
C	Epoxy	3	2	7	0	102.0	119.0	109.9	8.6	7.78	8061	8441.7	8193.0	215.5	2.63
C	Epoxy	5	2	7	0	90.1	93.4	92.1	1.8	1.92	7198	7651.6	7432.4	227.2	3.06
A	Epoxy	3	1	7	20000	122.8	134.3	127.4	6.1	4.81	7411	8238.3	7950.2	467.4	5.88
A	Epoxy	5	1	7	20000	73.5	112.8	90.5	20.2	22.27	6569	7272.3	6939.7	353.5	5.09
A	Epoxy	5	2	7	20000	125.9	132.1	127.9	3.6	2.78	6755	8466.1	7721.7	876.7	11.35
B	VinylEster	3	1	7	20000	99.1	117.5	107.9	9.2	8.56	7139	7651.7	7368.6	260.6	3.54
B	VinylEster	5	1	7	20000	117.5	122.7	120.3	2.7	2.21	8245	8394.6	8309.2	76.9	0.93
B	VinylEster	3	2	7	20000	125.0	128.8	127.3	2.0	1.60	7398	7974.3	7695.7	288.4	3.75
B	VinylEster	5	2	7	20000	107.6	132.4	123.7	14.0	11.27	7932	8053.9	7982.0	63.8	0.80
C	Epoxy	3	1	7	20000	111.9	120.5	116.9	4.5	3.85	7668	8222.4	7971.8	281.3	3.53
C	Epoxy	5	1	7	20000	88.3	102.8	95.6	10.2	10.73	6994	7488.4	7241.4	349.4	4.83
C	Epoxy	3	2	7	20000	105.8	117.4	110.4	6.1	5.54	7564	8552.1	8044.6	494.5	6.15
C	Epoxy	5	2	7	20000	101.6	117.0	111.4	8.5	7.67	6973	7488.9	7163.8	283.0	3.95
A	Epoxy	3	1	7	Seawater	76.1	107.8	91.5	15.8	17.30	7223	7547.9	7363.8	166.7	2.26
A	Epoxy	5	1	7	Seawater	75.2	126.5	100.9	36.3	35.98	7190	7512.8	7351.6	228.0	3.10
A	Epoxy	5	2	7	Seawater	67.6	109.5	95.2	23.9	25.09	6725	7179.0	6924.9	231.7	3.35
B	VinylEster	3	1	7	Seawater	99.3	109.5	104.6	5.1	4.85	7153	7586.5	7382.8	217.9	2.95
B	VinylEster	5	1	7	Seawater	116.9	130.2	124.8	6.6	5.28	2020	9157.2	6645.6	3159.3	47.54
B	VinylEster	3	2	7	Seawater	110.6	123.8	118.1	6.8	5.74	7971	8631.0	8224.4	355.7	4.32
B	VinylEster	5	2	7	Seawater	50.8	74.4	65.7	13.0	19.82	7435	8089.1	7776.9	327.8	4.22
C	Epoxy	3	1	7	Seawater	82.0	112.2	99.4	15.6	15.72	7491	7771.2	7641.3	141.1	1.85
C	Epoxy	5	1	7	Seawater	66.3	95.6	83.7	15.4	18.42	7036	7774.8	7478.7	390.7	5.22

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Table 8.45: 600Day Tensile strength test statistical values for each sample group (US Customary Units)

Sample group						Statistical Values									
						Tensile Strength					Elastic Modulus				
Manuf. Type	Resin Type	Size #	Lot No.	pH	Cl^{-}	$\wedge$ ksi	$\vee$ ksi	μ ksi	σ ksi	CV %	$\wedge$ ksi	$\vee$ ksi	μ ksi	σ ksi	CV %
C	Epoxy	3	2	7	Seawater	113.6	114.5	114.1	0.6	0.51	7558	7920.0	7739.0	255.9	3.31
C	Epoxy	5	2	7	Seawater	40.9	79.8	54.0	22.4	41.47	2721	6892.8	4155.0	2372.0	57.09

A total of 356 specimen, 5 per rebar size, type, lot, and exposure type were tested and analyzed to determine the results shown in the table. For numerical comparison and concluding values, Table 8.45 lists the minimum tensile stress ($\wedge$), the maximum tensile stress ($\vee$), the average tensile stress (μ), the standard deviation (σ), and the coefficient of variation (CV) for each individual test sample.

8.5.7 Bond-to-Concrete Strength

The bond stress τ_{max} (MPa or lbs./in.^{2}) for a circular bar diameter d (mm or in.) is given by Equation 8.1, in which F represents the recorded pullout load (N or lbs.) and L is the accurately measured bond length (mm or in.).

$$\tau_{max} = \frac{F}{d\pi L} \qquad [in \text{MPa } or \text{ psi}] \tag{8.1}$$

This formula was used to determine the bond behavior development and is the basis for the following graphs; Figure 8.116, 8.117, 8.118, 8.119, 8.120, and 8.121 depict the measured bond stresses along the rebar surfaces relative to the rebar slip at the free end. For clarity, the post failure measurements (at the onset of a 50 % load drop) were removed from these graphs. All tested specimens failed at the rebar-concrete interface in bond slip, without splitting the concrete open or without tensile failure. The bond capacity and the failure behavior of the BFRP rebar-concrete interface were affected by the surface enhancement features.

Bond-to-Concrete Behavior — Slip at Free End

The graphs in this section compare the bond stress - slip at free end of rebar. Graphs in Figure 8.116, 8.117, 8.118, 8.119, 8.120, and 8.121 portray bond stresses - slip at free end of the rebars of both the sizes. The x-axis of the graph signifies the measured bond stress, while the y-axis represents the slip of rebar at the free end. Generally, from the graphs in Figure 8.116, 8.117, and 8.118 it can be seen that each rebar type resulted in a consistent but distinct failure mode with ultimate stresses that were characteristic for each rebar type. All of the sand-coated rebars (Type B) showed a soft failure while the rebars with a deformed surface (Type A and C) failed suddenly with abrupt pullout.

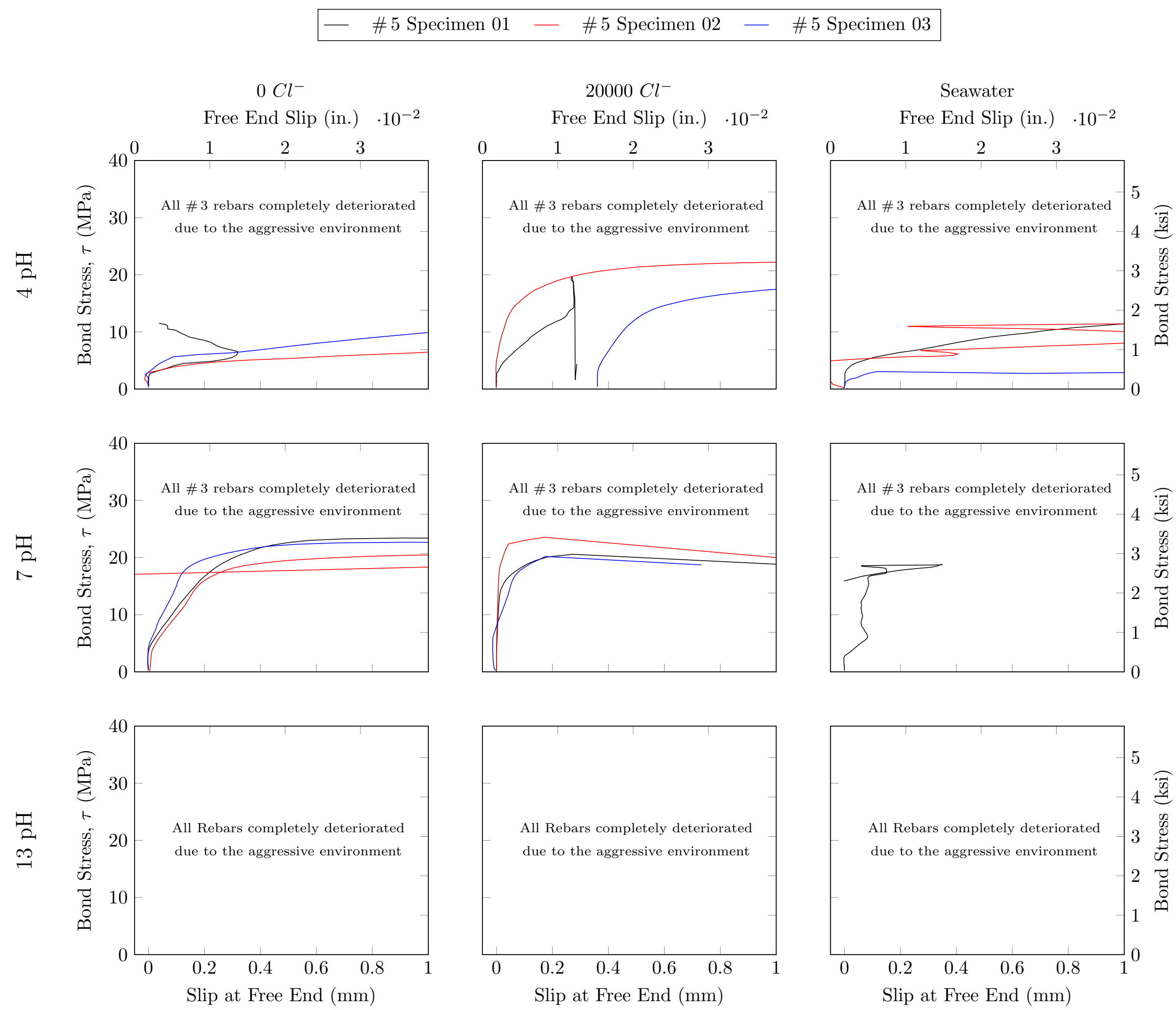

Figure 8.116: Bond stress - slippage behavior of rebar Type A Lot 1 rebars

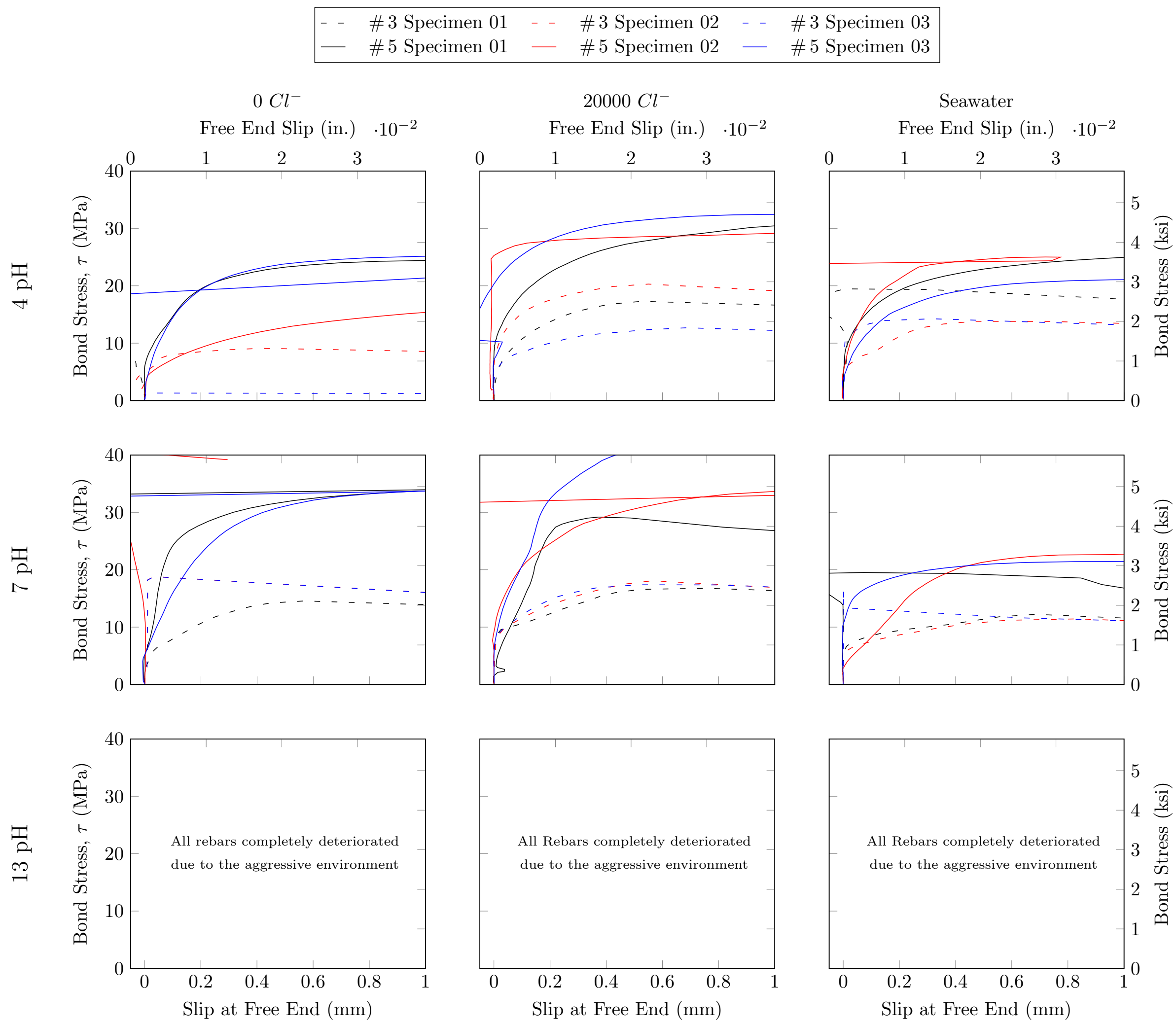

Figure 8.117: Bond stress - slippage behavior of rebar Type B Lot 1 rebars

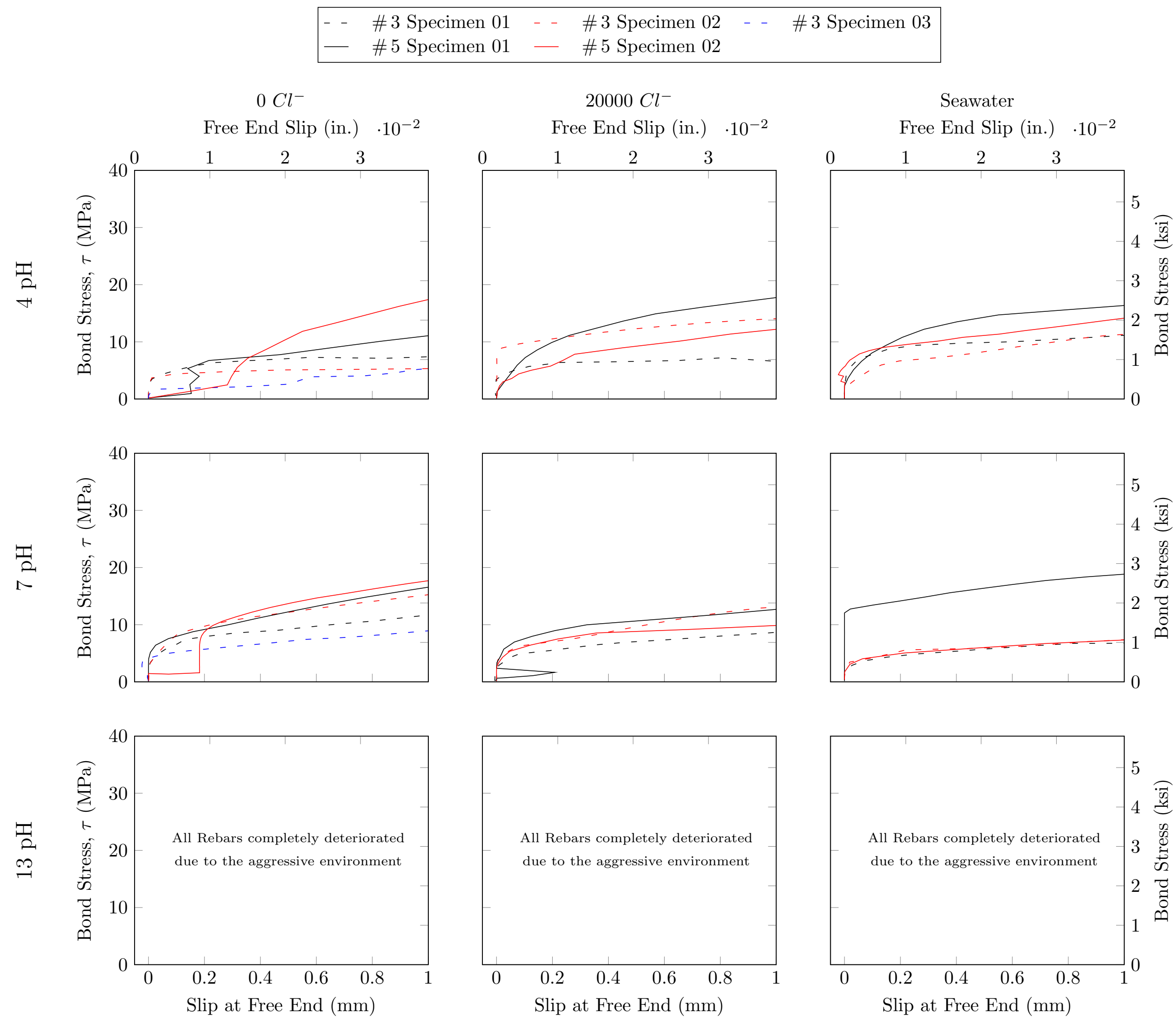

Figure 8.118: Bond stress - slippage behavior of rebar Type C Lot 1 rebars

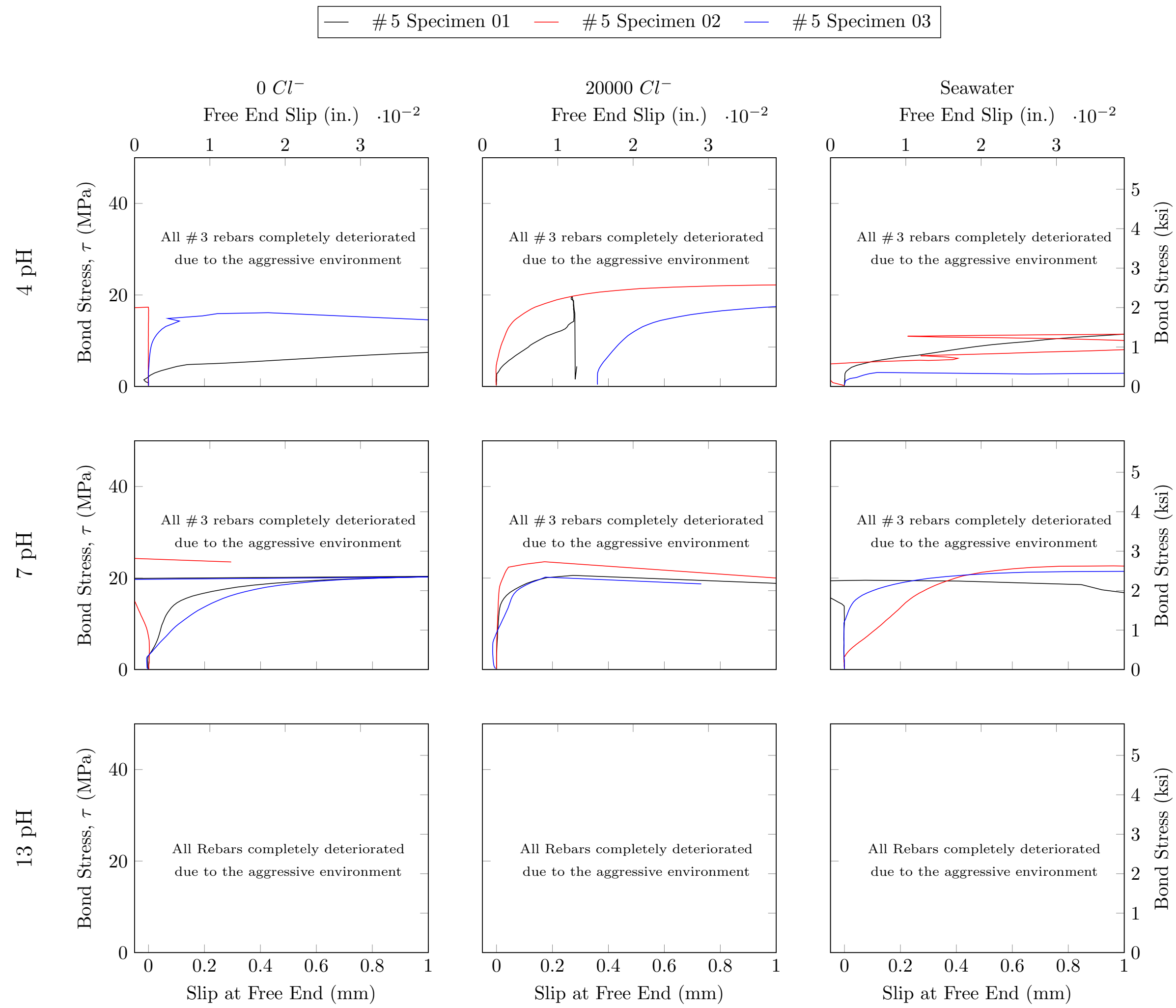

Figure 8.119: Bond stress - slippage behavior of rebar Type A Lot 2 rebars

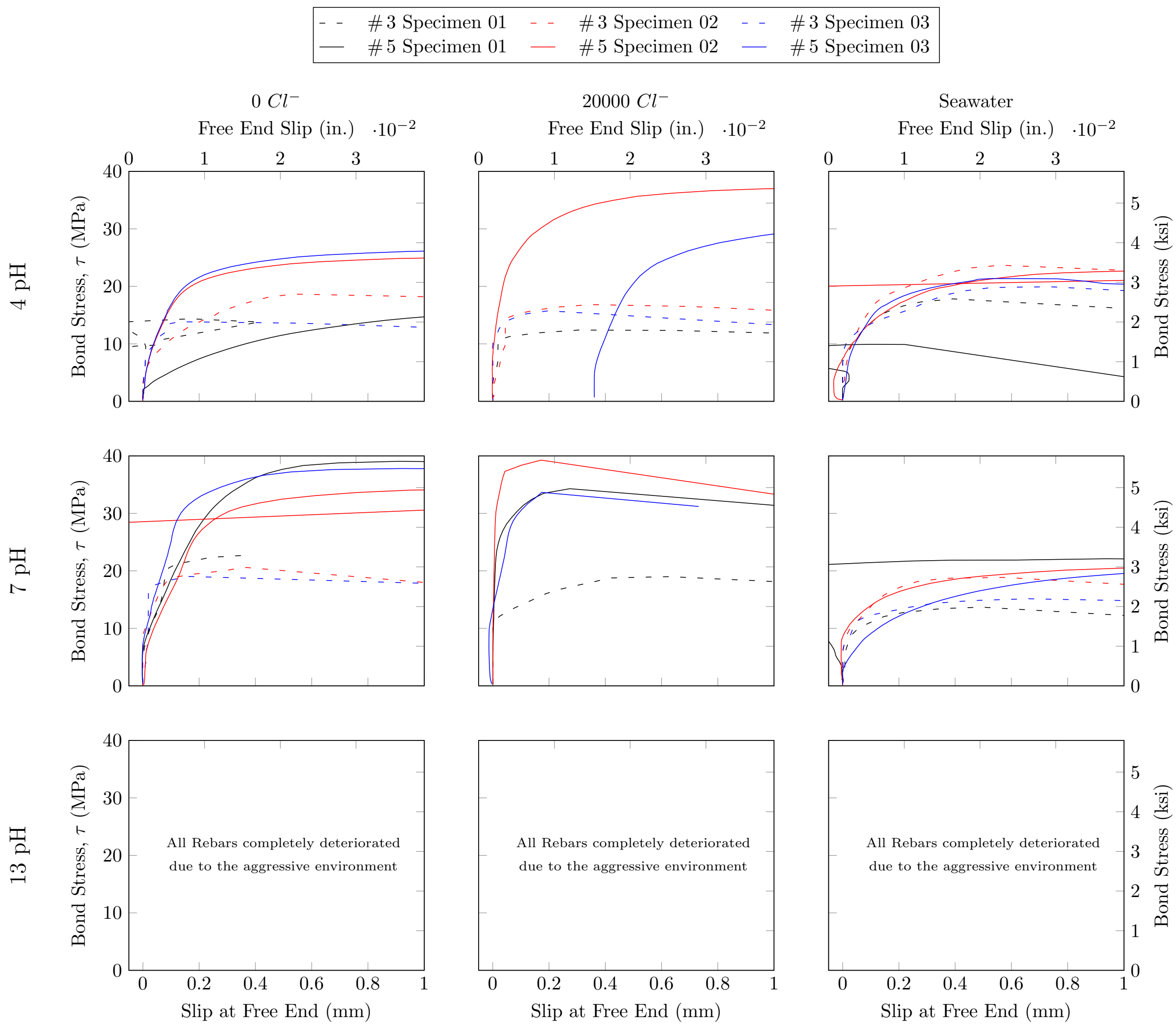

Figure 8.120: Bond stress - slippage behavior of rebar Type B Lot 2 rebars

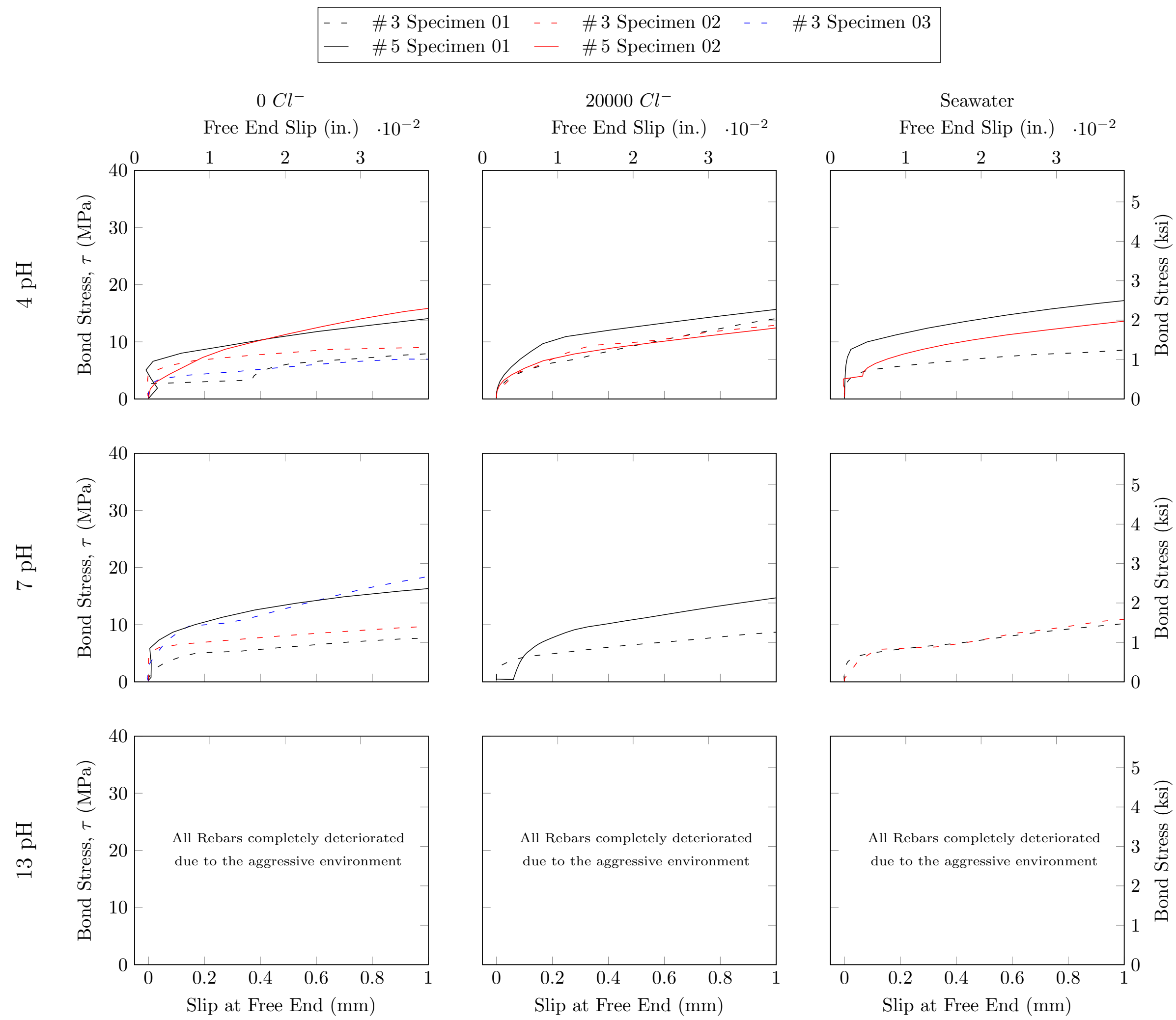

Figure 8.121: Bond stress - slippage behavior of rebar Type C Lot 2 rebars

Chapter 9

BFRP Rebar Characterization and Performance

In an effort to support the development of basalt-specific design criteria for AASHTO-LRFD Bridge Guidelines for BFRP bars, BFRP rebar specifications in FDOT Specifications Section 932, and ACI 440.1R, this research was conducted with a focus on virgin and aged physio-mechanical properties of readily available BFRP rebars and their material components, namely, fibers, sizing and resin matrices. A test plan was developed with a focus on physical properties of rebars such as cross-sectional properties, fiber content, moisture absorption, XRF analysis, and glass transition temperature, as well as mechanical properties including transverse shear strength, apparent horizontal shear strength, tensile properties, and bond-to-concrete characteristics for three dissimilar rebars including two sizes (# 3 and # 5) to evaluate the essential material properties for BFRP rebar characterization. A detailed test matrix consisting of nine different aggressive environments (3 pH levels and 3 Cl^- concentrations) was developed to study the effects of environmental degradation on BFRP rebars and their components, after the test samples were exposed to these aggressive environments at 60 °C for 300 d and 600 d. In the following sections, the findings of this research are discussed in further detail and studied in the context of the available and relevant literature to provide BFRP rebar implementation recommendations and suggestions for future design specifications. Because various material properties were experimentally evaluated throughout this research project and each property has its own specific relevance, these properties are individually discussed, before they are summarized. The individual properties were also correlated to each other, and these correlations are discussed too. Based on the established test standards and acceptance criteria for GFRP bars, BFRP rebars were classified for performance, and it was found that all test samples (specimen groups for rebar types A, B, and C) in their virgin state satisfied the minimum requirements available for GFRP rebars.

9.1 Research Significance

While BFRP rebars are regarded as a new material in civil engineering construction, they have been used successfully in demonstration and low-risk projects throughout the US and around the world. Because basalt specific acceptance criteria or material specifications do not exist and BFRP rebar properties are generally still determined, the results presented here are compared to the existing GFRP rebar criteria and specifications (Singha, 2012; Patnaik, 2009; Elgabbas et al., 2016). Before using new or emerging materials safely for infrastructure projects, the physical and mechanical properties must be evaluated and compared to acceptance criteria. In the case of emerging materials such as BFRP bars, acceptance criteria might not have been fully established yet and research is needed to characterize a variety of products to determine general market quality and to define adequate limiting values. More specifically, FDOT Specifications Section 932 provides defined minimum criteria for glass and carbon based FRP rebars, with values for BFRP rebars initially implemented in July 2020 based on the the same values as GFRP rebars. Likewise, while some design codes, e.g. the international building code AC454 (International Code Council, 2017), generally allow the use of BFRP rebars for engineering structures, some design guidelines in the USA, such as AASHTO LRFD guidelines (AASHTO, 2012, 2018), already provide specific procedures for the structural design with glass and carbon FRP rebars — using defined adjustment factors — explicit values for basalt have not been proposed yet. Therefore, to develop basalt specific criteria, in this report, recommendations for physical properties such as cross-sectional dimensions, fiber content, and moisture absorption properties for BFRP rebars are proposed based on the existing GFRP rebar recommendations in FDOT Specifications Section 932. In addition, recommendations for minimum mechanical properties, including the apparent horizontal shear strength, the transverse shear strength, the tensile properties, and the bond-to-concrete characteristics are suggested based on mechanical strength recommendations currently in use for GFRP bars as per FDOT Specifications Section 932. These suggestions are based on experimental material evaluations, the above presented analyses, and the accompanying literature. These efforts were necessary because acceptance criteria for the specific use of BFRP rebars in the U.S. are still missing. To address the shortcoming with environmental degradation factors for BFRP bars, rebars were exposed in nine different aggressive environments as discussed in the previous sections, and a long-term strength prediction model was developed to predict environmental degradation factor based on several factors. Therefore, this research project was needed to initiate the development of BFRP rebar specific acceptance criteria and to open the discussion about strength reduction factors for another rebar alternative. A detailed discussion addressing individual properties of BFRP bars based on the obtained results and long-term durability model is offered in the following sections.

9.2 Significant Findings

9.2.1 pH

pH of all liquid samples increased except for 13 pH samples, liquid samples of Type-A and C rebars and resin samples. The later three showed a decreasing trend. A partial explanation for the pH increase could be the diffusion of some of the alkali matters (K, Ca, Fe, Al etc.) from the surface of the solid specimens into the liquid samples. The reason for the resin samples to have a decreasing trend was its composition. The primary component of any organic compound is carbon (C), hydrogen (H) and oxygen (O). So, both the synthetic and the seawater environments had such effects on the resin which may have led to the diffusion of C and O into the liquid sample and forming carbon dioxide. Also, the pH droped significantly more for the Epoxy rebars in Lots A and C than the vinyl-ester rebar in Lots B. As mentioned earlier, resin is generally a composition C, H and O. The pH decreases leads to a release of more C and O into the solution. For the epoxy rebars, it is anticipated that the resin has degraded more into the solution, which has promoted more release of C and O that ultimately resulted in more pH drop than it was observed for the vinyl-ester rebar.

9.2.2 Salinity

The salinity concentration increased over time for all liquid samples except for the 13 pH samples. But for both types of resin samples, even the 13 pH solutions showed an increasing trend. A reasons for the salinity increase can be traced back to the diffusion of metal elements from the solid specimens into the liquid samples. This is true for samples having a pH level within 4-10. But for the pH 13 solutions, the degradation of the specimens were more severe, and the liquid samples for fiber and rebar showed some metal precipitation at the bottom which may be a reasons for the salinity decrease observed for these samples.

9.2.3 Dissolved Oxygen (DO)

The concentration of dissolved oxygen decreased for all liquid samples. The chemical concentration has an effect on the concentration of dissolved oxygen. It tends to decrease with the increase in chemical concentration. As more days passed, more chemicals were infused into the liquid which ultimately led to a decrease in dissolved oxygen. The chemical infusion increased when samples were exposed to higher pH and salinity environments. That led to a decrease in DO concentration. However, water temperature and atmospheric pressure also may have effected the amount of dissolved oxygen, which is reflected by the results.

9.2.4 Alkalinity

The alkalinity for all liquid samples increased, except for all 13 pH samples, all liquid samples of types A and C rebars and all resin samples. The later three showed a decreasing trend. Generally, alkalinity increases as pH increases and vice versa. Therefore, the alkalinity data of this study is consistent with the pH data for all samples, which was a expected outcome for this study. In general, the alkalinity content continued to decrease, with a few exceptions (vinyl-ester rebar sample combined in seawater with pH 10 or less, and all fiber only samples with pH 10 or less) but all trended toward a slower rate of change, especially for the rebar in the pH 13 environment.

9.2.5 Anions

Two types of anions had been measured for this study; chlorides and sulfates.

Chloride

The chloride concentration increased for all liquid samples, except for the 20000 ppm synthetic solution and the seawater environment. The latter two showed a decreasing trend. Chloride is normally one of the major component that causes severe rebar corrosion. This reduction in concentration was anticipated due to the reaction between chloride and iron which attacked the surface of the samples that were exposed to higher salinity. Also for high alkaline and saline solutions, the degradation of the specimens were more severe, and the liquid samples showed some metal precipitation at the bottom, which is considered one of the reasons for the chloride ion decrease for these samples. In addition, for the diffusion mechanism, chemicals tend to pass from higher concentration to lower ones and as the 20000 ppm and seawater environments measured a higher salinity concentration than the solid elements, the fibers took up chlorides, which led to a concentration decrease. However, the sizing did not have a such significant effect on the change of chloride content. The sized and unsized fiber results were noted to be very similar to each other.

Sulfate

The sulfate concentration also increased for all liquid samples, except for the seawater environment. The latter one showed a decreasing trend. Like chloride, sulfate is one of the major component that caused severe degradation of rebar samples. This reduction in concentration is assumed to be due to the intake of sulfate ion into the micro cracks of the samples. Additionally, the diffusion mechanism, chemicals tend to pass from higher concentration to lower ones and as the seawater environments measured a higher sulfate concentration than the solid elements, the fibers took up sulfates, which led to a decrease in concentration for the seawater environments. Although the 20000 ppm synthetic environments and the seawater had almost similar chloride concentration, the degradation was more severe for the samples exposed to the seawater environment. Sulfate concentration in the seawater plays an important role in this context. The sulfate ion entered through the micro cracks of the samples and lead to the material degradation. However, the sizing did not lead to a significant effect on the change of sulfate content. The sized and unsized fiber results were not significantly different from one another.

9.2.6 Metals

Eight types of metal cations (sodium, potassium, calcium, magnesium, iron, aluminum, silicon and chromium) had been measured for this study.

Aluminum

From day-0 onwards, the aluminum (Al) concentrations increased for all rebar and fiber samples. The resin samples did not measure any significant change in Al content. The increments were more significant for the rebar samples. For all tested products, Lot-2 appeared to show more Al concentration than Lot-1, which apparently meant the Lot-2 rebars degraded more that the Lot-1 rebars, which in turn led to a higher chemical concentration. For all manufacturers, the sized fibers had slightly more Al concentration than the unsized fibers, which is due to the sizing material that coated the fibers. Such comparison cannot be specifically said for Type C fibers because only the sized fibers were analyzed here. Because all these metals increased in the liquid solution, they decreased from all the fiber surfaces. The sizing around the sized fiber completely disintegrated into the exposure solutions which led to higher chemical concentration for the sized samples. But considering the fiber and resin solid samples, it was noted from the SEM images, that after 300 and 600 day exposure, the sized fiber had more resistance to corrosion than the unsized ones. Therefore, the sizing protected the material to a certain extent from degradation, though it led to more chemical infusion into the liquid solutions. On the other hand, as resin is an organic compound composed of C, O and H, it appears that there is no chance for any up take or leaching out of Al content into the solution for the resin. All of them had an Al concentration that was below the detection limit (less than 0.01 mg/L) except for the seawater samples. The seawater samples initially had an Al concentration and even after day 300 and day 600, the samples measured a concentration close to the day-0 data.

Calcium

Calcium (Ca) concentration also increased from the day-0 data for all rebar and fiber samples. The resin samples did not show any significant change in Ca content from day-0. The increase was more elevated for the rebar samples. For all tested products, Lot-2 appeared to show more Ca concentration than Lot-1, which apparently meant the Lot-2 rebars degraded more that the Lot-1 rebars, which in turn led to a higher chemical concentration. For all manufacturers, the sized fibers had slightly more Ca concentration than the unsized fiber, which is due to the sizing material which coated the fibers. Such comparison cannot be specifically said for Type C fibers because only the sized fibers were analyzed here. As these metals had increased in the liquid solution, they had to decrease from the fiber surfaces. The sizing around the sized fiber completely disintegrated into the exposure solution which led to a higher chemical concentration in the sized samples. But considering the fiber and resin solid samples, it was noticed through the SEM images, that after 300 and 600 days of exposure, the sized fiber offered more resistance to corrosion than the unsized ones. Accordingly, the sizing properly protected the material from degradation though it led to more chemical infusion into the liquid samples. On the other hand, as resin is an organic compound composed of C, O and H, it appears that there was no chance for any up-take or leaching out of Ca content into the solution for resin. All of them measured a Ca concentration that was below the detection limit (less than 0.05 mg/L), except for the seawater samples. Those samples initially had a Ca concentration, and after 300 and 600 days, the samples measured a concentration close to the day-0 base line data.

Chromium

For each type of samples (rebar, resin and fibers) Chromium (Cr) concentration did not show any change from day-0 to day-300 or day-600, which was expected because Cr is not an element use in the making of basalt fibers. Therefore, there appears to be no chance of any up take or leaching out of Cr content into the solution. So, all the samples had a Cr concentration that was below the detection limit (less than 0.01 mg/L).

Iron

Relative to the 0-day baseline date, the iron (Fe) concentration increased from for all rebar and fiber samples. The resin samples did not show any significant change in Fe content, as this element is not common for resin materials. The increment was more pronounced for the rebar samples. Across the board, Lot-2 appeared to show more Fe concentration than Lot-1 which apparently meant that the Lot-2 rebars degraded more that the Lot-1 rebars, which led to a higher chemical concentration. For all evaluated products, the sized fibers measured slightly elevated Fe concentration, in comparison to the unsized fiber due to the sizing material which coated/protected the sized fibers. Such comparison cannot be specifically said for Type C fibers because only the sized fibers were analyzed here. Because these metals increased in the liquid solution, they decreased from all the fiber surfaces. The sizing around the sized fiber completely disintegrated into the exposure solution which led to more chemical concentration for the sized samples. But considering the fiber and resin solid samples, it was noticed through the SEM images, that after 300 and 600 days of exposure, the sized fiber showed more resistance to corrosion than the unsized ones. Accordingly, the sizing properly protected the material from degradation, though it led to more chemical infusion into the liquid samples. On the other hand, as resin is an organic compound composed of C, O and H, it appears that there is no chance of any up take or leaching out of Fe content into the solution for resin materials. All resins had a Fe concentration that was below the detection limit (less than 0.05 mg/L).

Magnesium

Magnesium (Mg) concentration decreased for all rebar and fiber samples, as time continued throughout the exposure periods. The resin samples did not show any change in Mg content. The decreasing effect was clearly observed for the seawater samples. The other synthetic environments measured a very low Mg concentration, such that the concentration went below the detection limit (less than 0.01 mg/L). It was suspected that the Mg content entered through the micro cracks of the samples, which led to material degradation. This also led to the reduction of Mg in the liquid samples. In comparison, because resin is an organic compound composed of C, O and H, no up take or leaching out of Mg content into the solution was found for the resin materials . All resin samples showed a Mg concentration that was close to the day-0 baseline data.

Potassium

The potassium (K) concentration increased for all rebar and fiber samples, relative to the day-0 data. However, the resin samples did not show any significant change in K content. The increase in concentration was more pronounced for the rebar samples. For all tested products, Lot-2 appeared to show more K concentration than Lot-1, which apparently meant the Lot-2 rebars degraded more that the Lot-1 rebars, which in turn led to a higher chemical concentration. For all manufacturers, the sized fibers showed slightly more K concentration than the unsized fiber and the reason is suspected to be the sizing material. Such comparison cannot be specifically said for Type C fibers because only the sized fibers were analyzed here. Because these metals increased in the liquid solution (throughout the exposure periods), they had to decrease from all fiber surfaces. The sizing around the sized fiber completely disintegrated into the exposure solution which led to an elevated chemical concentration for the sized samples. But considering the fiber and resin solid samples, it was noticed through the SEM images, that the sized fiber offered additional resistance to corrosion throughout the 300 and 600 day exposure periods, in comparison to the unsized fibers. Therefore, the sizing protected the material to some extent from degradation though it led to additional chemical infusion into the liquid samples. On the other hand, because resin is an organic compound composed of C, O and H, any up take or leaching out of K content into the solution from the resin appears unlikely. All samples measured a K concentration that was close to the day-0 baseline data.

Silicon

Silicon (Si) concentration increased from the day-0 data for all the samples, except for the seawater ones. Throughout the exposure periods, the resin samples did not show any change in Si content. The increases were more pronounced for the rebar samples. For all evaluated products, Lot-2 appears to show more Si concentration than Lot-1, which apparently meant the Lot-2 rebars degraded more that the Lot-1 rebars and that the chemical concentration increased. It was anticipated that silicon had leached out of the surfaces of the fiber and rebar solid samples and into the exposure solutions for the synthetic environments, but in case of the seawater environments the surface of the solid samples took up silicon. The sized fibers measured a slightly increased Si concentration, in comparison to the unsized fibers. The sizing around the fiber also disintegrated into the exposure solution, which led to higher chemical concentration for the sized samples. But considering the solid samples, it was noticed through the SEM images that the sized fibers offered more resistance to corrosion than the unsized ones. As a result, the sizing better protected the material from degradation. On the other hand, organic resin compounds are composed of C, O and H, and therefore, no up take or leaching out of Si content into the solution for resin was possible. All of the resin sample measured a Si concentration that was below the detection limit (less than 0.05 mg/L), except for the seawater samples because for the 12 synthetic ones, Si was not initially present, so the concentration remained unchanged over time. But, the seawater environment had an initial Si concentration, which did not change significantly overtime. From the graphs only few fractions of changes can be noticed because resin is an organic compound that does not contain any Si. Therefore, no up take or leaching out of Si content into the solution for resin was possible. For the seawater samples, a Si concentration was initially measured, but it remained nearly constant or close to the day-0 base data.

Sodium

From day-0 onwards, the sodium (Na) concentration decreased for all rebar and fiber samples but the change was not significant. The resin samples, on the other hand, did not show any changes in Na content, relative to the day-0 data. The reduction was most significant for the rebar samples. The reduction for the sized fibers was slightly more than it was for the unsized fiber, which is due to the additional sizing material. Similar to the Mg content, it was anticipated that the Na content also entered through the micro cracks of the samples and led to the material degradation. This also cause a reduction of Na in the liquid samples. On the other hand, as resin is an organic compound composed of C, O and H, there appears to be no chance for any up take or leaching out of Na content into the solution for resin. Accordingly, all of the resin sample measured a Na concentration that was close to the day-0 baseline data.

9.2.7 Scanning Electron Microscopic (SEM) Image Analysis

From the SEM images of all fiber and resin samples, the corrosive mechanism can be better understood. The images of the sized fibers showed that as the test matrix approached high salinity and pH environments, the degradation became more severe, hence the corrosive layer increased in thickness. Globular shaped corrosive structure were found in these images. In addition, metal depositions were noticed. These depositions are mainly from iron (Fe) and Calcium (Ca) (Nasir and Dootejtema, 2012). From visually looking at the exposed samples, it could be noticed that the sizing material completely came off from the sized fibers. In addition, the fiber diameter decreased as the exposure period increased. Moreover, the reduction of the diameter dimensions became more pronounced as the exposure environment approached more corrosive conditions. For the sized fibers after day 300 and 600 exposure, the sizing came off completely and dissolved into the solution. Along with the dissolving sizing, some portion of the fibers degraded as well. So both the fiber and the sizing contributed to the chemical increase. But for the unsized fibers the only degradation resulted for the fibers alone. This is why the exposure solutions containing sized fibers measured a higher chemical concentration than the solutions containing unsized ones. The seawater environment had a presence of high sulfate ion concentrations and also, other metallic cations such as calcium, magnesium etc. and other forms of minerals which additionally appeared to accelerate the degradation of the samples more than the other 12 synthetic environments and that became clearly visible during the SEM analyses. Perhaps the most significant finding to notice in this context was how the sized and the unsized fibers performed in the 2 extreme environments (at pH 4 and 13 with different salinity concentration). From the SEM images for both the extreme acidic and extreme alkaline environments, it was analyzed and found that the sized fibers were able to better resist the corrosion that the unsized fibers (in a relative comparison). In some cases (for the harsh environments), it was found that layers of the fiber were peeling off. In summary, it can be noted that the sizing material protected the basalt fibers (to a limited extent) in the extreme environments. However, the sizing also lead to more chemical release or higher chemical concentrations, as the sizing completely came off and leached into the exposure environments. In a direct comparison between the three types of fiber, it appeared that type B fibers suffered lesser corrosion or produced smaller corrosive layers than the type A and C fibers.

Again, the SEM images for resin samples showed that the corrosive layers became more prominent and dense as the exposure conditions approached higher pH and higher salinity levels; the most degrading effects were noted for the 13 pH and seawater environment. Accordingly, it appears that type A resin (epoxy resin) suffered more and degraded more significantly than type B resin (vinyl-ester resin) in harsh environments.

9.2.8 Transverse Shear Strength

ASTM D 7617 (ASTM-International, 2012b) was followed to test and analyze the transverse shear performance of BFRP rebars. FRP rebars are weak in the transverse direction or perpendicular to the rebar longitudinal axis due to the unidirectional alignment of the fibers and the inherent low shear strength of the fibers. Therefore it is important to study the transverse shear properties of these rebars before using them in any infrastructure projects. As discussed earlier, BFRP bars are intended to be used in concrete structures situated in aggressive environments, and accordingly, it is very important to study the transverse shear behavior of these bars after accelerated aging. According to FDOT Specification Section 932, which is in agreement with AC454 (International Code Council, 2017), GFRP rebars are required to reach a minimum shear strength of 22 ksi before rupture. These values are more critical than the 19 ksi minimum transverse shear strength required by ASTM D 7957 (ASTM-International, 2017). After extensive testing and analyses, the evaluated virgin # 3 BFRP rebars sustained shear stresses before ultimate failure ranging from 30.5 ksi to 41 ksi and # 5 rebars sustained stresses between 29.3 ksi and 35.8 ksi. The minimum average transverse shear strength of rebars after 300 d exposure was found to be 28.5 ksi, 18.3 ksi, and 17.9 ksi for 4,7, and

13 pH respectively, and after 600 d exposure was found to be 11.8 ksi and 9.6 ksi for 4 and 7 pH respectively. The rebars exposed to the 4 pH-0Cl^- environment retained the highest strength and rebars exposed to the 13 pH-seawater environment suffered the highest strength losses. It was seen that an increase in salinity played a minor roll in rebar deterioration, while an increase in pH level significantly affected the long-term rebar performance. When comparing the virgin properties obtained from this study and other BFRP rebar research projects (Ali, Ahmed H and Mohamed, Hamdy M and Benmokrane, Brahim and ElSafty, Adel and Chaallal, Omar, 2019; Serbescu et al., 2014) to GFRP rebar performances published in the literature (Kampmann et al., 2018; Chen et al., 2007; ElSafty et al., 2014), BFRP rebars appear to offer a higher strength capacity than GFRP rebars. Therefore, based on the available research data and results obtained in this study, these results suggests that the minimum transverse shear strength criteria for BFRP rebars can be set equal to the specification for GFRP rebars, given that other rebars sizes have not been evaluated in this study, but the specification should remain consistent, regardless of the rebar size. Additional research with a focus on transverse strength properties of BFRP bars and additional test data, appears necessary to ultimately allow an increase the transverse shear strength requirements for BFRP rebars by as much as 20 %. This specification needs to be validated for both, the average value as well as the guaranteed value, such that BFRP products may be considered for dowel applications, since the higher transverse shear capacity of BFRP (compared to GFRP) may be beneficial (Brown and Bartholomew, 1993; Eddie, 1999).

9.2.9 Apparent Horizontal Shear Strength

The apparent horizontal shear test was conducted according to ASTM D 4475 (ASTM-International, 2012a) standards. The horizontal shear failure, is an indicator of the resin strength and the resin-to-sizing-to-fiber interface and as such important for the load transfer mechanism and horizontal shear tests are one of the most common quality control methods that manufacturers use to ensure production consistency (because it is a mechanical test that can be conducted quickly). Therefore, this mechanical property is a suitable quality control measure to study the performance of resin-fiber interface. Accordingly, FDOT Specifications Section 932 would benefit from limiting minimum values for the acceptance of FRP rebars because it would provide a direct benefit to the manufacturing community and the intersection between FDOT and technology implementation; this quality control parameter could be directly targeted during production — and quickly evaluated. AC454 (International Code Council, 2017) specifies a minimum of 5.5 ksi horizontal shear strength for GFRP bars. Generally, the horizontal shear strength of # 3, and # 5 GFRP rebars appears to range around 6 ksi (c.f. Kampmann et al. (2018)) with a minimum average of 5.2 ksi. Based on the experimental results obtained in this study, basalt BFRP rebars with a size of # 3 and # 5 measured a minimum average apparent horizontal shear strength of 6.4 ksi in their virgin state, and an average value of 4.5 ksi, 4 ksi, and 1.2 ksi after exposure to the 4, 7, and 13 pH environments respectively for 300 d. The average shear strengths after 600 d exposure were 3.8 ksi and 1.5 ksi for 4 and 7 pH respectively. As seen in horizontal shear stress vs extension graphs, the horizontal shear strength for some of the aged rebars increased compared to the virgin properties. This appears to be due to the post curing effects of the resin (Ruiz Emparanza, 2020). According to AC454 (International Code Council, 2017) and Canadian Standard Association (2018), the minimum horizontal shear strength of BFRP rebars is 5.5 ksi. Hence, at this moment, a minimum requirement of 5.5 ksi for the apparent horizontal shear strength, tested on at least five specimens, appeared to be an adequate addition to FDOT Specifications Section 932.

9.2.10 Tensile Properties

The tensile strength and elastic modulus of BFRP rebars were evaluated based on procedures and methods detailed in ASTM D 7205 (ASTM-International, 2015a). The minimum required guaranteed tensile load for # 3 and # 5 GFRP rebars according to FDOT Specifications Section 932, AC454 (International Code Council, 2017), and ASTM D 7957 (ASTM-International, 2017) are 13.2 kip and 29.1 kip, respectively. Based on the findings from this research project and other projects available in the literature targeting both glass and basalt fiber based rebars (Kampmann et al., 2018; Morales et al., 2021; Benmokrane et al., 2015; Weber, A, 2013; Renaud, Claude M and Greenwood, Mark E, 2005; Rolland et al., 2021),BFRP rebars, on average, provide a measurable higher ultimate tensile load capacity and and elastic modulus — as compared to GFRP rebars. In this research, two of the three tested rebar types were made with epoxy resins and the third rebar was made of vinyl-ester resin and it was found that the minimum tensile load sustained by virgin epoxy # 3 BFRP rebars was 23 kip and that of # 5 rebars was 52 kip. In addition, the elastic moduli of BFRP rebars were measured with a minimum of 6500 ksi. In a previous study, it was shown that the elastic moduli of GFRP rebar according to Kampmann et al. (2018) reached average values of approximately 7000 ksi, but is significantly dependent on the fiber content and other factors, since several manufacturers are now offering GFRP rebar with elastic modulii values in excess of 8700 psi. It was found that all tested BFRP rebar types that were evaluated for this project, superseded the minimum strength criteria for GFRP rebars, in addition, the maximum strain of BFRP was higher. Comparing the findings from this research to the findings made in a previous study with a focus on GFRP bars (Kampmann et al., 2018; Morales et al., 2021; Renaud, Claude M and Greenwood, Mark E, 2005), it can be seen that the maximum strain and elongation of BFRP rebars surpasses the maximum strains of glass fiber based rebars. In the experiments conducted for this study, it was seen that the aged BFRP bars retained more than 75 % of their virgin strength after exposure to 4 and 7 pH environments, while they retained merely 30 % of their original strength when they were exposed to 13 pH environments for 300 d at 60 °C. After 600 d of exposure, rebars retained 75 % of their virgin strength in 4 and 7 pH, respectively, while rebars exposed to 13 pH environments completely disintegrated and could not be tested. Comparing these results to Rolland et al. (2021) findings that GFRP rebars submerged in pH 13.1 to pH 13.5 solution, (no chlorides or seawater added) at 60 °C for 240 days, retained at least 58 °C of the original tensile strength. Also, Kampmann et al. (2018) investigation of 3 different types of GFRP rebar submerged in pH 8.2 seawater at 60 °C for 365 days. Rebars retained 60% to 80% of their original strength, depending on the manufacturer. Similarly, 600 day exposure conditions for GFRP bars could not be found in the literature for comparison. However, Morales et al. (2021) investigated GFRP rebar embedded in concrete beams made with seawater concrete, and then submerged in seawater tanks (approximate pH 8.2) at 60 °C for 24 month (730 days). These vinyl-ester resin and EC-R glass fibers rebars, retained an average 69 % of the original tensile load capacity. The researchers acknowledged that the environment inside concrete is not as aggressive as that for rebars submerged in aqueous solutions, as used in this study, so the results are not easily comparable. The results in this study indicated that the mechanical performance of rebars made from vinyl-ester resin was higher than tensile strength of bars made from epoxy resin and the results presented here shows that the minimum elastic modulus of these rebars was measured with 7500 ksi after the rebars were exposed to the aggressive environments. According to research completed by Patnaik (2009); Wang et al. (2017), BFRP rebars are stronger in tension. However, Wang et al. (2017) found that the long-term durability in harsh environments (combined pH 13 and seawater at 60 °C for 63 days) is higher for GFRP rebars than it is for BFRP rebars when both were made from the same epoxy resin. Through the state-of-the-production-practice review, it was noted that many/most basalt rebar producers across the globe uses epoxy resin in the manufacturing processes while some of the manufacturers use the vinyl-ester resin (Telikapalli et al., 2019). It appears that vinyl-ester resins are suitable for the production of basalt FRP rebars and that such constituent materials should continue to be under FDOT Specifications Section 932. However, if basalt fiber specific criteria are desirable for the tensile properties, the data in this research suggests that the minimum strength and elastic modulus should be similar to the GFRP rebars. A detailed testing of a wide range of rebars from several manufacturers, would be necessary to fully study the strength properties of rebar and to properly define a minimum required criteria that is more critical than the one given for glass based FRP rebars.

It should be recognized that the alkali resistance evaluation for acceptance of GFRP bars under ASTM D 7957 (ASTM-International, 2017) is based on ASTM D 7705 (ASTM International, 2019) and uses much less severe conditions than those evaluated in this research project. GFRP Bars must retain 80 % of their average tensile strength after conditioning for 90 days in an aqueous solution at 60 °C with a pH between 12.6 -13.0, and without the addition of chlorides or seawater. As such the same protocol should be retained for BFRP rebars. However, if BFRP rebars are to be used in submerged seawater environments by FDOT, then additional chlorides to the aqueous solution should be considered under FDOT Specification Section 932.

9.2.11 Bond-to-Concrete Strength

The bond-to-concrete strength of the BFRP rebar specimens was tested according to procedure described in ASTM D 7913 (ASTM International, 2014). The minimum guaranteed bond strength required for GFRP rebars according to FDOT Specifications Section 932, AC454 (International Code Council, 2017) and ASTM D 7957 (ASTM-International, 2017) is 1.1 ksi. Based on the measurements obtained in this research and a careful analyses of the results, the bond-to-concrete strength of virgin # 3 rebars ranged from 2.2 ksi to 3.2 ksi and it varied between 2.8 ksi and 3.3 ksi for the # 5 BFRP rebars. The bond strength retention of aged BFRP rebars exposed to 4 and 7 pH environments was found to be more than 80 %, while the surface enhancement features did not last in high pH environments. These results, in comparison to other studies (Ruiz Emparanza et al., 2018; Chen et al., 2007; Brik, 2003; Li et al., 2017; Hassan et al., 2016), show that the bond-to-concrete strength of basalt FRP rebars is similar to the bond strength that has been reported for GFRP rebars. This is because bond strength of FRP rebars is a function of the geometric and surface enhancement features in which the surface properties of the rebars play a dominant role (Ruiz Emparanza et al., 2018). As the surface for FRP rebars is either deformed or sand coated (or possibly both), it is reasonable to assume that the bond behavior of basalt FRP rebars is similar to the bond behavior of glass or other FRP rebars since the friction and interlocking mechanisms are not directly dependent on the fiber type. However, for the friction mechanism, the resin type and manufacturing process are important because resin plays a significant role in holding the fibers together and blending the surface enhancement treatment into the rebar during the manufacturing process. The manufacturing process plays a key role in ensuring surface enhancement treatment is adequately bonded to and/or formed on the surface of pultruded bar.

A detailed durability study addressing several types of surface enhancement of BFRP bars is suggested to study the bond to concrete property of FRP bars in aggressive environments. But for now, this research suggests that the minimum bond-to-concrete strength criteria for BFRP rebars can be defined analogous to the available minimum bond-to-concrete criteria defined for GFRP rebars, at 1.1 ksi. This is sufficient for a unified strain compatible behavior between the surrounding concrete and the rebar, independent of the chosen rebar material.

9.2.12 BFRP Design Specifications

Currently, Canadian standards (Canadian Standard Association, 2018) accept BFRP reinforcement bars as an alternative for steel rebars for concrete coastal and marine structures and ICC-ES Acceptance Criteria AC454 (International Code Council, 2017) provides referenced design recommendations and a method of acceptance for BFRP reinforcing alongside other FRP bars under US building codes for alternative materials. While the current FDOT Standard Specifications for Road and Bridge Construction Section 932, which details FRP internal reinforcement for concrete structures included or addressed the requirements and minimum criteria for basalt fiber rebars, AASHTO-LRFD specifications for the design of concrete bridges reinforced with BFRP rebars are yet to be developed. One of the the major goals of this research project was to address the current knowledge gap by providing degradation factors for AASHTO LRFD bridge design guidelines for BFRP rebars. To properly develop the BFRP requirement criteria, five different physical properties and four different mechanical properties were studied through an extensive analysis of the results findings. As per AASHTO LRFD (AASHTO, 2018) design codes, FRP rebars must satisfy the minimum guaranteed strength criteria, such that they can be considered in design and safely used for concrete structures. According to ACI Committee 440 (2015), the guaranteed strength, f^*_{fu}, of GFRP rebars is defined as the experimentally obtained average tensile strength minus three times the measured standard deviation, as shown in equation 9.1, while the guaranteed elastic modulus, $E_f = E_{f,ave}$, is defined as the mean elastic modulus of a test sample (specimen group).

$$f^*_{fu} = f_{fu_{average}} - 3\sigma \tag{9.1}$$

Accordingly, the calculated value for f^*_{fu} corresponds to the 99^{th} percentile (Rossini et al., 2018), such that the chance for material failure (before any design factors are applied) remains below 1 %. The strength of commercially available GFRP rebars differs based on the fiber content and manufacturing techniques (Emparanza et al., 2017), and the guaranteed strength is typically experimentally determined. ASTM D 7957 ASTM-International (2017) and FDOT Specification 932 have minimum guaranteed strength requirements for each standard bar size. FDOT designers uses these values as the specified design strength, even though specific manufacturer's rebar products must exceed these values. This specified design strength, f'_{fu}, is always less than the guaranteed strength (c.f. equation 9.2) of the particular rebar lot that is to be used for construction.

$$f'_{fu} < f^*_{fu} \tag{9.2}$$

While most strength values for the basalt FRP rebars tested in this research showed that basalt rebars have a higher performance than ASTM D7957 and FDOT Specifications Section 932, the general material behavior appeared to be similar to the behavior of GFRP bars, and it is reasonable to assume that Equation 9.2 applies and can be adopted to calculate the guaranteed strength of basalt rebars. Accordingly, Table 9.1 lists the guaranteed strength values and elastic moduli for the three different virgin BFRP rebar types (A, B, C) tested in this study, and it quantifies the guaranteed performance relative to the criteria for GFRP rebar according to FDOT Specifications Section 932 (under the column % FDOT). Similarly Table 9.2 lists the table values of tested bars after 300 d of accelerated aging. The results in Table 9.1 show that both # 3 and # 5 type B rebars were the strongest among all tested rebar samples. however, the standard deviation of # 3 type A rebars was the smallest, while the type C # 5 rebars measure the highest standard deviation. The graphs in Figures 9.1 and 9.2 visualize the Gaussian distribution for the measured tensile strength results for virgin # 5 and # 3 rebar, respectively. The mean value and guaranteed tensile strength ($\mu - 3\sigma$) are indicated on the curves. It can be seen in graphs that the guaranteed tensile strength for both # 3 and # 5 virgin BFRP bars of all types and both lots behaved similar to GFRP bars. Therefore, this research suggests that the guaranteed tensile strength criteria of BFRP rebars can be derived similar to GFRP rebar criteria.

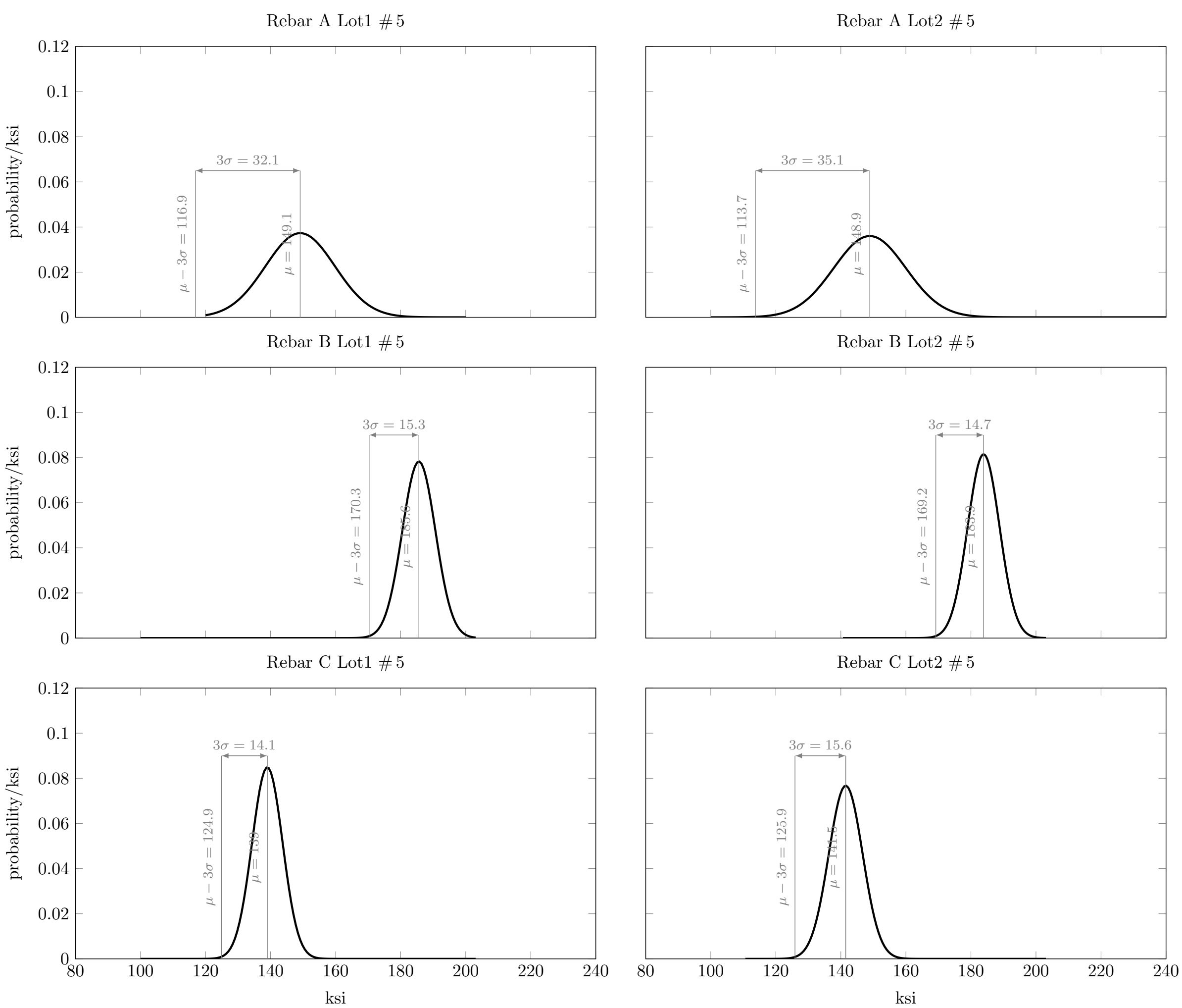

Figure 9.1: Gaussian distribution for tensile strength of # 5 rebars

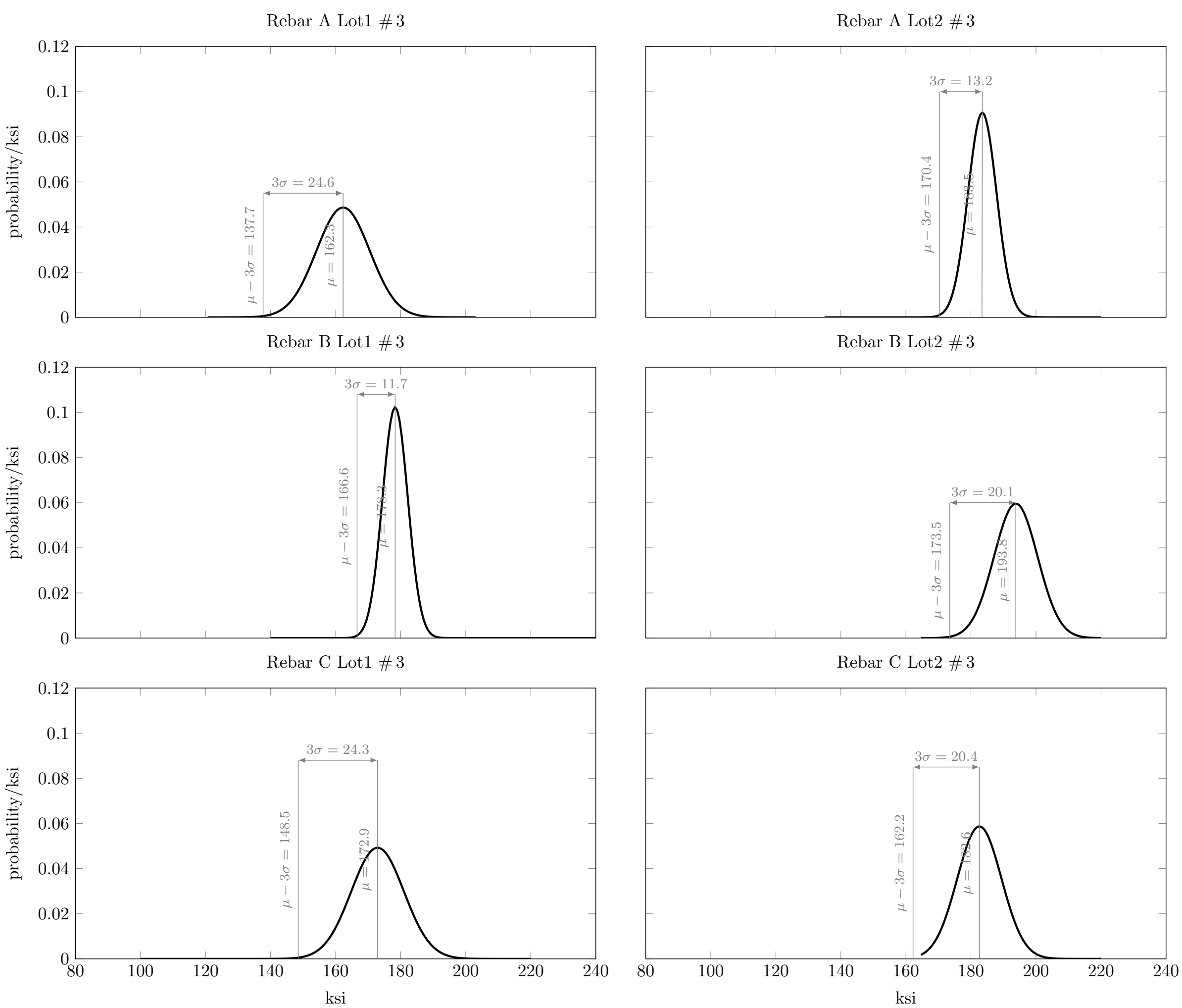

Figure 9.2: Gaussian distribution for tensile strength of # 3 rebars

Table 9.1: Guaranteed tensile strength of tested rebars a day 0 (virgin bars)

Sample group				Tensile Strength							Elastic	
				Mean		Sta. Deviation		Guaranteed			Modulus	
Manuf.	Resin	Size	Lot	μ		σ			$\mu - 3\sigma$		E	
Type	Type	#	No.	ksi	MPa	ksi	MPa	ksi	MPa	%	ksi	GPa
TypeA	Epoxy	3	1	162.3	1119.2	8.2	56.6	137.7	949.4	114.9	7787.6	53.7
TypeA	Epoxy	5	1	149.1	1027.8	10.7	74.0	116.9	805.7	124.3	7241.0	49.9
TypeA	Epoxy	3	2	183.5	1265.0	4.4	30.1	170.4	1174.8	142.2	8957.7	61.8
TypeA	Epoxy	5	2	148.9	1026.4	11.7	80.8	113.7	784.0	121.0	6779.2	46.7
TypeB	VinylEster	3	1	178.3	1229.5	3.9	26.9	166.6	1148.9	139.1	7440.3	51.3
TypeB	VinylEster	5	1	185.6	1279.8	5.1	35.3	170.3	1174.0	181.1	8319.0	57.4
TypeB	VinylEster	3	2	193.8	1336.0	6.7	46.5	173.5	1196.4	144.8	8424.1	58.1
TypeB	VinylEster	5	2	183.9	1267.7	4.9	34.1	169.0	1165.5	179.8	7954.2	54.8
TypeC	Epoxy	3	1	172.9	1192.2	8.1	56.2	148.5	1023.6	123.9	8423.3	58.1
TypeC	Epoxy	5	1	139.0	958.1	4.7	32.4	124.9	861.0	132.9	7800.9	53.8
TypeC	Epoxy	3	2	182.6	1258.9	6.8	46.9	162.2	1118.3	135.4	8352.0	57.6
TypeC	Epoxy	5	2	141.5	975.8	5.2	35.8	125.9	868.3	134.0	7762.4	53.5

Table 9.2: Guaranteed tensile strength of tested rebars after 300 d of exposure

Sample group						Tensile Strength							Elastic	
						Mean		Sta. Deviation		Guaranteed			Modulus	
Manuf.	Resin	Size	Lot	pH	Cl^-	μ		σ		$\mu - 3\sigma$			E	
Type	Type	#	No.			ksi	MPa	ksi	MPa	ksi	MPa	%	ksi	GPa
TypeA	Epoxy	3	1	4	0	143.9	992.0	7.3	50.3	122.0	841.2	101.8	8139.0	56.1
TypeA	Epoxy	5	1	4	0	122.5	844.8	1.3	8.8	118.7	818.5	126.3	7431.4	51.2
TypeA	Epoxy	3	2	4	0	150.0	1034.5	5.7	39.3	133.0	916.7	111.0	7281.5	50.2
TypeA	Epoxy	5	2	4	0	121.4	837.2	15.2	104.8	75.8	522.9	80.7	7345.5	50.6
TypeB	VinylEster	3	1	4	0	114.4	789.0	10.7	73.9	82.3	567.4	68.7	8163.1	56.3
TypeB	VinylEster	5	1	4	0	143.6	990.1	2.9	19.7	135.0	931.0	143.6	8406.9	58.0
TypeB	VinylEster	3	2	4	0	138.8	956.8	3.8	26.5	127.2	877.3	106.2	8654.2	59.7
TypeB	VinylEster	5	2	4	0	144.4	995.8	5.3	36.4	128.6	886.6	136.8	8395.2	57.9
TypeC	Epoxy	3	1	4	0	130.9	902.5	23.4	161.0	60.8	419.5	50.8	8893.0	61.3
TypeC	Epoxy	5	1	4	0	108.6	748.9	4.3	30.0	95.6	659.0	101.7	7520.7	51.9
TypeC	Epoxy	3	2	4	0	131.6	907.6	10.3	71.3	100.6	693.8	84.0	8353.1	57.6
TypeC	Epoxy	5	2	4	0	113.5	782.4	5.8	40.1	96.0	662.0	102.1	7745.7	53.4
TypeA	Epoxy	3	1	4	20000	149.0	1027.0	1.7	12.0	143.7	990.9	120.0	7684.0	53.0
TypeA	Epoxy	5	1	4	20000	139.1	959.1	13.7	94.4	98.0	675.9	104.3	7403.8	51.0
TypeA	Epoxy	3	2	4	20000	158.9	1095.6	6.6	45.4	139.1	959.4	116.2	8719.9	60.1
TypeA	Epoxy	5	2	4	20000	134.1	924.4	14.6	100.3	90.4	623.4	96.2	7540.5	52.0
TypeB	VinylEster	3	1	4	20000	150.8	1039.9	1.7	11.5	145.8	1005.4	121.7	8554.8	59.0
TypeB	VinylEster	5	1	4	20000	148.8	1025.8	8.7	60.3	122.5	844.9	130.4	8318.0	57.4
TypeB	VinylEster	3	2	4	20000	121.9	840.8	2.7	18.3	114.0	785.9	95.1	7192.0	49.6
TypeB	VinylEster	5	2	4	20000	144.2	993.9	2.6	17.9	136.4	940.1	145.1	NA	NA
TypeC	Epoxy	3	1	4	20000	137.9	950.6	10.4	71.7	106.7	735.4	89.0	8581.5	59.2
TypeC	Epoxy	5	1	4	20000	126.0	868.5	5.4	37.1	109.8	757.1	116.8	7583.5	52.3
TypeC	Epoxy	3	2	4	20000	127.1	876.4	10.0	69.0	97.1	669.4	81.0	8795.0	60.6
TypeC	Epoxy	5	2	4	20000	109.9	757.4	5.5	37.8	93.4	644.0	99.4	7385.0	50.9
TypeA	Epoxy	3	1	4	SeaWater	149.3	1029.2	0.4	2.8	148.1	1020.9	123.6	7781.7	53.7
TypeA	Epoxy	5	1	4	SeaWater	132.5	913.6	8.1	55.9	108.2	745.9	115.1	7700.0	53.1
TypeA	Epoxy	3	2	4	SeaWater	109.1	752.5	11.2	77.3	75.5	520.6	63.0	7981.9	55.0
TypeA	Epoxy	5	2	4	SeaWater	141.7	977.1	3.8	26.0	130.4	899.1	138.7	7604.2	52.4
TypeB	VinylEster	3	1	4	SeaWater	126.7	873.7	12.5	86.3	89.1	614.6	74.4	7231.7	49.9
TypeB	VinylEster	5	1	4	SeaWater	146.4	1009.5	4.9	33.9	131.7	908.0	140.1	8164.7	56.3
TypeB	VinylEster	3	2	4	SeaWater	148.0	1020.4	4.8	33.3	133.5	920.6	111.5	8198.9	56.5
TypeB	VinylEster	5	2	4	SeaWater	147.5	1017.1	4.5	30.8	134.1	924.7	142.7	8375.1	57.7
TypeC	Epoxy	3	1	4	SeaWater	145.6	1004.0	2.4	16.7	138.3	953.8	115.5	8139.6	56.1
TypeC	Epoxy	5	1	4	SeaWater	102.7	708.0	2.2	15.4	96.0	661.9	102.1	7715.8	53.2
TypeC	Epoxy	3	2	4	SeaWater	136.7	942.8	5.6	38.9	119.8	826.1	100.0	8633.2	59.5
TypeC	Epoxy	5	2	4	SeaWater	114.4	788.6	9.4	65.1	86.1	593.4	91.6	7722.8	53.2
TypeA	Epoxy	3	1	7	0	159.7	1100.9	4.0	27.5	147.7	1018.5	123.3	7808.7	53.8
TypeA	Epoxy	5	1	7	0	128.6	886.6	11.2	77.5	94.9	654.2	100.9	7315.2	50.4
TypeA	Epoxy	3	2	7	0	148.0	1020.3	6.2	42.4	129.5	893.0	108.1	8686.9	59.9

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Table 9.2: Guaranteed tensile strength of tested rebars after 300 d of exposure

Sample group						Tensile Strength							Elastic	
						Mean		Sta. Deviation		Guaranteed			Modulus	
Manuf.	Resin	Size	Lot	pH	Cl^-	μ		σ		$\mu - 3\sigma$			E	
Type	Type	#	No.			ksi	MPa	ksi	MPa	ksi	MPa	%	ksi	GPa
TypeA	Epoxy	5	2	7	0	137.5	948.3	6.4	44.4	118.2	815.0	125.7	7875.1	54.3
TypeB	VinylEster	3	1	7	0	115.9	799.0	3.8	25.9	104.6	721.4	87.3	7313.6	50.4
TypeB	VinylEster	5	1	7	0	137.6	948.5	2.2	15.5	130.8	902.0	139.2	8707.7	60.0
TypeB	VinylEster	3	2	7	0	140.3	967.3	1.8	12.5	134.9	929.9	112.6	8239.9	56.8
TypeB	VinylEster	5	2	7	0	145.8	1005.1	3.3	22.6	135.9	937.3	144.6	8362.6	57.7
TypeC	Epoxy	3	1	7	0	136.7	942.7	11.8	81.3	101.4	698.8	84.6	7913.0	54.6
TypeC	Epoxy	5	1	7	0	110.8	764.2	6.5	45.0	91.2	629.1	97.1	7444.4	51.3
TypeC	Epoxy	3	2	7	0	127.7	880.3	9.9	68.0	98.1	676.1	81.9	8652.8	59.7
TypeC	Epoxy	5	2	7	0	126.7	873.4	8.6	59.6	100.7	694.5	107.2	7698.9	53.1
TypeA	Epoxy	3	1	7	20000	149.5	1030.7	3.7	25.3	138.5	954.8	115.6	7703.7	53.1
TypeA	Epoxy	5	1	7	20000	99.1	683.3	29.4	202.5	11.0	75.8	11.7	7715.0	53.2
TypeA	Epoxy	3	2	7	20000	90.1	620.9	2.1	14.8	83.6	576.5	69.8	8440.1	58.2
TypeA	Epoxy	5	2	7	20000	134.3	926.1	12.2	83.9	97.8	674.5	104.1	7660.6	52.8
TypeB	VinylEster	3	1	7	20000	118.5	816.9	6.4	44.5	99.1	683.5	82.8	7529.4	51.9
TypeB	VinylEster	5	1	7	20000	144.1	993.3	6.9	47.4	123.5	851.2	131.3	8538.1	58.9
TypeB	VinylEster	3	2	7	20000	152.3	1050.3	4.7	32.4	138.3	953.3	115.4	7870.7	54.3
TypeB	VinylEster	5	2	7	20000	148.6	1024.4	1.7	11.6	143.5	989.7	152.7	5991.4	41.3
TypeC	Epoxy	3	1	7	20000	133.4	919.8	19.5	134.7	74.8	515.6	62.4	8423.6	58.1
TypeC	Epoxy	5	1	7	20000	104.8	722.3	11.2	77.4	71.1	490.1	75.6	7503.1	51.7
TypeC	Epoxy	3	2	7	20000	129.3	891.6	8.8	60.7	102.9	709.6	85.9	8724.8	60.2
TypeC	Epoxy	5	2	7	20000	119.4	823.5	12.2	83.9	83.0	572.0	88.2	7490.7	51.6
TypeA	Epoxy	3	1	7	SeaWater	125.2	863.0	6.1	41.8	107.0	737.6	89.3	7815.1	53.9
TypeA	Epoxy	5	1	7	SeaWater	139.9	964.3	8.3	57.0	115.1	793.4	122.4	7459.9	51.4
TypeA	Epoxy	3	2	7	SeaWater	151.5	1044.5	7.4	50.9	129.3	891.7	108.0	8825.8	60.9
TypeA	Epoxy	5	2	7	SeaWater	144.0	992.8	13.8	95.2	102.6	707.1	109.1	7251.6	50.0
TypeB	VinylEster	3	1	7	SeaWater	151.5	1044.5	7.4	50.9	129.3	891.7	108.0	8825.8	60.9
TypeB	VinylEster	5	1	7	SeaWater	150.5	1037.6	3.6	25.1	139.6	962.3	148.5	8539.8	58.9
TypeB	VinylEster	3	2	7	SeaWater	139.8	963.7	16.8	115.9	89.3	615.9	74.6	8063.8	55.6
TypeB	VinylEster	5	2	7	SeaWater	141.4	974.9	7.5	52.0	118.8	819.0	126.4	8465.1	58.4
TypeC	Epoxy	3	1	7	SeaWater	140.6	969.3	18.0	124.1	86.6	596.9	72.3	8660.3	59.7
TypeC	Epoxy	5	1	7	SeaWater	121.8	839.9	13.0	89.5	82.9	571.5	88.2	7899.6	54.5
TypeC	Epoxy	3	2	7	SeaWater	127.5	879.2	0.5	3.5	126.0	868.6	105.2	9543.3	65.8
TypeC	Epoxy	5	2	7	SeaWater	109.5	754.6	8.7	59.9	83.4	575.1	88.7	7646.5	52.7
TypeA	Epoxy	5	1	13	0	82.0	565.6	30.7	211.4	−10.0	−68.7	−8.3	7489.8	51.6
TypeA	Epoxy	5	2	13	0	91.1	628.4	20.5	141.4	29.6	204.2	31.5	7513.4	51.8
TypeB	VinylEster	3	1	13	0	55.6	383.1	45.5	313.6	−80.9	−557.6	−67.5	NA	NA
TypeB	VinylEster	5	1	13	0	86.1	593.4	4.7	32.3	72.0	496.5	76.6	8841.7	61.0
TypeB	VinylEster	3	2	13	0	33.8	232.9	9.8	67.8	4.3	29.6	3.6	NA	NA
TypeB	VinylEster	5	2	13	0	96.8	667.3	19.4	133.8	38.6	265.9	41.0	8552.0	59.0

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Table 9.2: Guaranteed tensile strength of tested rebars after 300 d of exposure

Sample group						Tensile Strength							Elastic	
						Mean		Sta. Deviation		Guaranteed			Modulus	
Manuf.	Resin	Size	Lot	pH	Cl^-	μ		σ		$\mu - 3\sigma$			E	
Type	Type	#	No.			ksi	MPa	ksi	MPa	ksi	MPa	%	ksi	GPa
TypeC	Epoxy	5	1	13	0	107.1	738.6	5.9	40.6	89.4	616.7	74.7	7598.9	52.4
TypeC	Epoxy	5	2	13	0	108.7	749.2	7.2	49.5	87.1	600.7	92.7	7545.3	52.0
TypeB	VinylEster	3	1	13	20000	45.7	314.8	36.2	249.7	−63.0	−434.4	−52.6	NA	NA
TypeB	VinylEster	5	1	13	20000	92.6	638.7	2.1	14.8	86.2	594.3	91.7	8455.2	58.3
TypeB	VinylEster	3	2	13	20000	49.0	337.9	5.7	39.2	31.9	220.2	26.7	5820.2	40.1
TypeB	VinylEster	5	2	13	20000	105.7	728.5	14.8	102.2	61.2	421.9	65.1	8455.2	58.3
TypeB	VinylEster	3	1	13	SeaWater	4.5	31.0	0.6	4.0	2.8	19.0	2.3	NA	NA
TypeB	VinylEster	5	1	13	SeaWater	55.0	378.9	17.3	119.4	3.0	20.9	3.2	5689.7	39.2
TypeB	VinylEster	3	2	13	SeaWater	10.2	70.5	3.0	20.7	1.2	8.5	1.0	NA	NA
TypeB	VinylEster	5	2	13	SeaWater	33.0	227.8	3.2	22.0	23.5	161.8	25.0	5697.9	39.3

9.3 Supplementary Findings

Three different physical properties of BFRP rebars were evaluated in this study and alongside the major findings, this research revealed some supplementary findings based on the obtained results. In this section, cross-sectional properties, moisture absorption properties, and fiber content properties of virgin rebars are discussed in detail.

9.3.1 Cross-Sectional Property

The cross-sectional properties were measured according to ASTM D 792 (ASTM-International, 2015b), which is an important characteristic because rebars are classified based on that diametric size and the strength requirements are dependent on the actual rebar size (in form of the nominal diameter). For traditional steel rebars, the tensile strength of rebar is directly related to effective area. While this is not ultimately true for FRP rebars — as only the fibers carry the tensile loads — it is a measurement that is needed for the design and detailing of reinforcement in concrete elements, and to implement the use of FRP rebars, the same nominal geometry used in steel rebar is specified for FRP rebars with the exception of a range to account for different surface treatments, for classification and because structural design engineers rely on size-dependent properties. Accordingly, to implement the use of FRP rebars, the same nominal geometry used for design with steel rebars must be specified for FRP rebars, but to account for different surface treatments and manufacturing processes, allowable rebar size ranges must be considered. For example, per FDOT Specifications Section 932, AC454 (International Code Council, 2017) and ASTM D7957 (ASTM-International, 2017), the nominal cross-sectional area for # 3 GFRP rebar is 0.11 in.^2, with a minimum measured area of 0.104 in.^2 and a maximum measured area of 0.161 in.^2. For # 5 rebars, the nominal cross-sectional area is given as 0.31 in.^2, with a minimum measured cross-sectional area of 0.228 in.^2 and a maximum of 0.338 in.^2. In this research, it was found that Type B rebars measured the highest diameter and highest tensile strength, while Type C rebar measured the least diameter and least tensile strength. The production sequence for BFRP rebars and the load transfer is similar to glass fiber based rebars, which allows similar definitions for both rebar types (Kampmann et al., 2018). Further alteration in cross-sectional properties will lead to the change in tensile properties of the rebars. It is suggested that BFRP rebars should be within that range to avoid errors in assumed centroid position for structural resistance calculations, any fit up errors in detailing such as spacing, cover or clearance, and consistency in product approval (Florida Department of Transportation, 2018; AASHTO, 2018).

9.3.2 Fiber Content

The experiments and the accompanying mathematical procedures to determine the fiber content percentage for FRP rebars are specified in material standard ASTM D 2584 -11(ASTM-International, 2011). Fiber content (given in percent) plays a key role in the tensile behavior and load capacity of FRP rebars because induced stresses are mostly carried by the fibers, while the resin matrix is responsible for transfering the loads between the individual fibers. The minimum fiber content percentage required for GFRP rebars according to FDOT Specifications Section 932, AC454 (International Code Council, 2017), and ASTM D 7957 (ASTM-International, 2017) which follows ASTM D 2584 -11 (ASTM-International, 2011), is 70 %. After careful evaluation on the tested samples, it was seen that two of the three BFRP rebar products exceeded the required minimum criteria by at least 10 %. The third type of rebar exceeded the criteria by 5 % on average. In this study, it was seen that regardless of rebar type and production lot, rebars with higher fiber content had higher tensile strength compared to the bars with lower fiber content. As mentioned by You et al. (2015); ACI Committee 440 (2015), fiber contents less than 70 % (by weight) are not acceptable because the fiber-volume faction significantly affects the tensile strength and quality of FRP rebars. Further alteration in the fiber content percentage may affect the stress transfer capacity of the rebar (Kampmann et al., 2021). Therefore, it appears reasonable to suggest a minimum fiber content percentage (by weight) for BFRP rebars that is similar to that for GFRP products because the observed load carrying and stiffness behaviors were closely related to GFRP rebar performance in the context of the measured fiber contents. Additional research and analyses are required to establish a precise correlation between fiber content percentage and its effects on the rebar strength to support any modifications of the GFRP specifications for a BFRP specific minimum. For now, the 70 % minimum criteria seems to be appropriate for BFRP rebars as well.

9.3.3 Moisture Absorption of BFRP Rebar

ASTM D 5229 (ASTM, 2014) details seven different test procedures (A through E,Y, and Z) for estimating moisture absorption properties for FRPs in different environments. Procedure A is most commonly used, and therefore, was followed for this research project. It is considered that the moisture absorption correlates to durability and the corresponding strength retention, where high moisture absorption values are indicative of a porous rebar that is more prone to degradation (Kampmann et al., 2018). According to FDOT Specifications Section 932, which follows ASTM D 5229 (ASTM, 2014) section 7.1, AC454 (International Code Council, 2017), and ASTM D7957 (ASTM-International, 2017), the maximum short-term moisture absorption limit for GFRP rebars is 0.25 % by weight. In addition, the long-term moisture absorption specified by FDOT Specifications Section 932 and ASTM D7957 (ASTM-International, 2017) is less than 1 %. After proper evaluation of the specimens tested for this research project, it was found that the long-term moisture absorption of BFRP rebars was less than 1 % for all test groups. As increased moisture absorption affects the strength and strength retention of FRP rebars (Kampmann et al., 2018), it is reasonable to suggest that the BFRP rebar should follow the criteria established for GFRP moisture absorption properties. Nevertheless, it must be emphasized that basalt fibers contain approximately 7 % iron oxide, which makes them potentially more vulnerable in alkaline-chloride (concrete-saltwater) environments (Stekloplastics, 2014; Toni Schneider, 2015; Kochergin et al., 2013). Therefore, in this research, long-term durability analysis of these bars was performed and mechanical properties were evaluated on aged rebars to characterize the degradation due to aggressive environments. It was found that after 300 d of exposure in aggressive environments, though the long-term moisture absorption was less than 1 % for all types of rebars that many of, the rebars manufactured with epoxy resin (Type A & C) did not sustain in high pH environments due to the aggressiveness of the environments and high exposure temperature and even the vinyl-ester rebars (Type B) were severely compromised. As stated by (Kampmann et al., 2018), it was found that the strength retention of FRP bars is inversely proportional to those with higher moisture absorption property. However, this correlation did not always apply in this project, since moisture absorption is not the sole indicator of deterioration. Type A and C # 3 bars had higher moisture absorption and hence sustained less loads after the aging period while Types A and C # 5 bars had lower moisture absorption property, but they retained lower strength compared to Type B rebars. It can be said that, for now, the 1 % maximum long-term moisture absorption criteria seems to be appropriate for BFRP rebars as well.

9.4 Limitations

This research project was focused on durability evaluation in artificial environments of three types of BFRP rebars from two different production lots, with a focus on the two most commonly used rebar sizes in the US, # 3 and # 5. The conditions are not realistic representations of real world conditions of BFRP rebars embedded in concrete, but instead are extreme conditions used to force deterioration of the BFRP rebars and thus help determine which environmental exposure elements are most critical. Rebars, along with resin, sized and un-sized fibers were exposed to 16 different aggressive environments (4 pH and 4 Cl^-) at 60 °C for 300 d and 600 d to study the physical properties such as microstructure changes, XRF analysis and mechanical properties such as tensile strength. In addition, eight different chemical properties of exposure conditions were analyzed in the research along with physical and mechanical properties of rebar components. Four types of mechanical properties, namely, tensile strength, horizontal and transverse shear, and bond-to-concrete strength, and five types of physical properties such as fiber content, cross-sectional analysis, moisture absorption, XRF analysis, and microstructure observation via SEM analysis of virgin rebars were studied. Rebars were then exposed to nine different aggressive environments (3 pH and 3ceCl-) at 60 °C for 300 d and 600 d. Further, five test repetitions for shear tests and three repetitions for other mechanical properties in each exposure condition were conducted to validate the conclusion drawn from the experimental data collected. In this research rebars were embedded in concrete after the aging period to study the bond-to-concrete properties and the concrete was not exposed to aggressive environments. Accordingly, the results and analyses presented in this research report shall be understood or interpreted within the context of the here listed boundary conditions. The results cannot be directly related to a quantifiable long-term performance period of BFRP rebars embedded in concrete. When extrapolating the findings to other material behavior or to different/new/other BFRP products, care must be taken.

9.5 Further Directions

In the literature review, it was noted that very limited durability tests were performed on BFRP reinforced concrete beams and slabs, and that additional durability analyses for BFRP rebars in extreme environments needs to be conducted to better understand the performance of these bars in aggressive environments when embedded in concrete. It is important because of the unique chemical composition of basalt fibers and the interaction they can potentially undergo in saline-rich environments combined with high pH concentrations. This may be one of the most important aspects for determining the proper life cycle of concrete structures reinforced with BFRP rebars in aggressive environments (e.g.; coastal bridges) because cementitious paste surrounding the rebar produces highly alkaline conditions.

Additionally, it was found in the literature that very limited research is available regarding long term mechanical and environmental performance of reinforced and prestressed concrete beams reinforced with FRP bars (Inmana et al., 2017), cracking behavior of beams reinforced with BFRP bars (Masmoudi, R and Benmokrane, B and Chaallal, Omar, 1996), and tensile, flexural and serviceability performance of beams reinforced with BFRP bars (Kassem, Chakib and Farghaly, Ahmed Sabry and Benmokrane, Brahim, 2011; Elgabbas, Fareed and Vincent, Patrick and Ahmed, Ehab A and Benmokrane, Brahim, 2016). It is important to assess these properties along with the degradation analyses of concrete beams reinforced with BFRP rebars in harsh environments because these rebars are intended to be used in coastal and marine bridges and BFRP rebars may be susceptible to degradation in such conditions. Likewise, the elastic lengthening of BFRP tendons is higher than that of steel (Thorhallsson and Jonsson, 2012; Pearson et al., 2013) and it might be beneficial to evaluate basalt fiber materials for the use of prestressing tendons to make additional alternatives available that can be used for prestressed concrete elements that are completely steel- or corrosion-free.

The micro-structure porosity, the moisture absorption, and tensile strength properties of FRP rebars are closely related (Kampmann et al., 2018). If the moisture absorption of rebars is high, it may lead to lower tensile strengths, especially the long-term strength of these bars.

Bond-to-concrete strength is an important property of these rebars both for development length and crack width control. Several types of surface enhancements are currently being used in rebar manufacture and their performance varies based on the manufacturing type and resin used. The pullout test conducted under this research were primarily to validate that the ASTM D7957 (2017) minimum 1.1 ksi guaranteed bond strength is available. This allows confident use of the rebar development equations in the AASHTO LRFD Bridge Design Guidelines. For the design of FRP rebar reinforced concrete structures in AASHTO LRFD Bridge Design Guidelines, a bond reduction factor (C_b) has to be applied to calculate flexural crack widths under service loading. It is assumed to be dependent but is not directly related to the pullout strength. Flexural testing must be conducted to more accurate establish the bond reduction (C_b) factor. But was beyond the scope of this reseach The current bond reduction factor suggested by ACI 440.1R (ACI Committee 440, 2015) is 0.71, and according to AASHTO LRFD BDS for GFRP bars is 0.83 (AASHTO, 2018). In this research, it was seen that, BFRP rebars retain up to 80 % of their bond strength after 300 d and 600 d of exposure to aggressive environments at 60 °C. Based on the research data from this research, for now, it can be stated that the bond factor for BFRP bars can be similar to that of GFRP bars from AASHTO guidelines. It was observed that only limited research on bond reduction factor (C_b) is currently available. In addition to the need for these flexural bond reduction factor studies, a bond strength deterioration study similar to Ruiz Emparanza (2020), focusing on the durability of bond-to-concrete strength of beams designed with BFRP rebars after exposure to aggressive environments for prolonged exposure can be very useful and can lead to a more precise definition of the bond strength, ultimately helping with the development of bridge design guidelines for BFRP bars. A study focusing on bond-to-concrete property of BFRP bars embedded in concrete beams is suggested to develop BFRP rebar specific bond factors for bridge design based on AASHTO LRFD guidelines is suggested.

BFRP rebars are comparatively new in the market and various types of bars made from different types of sized basalt fibers and resins are currently available in the market. These rebars have dissimilar physical and mechanical properties based on the source of fibers, type of resin used in the manufacturing process, and types of hardeners used in the manufacture of resin. Therefore, for the ease of manufacturers, researchers, practicing engineers, and construction industry, the development of a product database is suggested which includes manufacturer details and production capabilities; various types, shapes, and sizes of rebars available at each manufacturer; sources of fibers and composition of resin used in rebar manufacturing process; each manufacturer product's physical and mechanical properties; and types of surface enhancement used in the manufacturing process.

Chapter 10

Proposed BFRP Rebar Specifications

The current 2022 FDOT Specifications Section 932-3 for BFRP reinforcing includes adequate mechanical properties based on the findings from this research. There may be opportunity to raise the mechanical limits for some properties in the future, but it is recommend to keep the same as those for GFRP reinforcing at this time. Regarding the durability of BFRP reinforcing within concrete elements submerged in seawater or other high chloride environments, there is potential for deterioration beyond that expected from GFRP rebar, when combined with high alkalinity (pH 13) that might be expected in the concrete pore solution. It should be acknowledged that the exposure condition is this research are considered much more extreme than would be experienced with a concrete element under normal service conditions (Morales, 2021). Current durability acceptance criteria under alkaline conditions for GFRP reinforcing according to ASTM D7957 (2017) and FDOT Specifications Section, is no more than 20 % degradation in the average tensile strength when bars are exposure to pH 12.6-13 alkaline aqueous solution at 60 °C for 90 d. This threshold should be maintained for BFRP reinforcing, but including a chloride ion concentration in the aqueous specification should also be considered, given the observations from this research. Alternatively the FDOT could continue to restrict BFRP reinforcing in permanently submerged conditions per FDOT Structures Manual, Volume 4, Chapter 2. It is suspected that that the iron oxide component of BFRP fibers may make them more susceptible than GFRP to degradation under a combined high pH and high salinity aqueous environment.

Chapter 11

Long-Term Durability Prediction

11.1 Introduction

A major goals in this research was the prediction of the BFRP Rebar service life based on the experimental results obtained from virgin material characteristics and the results obtained throughout the durability performance analysis (aged characteristics). Accordingly, different degradation models, which determine the degradation rates, were evaluated, and a prediction model based on a redefined/adapted approach for durability specification for FRP according to fib bulletin 40 (International Federation for Structural Concrete, 2007) was developed. The application of the fib Bulletin 40 model to the research data was expected to be very conservative when compared to in-service performance, as the rebar conditioning methods (aqueous solutions with high pH levels and rich in salinity, which fully saturated the rebars) applied throughout this research study are not truly identical to in-service rebar exposure environment inside concrete. Additionally, the influence factors considered in the model (c.f. Table 11.1) are considered slightly subjective, as they have not been fully verified in this research. However, the model was further developed and adjusted to evaluate the potential impact of the influence factors encountered throughout the experimental program. In this chapter, the implementation and adaptation of the prediction model for strength retention of FRP bars, FRP design strength equations, environmental strength reduction factors, and long-term strength prediction are explained in detail.

11.2 Previous Durability Studies on BFRP Bars

Durability performance and long-term prediction models of sand-coated basalt FRP bars were studied by Ali, Ahmed H and Mohamed, Hamdy M and Benmokrane, Brahim and ElSafty, Adel and Chaallal, Omar (2019). The physical, mechanical properties and micro-structural characteristics of unconditioned BFRP bars were evaluated first. Then, the durability performance of the BFRP bars was assessed by conducting mechanical tests, such as transverse-shear tests, flexural tests, and inter-laminar shear tests, after the specimens were exposed in alkaline environments at 12.8 pH for different periods (1000; 3000; and 5000 h) at 60 °C. Long-term behavior and service-life performance was predicted via Arrhenius concepts and the fib Bulletin 40 method. The primary assumption that drives the Arrhenius model is that only one dominant degradation mechanism affects the material throughout the reaction and that this mechanism will not change with time or temperature throughout the exposure. The fib model, on the other hand, is based on a durability design approach for FRP rebars by incorporating factors such as relative humidity (RH), exposed mean average temperature (MAT), and services life International Federation for Structural Concrete (2007). The test observations from the literature data indicated that the basalt fiber content is 81 % by weight and the water uptake at saturation is equal to 0.25 %. The literature data also showed that the cure ratio of the material was very high (close to 100 %) but its glass transition temperature was 116 °C by DSC. The mechanical test results from the literature indicate that the transverse-shear strength of the BFRP specimens was slightly affected by increasing the immersion duration at higher temperature levels. After 5000 h of immersion in the alkaline solution at 60 °C, test results indicated that 12 % degradation in the transverse-shear occurred. It was found that the flexural strength of the BFRP bars was significantly affected by accelerated aging (19 % reduction after 5000 h, at 60 °C). The inter-laminar shear strength of the BFRP bars was highly affected by accelerated aging (21 % reduction after 5000 h, at 60 °C). It was also found that the fiber-resin interface played a significant role in controlling the degradation due to conditioning. According to the long-term predictions, the transverse shear strength retention of the BFRP bars immersed in alkaline solution will decrease by 19.8 % and 23.0 % after 150 years at an isotherm temperature of 10 °C and 30 °C, respectively. It was shown that the BFRP bars service life with a transverse shear-strength retention of at least 79.6 % and 76.1 % at 10 °C and 30 °C, respectively, should be infinite. While the Arrhenius model and the fib model appropriately predicted the strength retention of the rebars in alkaline solutions, they do not address the strength retention of bars exposed to saline solutions (seawater). Therefore, a more robust prediction model was needed to predict long-term strength retention of FRP bars, regardless of exposure environment type.

Similarly, Serbescu et al. (2014) examined the degradation of BFRP bars after exposure to accelerated environmental conditions. Two types of BFRP rebar specimens with seven different diameters were tested in tension after they were conditioned in water at 20 °C for 1000 h, water at 60 °C for 100 and 1000 h, in 9 pH solutions at 20, 40, and 60 °C for 100, 200, 1000, and 5000 h; and in 13 pH solution at 20 and 60 °C for 1000 h. Based on the test results, a methodology to predict the comprehensive long-term strength of FRP bars in multiple environments was proposed based on fib Bulletin 40 model. Two new parameters, n_{pH} and n_{mo} were introduced to account for pH and the degradation onset. It was found that the tested BFRP bars measured a tensile strength of 972 MPa to 1481 MPa and an elastic modulus of 34 GPa to 47 GPa. Among all parameters examined, temperature was found to be the most important factor affecting the degradation process. Rebars exposed to 9 pH solution at 60 °C for 5000 h retained the lowest strength of 69 %. An 8 % loss in tensile strength was observed in bars which were exposed to 7 pH and 13 pH environments and an increase of 6.5 % in elastic modulus was observed, which was explained through the post curing effects of resin. While this research presents a durability model that can predict the long-term strength of rebars in alkaline environments, it cannot be used to predict the strength retention of bars in saline environments or alkaline and saline environment combination. To address the shortcomings in the existing models, a comprehensive prediction model was developed based on existing models. The individual details of the models and the relevant factors are addressed in the following sections.

11.3 fib Bulletin 40 Model

According to fib Bulletin 40, the existing approaches for durability specifications of FRP do not take into account all parameters that, according to the literature, have been identified as significant influence factors for FRP durability in concrete (International Federation for Structural Concrete, 2007). The refined approach as it is used in fib Bulletin 40 addresses these issues and conservatively quantifies the impact of various aggressive environments on the FRP design life. It was suggested that FRP rebars shall be exposed to aggressive environments for 1000 h such that the chemical reactions between the rebars and the exposure solutions can stabilize, before conducting strength tests on aged material to determine the long-term strength retention International Federation for Structural Concrete (2007); Serbescu et al. (2014). However, in this research, BFRP rebars were exposed to aggressive environments for 300 d and 600 d and the prediction model was developed based on such durability results. Accordingly, the following subsections 11.3.1, 11.3.2, 11.3.3

describe the applicable and relevant FRP design strength equations, environmental strength reduction factors, and long-term strength of FRP.

11.3.1 FRP Design Strength Equation

Currently, fib Bulletin 40 proposes that the durability design of FRP rebars shall be based on a simple design strength equation that multiplies the characteristic tensile strength by a factor, which is linked to various environmental parameters that increase or decrease the factored tensile strength depending on the severity of the exposure environment, as seen in equation 11.1.

$$f_{fd} = \frac{f_{fk0}}{\eta_{env,t}\ \gamma_f} \tag{11.1}$$

Where f_{fd} is the design strength, f_{fk0} is the tensile strength at day 0, and $\eta_{env,t}$ is the environmental strength reduction factor. Accordingly, it is important to evaluate the environmental strength reduction factor because the design strength of FRP depends on this factor. Hence this factor is detailed in the following subsection.

11.3.2 Environmental Strength Reduction Factor ($\eta_{env,t}$)

fib Bulletin 40 describes $\eta_{env,t}$ as the ratio between the characteristic short term strength and the characteristic long term strength, i.e. the creep rupture stress limit (International Federation for Structural Concrete, 2007) which can be defined according to equation 11.2.

$$\eta_{env,t} = \frac{\frac{f_{fk1000h}}{f_{fk0}}}{\left(\frac{100-R_{10}}{100}\right)^n} \tag{11.2}$$

Where $f_{fk1000h}$ is the rebar tensile strength after 1000 h of exposure in aggressive environments, R_{10} is the standard reduction of strength, and n is the sum of influence terms, which fib defines through the following equation 11.3.

$$n = n_{mo} + n_T + n_{SL} + n_d \tag{11.3}$$

Where n_{mo} is the term for moisture condition of exposure environment, n_T is the term for average temperature of exposure environment, n_{SL} is the term for desired service life period of FRP rebar, and n_d is the term for diameter correction factor as can be seen in Table 11.1. As per fib Bulletin 40, for normal exposure conditions, exposure solutions are not aggressive toward exposed rebars, and therefore, n is conservatively equated to 3. Figure 11.1 visualizes the degradation curves of two different GFRP bars, standard reduction per logarithmic decade, and 1000h strength for two different GFRP materials with different durability (International Federation for Structural Concrete, 2007). The figure also visualizes the standard reduction per logarithmic decade (R_{10}), which is the difference in the strength retention of FRP bars in any given logarithmic decade, 1000 h ($f_{fk1000h}$) strength of two GFRP bars, and creep rupture stress limit for 100 years. In this research the measure of the degradation rate was given by the standard strength reduction per logarithmic decade (11.4) because it represents the percentage of strength loss during each logarithmic decade of exposure.

$$R_{10} = 100 - (10^m \times 100)\% \tag{11.4}$$

Where m is the slope of degradation line, shown in Figure 11.1, which can be defined per equation 11.5.

$$m = \frac{log(f_{fk0}) - log(f_{fk7200})}{log(1) - log(7200)} \tag{11.5}$$

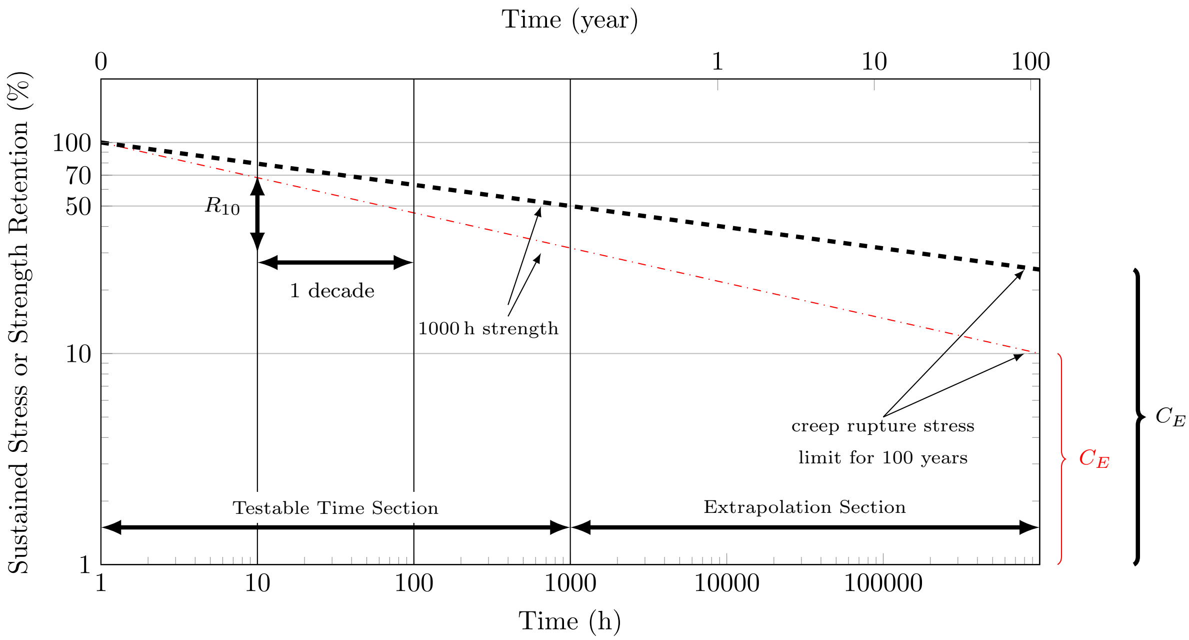

Figure 11.1: Environmental strength reduction factor and 1000h strength for two different GFRP materials with different durability (International Federation for Structural Concrete, 2007)

Where f_{fk0} is the virgin strength or the 100 % value, and f_{fk7200} is the retained strength of FRP bars measured after 7200h of exposure. Figure 11.2 shows how the results from this research could be applied to the fib Bulletin 40 model assuming the log-log relationship. In this research, f_{fk7200} is used to determine the slope of degradation line because the rebars were exposed for 300 d instead of 1000 h to determine a more reliable degradation line and the environmental degradation factors. Two new degradation parameters, n_t — the term for exposure time — and n_{Cl} — the term for Cl^- — were introduced in this research to refine the model based on the experimental data obtained along with n_{ph} — the term for pH introduced by Serbescu et al. (2014). The term for exposure time (n_t) is considered 1 in this research and it can be considered 1 if the exposure time is more than 300 d. If the exposure period is less than 300 d, n_t can be considered 0. Similarly, n_{Cl} was considered 0.5 for rebars exposed to chloride ions less than 20000 ppm and it was considered 1 for rebars exposed to chloride ions greater than or equal to 20000 ppm. These values are derived based on the obtained experimental results of 0 and 300 d experiments. The validity of these values has been verified by comparing the predicted values and 600 d test results. Based on the newly introduced parameters, the summation of influencing terms must be updated and the redefined value for n can be seen in equation 11.6.

$$n = n_{mo} + n_T + n_{SL} + n_d + n_t + n_{pH} + n_{Cl} \tag{11.6}$$

The numerical ranges and corresponding values for each influence factor including the newly introduced parameters based on this research project are listed in Table 11.1. After determining the equations for the environmental degradation factor and it's influence factors, the long-term strength performance of FRP rebars can be predicted using short-term and long-term strength, in combination with the afore mentioned factors. Based on the severe degradation of the rebars at 600 days in pH 13 solutions at 60 °C, it appears that the linear log-log relationship may not reliably apply to all the results from this research. However, the following subsection 11.3.3 outlines the long-term strength retention of FRP rebars in detail, using to this

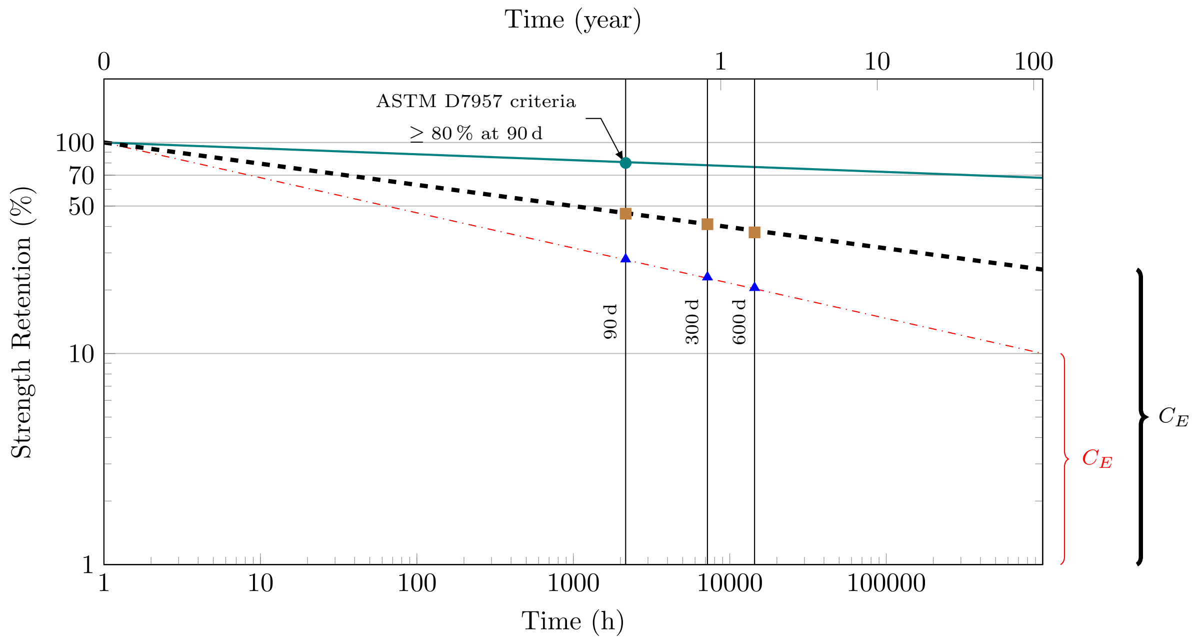

Figure 11.2: Conceptual application of strength retention (in %) vs. time (in h), assuming a linear degradation rate on a log-log scale (based on the fib Bulletin 40 model approach)

model.

11.3.3 Long-Term Strength

The long-term strength retention of FRP bars in any exposure environment can be estimated by extrapolating the degradation line shown in Figure 11.1. If R_{10} is available, the long-term strength f_{fkt} can be expressed according to the following equation 11.7 and the long-term strength percentage retention can be calculated through equation 11.8.

$$f_{fkt} = \frac{f_{fk0}}{\eta_{env,t}} (\text{MPa}) \tag{11.7}$$

Where $\eta_{env,t}$ is the environmental factor which changes based on several influence factors. Hence, the long-term strength retained in percentage can be calculated by dividing a total of 100 % with the environmental degradation factor obtained based on different exposure conditions and degradation parameters as per below equation 11.8.

$$f_{fkt}\% = \frac{1}{\eta_{env,t}} 100 \tag{11.8}$$

When R_{10} and n are known, the environmental degradation factor used in equation 11.8 can be determined by equation 11.9 below.

$$\eta_{env,t} = \frac{1}{\left(\frac{100-R_{10}}{100}\right)^n} \tag{11.9}$$

Table 11.1: Influence factors

Influence Factors	Value	Factor
Diameter (n_d)	$\geqslant tested$	0.0
	75% tested	0.5
	50% tested	1.0
Service life (n_{SL})	1 year	1.0
	10 years	2.0
	50 years	2.7
	100 years	3.0
Temperature (n_T)	0 °C	-0.5
	10 °C	0.0
	20 °C	0.5
	30 °C	1.0
	40 °C	1.5
	50 °C	2.0
	60 °C	2.5
Moisture (n_{mo})	Dry (50%)	-1.0
	Moist (80%)	0.0
	Saturated (100%)	1.0
Time (n_t)	$\leqslant 7200h$	0.0
	$\geqslant 7200h$	1.0
pH (n_{pH})	4	0.0
	7	0.0
	13	1.0
Cl (n_{Cl})	0	0.0
	$\leqslant$ 20000	0.5
	$\geqslant$ 20000	1.0
	Seawater	1.0

11.4 Durability Prediction

A single logarithmic (Banibayat and Patnaik, 2014) or a double logarithmic scale (International Federation for Structural Concrete, 2007; Weber, Andre and Baquero, Christian Witt, 2010) is usually adopted to graphically represent the strength loss with time (Serbescu et al., 2014). Bhise (2002) found that the degradation lines at different temperatures in a single logarithmic scale are generally not parallel, which was attributed to the effects of moisture diffusion throughout the degradation mechanism. Numerous other tests at room and elevated temperatures (International Federation for Structural Concrete, 2007; Renaud, Claude M and Greenwood, Mark E, 2005; Weber, A, 2013) showed a linear behavior of stress-time in double logarithmic scale. In this research, long-term tensile strength, transverse shear strength, and horizontal shear strength of tested BFRP bars were determined using double logarithmic analysis. Three types of BFRP rebars were exposed to 9 different exposure environments (3 pH and 3 Cl^-) at 60 °C for up to 600 d. The long-term strength retention of tested rebars was predicted using virgin and conditioned properties, by determining discrete environmental degradation factors and applying them in the developed prediction model for all exposure environments individually. Based on this approach, Figures 11.3, 11.4, 11.5 show the predicted long-term strength retention for the tested bars for a service life of up to 100 years at an average environmental temperature of 60 °C. In addition, Figures 11.6, 11.7, 11.8 visualize the same data for a projected service life of 100-years (long-term strength retention) on semi-log graphs (with the y-axis being linear) for improved readability. The log-log graphs also show the environmental degradation factors for individual rebars based on exposure environment, temperature, and service life. No graphs for the pH 13 environments are provided here, due to a lack of confidence in the applicability of the model, as no rebars survived the highly aggressive accelerated aging conditions at the 600 d mark. It can be seen in Figure 11.3 that rebars exposed to 4 pH and 7 pH environments were predicted to retain 70 % to 90 % of their virgin tensile strength. Figure 11.4 demonstrates that the long-term transverse shear strength retention of rebars exposed to 4 pH and 7 pH retain 100 % of their initial strength throughout the 100 year service life, for the best performing rebars. The long-term horizontal shear strength retention of tested rebars shown in Figure 11.5 illustrates that the rebars exposed to 4 pH and 7 pH environments retain 100 % of their corresponding virgin strength for the best performing rebars. The same observations and trends are noted for Figures 11.6 through 11.8. From these graphs, it can be observed that many of the rebar specimens were predicted to have a much lower strength retention than 70 %, which is the typical value assumed in design of GFRP reinforcing. This highlights the wide variation in predicted durability depending on the manufacturer, resin, and fiber source. Therefore, it appears important to conduct durability testing for each product line (per manufacturer) based on the potential unique combination of constituent materials.

Since BFRP rebars will be used in infrastructure exposed to high saline and alkaline environments, it is important to generate as well as validate the generated long-term strength predicting models using real time data and include a factor of safety if necessary. Therefore, the following section 11.5 describes the literature data obtained and validation of generated model based on the data obtained in this research.

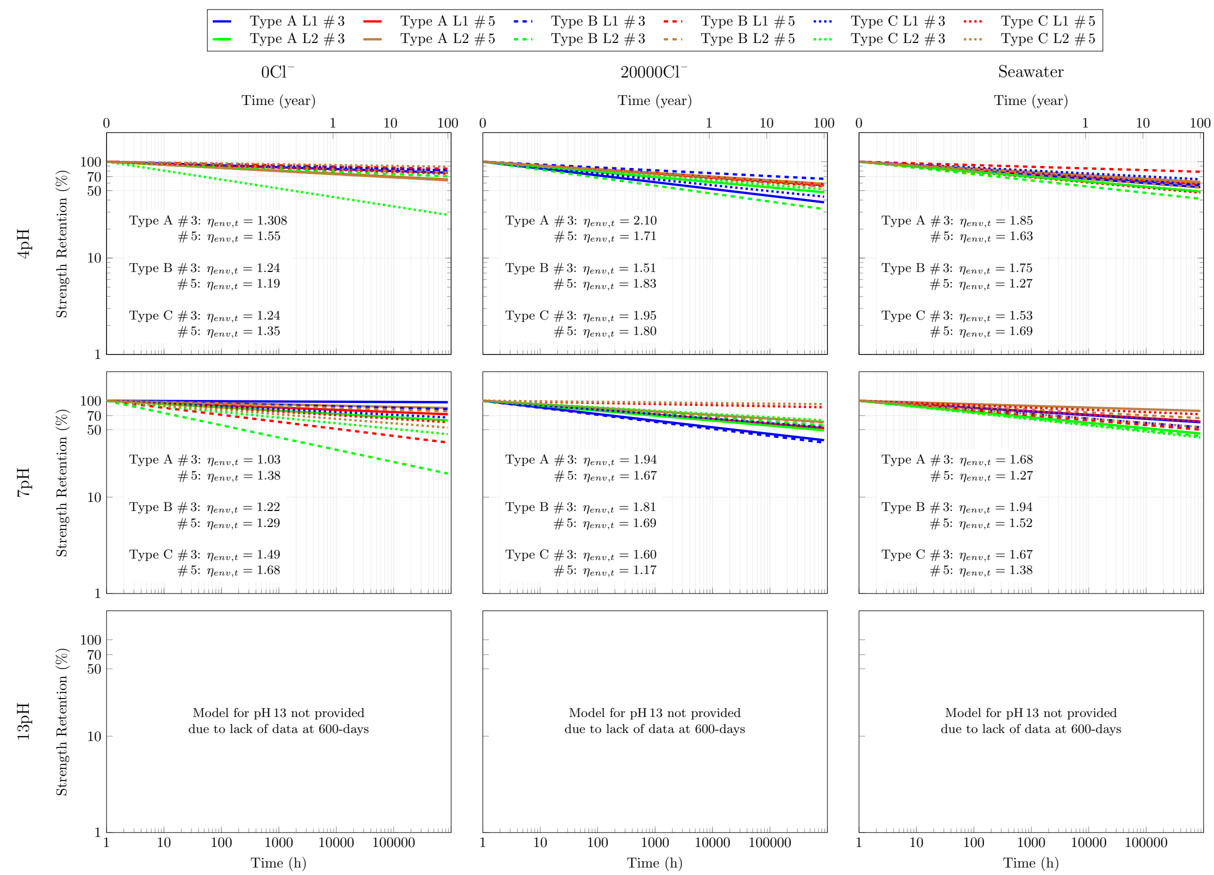

Figure 11.3: Long-term tensile strength retention of all tested bars (log-log scale) for 60 °C average environment temperature

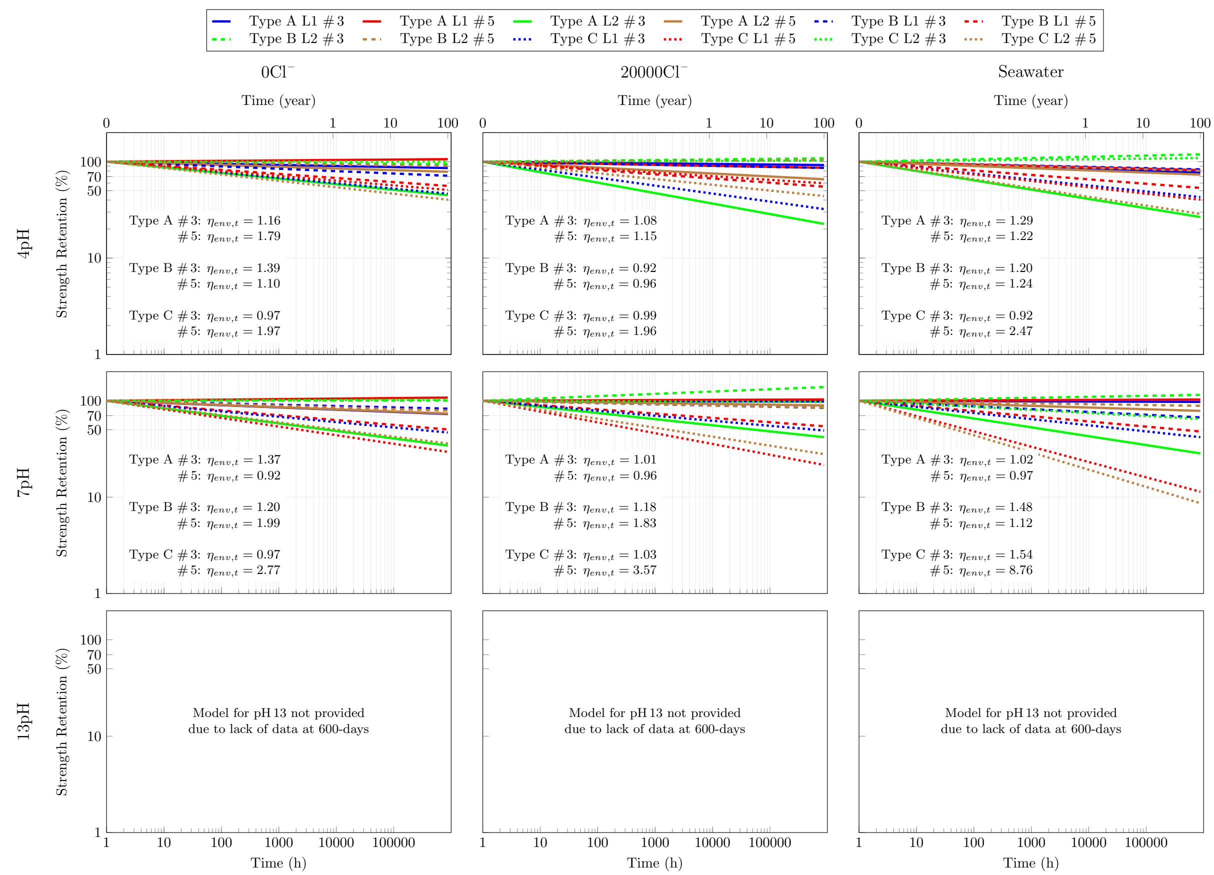

Figure 11.4: Long-term transverse shear strength retention of all tested bars (log-log scale) for 60 °C average environment temperature

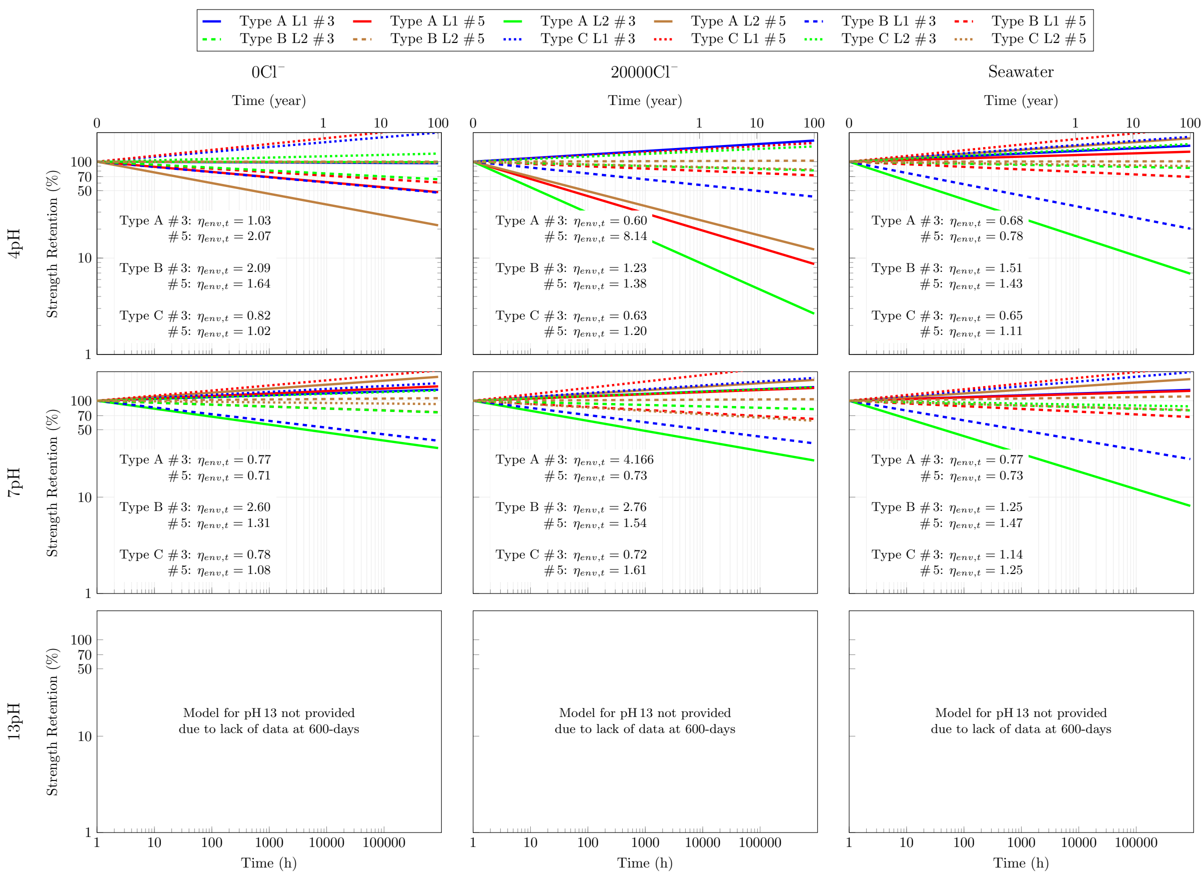

Figure 11.5: Long-term horizontal shear strength retention of all tested bars (log-log scale) for 60 °C average environment temperature

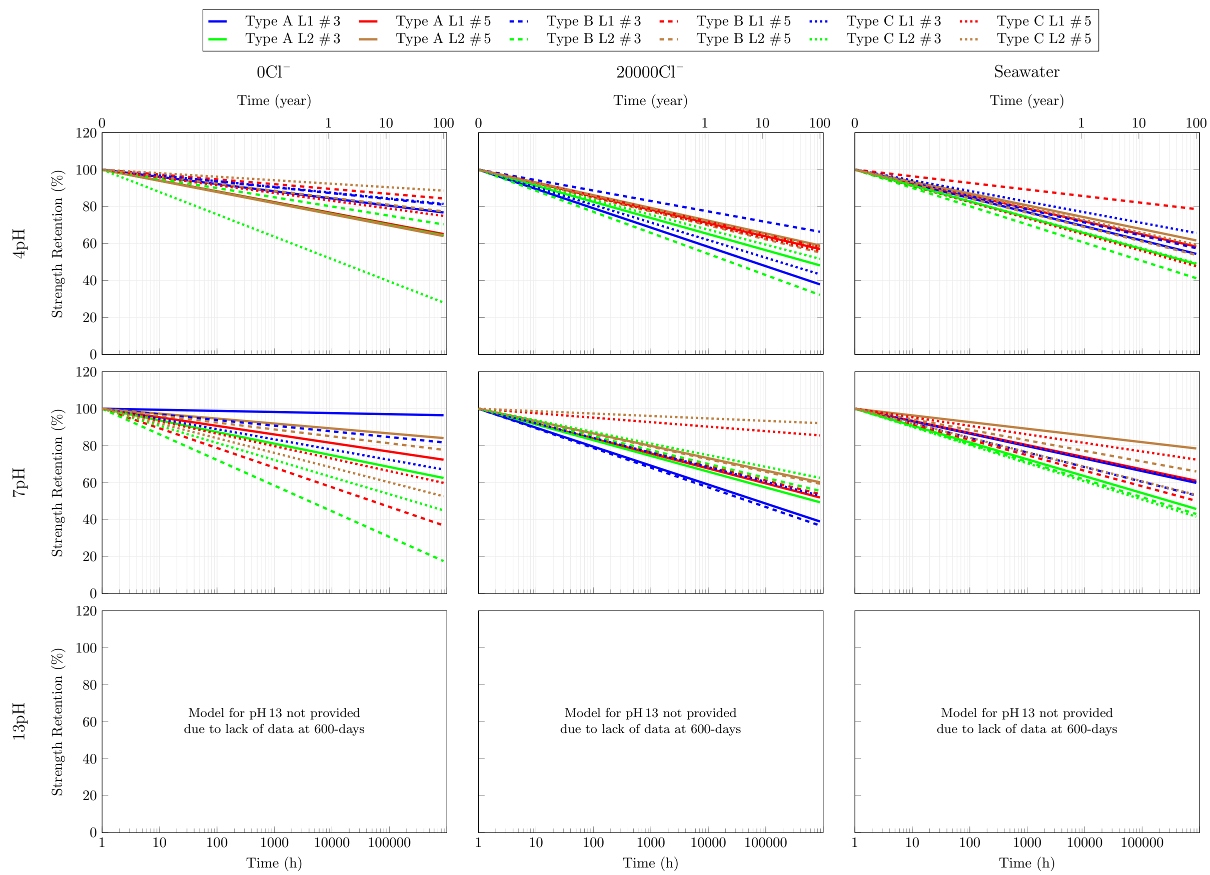

Figure 11.6: Long-term tensile strength retention of all tested bars (semi-log scale) for 60 °C average environment temperature

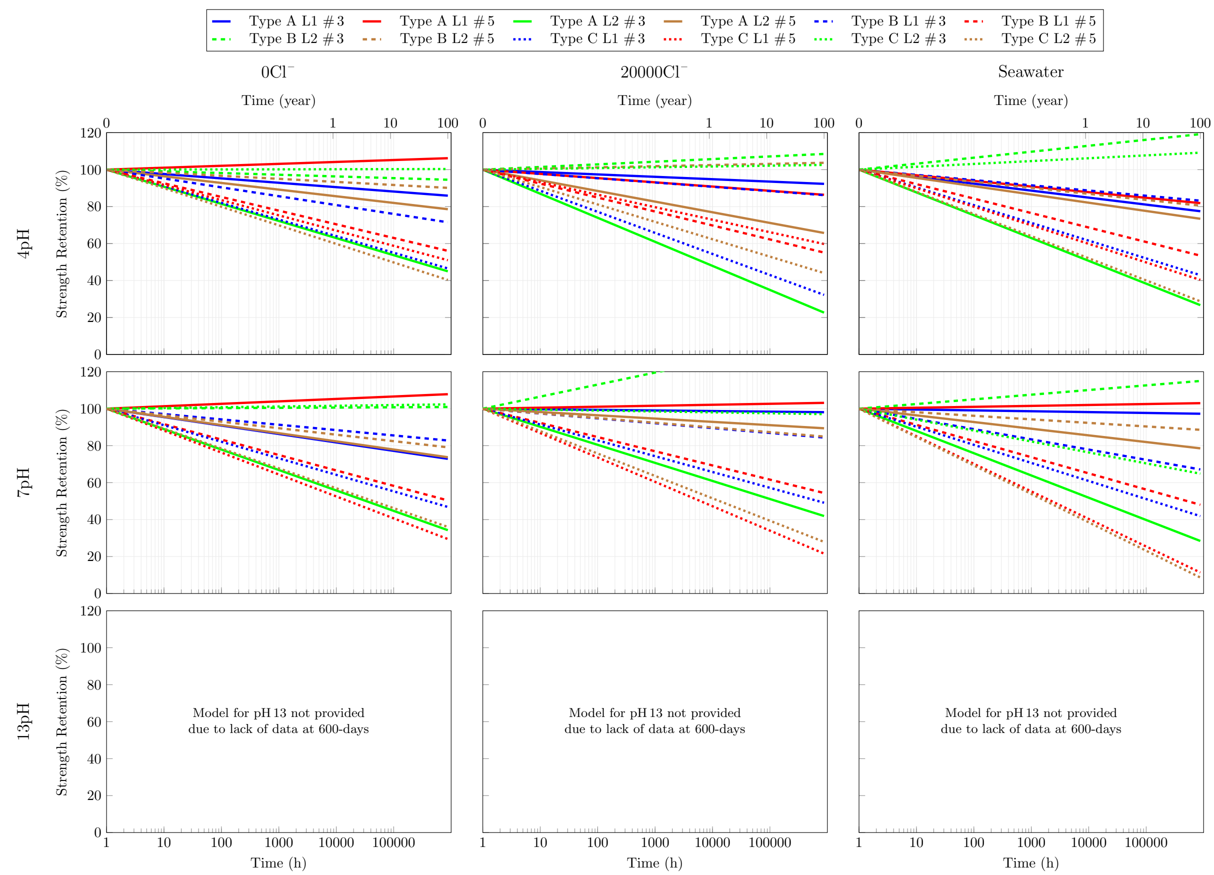

Figure 11.7: Long-term transverse shear strength retention of all tested bars (semi-log scale) for 60 °C average environment temperature

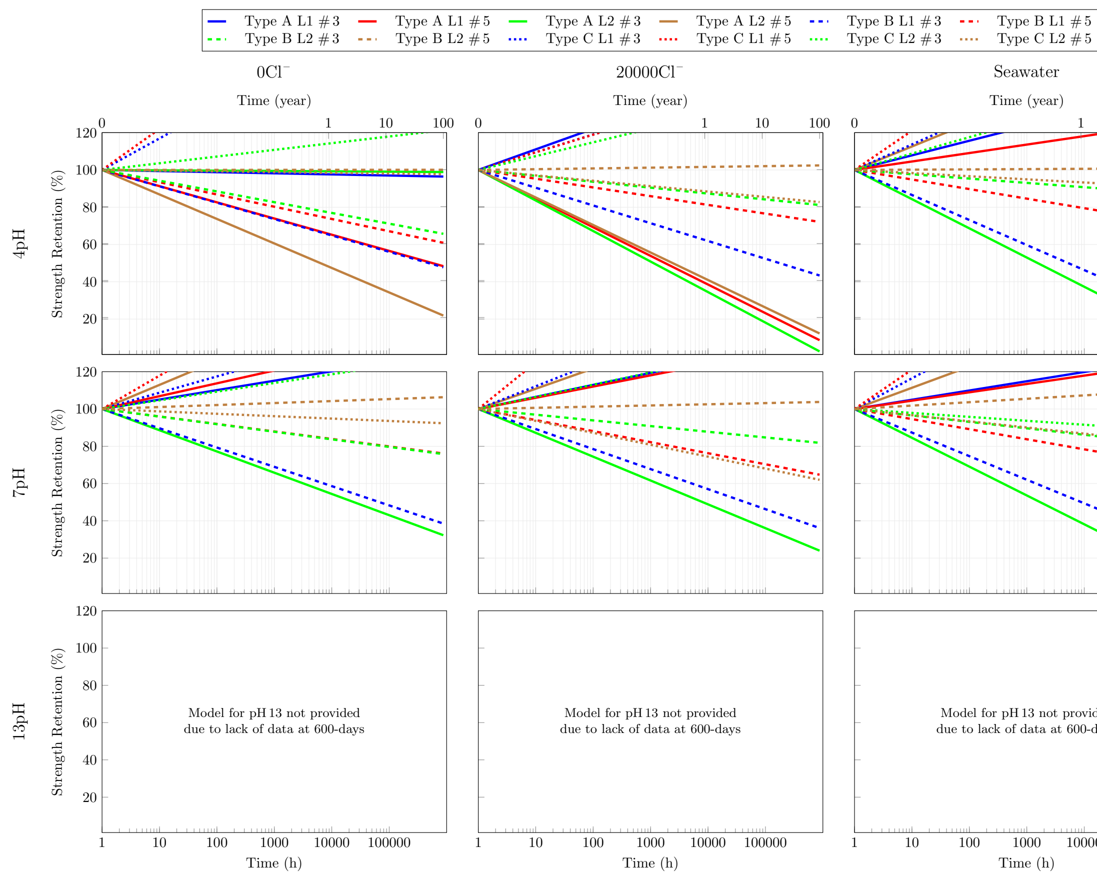

Figure 11.8: Long-term horizontal shear strength retention of all tested bars (semi-log scale) for 60 °C average environment temperature

11.5 Validation of Prediction Model

To validate the prediction model developed based on the virgin strength of rebars and 300 d data, strength retention graphs were plotted for both 300 d and 600 d results. The retention data was then compared to the predicted strength. The model was also validated using the experimental data reported in the literature for GFRP rebars, which was identified and prepared for use in the presented prediction model to determine the theoretically prognosticated long-term strength retention and compared it to the available test data. Figure 11.9 shows the strength retention for the tested rebars after exposure to different aggressive environments for 600 d, where 100 % is the virgin rebar strength at 0 d. It can be seen that most of the evaluated BFRP bars retained more than 60 % of their virgin strength after exposure to 4 pH environments and they retained more than 50 % strength in and 7 pH environments as per predicted in Figure 11.3, while they degraded significantly when they were exposed to 13 pH environments for 300 d and deteriorated completely after 600 d at 60 °C. Figure 11.10 below shows the transverse shear strength retention of these rebars after 600 d of exposure

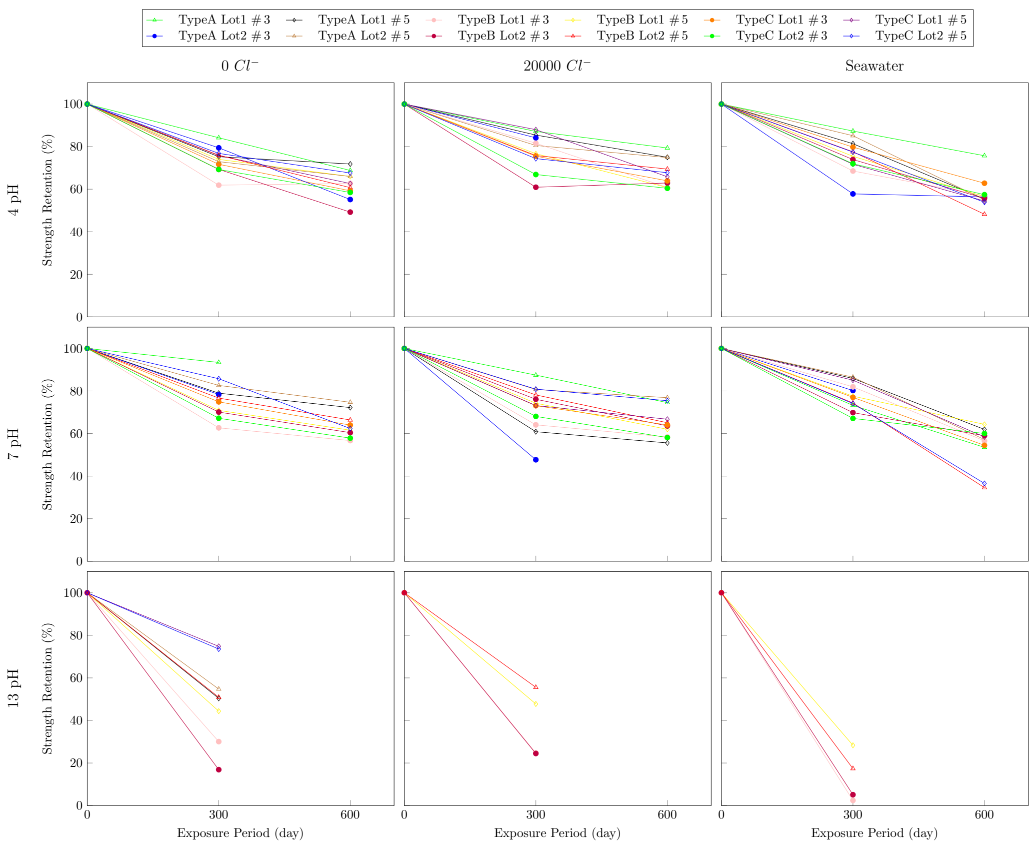

Figure 11.9: Tensile strength retention after exposure period

in different aggressive environments, where 100 % is the virgin rebar strength before exposure to aggressive environments. It can be seen that the rebar strength retention decreased more as we moved from the top-left graph of the matrix to the bottom-right graph. Most rebars retained more than 70 % of their strength in 4 pH and 7 pH environments after exposure for 600 d, which is higher than predicted in 11.4 while rebars exposed in 13 pH environments deteriorated completely. Figure 11.11 shows the horizontal strength retention of the tested BFRP rebars after 600 d of exposure in different aggressive environments, where 100 % is the virgin rebar strength before exposure to aggressive environments. It can be seen that most rebars exposed

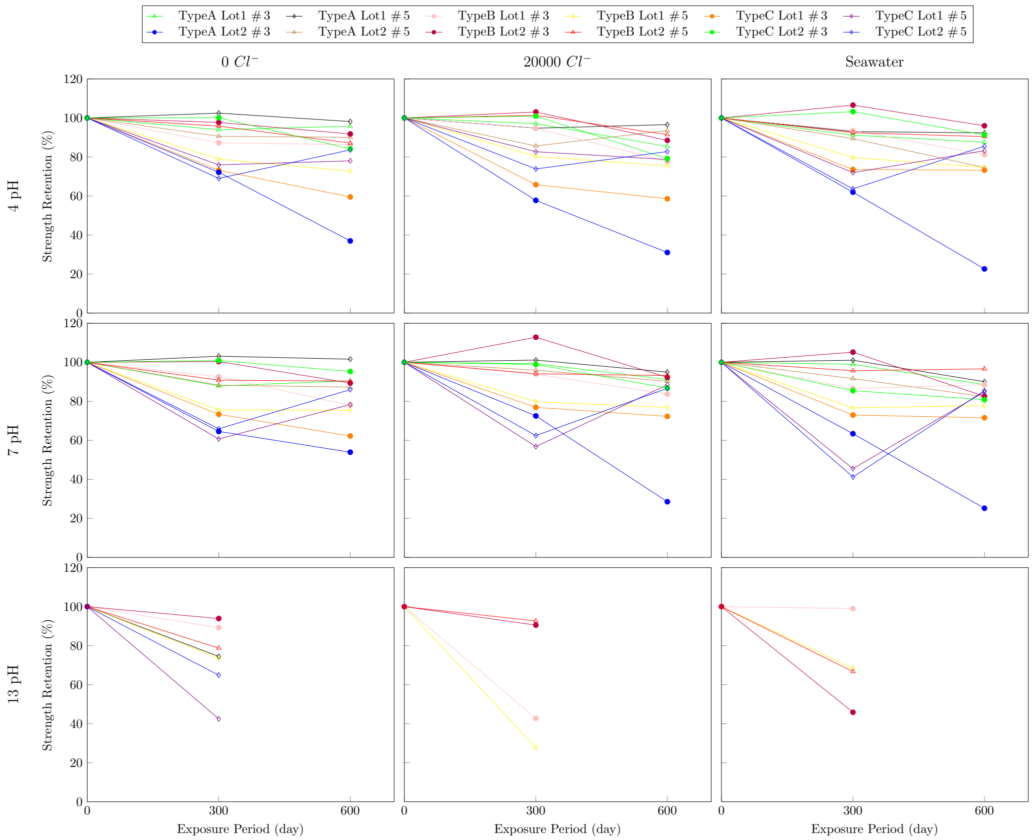

Figure 11.10: Transverse shear strength retention after exposure period

to both 4 and 7 pH environments retained more than 70 % of the strength as per the predicted strength in Figure 11.5, while rebars exposed to 13 pH environments completely deteriorated.

In the available literature data (Morales et al., 2021), three types of # 3 GFRP bars were exposed to seawater at three different temperatures (23 °C, 40 °C, and 60 °C) for 60 d, 120 d, 210 d, and 365 d. No additional alkalinity was forced upon the seawater solution and so the pH was approximately 8. Tensile strength, transverse, and horizontal shear strength tests were performed on bars before and after exposure in aggressive environments. Similar to this research, Morales et al. (2021) also predicted the long-term strength retention for GFRP rebars for a service life of 100 years and the predicted data was compared to tested data via double logarithmic graphs. Since the research performed by (Morales et al., 2021) appeared similar to the current research, experimentally obtained short-term strength of GFRP bars was used to predict the long-term strength, and predicted strength was compared to the long-term strength obtained via laboratory testing and graphically represented in the following figures. Figures 11.12, 11.13, 11.14 visualizes the long-term predicted strength (according to the here developed prediction model) vs. the reported tested strength for all GFRP rebars in all evaluated aggressive environments. The x-axis of the graph represents exposure time or service life period of rebars both in hours and years, while the y-axis shows the strength retention of tested rebars in percentage. Graph in figure 11.12 shows the long-term tensile strength retention of all GFRP bars. It can be seen that, regardless of the exposure temperature, rebars retained 70 % of their original strength after 1 year of exposure and it can also be seen that the tested rebar strength retention is higher than the predicted strength. Figure 11.13 shows the long-term transverse strength retention of all GFRP bars. It can be seen that, regardless of the exposure temperature, the predicted strength retention graphs have a

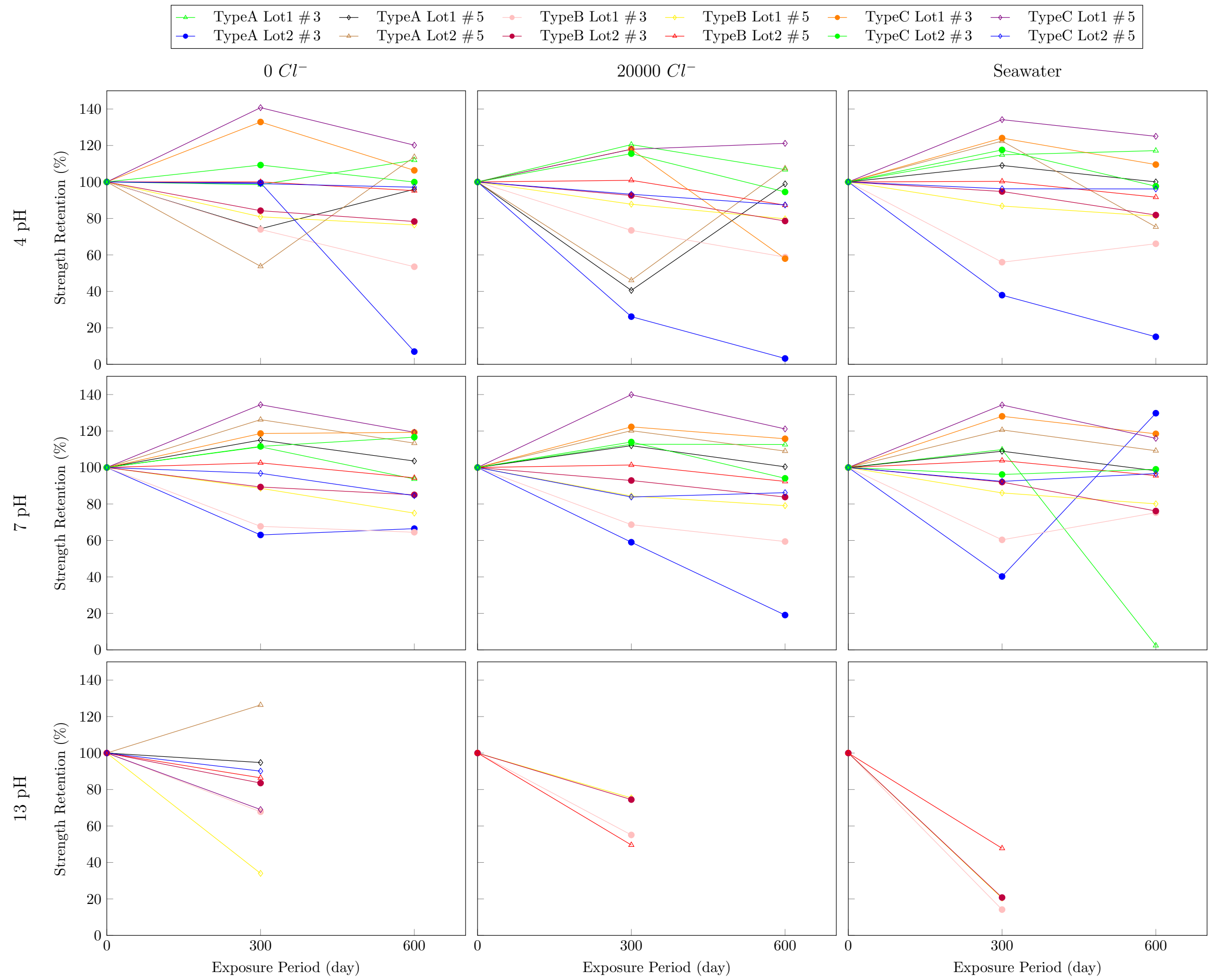

Figure 11.11: Horizontal shear strength retention after exposure period

positive slope. This is because the short-term transverse strength of GFRP bars used to predict the long-term strength was found to be higher than the virgin rebar strength. The short-term strength was explained to be higher due to the post curing effect of resin. Figure 11.14 shows the long-term horizontal strength retention of all GFRP bars. Similar to long-term transverse shear strength retention graphs, horizontal shear strength retention graphs have a positive slope. To further analyze the validity of the prediction model based on the literature data, predicted data was compared with the experimentally obtained data and Table 11.2 lists the differences between the predicted and the tested tensile strength of rebars in all exposed environments. Based on this analysis and the low differences between the predicted data and the actual tested data, it appears that the adjusted long-term strength prediction model is well suited to predict the GFRP rebar service life data accurately. After presenting the generated prediction model, environmental degradation factors based on exposure environments, and model validation; the results, analysis, and prediction model are discussed in detail below.

11.5.1 Long-Term Strength Prediction

FRP rebars are sought to be more suitable for use in harsh environments because such rebars do not corrode. However, the literature (Ali, Ahmed H and Mohamed, Hamdy M and Benmokrane, Brahim and ElSafty,

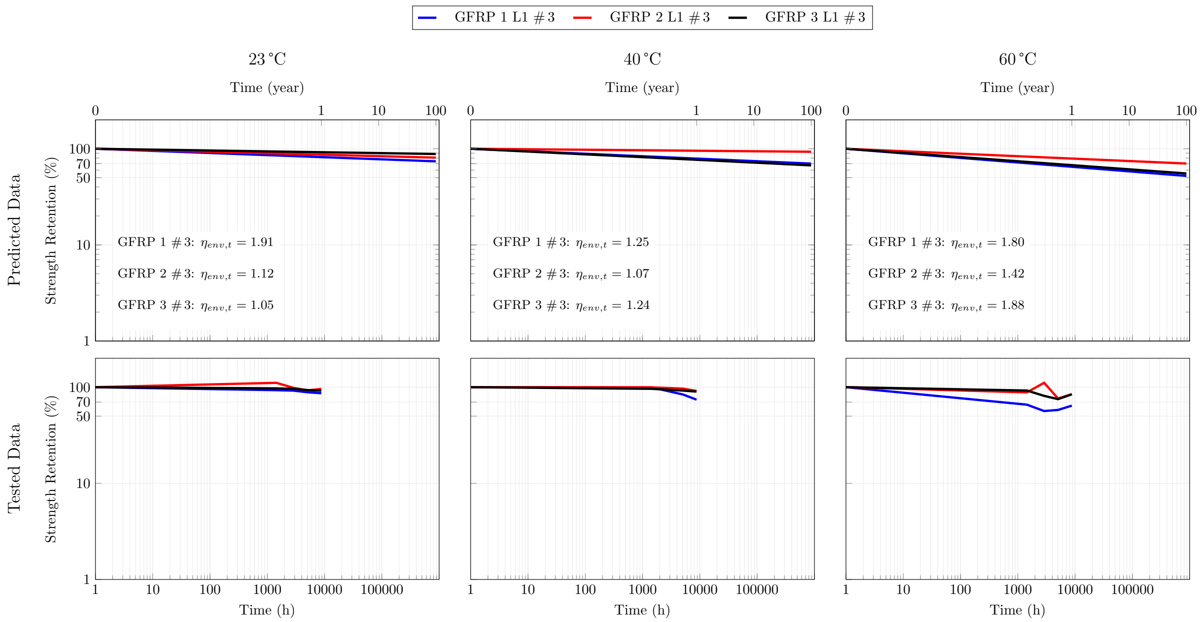

Figure 11.12: Predicted vs. tested long-term tensile strength retention of all GFRP bars (test data from Morales et al. (2021) based on seawater (∼ pH 8) exposure)

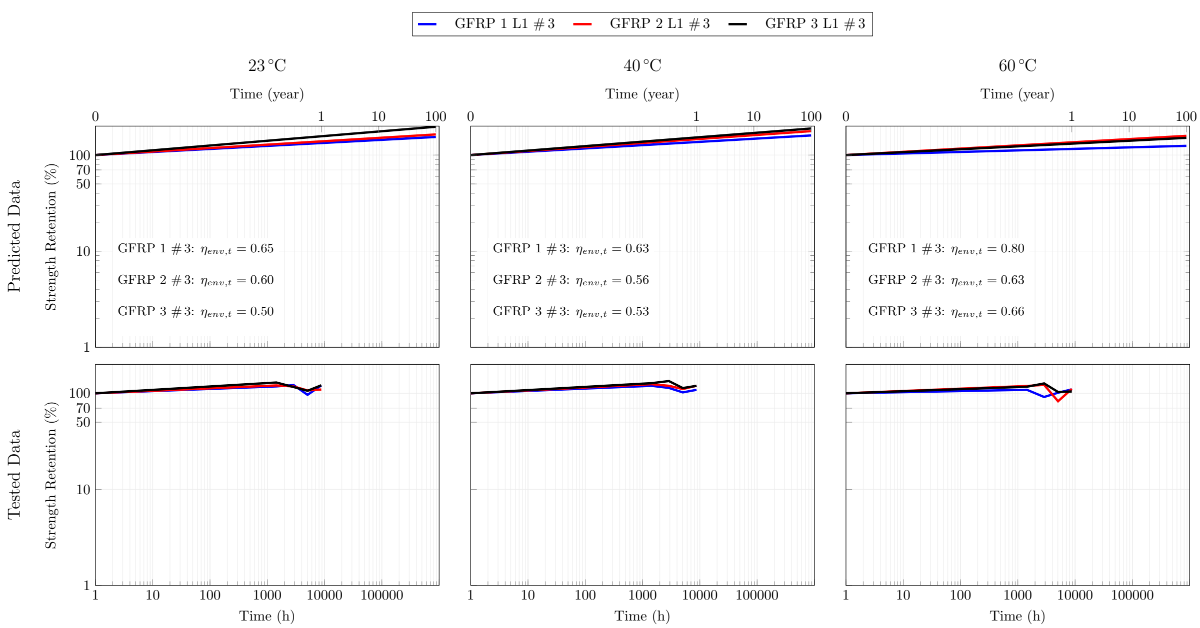

Figure 11.13: Predicted vs. tested long-term transverse shear strength retention of all GFRP bars (test data from Morales et al. (2021) based on seawater (∼ pH 8) exposure)

Adel and Chaallal, Omar, 2019; Serbescu et al., 2014) and this research has shown that other degradation mechanisms exist and FRP rebars are susceptible to degradation when exposed to aggressive environments for extended periods. In this research, it was seen that BFRP rebars may loose 5 % to 20 % of their initial shear strength and 20 % to 50 % of initial tensile strength when directly exposed to 4 and 7 pH environments at 60 °C for 300 d and 60 % to 80 % of their initial shear strength after exposure for 600 d. It was also found that

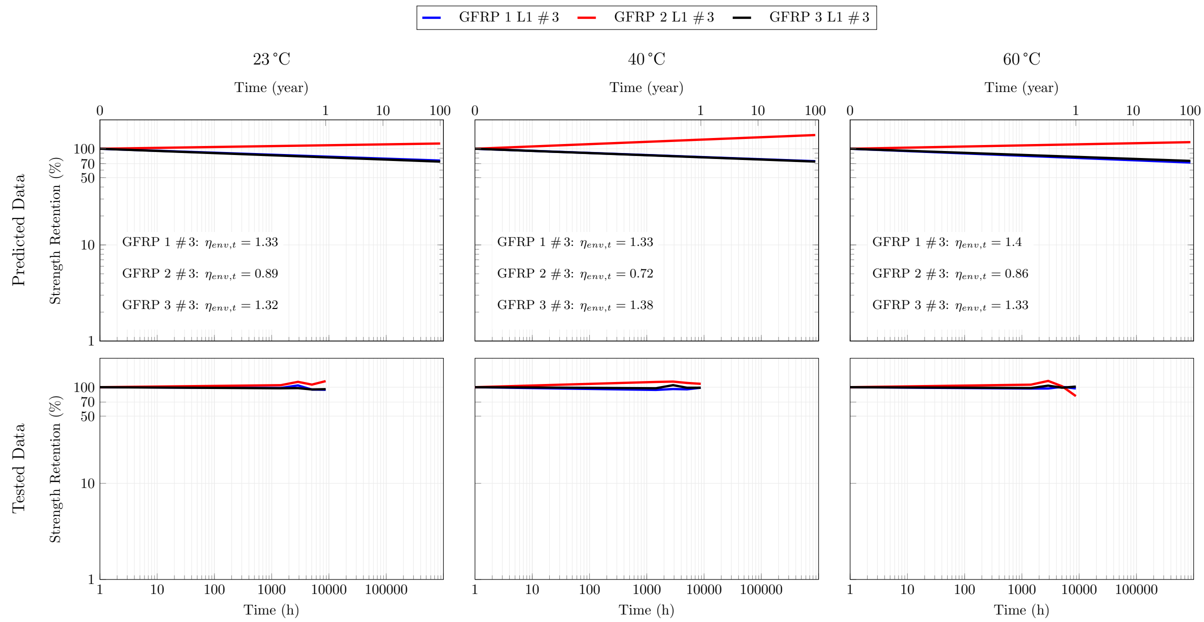

Figure 11.14: Predicted vs. tested long-term horizontal shear strength retention of all GFRP bars (test data from Morales et al. (2021) based on seawater (∼ pH 8) exposure)

Table 11.2: Differences in predicted and tested tensile strength retention percentage of all GFRP bars

Time		GFRP 1			GFRP 2			GFRP 3		
d	h	23 °C	40 °C	60 °C	23 °C	40 °C	60 °C	23 °C	40 °C	60 °C
120	2080	4.73	-23.12	1.16	-	-	-	37.01	33.77	-1.06
210	5040	1.46	-31.83	-1.49	-17.53	-2.63	0.56	40.58	4.40	-8.60
365	8600	2.06	-32.61	-1.66	-32.77	-8.26	-0.37	54.49	18.01	6.23

rebars retained more than 80 % of shear strength and 20 % to 60 % of tensile strength when directly exposed to 13 pH for all chloride ion concentration environments at 60 °C for 300 d, but completely disintegrated when exposed for 600 d. Therefore it is important to study the long-term performance of these rebars in aggressive environments to understand the degradation mechanisms but also in a representative concrete matrix that is assumed to be a much less aggressive (alkaline) environment, as the concrete pore solution is only in contact with the rebar surface and may not saturate the rebar (as it was the case for the accelerated aging conditions used in this study). Rebar degradation is an important aspect that needs to be better understood to develop a long-term durability prediction model because blindly using these products in infrastructure can be dangerous to public. Long-term durability prediction models are used to develop the environmental degradation factors (C_E) which are used in design of concrete structures using FRP bars. International design guidelines use the same environmental degradation[1] factors for FRP rebars, for example regardless of exposure type fib: 0.55,

[1]Note: degradation assumed included in other structural resistance factors.

CSA: 1.0, ACI: 0.7, and AASHTO: 0.7 (International Federation for Structural Concrete, 2007; Canadian Standard Association, 2010; ACI Committee 440, 2015; AASHTO, 2018). Generally, single logarithmic and double logarithmic models, Arrhenius models, exponential model, and fib Bulletin 40 model are used to predict the long-term strength of FRP bars (Ali, Ahmed H and Mohamed, Hamdy M and Benmokrane, Brahim and ElSafty, Adel and Chaallal, Omar, 2019; Serbescu et al., 2014; Morales et al., 2021; Renaud, Claude M and Greenwood, Mark E, 2005; Bhise, 2002; Weber, Andre and Baquero, Christian Witt, 2010). Single and double logarithmic models ,and exponential model can only predict long-term strength for bars exposed to different temperatures in the same type of environment while modified fib bulletin 40 model by (Serbescu et al., 2014) addressed the issue of pH of the environment. Since BFRP bars are intended to be used in marine and coastal structures, it is important to study the effects of saline environments and develop a model addressing the degradation mechanisms caused by saline environments. In this study, it was seen that BFRP products from different sources potentially age differently, and possibly should rely on dissimilar C_E factors. Similarly, the exposure environments played a dominate role in degradation mechanisms. Therefore, a strength prediction model that estimates the long-term strength retention and environmental degradation factors in different environments was further improved based on the observations during testing of aged specimens. Therefore, the model based on fib Bulletin 40 model and modified by (Serbescu et al., 2014) was adjusted and additional degradation factors addressing degradation due to saline environments and exposure time was proposed and evaluated. In Chapter 11, the test data from this project was applied to the developed prediction model to determine the long-term tensile and shear strengths of the tested BFRP bars for a 100 year service life. According to the prediction model, it appears that the evaluated BFRP bars exposed to 4 and 7 pH environments retain at best 75 % of their initial tensile strength (on the raw material level) at the 100 years service life mark. Rebars exposed to 13 pH and seawater environments deteriorated more significantly due to the degradation caused by sulphates, chlorides, and metal ions in seawater reacting with high alkalinity of the exposure solution at 60 °C. After generating the prediction model, an attempt was made to validate it by applying the model to the mechanical properties of GFRP bars obtained via experimental analysis by Ruiz Emparanza (2020), in that research, long-term strength retention of GFRP bars was analyzed by exposing specimens to seawater environments at 20, 40, and 60 °C for up to 1 year period without the adjustment of alkalinity. To validate the model generated in this study, experimental data from the aforementioned research was collected and, long-term strength retention and environmental degradation factors were predicted by using virgin material properties and short-term strength retention. Based on this approach, it was found that the difference between the predicted and tested long-term tensile strength retention was within reasonable ranges up to 365 days. In addition, the model was used to predict transverse and horizontal shear strength retention of GFRP bars and it was found that the predicted data was in line with reported experimental data. The relatively minute difference between the various data demonstrated that the prediction model was properly validated and can be successfully but cautiously (to a limited extent) applied to data beyond this research. however, extrapolation of this model up to 100-years shall still be confirmed by others. After discussing the developed model, the following subsection discusses the application of environmental degradation factors in AASHTO LRFD bridge design specifications.

11.6 Direct comparison to previous FDOT GFRP test results

In an attempt to provide a more direct comparison of the tensile strength retention of BFRP and GFRP bars after accelerated conditioning, the results from this research were compared to the results obtained from previously sponsored FDOT research, BDV30 977-18 (also referenced in (Morales et al., 2021)). In research BDV30 977-18, three types of GFRP bars namely GA, GB, and GC were conditioned in accelerated seawater environments at 23, 40, and 60 °C for 060, 120, 210, and 365 d. It was seen that the Type GA bars retained

75 % of the initial strength after 60 d of exposure while they retained around 60 % strength after 120, 210, and 365 d of exposure. Similarly types GB and GC bars retained more than 90 % of the strength after 60 d of exposure while they retained more than 80 % strength after 120, 210, and 365 d exposure. In this research, BFRP bars were conditioned in 9 different aggressive environments at 60 °C for 300 and 600 d, of which, 7 pH and seawater environment is similar to GFRP conditioning. After 300 d of conditioning, # 3 and # 5 Type A rebars from both the lots retained at least 75 % and 80 % of the strength. Similarly, # 3 and # 5 Type B rebars retained at least 70 % and 75 % strength while their Type C counterparts retained 67 % and 75 %. By directly comparing the results of GFRP and BFRP bars, it can be seen that all types of BFRP rebars performed better than Type GA GFRP bars, while Type GB and GC GFRP bars had the similar strength retention after 300 d of conditioning in aggressive seawater environments with relatively neutral alkalinity (pH 7 to 8).

11.7 Durability evaluation using a modified ASTM D7957 Alkaline Resistance Test

As an alternative to the long-term prediction model that was developed in the previous sections, a more direct approach was explored by comparing the project test results for tensile strength retention using the current alkaline resistance strength retention limits used for acceptance of GFRP reinforcing bars under ASTM D7957-17 (ASTM-International, 2017). This may allow for designs using BFRP reinforcing with the same environmental reduction factor as that for GFRP bars. Under this approach, the aqueous solution used for alkaline resistance testing could be modified to an artificial seawater solution to include the presence of chlorides, sulfates, and other significant compounds commonly found in seawater. The ASTM D7957-17 (ASTM-International, 2017) tensile strength retention limit (80 %), after 90 d alkaline resistance testing, is plotted in Figure 11.15 based on the previously presented charts from Figure 11.9 for only the tensile strength retention in the 13 pH solutions. This approach shows that the BFRP bar specimens from this

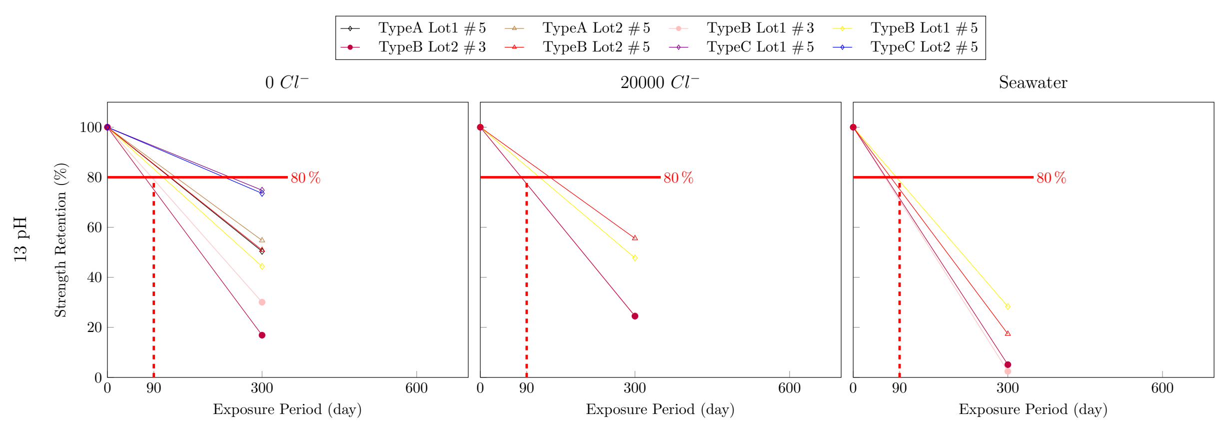

Figure 11.15: Interpolation of ASTM D7957-17 Alkaline Resistance limit to BFRP Rebar

project would likely not meet the minimum 80 % mean tensile strength retention limit in ASTM D7957-17 (ASTM-International, 2017) in 13 pH seawater. Therefore this might be considered an interim approach for acceptance of higher durability BFRP reinforcing intended for use in submerged marine applications.

Chapter 12

Conclusions

To provide a concise overview of the tasks performed for this research project, a brief summary of the experimental work and the analysis is provided in this chapter, before the final conclusion and future recommendations — based on the overall findings and the presented discussion — are listed here.

12.1 Summary

This research was conducted to evaluate the performance of three commercially available BFRP rebar products and their individual raw material components before and after exposure to nine different aggressive environments at 60 °C for 300 d and 600 d in an effort to development acceptance criteria specifically for basalt based fiber reinforced polymer (BFRP) reinforcing bars which can further refine FDOT Specifications Section 932 — Nonmetallic Accessory Materials for Concrete Pavement and Concrete Structures. Three high-quality rebar products from different established FRP rebar producers were selected to evaluate two of the most commonly used rebar sizes (# 3 and # 5) and to fully characterize the relevant material properties. It was the goal to study the effects of the aggressive environments on the raw material constituents as well as on the BFRP rebars. For the purpose of this research, a total of five different physical properties (cross-sectional dimensions, moisture absorption, fiber content, XRF analysis, and glass transition temperature) and four mechanical strength characteristics (transverse shear strength, apparent horizontal shear strength, tensile strength and elastic modulus, and bond-to-concrete strength) were experimentally quantified — first for virgin materials, and then for the aged constituent materials and BFRP rebars. In addition, the tensile strengths of resin matrices and individual fibers (sized and unsized) were analyzed via XRF methods. Because acceptance criteria for basalt FRP rebars are not well established in the US, the findings were compared to the prevalent minimum criteria for glass FRP rebars and it was seen that, in general, BFRP rebars are stronger and more durable than the minimum criteria for GFRP bars. The measured and analyzed data showed that all three rebar products, irrespective of their size, met the GFRP rebar criteria defined in FDOT Specifications Section 932 (in the virgin state). Performance differences were noted for rebar products from different manufacturers because of dissimilarities in material production and surface enhancement properties. However, basalt fiber rebar products appear to be a viable alternative as a non-corrosive rebar option for future FDOT construction projects, and the data gathered throughout this research showed that high-quality BFRP rebars are available in the American market. A standardized use of such rebars seem feasible based on appropriate acceptance criteria because the short-term mechanical properties of BFRP rebars outperform the already accepted/established criteria for GFRP rebars. While the development of acceptance criteria for BFRP rebars has been initiated through this project, and an implementation of this alternative reinforcing technology should be strongly considered by the FDOT, more critical BFRP-specific performance criteria

— beyond GFRP performance criteria — can be developed in future projects to further differentiate the various fiber types and to take full advantage of the available material characteristics. A long-term strength prediction model which can predict strength retention of FRP bars, dependent on the type of exposure environment, was developed based on fib bulletin 40 model. Two new degradation terms, n_{Cl} and n_t, addressing chloride ion concentration of the exposure environment and exposure time were addressed in the newly developed model to predict the environmental degradation factor (C_E) for FRP bars. The model was fed with empirical data from BFRP rebar testing in virgin and conditioned state and long-term strength retention was predicted. The long-term prediction model developed in this research was used to predict long-term strength retention of GFRP bars by using data available in literature. The model was successfully validated by comparing predicted data and tested data for GFRP rebars up to 365 days. Extrapolation of this model up to 100-years service life in a de facto concrete environment is still difficult to validate and requires further research. An interim approach for acceptance of BFRP reinforcing using the current environmental exposure factor $C_E = 0.7$ in design, and a modified Alkaline Resistance test under ASTM D 7957 was proposed.

12.2 Conclusions

- The relationship between rebar composition and chemical stability in water depends mainly on three factors, namely:
  - The chemical agent, which the rebars are exposed to
  - The pH and salinity level of the chemical
  - The microstructure of the fiber
- Based on all tests results for the anions and metals tests, it appears clear that alkaline environments lead to more degrading effects than the acidic or neutral situation.
- The composition of the BFRP rebars are more complex because of the presence of iron and silicon. Iron oxide is the element that primarily separates BFRP rebars from the GFRP rebar. Its degradation mechanism appears to be closely related to these two elements.
- The alkali-silica reaction is one of the main causes for the degradation of GFRP and BFRP bars, because, when the BFRP rebars were exposed to alkaline solution such as NaOH, a reactive layer was formed due to the dissolution of the silica network (Si–O) and the Si–OH gel appeared on the surface of the fibers. Hydroxyl ($OH-$) ions from the alkaline solution attacked the silica network (Si–O–Si–) of the basalt fibers to break it down. The alkaline attack weakened the original lattice bonds by forming weak hydroxyl ion bonds with silicon atoms on the surface of basalt bars (Cousin et al., 2019).
- The acidic or neutral environments do not attack the original lattice bond of silicon as much as the alkaline solution which is why the rebars appeared to have lesser degradation under these conditions.
- The next important degradation mechanism lies with high salinity levels. When the rebar samples were exposed to high salinity environments, molecules such as H_2O and ions such as Cl^- and Na^+ penetrate the surface and form voids and oxides, such as iron oxide, by reacting with (Fe^{2+}) and OH^- (Wei et al., 2011).
- During immersion, H_2O, O_2, CO_2 molecules and Cl^-, Na^+ ions penetrated into the resin matrix through channels or voids and react with either the resin or fiber or both at the same time. One of the degradation mechanism of BFRP appears to originate from chemical reactions involving Cl^- and (Fe^{2+}) which ultimately leads to corrosion on the BFRP surface that became visible in the SEM

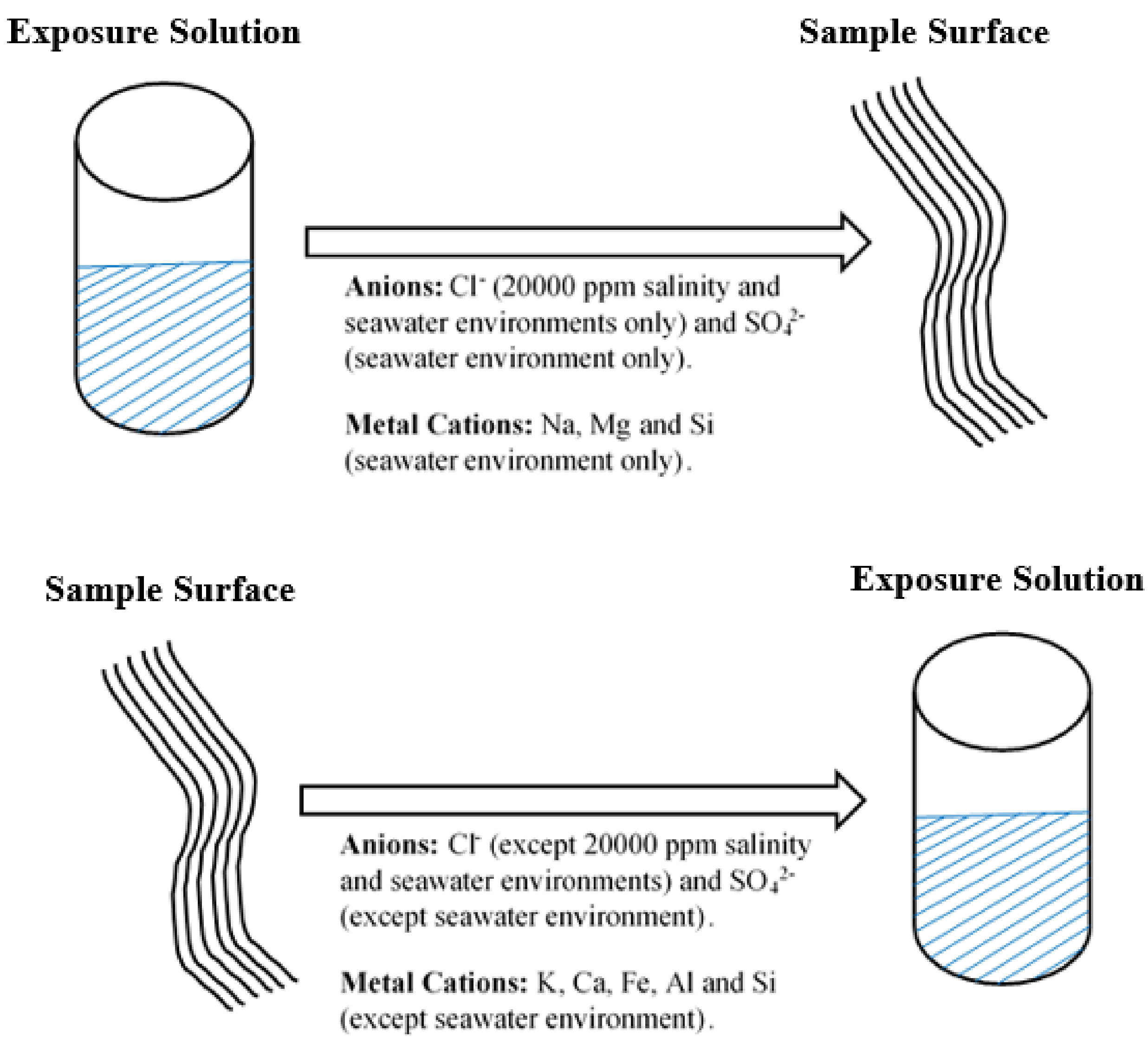

Figure 12.1: Chemical Transfer Direction

images. The following figure 12.1 represents the direction of chemical transfer between the exposure solution and sample surface which is particularly for this research.

- Similarly for fiber samples as the test matrix approached high salinity and pH environment the degradation of both the sized and unsized fibers became more severe, hence the corrosive layer became thicker. From the scanning electron microscopic (SEM) image analysis it was clear that the sizing material was completely removed from the sized fiber, and the fiber diameter decreased after exposure. The 13 pH seawater environment had more degrading impact because of the presence of high concentration of sulfate ion.

- The exposure solutions containing sized fibers measured higher chemical concentration than the solutions containing unsized fibers. While the sizing material protected the basalt fibers to a certain extent in extreme environments, the sizing also led to higher chemical concentration because it completely leached into the exposure environments. Apparently Type A and C fibers degraded more than Type B ones.

- For the resin samples, although not much degradation could be noticed by visual examination, the SEM images clearly showed the deterioration layers. As the test matrix approached high salinity and pH environment, the degradation became more severe.

- Resin degradation also led to a decrease in pH and alkalinity in some of the cases. From the evaluations of metal concentration, no significant change for the solutions containing resin samples were noted because of its organic nature which is mainly composed of carbon (C), hydrogen (H) and oxygen (O). Apparently Type A resin degraded more than Type B resin.

- Sizing is a very important property of fibers and it protects naked fibers from disintegration due to external chemical attacks.

- FRP rebars are a product of composite materials in which thermoset resin binds the sized fiber layers together to form the rebar. Resin also plays a crucial role in transferring the load between layers of fibers. In addition, resin protects the fibers from chemical attacks. Resin degradation leads to an unfavorable conditions, because aggressive media can enter and increase the porosity, which then leads to further rebar deterioration.

- A variety of BFRP rebar types and sizes, with dissimilar physical and strength properties, are currently available in the market. The strength properties of different rebar types vary vastly based on the production characteristics, raw materials, and surface enhancement property. While manufacturer reported properties vary, BFRP rebars appear to be [notably] stronger than minimum requirement for ASTM D 7957 GFRP rebars.

- The relative weight percentage of fibers in BFRP rebars appears to be well-controlled throughout the manufacturing process, and it seems to be nearly identical between various products (within the tested rebar types). Because the tensile and transverse shear capacities are significantly affected by the fibers, BFRP rebars with higher fiber content were found to offer higher tensile strengths and higher transverse shear strengths (than rebars with lower fiber-to-resin ratios), in both the virgin state as well as after aging.

- Differences in performance of rebars were observed based on the moisture absorption property. It appears that the rebar strength is inversely proportional to the measured moisture absorption characteristics because the moisture absorption behavior is inherently related to the rebar porosity, which promotes material imperfections and deterioration from infiltration of aggressive solutions. In addition, it was seen that the tensile and shear strengths of aged BFRP rebars were reduced more significantly for rebars with higher moisture absorption characteristics (and porosity).

- The transverse shear strength of BFRP rebars appears to be measurably stronger than the transverse shear strength of GFRP rebars. The data showed that virgin BFRP rebars outperformed the minimum GFRP criteria in FDOT Specifications (Florida Department of Transportation, 2019) and AC454 (International Code Council, 2017) by at least 120 %. Bars exposed to all 4 and 7 pH environments for 300 and 600 d surpassed the minimum required criteria for virgin GFRP bars by 25 %. After 300 d of exposure, bars in two 13 pH ($0Cl^-$ and $20000Cl^-$) environments surpassed the minimum required criteria, while bars exposed for 600 d deteriorated completely and bars exposed to 13 pH-seawater environment completely deteriorated after both 300 and 600 d of exposure because metal ions in saline environment reacted with high pH of the environment. Although, BFRP rebars have a potential to resist 120 % higher minimum transverse strength criteria in comparison to GFRP bars, a research focusing on transverse strength degradation of BFRP rebars is required to further substantiate this finding. For now, this research suggests that BFRP criteria for transverse shear strength can be in line with the current criteria listed for GFRP.

- Because the apparent horizontal shear strength is dependent on the quality of the resin and the resin-fiber interface — and less influenced by the fiber itself — this property was not significantly different from measurements usually obtained for GFRP products. Nevertheless, this property is a valuable quality control parameter that is used by many manufacturers around the world to quickly recognize/address production inconsistencies. Accordingly, it is suggested that FDOT Specifications Section 932 should maintain a minimum threshold value.

- Comparing the findings from this research to the findings made in previous studies with a focus on GFRP bars (Kampmann et al., 2018; Morales et al., 2021; Renaud, Claude M and Greenwood, Mark E, 2005), it was seen that the maximum tensile strain and elongation of BFRP rebars surpasses the maximum tensile strain of glass fiber based rebars.

- The tensile strength of tested virgin and some of the aged rebars was higher than the reported strength of GFRP (Ruiz Emparanza, 2020; Ali, Ahmed H and Mohamed, Hamdy M and Benmokrane, Brahim and ElSafty, Adel and Chaallal, Omar, 2019; Kampmann et al., 2018; Chen et al., 2007; ElSafty et al., 2014) and equal or higher than BFRP rebar (Serbescu et al., 2014; Patnaik, 2009; Wang et al., 2017) strength values made available in literature. Aged rebars exposed to 4 and 7 pH environments retained more than 75 % of their initial strength after 300 d of exposure and more than 60 % of the initial strength after 600 d exposure, while they retained 30 % strength in 13 pH environments after 300 d of exposure and completely deteriorated after 600 d of exposure. Although the elastic modulus and minimum tensile strength criteria for BFRP rebars appears to be higher than the existing criteria for GFRP rebars in FDOT Specifications Section 932, this research suggests that the BFRP specifications remain aligned with the existing GFRP rebar criteria until additional experimental analyses on a wide range of rebar sizes and types becomes available.

- Because BFRP rebars are a multi-layer product, during tensile testing, the external fibers are stretched first and most, while the inner layers stretch less towards the rebar core and can only be fully utilized after the outer fibers fail. This phenomenon is reflected in the size effect or shear lag effect and it was seen that the # 5 BFRP rebars measured lower strength values than the # 3 rebars.

- Due to the geometric interlocking effect, helically wrapped rebars measured the highest absolute bond-to-concrete strength, while the rebar slip was significantly minimized — in comparison to the measured slip for undeformed sand coated rebars. The minimum criteria for bond-to-concrete of ≥ 1.1 ksi appears to be at the lower limit for virgin BFRP bars, because all virgin rebars tested in this study outperformed this criteria by more than 200 %, with individual rebar types beyond 300 %. After 300 and 600 d of exposure, rebars exposed to 4 and 7 pH environments outperformed minimum required strength for GFRP bars by at least 200 %, while the surface enhancement treatments for rebars exposed to 13 pH completely degraded. This research study suggests that bond-to-concrete strength criteria of BFRP bars should remain inline with GFRP rebar criteria because more durability data needs to be evaluated for bars exposed to harsh environments for extended periods before altering the minimum required strength guidelines.

- Based on the performance analysis of the tested BFRP rebars and an evaluation of all obtained results in context of FDOT Specifications Section 932, AC454, and ASTM 7957, it can be concluded that the tested virgin BFRP bars generally outperform GFRP in most of the defined minimum criteria categories.

- FRP bars are generally desired when a concrete element is placed in an aggressive environments as a replacement for steel reinforcement to avoid corrosion. However, in this research, it was seen that BFRP bars are susceptible to degradation when directly exposed to aggressive environments. It was seen that BFRP rebars loose 5 % to 20 % of their initial shear strength and 20 % to 40 % of initial tensile strength when directly exposed to 4 and 7 pH environments at 60 °C for 300 and 600 d. In addition, it was found that rebars retained more than 80 % of shear strength and 20 % to 60 % of tensile strength when directly exposed to 13 pH all chloride ion concentration environments at 60 °C for 300 d, while they completely deteriorated after 600 d of exposure. Therefore, to address effects of degradation of bars due to chloride ion concentration of exposure environment and exposure time, two new degradation factors, C_{Cl} and C_t were developed (based on the tested BFRP data) and incorporated in the long-term durability model.

- A long-term durability prediction model was developed based on fib Bulletin 40 model and obtained experimental data to predict environmental degradation factors for FRP bars exposed in saline or alkaline or a combination of both environments, at any exposure temperature and exposure period.

- Based on the long-term prediction model and compared test data, it was found that BFRP rebars will retain 70 % to 85 % of tensile strength and 75 % to 80 % of their horizontal and transverse shear strengths after exposure in 4 and 7 pH environments for all chloride ion concentrations, while the model predicted that rebars will retain 25 % of tensile strength and 10 % to 50 % of horizontal and transverse shear strengths after exposing in 13 pH environments for 100 years.

- The newly developed long-term strength prediction model was validated for FRP bars with the help of short-term and long-term durability data obtained in this research as well as data available for GFRP bars (Ruiz Emparanza, 2020), and on average, a 5 % difference was seen between predicted and measured long-term data. Sufficient data was not available from this project to fully validate the model for BFRP bars, however it is assumed that the GFRP bar validation could be extended to BFRP bars if the degradation mechanisms are similar to that for GFRP bars.

12.3 Further Recommendations

Because FRP rebars are generally desirable for use in harsh environments and material properties of these bars may degrade in aggressive media (ACI Committee 440, 2015; du Béton, 2007), the long-term chemical durability performance of BFRP rebars in reinforced concrete elements needs to be studied and evaluated in various alkaline and saline environments before design criteria can be ultimately defined. However, it is important to recognize that, in this research, only rebars submerged in aqueous solutions — and not embedded in a true concrete environment — were evaluated. Further evaluations are necessary to properly define the differences in rebar vulnerability between a submerged and an embedded environment. As discussed in Section 9.5, for the implementation of BFRP rebar technology in future design codes, such as AASHTO design guidelines, ACI, or state design requirements, the following suggestions are made:

- A study evaluating long-term durability of BFRP rebars embedded in concrete in harsh environments is suggested before incorporating the environmental reduction factor (C_E) for BFRP rebars (as it was developed in this research based on fib Bulletin 40 model) in AASHTO LRFD guidelines.

- Bond-to-concrete strength is a very important characteristic of FRP bars because, it helps with the load transfer between rebars and concrete in reinforced concrete structures. It was seen that very limited research is available regarding bond-to-concrete strength of BFRP bars. The results from this project indicate that the rebar development length equations for GFRP are also applicable to BFRP. The bond-to-concrete strength results obtained through this research project cannot be used in the development of a bond reduction factor (C_b) for BFRP rebars, as this factor must be based on flexural beam testing not direct pullout testing. A detailed research focusing on long-term durability of bond-to-concrete strength of BFRP bars and concrete beams reinforced with BFRP bars is suggested to fully incorporate the bond reduction factor (C_b) in AASHTO design guidelines.

- Two most important characteristics of FRP reinforced concrete beams are the flexural and shear behaviors of beams and the crack behavior of beams reinforced with FRP. It was seen that very limited research is available regarding these behaviors of BFRP beams. Accordingly, a research study with a focus on flexural behavior of beams and a research targeting shear and cracking behavior of BFRP reinforced concrete beams are suggested.

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Appendices

Appendix A

Individual Specimen Results

This appendix supplements the results chapter to present the individual test results for every tested specimen and the corresponding statistical results that were determined for each control and test group (of relevant specimen sets). The tables with individual specimen results are sorted by rebar type, size, lot, and specimen count. Dependent on the test procedure, the tables for the individual test results list the most essential (e.g. maximum specimen strength, displacement at maximum strength, etc.) data, while the statistical tables present the minimum (∧), maximum (∧), mean (μ), standard deviation (σ), and coefficient of variation (CV) values. For the purpose of this research project, a wide variety of physical and mechanical tests were conducted on five specimens per sample of BFRP rebar materials. All statistical results that are presented in the main text above are based on those five individual specimen results.

A.1 Density and Cross-Sectional Dimension Test

The following Table A.1 lists all specimen measurements and results that were determined to derive the BFRP rebar diameters according to ASTM D792 (ASTM-International, 2015b). The diameter and the cross-sectional area of the rebars were calculated from the measured density and the individual specimen volume and lengths. The specific gravity was calculated by dividing the measured dry mass of the sample by the weight of the submerged specimen. Subsequently, the density of the samples was determined by multiplying the specific gravity and the density of the water in which the specimen was submerged. Because the density of every substance depends on its temperature, the water temperature was monitored as described in ASTM. The water temperature measured 19.8° (67.6 °F) for this project, and hence, the distilled water had a density of 998.25 kg/m^3 (62.319 lbs./ft^3). Then, the volume of the submerged rebar section was determined by dividing the dry mass of the sample by the density of the water. Afterwards, the volume of the rebar sample was divided by the average length of the sample to calculate the cross-sectional area. Finally, the diameter was calculated based on the assumption that the shape of the rebars was round.

Table A.1: Diameter measurements for each individual specimen

Specimen				Specimen Length				Weight				
Type	Lot No.	Size #	Specimen No.	L1 mm	L2 mm	L3 mm	Average mm	a g	a+s g	b g	s g	δ M g
A	1	3	1	30.20	30.30	30.40	30.30	5.05	12.68	10.33	7.63	2.70
A	1	3	2	29.70	29.30	29.50	29.50	5.01	12.64	10.31	7.63	2.68

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Table A.1: Continued												
Specimen				Specimen Length				Weight				
Type	Lot No.	Size #	Specimen No.	L1 mm	L2 mm	L3 mm	Average mm	a g	a+s g	b g	s g	δ M g
A	1	3	3	30.00	30.10	30.10	30.10	5.04	12.68	10.32	7.63	2.69
A	1	3	4	29.90	29.90	28.40	29.40	5.16	12.79	10.38	7.63	2.75
A	1	3	5	30.40	30.30	30.50	30.40	5.18	12.82	10.40	7.63	2.77
A	1	5	1	32.70	32.50	32.50	32.50	13.76	21.40	14.77	7.63	7.14
A	1	5	2	32.60	33.20	32.70	32.80	13.91	21.54	14.77	7.63	7.14
A	1	5	3	31.40	31.00	31.00	31.10	13.21	20.84	14.43	7.63	6.80
A	1	5	4	33.90	34.00	33.90	33.90	14.30	21.93	15.02	7.63	7.39
A	1	5	5	32.40	32.30	32.60	32.40	13.85	21.48	14.79	7.63	7.16
A	2	3	1	32.40	32.40	32.60	32.50	5.43	13.07	10.52	7.63	2.89
A	2	3	2	31.90	32.00	29.40	31.10	5.33	12.96	10.48	7.63	2.85
A	2	3	3	29.90	28.40	28.40	28.90	5.06	12.69	10.34	7.63	2.71
A	2	3	4	33.10	35.50	35.40	34.70	5.53	13.16	10.57	7.63	2.94
A	2	3	5	33.00	33.30	33.00	33.10	5.54	13.18	10.59	7.63	2.96
A	2	5	1	31.20	30.90	30.90	31.00	12.84	20.47	14.20	7.63	6.57
A	2	5	2	33.00	33.30	33.30	33.20	13.66	21.30	14.67	7.63	7.04
A	2	5	3	31.40	31.30	31.40	31.40	13.03	20.66	14.33	7.63	6.70
A	2	5	4	34.30	34.70	34.50	34.50	14.33	21.97	14.98	7.63	7.35
A	2	5	5	32.00	32.50	33.00	32.50	13.16	20.79	14.36	7.63	6.73
B	1	3	1	28.90	38.40	28.80	32.00	4.83	12.47	10.07	7.63	2.44
B	1	3	2	29.40	29.50	29.20	29.40	4.90	12.54	10.13	7.63	2.50
B	1	3	3	29.00	29.00	29.00	29.00	4.85	12.49	10.10	7.63	2.47
B	1	3	4	29.80	29.80	29.90	29.90	5.01	12.65	10.20	7.63	2.57
B	1	3	5	30.00	29.90	29.70	29.90	5.00	12.64	10.19	7.63	2.56
B	1	5	1	37.01	37.77	37.47	37.24	17.16	24.79	16.62	7.63	8.99
B	1	5	2	34.09	34.34	34.06	34.07	15.72	23.35	15.88	7.63	8.25
B	1	5	3	34.75	35.03	34.65	34.70	16.09	23.72	16.06	7.63	8.43
B	1	5	4	35.76	36.07	35.81	35.79	16.54	24.17	16.33	7.63	8.70
B	1	5	5	36.09	36.20	36.02	36.06	16.52	24.15	16.32	7.63	8.69
B	2	3	1	25.40	25.45	25.40	25.40	4.23	11.86	9.88	7.63	2.25
B	2	3	2	25.91	27.69	25.53	25.72	4.31	11.94	9.94	7.63	2.31
B	2	3	3	25.40	25.40	25.40	25.40	4.24	11.87	9.92	7.63	2.29
B	2	3	4	25.48	25.76	25.45	25.46	4.34	11.97	9.98	7.63	2.35
B	2	3	5	26.97	25.81	26.54	26.76	4.46	12.09	10.05	7.63	2.42
B	2	5	1	35.18	35.31	35.15	35.17	16.23	23.86	16.18	7.63	8.55
B	2	5	2	35.43	35.38	35.94	35.69	16.38	24.01	16.19	7.63	8.56
B	2	5	3	35.43	35.64	35.31	35.37	16.27	23.90	16.17	7.63	8.54
B	2	5	4	34.85	35.66	34.90	34.87	16.16	23.79	16.10	7.63	8.47
B	2	5	5	35.41	35.18	35.43	35.42	16.32	23.95	16.25	7.63	8.62
C	1	3	1	23.75	23.75	23.67	23.72	3.91	11.54	9.66	7.63	2.03
C	1	3	2	24.05	23.74	23.98	23.92	3.98	11.61	9.70	7.63	2.07
C	1	3	3	23.95	24.31	23.94	24.07	4.00	11.63	9.70	7.63	2.07
C	1	3	4	24.51	24.77	24.97	24.75	4.08	11.71	9.76	7.63	2.13
C	1	3	5	25.12	24.88	24.92	24.97	4.16	11.79	9.91	7.63	2.28
C	1	5	1	24.31	24.40	24.38	24.36	9.97	17.60	12.69	7.63	5.06
C	1	5	2	24.05	23.88	24.16	24.03	9.92	17.55	12.65	7.63	5.02
C	1	5	3	24.84	24.89	24.73	24.82	10.24	17.87	12.76	7.63	5.13
C	1	5	4	25.88	25.04	25.06	25.33	10.39	18.02	12.89	7.63	5.26
C	1	5	5	25.12	24.71	24.87	24.90	10.25	17.88	12.88	7.63	5.25
C	2	3	1	26.42	26.05	25.88	26.11	4.22	11.85	9.81	7.63	2.18
C	2	3	2	27.28	27.28	27.18	27.25	4.41	12.04	9.91	7.63	2.28
C	2	3	3	27.23	26.76	27.04	27.01	4.37	12.00	9.90	7.63	2.27
C	2	3	4	26.05	26.15	25.87	26.02	4.22	11.85	9.80	7.63	2.17
C	2	3	5	27.94	27.56	27.91	27.80	4.51	12.14	9.96	7.63	2.33
C	2	5	1	28.44	29.97	29.57	29.32	12.56	20.19	13.80	7.63	6.17
C	2	5	2	28.75	29.41	29.18	29.12	12.50	20.13	13.80	7.63	6.17
C	2	5	3	26.66	26.62	26.94	26.74	11.61	19.24	13.35	7.63	5.72
C	2	5	4	26.35	26.25	26.29	26.30	11.38	19.01	13.24	7.63	5.61
C	2	5	5	27.47	27.27	27.29	27.34	11.87	19.50	13.50	7.63	5.87

A.2 Fiber Content Test

The relative amount of constituent materials were determined based on weight measurements after lost on ignition tests. The percentage of fiber content is listed in Table A.2 along with the relative resin and sand (surface coating) quantities. For rebar types that included sand as part of the surface enhancement, the weight of sand was subtracted before the fiber and resin content percentage were calculated to achieve comparable results throughout all tested rebar types, independent on the surface enhancement.

Table A.2: Fiber content test results for each individual specimen

Specimen				Contents		
Type	Lot No.	Size #	Spec No.	Fiber percent	Resin %	Sand %
A	1	3	1	80.4	19.6	8.6
A	1	3	2	80.9	19.1	7.5
A	1	3	3	80.6	19.4	7.6
A	1	3	4	80.7	19.3	7.2
A	1	3	5	80.6	19.4	8.1
A	1	5	1	75.9	24.1	5.0
A	1	5	2	76.3	23.7	4.9
A	1	5	3	76.3	23.7	4.6
A	1	5	4	76.5	23.5	4.1
A	1	5	5	76.0	24.0	5.3
A	2	3	1	81.6	18.4	6.7
A	2	3	2	82.0	18.0	5.5
A	2	3	3	81.6	18.4	5.6
A	2	3	4	81.7	18.3	6.7
A	2	3	5	81.7	18.3	6.3
A	2	5	1	76.5	23.5	2.5
A	2	5	2	77.1	22.9	2.5
A	2	5	3	76.6	23.4	4.1
A	2	5	4	76.5	23.5	3.8
A	2	5	5	76.6	23.4	2.4
B	1	3	1	79.2	20.8	11.9
B	1	3	2	79.1	20.9	11.9
B	1	3	3	79.0	21.0	12.1
B	1	3	4	78.8	21.2	12.3
B	1	3	5	78.9	21.1	11.7
B	1	5	1	84.1	15.9	8.1
B	1	5	2	84.1	15.9	8.2
B	1	5	3	84.0	16.0	7.9
B	1	5	4	84.1	15.9	8.3
B	1	5	5	84.1	15.9	8.3
B	2	3	1	82.4	17.6	10.4
B	2	3	2	82.2	17.8	10.2
B	2	3	3	82.6	17.4	10.5
B	2	3	4	82.5	17.5	10.9
B	2	3	5	82.4	17.6	10.9
B	2	5	1	83.8	16.2	7.8
B	2	5	2	83.8	16.2	7.6
B	2	5	3	83.8	16.2	7.6
B	2	5	4	83.8	16.2	7.6
B	2	5	5	83.7	16.3	7.4
C	1	3	1	78.2	21.8	0.0

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Table A.2: Continued

Specimen				Contents		
Type	Lot No.	Size #	Spec No.	Fiber %	Resin %	Sand %
C	1	3	2	77.9	22.1	0.0
C	1	3	3	78.4	21.6	0.0
C	1	3	4	77.6	22.4	0.0
C	1	3	5	78.1	21.9	0.0
C	1	5	1	77.1	22.9	0.0
C	1	5	2	73.5	26.5	0.0
C	1	5	3	77.2	22.8	0.0
C	1	5	4	77.0	23.0	0.0
C	1	5	5	76.9	23.1	0.0
C	2	3	1	80.0	20.0	0.0
C	2	3	2	80.0	20.0	0.0
C	2	3	3	80.1	19.9	0.0
C	2	3	4	80.1	19.9	0.0
C	2	3	5	79.9	20.1	0.0
C	2	5	1	82.5	17.5	0.0
C	2	5	2	74.2	25.8	0.0
C	2	5	3	73.9	26.1	0.0
C	2	5	4	74.3	25.7	0.0
C	2	5	5	74.2	25.8	0.0

A.3 Transverse Shear Test

The following Table A.3 displays the most important measurements and results related to the transverse shear strength test for every individual rebar specimen. The shear strength results (based on the nominal diameter) and the corresponding cross-head displacements — measured at the same moment at which the maximum test load was reached and recorded — are provided.

Table A.3: Transverse shear test results (ultimate values) for each individual specimen

Specimen							Transverse Shear Strength		Displacement at Shear Strength	
Age Day	pH	Cl^- ppm	Type	Lot No.	Size #	Spec No.	ksi	MPa	in.	mm
0	-	-	TypeA	1	3	1	25.80	178	0.113	2.88
0	-	-	TypeA	1	3	2	26.96	186	0.116	2.94
0	-	-	TypeA	1	3	3	34.45	237	0.145	3.69
0	-	-	TypeA	1	3	4	40.40	279	0.114	2.89
0	-	-	TypeA	1	3	5	32.56	225	0.122	3.10
0	-	-	TypeA	1	5	1	15.27	105	0.205	5.22
0	-	-	TypeA	1	5	2	29.48	203	0.177	4.50
0	-	-	TypeA	1	5	3	34.32	237	0.195	4.95
0	-	-	TypeA	1	5	4	34.29	236	0.139	3.54
0	-	-	TypeA	1	5	5	33.19	229	0.100	2.54
0	-	-	TypeA	2	3	1	33.13	228	0.144	3.67
0	-	-	TypeA	2	3	2	30.04	207	0.149	3.79
0	-	-	TypeA	2	3	3	31.55	218	0.140	3.56

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Table A.3: Continued										
Specimen							Transverse Shear Strength		Displacement at Shear Strength	
Age Day	pH	Cl^{-} ppm	Type	Lot No.	Size #	Spec No.	ksi	MPa	in.	mm
0	-	-	TypeA	2	3	4	29.42	203	0.186	4.71
0	-	-	TypeA	2	3	5	38.31	264	0.124	3.15
0	-	-	TypeA	2	5	1	27.05	187	0.154	3.91
0	-	-	TypeA	2	5	2	30.06	207	0.163	4.14
0	-	-	TypeA	2	5	3	27.72	191	0.177	4.49
0	-	-	TypeA	2	5	4	27.30	188	0.166	4.22
0	-	-	TypeA	2	5	5	29.74	205	0.233	5.91
0	-	-	TypeB	1	3	1	36.65	253	0.093	2.36
0	-	-	TypeB	1	3	2	37.42	258	0.111	2.82
0	-	-	TypeB	1	3	3	38.80	268	0.105	2.67
0	-	-	TypeB	1	3	4	40.35	278	0.115	2.91
0	-	-	TypeB	1	3	5	37.29	257	0.097	2.47
0	-	-	TypeB	1	5	1	33.09	228	0.136	3.45
0	-	-	TypeB	1	5	2	26.69	184	0.148	3.75
0	-	-	TypeB	1	5	3	31.01	214	0.120	3.05
0	-	-	TypeB	1	5	4	30.02	207	0.129	3.26
0	-	-	TypeB	1	5	5	27.81	192	0.139	3.54
0	-	-	TypeB	2	3	1	42.48	293	0.106	2.70
0	-	-	TypeB	2	3	2	45.53	314	0.115	2.92
0	-	-	TypeB	2	3	3	42.27	291	0.109	2.78
0	-	-	TypeB	2	3	4	37.67	260	0.104	2.64
0	-	-	TypeB	2	3	5	37.04	255	0.101	2.57
0	-	-	TypeB	2	5	1	31.13	215	0.142	3.60
0	-	-	TypeB	2	5	2	30.84	213	0.129	3.29
0	-	-	TypeB	2	5	3	34.68	239	0.126	3.19
0	-	-	TypeB	2	5	4	32.42	224	0.145	3.68
0	-	-	TypeB	2	5	5	31.93	220	0.124	3.15
0	-	-	TypeC	1	3	1	31.86	220	0.127	3.22
0	-	-	TypeC	1	3	2	34.73	239	0.134	3.41
0	-	-	TypeC	1	3	3	28.51	197	0.077	1.96
0	-	-	TypeC	1	3	4	37.31	257	0.114	2.90
0	-	-	TypeC	1	3	5	35.59	245	0.121	3.08
0	-	-	TypeC	1	5	1	31.38	216	0.109	2.76
0	-	-	TypeC	1	5	2	29.56	204	0.177	4.49
0	-	-	TypeC	1	5	3	31.21	215	0.165	4.19
0	-	-	TypeC	1	5	4	28.60	197	0.193	4.90
0	-	-	TypeC	1	5	5	31.54	217	0.179	4.54
0	-	-	TypeC	2	3	1	35.33	244	0.124	3.15
0	-	-	TypeC	2	3	2	34.87	240	0.114	2.90
0	-	-	TypeC	2	3	3	36.03	248	0.124	3.15
0	-	-	TypeC	2	3	4	37.53	259	0.130	3.30
0	-	-	TypeC	2	3	5	35.08	242	0.116	2.94
0	-	-	TypeC	2	5	1	32.81	226	0.169	4.30
0	-	-	TypeC	2	5	2	31.27	216	0.178	4.52
0	-	-	TypeC	2	5	3	32.34	223	0.154	3.92
0	-	-	TypeC	2	5	4	30.96	213	0.158	4.01
0	-	-	TypeC	2	5	5	31.62	218	0.165	4.20
300	13pH	0Cl	TypeA	1	5	1	26.19	181	0.154	3.92
300	13pH	0Cl	TypeA	1	5	2	26.87	185	0.147	3.72
300	13pH	0Cl	TypeA	1	5	3	27.67	191	0.198	5.02
300	13pH	0Cl	TypeA	1	5	4	21.23	146	0.236	5.99
300	13pH	0Cl	TypeA	1	5	5	7.22	50	0.233	5.91
300	13pH	0Cl	TypeA	2	5	1	18.82	130	0.236	6.00

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Table A.3: Continued										
Specimen							Transverse Shear Strength		Displacement at Shear Strength	
Age Day	pH	Cl^- ppm	Type	Lot No.	Size #	Spec No.	ksi	MPa	in.	mm
300	13pH	0Cl	TypeA	2	5	2	29.14	201	0.199	5.05
300	13pH	0Cl	TypeA	2	5	3	28.22	195	0.234	5.95
300	13pH	0Cl	TypeA	2	5	4	27.99	193	0.213	5.40
300	13pH	0Cl	TypeB	1	3	1	29.39	203	0.139	3.52
300	13pH	0Cl	TypeB	1	3	2	28.17	194	0.110	2.79
300	13pH	0Cl	TypeB	1	3	3	29.89	206	0.120	3.05
300	13pH	0Cl	TypeB	1	3	4	34.44	237	0.124	3.15
300	13pH	0Cl	TypeB	1	3	5	28.00	193	0.126	3.21
300	13pH	0Cl	TypeB	1	5	1	25.77	178	0.161	4.08
300	13pH	0Cl	TypeB	1	5	2	25.03	173	0.160	4.07
300	13pH	0Cl	TypeB	1	5	3	25.87	178	0.151	3.83
300	13pH	0Cl	TypeB	1	5	4	27.36	189	0.153	3.87
300	13pH	0Cl	TypeB	1	5	5	27.54	190	0.146	3.71
300	13pH	0Cl	TypeB	2	3	1	16.46	113	0.107	2.71
300	13pH	0Cl	TypeB	2	3	2	37.69	260	0.115	2.93
300	13pH	0Cl	TypeB	2	3	3	34.22	236	0.108	2.74
300	13pH	0Cl	TypeB	2	3	4	25.52	176	0.113	2.87
300	13pH	0Cl	TypeB	2	3	5	38.68	267	0.126	3.20
300	13pH	0Cl	TypeB	2	5	1	16.69	115	0.141	3.59
300	13pH	0Cl	TypeB	2	5	2	22.56	156	0.144	3.65
300	13pH	0Cl	TypeB	2	5	3	26.17	180	0.152	3.87
300	13pH	0Cl	TypeB	2	5	4	25.55	176	0.153	3.88
300	13pH	0Cl	TypeB	2	5	5	26.11	180	0.141	3.59
300	13pH	0Cl	TypeC	1	5	1	13.60	94	0.043	1.09
300	13pH	0Cl	TypeC	1	5	2	12.81	88	0.048	1.22
300	13pH	0Cl	TypeC	1	5	3	13.71	95	0.063	1.59
300	13pH	0Cl	TypeC	1	5	4	14.82	102	0.072	1.84
300	13pH	0Cl	TypeC	1	5	5	13.46	93	0.059	1.50
300	13pH	0Cl	TypeC	2	5	1	13.85	95	0.091	2.30
300	13pH	0Cl	TypeC	2	5	2	16.43	113	0.064	1.62
300	13pH	0Cl	TypeC	2	5	3	29.73	205	0.095	2.42
300	13pH	0Cl	TypeC	2	5	4	21.40	148	0.096	2.43
300	13pH	0Cl	TypeC	2	5	5	21.72	150	0.093	2.37
300	4pH	0Cl	TypeA	1	3	1	32.34	223	0.153	3.88
300	4pH	0Cl	TypeA	1	3	2	30.29	209	0.142	3.60
300	4pH	0Cl	TypeA	1	3	3	30.03	207	0.147	3.74
300	4pH	0Cl	TypeA	1	3	4	29.35	202	0.140	3.55
300	4pH	0Cl	TypeA	1	3	5	28.55	197	0.149	3.79
300	4pH	0Cl	TypeA	1	5	1	30.17	208	0.204	5.17
300	4pH	0Cl	TypeA	1	5	2	30.99	214	0.173	4.39
300	4pH	0Cl	TypeA	1	5	3	28.71	198	0.199	5.05
300	4pH	0Cl	TypeA	1	5	4	30.08	207	0.205	5.20
300	4pH	0Cl	TypeA	1	5	5	30.23	208	0.198	5.03
300	4pH	0Cl	TypeA	2	3	1	26.48	183	0.147	3.73
300	4pH	0Cl	TypeA	2	3	2	25.49	176	0.155	3.95
300	4pH	0Cl	TypeA	2	3	3	28.99	200	0.158	4.00
300	4pH	0Cl	TypeA	2	3	4	31.36	216	0.145	3.67
300	4pH	0Cl	TypeA	2	3	5	25.14	173	0.162	4.11
300	4pH	0Cl	TypeA	2	5	1	29.55	204	0.209	5.31
300	4pH	0Cl	TypeA	2	5	2	28.70	198	0.220	5.60
300	4pH	0Cl	TypeA	2	5	3	29.08	200	0.181	4.59
300	4pH	0Cl	TypeA	2	5	4	28.15	194	0.212	5.40
300	4pH	0Cl	TypeA	2	5	5	28.10	194	0.171	4.35

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Table A.3: Continued										
Specimen							Transverse Shear Strength		Displacement at Shear Strength	
Age	pH	Cl^{-}	Type	Lot	Size	Spec				
Day		ppm		No.	#	No.	ksi	MPa	in.	mm
300	4pH	0Cl	TypeB	1	3	1	29.38	203	0.117	2.98
300	4pH	0Cl	TypeB	1	3	2	28.14	194	0.116	2.94
300	4pH	0Cl	TypeB	1	3	3	28.51	197	0.111	2.82
300	4pH	0Cl	TypeB	1	3	4	30.57	211	0.117	2.96
300	4pH	0Cl	TypeB	1	3	5	29.92	206	0.131	3.33
300	4pH	0Cl	TypeB	1	5	1	28.17	194	0.177	4.50
300	4pH	0Cl	TypeB	1	5	2	27.65	191	0.166	4.21
300	4pH	0Cl	TypeB	1	5	3	29.34	202	0.160	4.07
300	4pH	0Cl	TypeB	1	5	4	27.95	193	0.159	4.05
300	4pH	0Cl	TypeB	1	5	5	28.07	194	0.162	4.11
300	4pH	0Cl	TypeB	2	3	1	32.51	224	0.131	3.32
300	4pH	0Cl	TypeB	2	3	2	31.24	215	0.115	2.91
300	4pH	0Cl	TypeB	2	3	3	30.72	212	0.132	3.36
300	4pH	0Cl	TypeB	2	3	4	31.82	219	0.135	3.44
300	4pH	0Cl	TypeB	2	3	5	32.49	224	0.126	3.20
300	4pH	0Cl	TypeB	2	5	1	29.79	205	0.164	4.18
300	4pH	0Cl	TypeB	2	5	2	28.26	195	0.163	4.15
300	4pH	0Cl	TypeB	2	5	3	27.59	190	0.145	3.68
300	4pH	0Cl	TypeB	2	5	4	29.00	200	0.178	4.52
300	4pH	0Cl	TypeB	2	5	5	27.81	192	0.171	4.35
300	4pH	0Cl	TypeC	1	3	1	31.89	220	0.138	3.50
300	4pH	0Cl	TypeC	1	3	2	29.79	205	0.143	3.64
300	4pH	0Cl	TypeC	1	3	3	29.73	205	0.146	3.72
300	4pH	0Cl	TypeC	1	3	4	28.20	194	0.155	3.93
300	4pH	0Cl	TypeC	1	3	5	30.39	210	0.152	3.86
300	4pH	0Cl	TypeC	1	5	1	22.88	158	0.136	3.45
300	4pH	0Cl	TypeC	1	5	2	24.54	169	0.128	3.24
300	4pH	0Cl	TypeC	1	5	3	23.63	163	0.132	3.35
300	4pH	0Cl	TypeC	1	5	4	25.69	177	0.136	3.45
300	4pH	0Cl	TypeC	1	5	5	25.54	176	0.120	3.05
300	4pH	0Cl	TypeC	2	3	1	31.06	214	0.155	3.94
300	4pH	0Cl	TypeC	2	3	2	29.05	200	0.151	3.85
300	4pH	0Cl	TypeC	2	3	3	30.71	212	0.158	4.00
300	4pH	0Cl	TypeC	2	3	4	31.39	216	0.145	3.68
300	4pH	0Cl	TypeC	2	3	5	30.30	209	0.151	3.84
300	4pH	0Cl	TypeC	2	5	1	22.14	153	0.120	3.06
300	4pH	0Cl	TypeC	2	5	2	24.52	169	0.119	3.03
300	4pH	0Cl	TypeC	2	5	3	20.27	140	0.111	2.81
300	4pH	0Cl	TypeC	2	5	4	21.86	151	0.106	2.70
300	4pH	0Cl	TypeC	2	5	5	20.92	144	0.113	2.87
300	7pH	0Cl	TypeA	1	3	1	26.52	183	0.096	2.43
300	7pH	0Cl	TypeA	1	3	2	24.84	171	0.094	2.38
300	7pH	0Cl	TypeA	1	3	3	27.29	188	0.089	2.27
300	7pH	0Cl	TypeA	1	3	4	30.63	211	0.116	2.96
300	7pH	0Cl	TypeA	1	3	5	31.49	217	0.109	2.76
300	7pH	0Cl	TypeA	1	5	1	30.06	207	0.172	4.36
300	7pH	0Cl	TypeA	1	5	2	30.60	211	0.147	3.74
300	7pH	0Cl	TypeA	1	5	3	30.88	213	0.128	3.25
300	7pH	0Cl	TypeA	1	5	4	30.27	209	0.169	4.29
300	7pH	0Cl	TypeA	1	5	5	29.34	202	0.168	4.25
300	7pH	0Cl	TypeA	2	3	1	27.47	189	0.147	3.73
300	7pH	0Cl	TypeA	2	3	2	23.60	163	0.163	4.13
300	7pH	0Cl	TypeA	2	3	3	23.18	160	0.168	4.26

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Table A.3: Continued

Specimen							Transverse		Displacement	
Age	pH	Cl^-	Type	Lot	Size	Spec	Shear Strength		at Shear Strength	
Day		ppm		No.	#	No.	ksi	MPa	in.	mm
300	7pH	0Cl	TypeA	2	3	4	21.77	150	0.146	3.70
300	7pH	0Cl	TypeA	2	3	5	27.00	186	0.159	4.03
300	7pH	0Cl	TypeA	2	5	1	27.55	190	0.220	5.58
300	7pH	0Cl	TypeA	2	5	2	27.86	192	0.236	6.00
300	7pH	0Cl	TypeA	2	5	3	26.93	186	0.198	5.04
300	7pH	0Cl	TypeA	2	5	4	27.67	191	0.188	4.78
300	7pH	0Cl	TypeA	2	5	5	29.88	206	0.165	4.20
300	7pH	0Cl	TypeB	1	3	1	31.07	214	0.130	3.30
300	7pH	0Cl	TypeB	1	3	2	34.10	235	0.118	2.99
300	7pH	0Cl	TypeB	1	3	3	32.18	222	0.109	2.78
300	7pH	0Cl	TypeB	1	3	4	29.89	206	0.111	2.81
300	7pH	0Cl	TypeB	1	3	5	28.29	195	0.106	2.69
300	7pH	0Cl	TypeB	1	5	1	26.79	185	0.186	4.72
300	7pH	0Cl	TypeB	1	5	2	27.68	191	0.168	4.28
300	7pH	0Cl	TypeB	1	5	3	26.62	184	0.170	4.32
300	7pH	0Cl	TypeB	1	5	4	26.82	185	0.166	4.21
300	7pH	0Cl	TypeB	1	5	5	27.22	188	0.131	3.33
300	7pH	0Cl	TypeB	2	3	1	32.22	222	0.113	2.86
300	7pH	0Cl	TypeB	2	3	2	31.27	216	0.124	3.15
300	7pH	0Cl	TypeB	2	3	3	35.39	244	0.123	3.14
300	7pH	0Cl	TypeB	2	3	4	31.71	219	0.106	2.70
300	7pH	0Cl	TypeB	2	3	5	32.48	224	0.112	2.85
300	7pH	0Cl	TypeB	2	5	1	26.72	184	0.163	4.15
300	7pH	0Cl	TypeB	2	5	2	27.29	188	0.153	3.89
300	7pH	0Cl	TypeB	2	5	3	27.32	188	0.167	4.24
300	7pH	0Cl	TypeB	2	5	4	27.08	187	0.168	4.27
300	7pH	0Cl	TypeB	2	5	5	26.64	184	0.174	4.43
300	7pH	0Cl	TypeC	1	3	1	29.83	206	0.160	4.06
300	7pH	0Cl	TypeC	1	3	2	31.86	220	0.165	4.20
300	7pH	0Cl	TypeC	1	3	3	30.66	211	0.157	3.99
300	7pH	0Cl	TypeC	1	3	4	29.24	202	0.166	4.21
300	7pH	0Cl	TypeC	1	3	5	28.78	198	0.185	4.69
300	7pH	0Cl	TypeC	1	5	1	21.25	147	0.097	2.46
300	7pH	0Cl	TypeC	1	5	2	20.05	138	0.080	2.04
300	7pH	0Cl	TypeC	1	5	3	20.86	144	0.098	2.48
300	7pH	0Cl	TypeC	1	5	4	14.53	100	0.094	2.38
300	7pH	0Cl	TypeC	1	5	5	21.05	145	0.092	2.34
300	7pH	0Cl	TypeC	2	3	1	30.07	207	0.187	4.76
300	7pH	0Cl	TypeC	2	3	2	27.81	192	0.183	4.65
300	7pH	0Cl	TypeC	2	3	3	33.44	231	0.186	4.73
300	7pH	0Cl	TypeC	2	3	4	30.47	210	0.181	4.60
300	7pH	0Cl	TypeC	2	3	5	31.94	220	0.172	4.37
300	7pH	0Cl	TypeC	2	5	1	22.48	155	0.092	2.34
300	7pH	0Cl	TypeC	2	5	2	21.77	150	0.092	2.34
300	7pH	0Cl	TypeC	2	5	3	23.22	160	0.091	2.32
300	7pH	0Cl	TypeC	2	5	4	18.04	124	0.089	2.27
300	7pH	0Cl	TypeC	2	5	5	19.28	133	0.085	2.17
300	13pH	20000Cl	TypeB	1	3	1	32.47	224	0.140	3.55
300	13pH	20000Cl	TypeB	1	3	2	36.91	254	0.129	3.27
300	13pH	20000Cl	TypeB	1	3	3	33.02	228	0.124	3.16
300	13pH	20000Cl	TypeB	1	3	4	33.46	231	0.123	3.11
300	13pH	20000Cl	TypeB	1	3	5	30.49	210	0.123	3.13
300	13pH	20000Cl	TypeB	1	5	1	21.54	149	0.152	3.87

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Table A.3: Continued

Specimen							Transverse		Displacement	
Age	pH	Cl^-	Type	Lot	Size	Spec	Shear Strength		at Shear Strength	
Day		ppm		No.	#	No.	ksi	MPa	in.	mm
300	13pH	20000Cl	TypeB	1	5	2	20.92	144	0.143	3.63
300	13pH	20000Cl	TypeB	1	5	3	27.43	189	0.157	3.98
300	13pH	20000Cl	TypeB	1	5	4	26.69	184	0.155	3.94
300	13pH	20000Cl	TypeB	1	5	5	25.72	177	0.147	3.73
300	13pH	20000Cl	TypeB	2	3	1	22.99	159	0.132	3.35
300	13pH	20000Cl	TypeB	2	3	2	28.28	195	0.146	3.72
300	13pH	20000Cl	TypeB	2	3	3	28.45	196	0.127	3.24
300	13pH	20000Cl	TypeB	2	3	4	34.36	237	0.115	2.92
300	13pH	20000Cl	TypeB	2	3	5	33.00	228	0.122	3.09
300	13pH	20000Cl	TypeB	2	5	1	27.10	187	0.146	3.70
300	13pH	20000Cl	TypeB	2	5	2	26.54	183	0.135	3.43
300	13pH	20000Cl	TypeB	2	5	3	27.57	190	0.140	3.56
300	13pH	20000Cl	TypeB	2	5	4	27.19	187	0.131	3.33
300	13pH	20000Cl	TypeB	2	5	5	29.36	202	0.142	3.61
300	4pH	20000Cl	TypeA	1	3	1	31.83	219	0.129	3.28
300	4pH	20000Cl	TypeA	1	3	2	29.44	203	0.137	3.47
300	4pH	20000Cl	TypeA	1	3	3	29.93	206	0.116	2.96
300	4pH	20000Cl	TypeA	1	3	4	33.67	232	0.122	3.10
300	4pH	20000Cl	TypeA	1	3	5	30.64	211	0.119	3.02
300	4pH	20000Cl	TypeA	1	5	1	27.31	188	0.183	4.65
300	4pH	20000Cl	TypeA	1	5	2	27.61	190	0.175	4.44
300	4pH	20000Cl	TypeA	1	5	3	28.77	198	0.178	4.52
300	4pH	20000Cl	TypeA	1	5	4	25.82	178	0.185	4.70
300	4pH	20000Cl	TypeA	1	5	5	29.34	202	0.172	4.36
300	4pH	20000Cl	TypeA	2	3	1	19.62	135	0.171	4.33
300	4pH	20000Cl	TypeA	2	3	2	26.30	181	0.147	3.74
300	4pH	20000Cl	TypeA	2	3	3	20.73	143	0.172	4.37
300	4pH	20000Cl	TypeA	2	3	4	24.59	170	0.162	4.12
300	4pH	20000Cl	TypeA	2	3	5	18.82	130	0.170	4.31
300	4pH	20000Cl	TypeA	2	5	1	28.62	197	0.178	4.53
300	4pH	20000Cl	TypeA	2	5	2	26.51	183	0.201	5.11
300	4pH	20000Cl	TypeA	2	5	3	28.74	198	0.172	4.36
300	4pH	20000Cl	TypeA	2	5	4	25.19	174	0.152	3.87
300	4pH	20000Cl	TypeA	2	5	5	26.62	184	0.197	5.01
300	4pH	20000Cl	TypeB	1	3	1	34.14	235	0.133	3.38
300	4pH	20000Cl	TypeB	1	3	2	31.31	216	0.130	3.30
300	4pH	20000Cl	TypeB	1	3	3	32.97	227	0.129	3.27
300	4pH	20000Cl	TypeB	1	3	4	29.80	205	0.132	3.35
300	4pH	20000Cl	TypeB	1	3	5	30.82	212	0.124	3.16
300	4pH	20000Cl	TypeB	1	5	1	28.74	198	0.186	4.73
300	4pH	20000Cl	TypeB	1	5	2	28.95	200	0.180	4.56
300	4pH	20000Cl	TypeB	1	5	3	28.69	198	0.171	4.34
300	4pH	20000Cl	TypeB	1	5	4	29.12	201	0.185	4.69
300	4pH	20000Cl	TypeB	1	5	5	28.01	193	0.160	4.06
300	4pH	20000Cl	TypeB	2	3	1	36.93	255	0.135	3.42
300	4pH	20000Cl	TypeB	2	3	2	32.47	224	0.123	3.13
300	4pH	20000Cl	TypeB	2	3	3	33.71	232	0.121	3.06
300	4pH	20000Cl	TypeB	2	3	4	31.90	220	0.125	3.19
300	4pH	20000Cl	TypeB	2	3	5	32.41	223	0.118	2.99
300	4pH	20000Cl	TypeB	2	5	1	29.95	207	0.179	4.53
300	4pH	20000Cl	TypeB	2	5	2	29.84	206	0.169	4.30
300	4pH	20000Cl	TypeB	2	5	3	30.18	208	0.165	4.20
300	4pH	20000Cl	TypeB	2	5	4	29.87	206	0.173	4.40

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Table A.3: Continued

Specimen							Transverse Shear Strength		Displacement at Shear Strength	
Age	pH	Cl^{-}	Type	Lot	Size	Spec				
Day		ppm		No.	#	No.	ksi	MPa	in.	mm
300	4pH	20000Cl	TypeB	2	5	5	30.78	212	0.161	4.09
300	4pH	20000Cl	TypeC	1	3	1	28.19	194	0.163	4.14
300	4pH	20000Cl	TypeC	1	3	2	27.30	188	0.158	4.01
300	4pH	20000Cl	TypeC	1	3	3	24.82	171	0.155	3.94
300	4pH	20000Cl	TypeC	1	3	4	27.14	187	0.149	3.79
300	4pH	20000Cl	TypeC	1	3	5	27.48	189	0.164	4.17
300	4pH	20000Cl	TypeC	1	5	1	27.31	188	0.117	2.96
300	4pH	20000Cl	TypeC	1	5	2	28.64	197	0.128	3.26
300	4pH	20000Cl	TypeC	1	5	3	28.16	194	0.119	3.03
300	4pH	20000Cl	TypeC	1	5	4	20.80	143	0.123	3.11
300	4pH	20000Cl	TypeC	1	5	5	28.20	194	0.101	2.58
300	4pH	20000Cl	TypeC	2	3	1	30.06	207	0.156	3.96
300	4pH	20000Cl	TypeC	2	3	2	30.66	211	0.160	4.07
300	4pH	20000Cl	TypeC	2	3	3	29.50	203	0.158	4.01
300	4pH	20000Cl	TypeC	2	3	4	30.63	211	0.156	3.95
300	4pH	20000Cl	TypeC	2	3	5	32.87	227	0.142	3.61
300	4pH	20000Cl	TypeC	2	5	1	20.39	141	0.109	2.77
300	4pH	20000Cl	TypeC	2	5	2	24.96	172	0.112	2.83
300	4pH	20000Cl	TypeC	2	5	3	24.52	169	0.113	2.86
300	4pH	20000Cl	TypeC	2	5	4	23.21	160	0.112	2.85
300	4pH	20000Cl	TypeC	2	5	5	24.39	168	0.115	2.92
300	7pH	20000Cl	TypeA	1	3	1	33.63	232	0.139	3.54
300	7pH	20000Cl	TypeA	1	3	2	31.52	217	0.150	3.82
300	7pH	20000Cl	TypeA	1	3	3	34.42	237	0.137	3.48
300	7pH	20000Cl	TypeA	1	3	4	28.67	198	0.140	3.57
300	7pH	20000Cl	TypeA	1	3	5	30.81	212	0.141	3.59
300	7pH	20000Cl	TypeA	1	5	1	29.64	204	0.173	4.40
300	7pH	20000Cl	TypeA	1	5	2	28.13	194	0.169	4.29
300	7pH	20000Cl	TypeA	1	5	3	31.31	216	0.163	4.15
300	7pH	20000Cl	TypeA	1	5	4	31.42	217	0.187	4.75
300	7pH	20000Cl	TypeA	1	5	5	27.73	191	0.133	3.39
300	7pH	20000Cl	TypeA	2	3	1	29.20	201	0.160	4.07
300	7pH	20000Cl	TypeA	2	3	2	25.35	175	0.171	4.33
300	7pH	20000Cl	TypeA	2	3	3	28.54	197	0.167	4.24
300	7pH	20000Cl	TypeA	2	3	4	26.39	182	0.158	4.01
300	7pH	20000Cl	TypeA	2	3	5	28.71	198	0.151	3.84
300	7pH	20000Cl	TypeA	2	5	1	32.33	223	0.153	3.90
300	7pH	20000Cl	TypeA	2	5	2	31.08	214	0.143	3.64
300	7pH	20000Cl	TypeA	2	5	3	30.65	211	0.170	4.32
300	7pH	20000Cl	TypeA	2	5	4	29.88	206	0.204	5.18
300	7pH	20000Cl	TypeA	2	5	5	28.08	194	0.188	4.77
300	7pH	20000Cl	TypeB	1	3	1	31.05	214	0.128	3.26
300	7pH	20000Cl	TypeB	1	3	2	30.20	208	0.126	3.21
300	7pH	20000Cl	TypeB	1	3	3	34.61	239	0.122	3.10
300	7pH	20000Cl	TypeB	1	3	4	29.84	206	0.130	3.31
300	7pH	20000Cl	TypeB	1	3	5	32.11	221	0.122	3.11
300	7pH	20000Cl	TypeB	1	5	1	30.14	208	0.181	4.59
300	7pH	20000Cl	TypeB	1	5	2	28.83	199	0.160	4.07
300	7pH	20000Cl	TypeB	1	5	3	28.68	198	0.151	3.83
300	7pH	20000Cl	TypeB	1	5	4	28.52	197	0.163	4.13
300	7pH	20000Cl	TypeB	1	5	5	26.64	184	0.147	3.74
300	7pH	20000Cl	TypeB	2	3	1	36.31	250	0.121	3.06
300	7pH	20000Cl	TypeB	2	3	2	38.94	268	0.123	3.13

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Table A.3: Continued										
Specimen							Transverse Shear Strength		Displacement at Shear Strength	
Age Day	pH	Cl^{-} ppm	Type	Lot No.	Size #	Spec No.	ksi	MPa	in.	mm
300	7pH	20000Cl	TypeB	2	3	3	40.51	279	0.120	3.04
300	7pH	20000Cl	TypeB	2	3	4	35.31	243	0.124	3.16
300	7pH	20000Cl	TypeB	2	3	5	32.27	222	0.128	3.26
300	7pH	20000Cl	TypeB	2	5	1	26.90	186	0.135	3.42
300	7pH	20000Cl	TypeB	2	5	2	27.73	191	0.169	4.29
300	7pH	20000Cl	TypeB	2	5	3	28.70	198	0.171	4.34
300	7pH	20000Cl	TypeB	2	5	4	27.76	191	0.178	4.52
300	7pH	20000Cl	TypeB	2	5	5	28.83	199	0.169	4.30
300	7pH	20000Cl	TypeC	1	3	1	30.83	213	0.166	4.22
300	7pH	20000Cl	TypeC	1	3	2	32.70	225	0.178	4.51
300	7pH	20000Cl	TypeC	1	3	3	33.12	228	0.171	4.36
300	7pH	20000Cl	TypeC	1	3	4	30.80	212	0.170	4.33
300	7pH	20000Cl	TypeC	1	3	5	30.19	208	0.154	3.90
300	7pH	20000Cl	TypeC	1	5	1	19.38	134	0.083	2.10
300	7pH	20000Cl	TypeC	1	5	2	15.67	108	0.077	1.96
300	7pH	20000Cl	TypeC	1	5	3	17.63	122	0.081	2.07
300	7pH	20000Cl	TypeC	1	5	4	17.89	123	0.081	2.06
300	7pH	20000Cl	TypeC	1	5	5	20.82	144	0.076	1.93
300	7pH	20000Cl	TypeC	2	3	1	31.07	214	0.077	1.95
300	7pH	20000Cl	TypeC	2	3	2	28.51	197	0.121	3.07
300	7pH	20000Cl	TypeC	2	3	3	30.62	211	0.135	3.44
300	7pH	20000Cl	TypeC	2	3	4	31.42	217	0.134	3.41
300	7pH	20000Cl	TypeC	2	3	5	29.01	200	0.146	3.70
300	7pH	20000Cl	TypeC	2	5	1	21.98	152	0.083	2.12
300	7pH	20000Cl	TypeC	2	5	2	18.58	128	0.091	2.30
300	7pH	20000Cl	TypeC	2	5	3	21.83	150	0.090	2.28
300	7pH	20000Cl	TypeC	2	5	4	18.16	125	0.086	2.17
300	7pH	20000Cl	TypeC	2	5	5	18.73	129	0.089	2.26
300	13pH	SeaWater	TypeB	1	3	1	14.39	99	0.110	2.80
300	13pH	SeaWater	TypeB	1	3	2	13.92	96	0.112	2.83
300	13pH	SeaWater	TypeB	1	3	3	14.18	98	0.100	2.55
300	13pH	SeaWater	TypeB	1	3	4	12.77	88	0.095	2.42
300	13pH	SeaWater	TypeB	1	3	5	13.87	96	0.104	2.63
300	13pH	SeaWater	TypeB	1	5	1	19.07	131	0.127	3.22
300	13pH	SeaWater	TypeB	1	5	2	18.50	128	0.134	3.41
300	13pH	SeaWater	TypeB	1	5	3	16.91	117	0.118	2.99
300	13pH	SeaWater	TypeB	1	5	4	18.26	126	0.117	2.97
300	13pH	SeaWater	TypeB	1	5	5	16.80	116	0.112	2.85
300	13pH	SeaWater	TypeB	2	3	1	12.95	89	0.090	2.28
300	13pH	SeaWater	TypeB	2	3	2	14.78	102	0.106	2.69
300	13pH	SeaWater	TypeB	2	3	3	14.23	98	0.100	2.54
300	13pH	SeaWater	TypeB	2	3	4	16.15	111	0.105	2.67
300	13pH	SeaWater	TypeB	2	3	5	16.39	113	0.105	2.66
300	13pH	SeaWater	TypeB	2	5	1	20.35	140	0.134	3.41
300	13pH	SeaWater	TypeB	2	5	2	21.55	149	0.148	3.76
300	13pH	SeaWater	TypeB	2	5	3	19.99	138	0.125	3.16
300	13pH	SeaWater	TypeB	2	5	4	17.58	121	0.119	3.02
300	13pH	SeaWater	TypeB	2	5	5	19.73	136	0.121	3.07
300	4pH	SeaWater	TypeA	1	3	1	31.44	217	0.107	2.71
300	4pH	SeaWater	TypeA	1	3	2	28.71	198	0.114	2.91
300	4pH	SeaWater	TypeA	1	3	3	27.84	192	0.110	2.79
300	4pH	SeaWater	TypeA	1	3	4	30.78	212	0.103	2.61
300	4pH	SeaWater	TypeA	1	3	5	27.28	188	0.106	2.69

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Table A.3: Continued										
Specimen							Transverse Shear Strength		Displacement at Shear Strength	
Age Day	pH	Cl^- ppm	Type	Lot No.	Size #	Spec No.	ksi	MPa	in.	mm
300	4pH	SeaWater	TypeA	1	5	1	25.77	178	0.218	5.55
300	4pH	SeaWater	TypeA	1	5	2	26.25	181	0.236	6.00
300	4pH	SeaWater	TypeA	1	5	3	28.35	195	0.236	6.00
300	4pH	SeaWater	TypeA	1	5	4	28.80	199	0.194	4.93
300	4pH	SeaWater	TypeA	1	5	5	27.14	187	0.236	5.99
300	4pH	SeaWater	TypeA	2	3	1	25.83	178	0.128	3.25
300	4pH	SeaWater	TypeA	2	3	2	21.42	148	0.156	3.96
300	4pH	SeaWater	TypeA	2	3	3	22.31	154	0.145	3.69
300	4pH	SeaWater	TypeA	2	3	4	22.79	157	0.167	4.24
300	4pH	SeaWater	TypeA	2	3	5	25.68	177	0.142	3.62
300	4pH	SeaWater	TypeA	2	5	1	28.74	198	0.228	5.78
300	4pH	SeaWater	TypeA	2	5	2	25.83	178	0.193	4.90
300	4pH	SeaWater	TypeA	2	5	3	29.55	204	0.196	4.98
300	4pH	SeaWater	TypeA	2	5	4	27.60	190	0.182	4.62
300	4pH	SeaWater	TypeA	2	5	5	29.92	206	0.179	4.55
300	4pH	SeaWater	TypeB	1	3	1	33.18	229	0.130	3.29
300	4pH	SeaWater	TypeB	1	3	2	30.24	208	0.128	3.26
300	4pH	SeaWater	TypeB	1	3	3	29.99	207	0.125	3.18
300	4pH	SeaWater	TypeB	1	3	4	32.97	227	0.124	3.16
300	4pH	SeaWater	TypeB	1	3	5	30.81	212	0.133	3.38
300	4pH	SeaWater	TypeB	1	5	1	28.19	194	0.185	4.70
300	4pH	SeaWater	TypeB	1	5	2	27.68	191	0.179	4.54
300	4pH	SeaWater	TypeB	1	5	3	29.48	203	0.174	4.43
300	4pH	SeaWater	TypeB	1	5	4	28.27	195	0.168	4.27
300	4pH	SeaWater	TypeB	1	5	5	28.91	199	0.153	3.89
300	4pH	SeaWater	TypeB	2	3	1	32.61	225	0.121	3.08
300	4pH	SeaWater	TypeB	2	3	2	34.73	239	0.116	2.95
300	4pH	SeaWater	TypeB	2	3	3	35.85	247	0.120	3.06
300	4pH	SeaWater	TypeB	2	3	4	34.41	237	0.127	3.22
300	4pH	SeaWater	TypeB	2	3	5	35.54	245	0.122	3.09
300	4pH	SeaWater	TypeB	2	5	1	28.00	193	0.183	4.64
300	4pH	SeaWater	TypeB	2	5	2	26.90	185	0.183	4.64
300	4pH	SeaWater	TypeB	2	5	3	27.06	187	0.186	4.71
300	4pH	SeaWater	TypeB	2	5	4	28.18	194	0.181	4.60
300	4pH	SeaWater	TypeB	2	5	5	27.27	188	0.172	4.36
300	4pH	SeaWater	TypeC	1	3	1	30.07	207	0.153	3.88
300	4pH	SeaWater	TypeC	1	3	2	31.49	217	0.158	4.01
300	4pH	SeaWater	TypeC	1	3	3	29.24	202	0.155	3.95
300	4pH	SeaWater	TypeC	1	3	4	31.14	215	0.147	3.74
300	4pH	SeaWater	TypeC	1	3	5	28.93	199	0.159	4.04
300	4pH	SeaWater	TypeC	1	5	1	21.03	145	0.106	2.68
300	4pH	SeaWater	TypeC	1	5	2	20.85	144	0.107	2.72
300	4pH	SeaWater	TypeC	1	5	3	24.58	169	0.104	2.65
300	4pH	SeaWater	TypeC	1	5	4	23.78	164	0.107	2.72
300	4pH	SeaWater	TypeC	1	5	5	25.63	177	0.105	2.67
300	4pH	SeaWater	TypeC	2	3	1	32.52	224	0.149	3.77
300	4pH	SeaWater	TypeC	2	3	2	30.53	210	0.163	4.13
300	4pH	SeaWater	TypeC	2	3	3	32.65	225	0.152	3.87
300	4pH	SeaWater	TypeC	2	3	4	31.61	218	0.155	3.94
300	4pH	SeaWater	TypeC	2	3	5	29.91	206	0.156	3.96
300	4pH	SeaWater	TypeC	2	5	1	19.77	136	0.094	2.39
300	4pH	SeaWater	TypeC	2	5	2	19.49	134	0.100	2.53
300	4pH	SeaWater	TypeC	2	5	3	21.70	150	0.095	2.42

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Table A.3: Continued

Specimen							Transverse Shear Strength		Displacement at Shear Strength	
Age Day	pH	Cl^- ppm	Type	Lot No.	Size #	Spec No.	ksi	MPa	in.	mm
300	4pH	SeaWater	TypeC	2	5	4	19.35	133	0.095	2.42
300	4pH	SeaWater	TypeC	2	5	5	20.91	144	0.095	2.41
300	7pH	SeaWater	TypeA	1	3	1	33.90	234	0.139	3.52
300	7pH	SeaWater	TypeA	1	3	2	29.23	202	0.141	3.58
300	7pH	SeaWater	TypeA	1	3	3	31.18	215	0.128	3.25
300	7pH	SeaWater	TypeA	1	3	4	32.40	223	0.137	3.49
300	7pH	SeaWater	TypeA	1	3	5	31.87	220	0.128	3.26
300	7pH	SeaWater	TypeA	1	5	1	30.25	209	0.144	3.65
300	7pH	SeaWater	TypeA	1	5	2	28.68	198	0.196	4.99
300	7pH	SeaWater	TypeA	1	5	3	29.83	206	0.215	5.45
300	7pH	SeaWater	TypeA	1	5	4	29.73	205	0.221	5.62
300	7pH	SeaWater	TypeA	2	3	1	24.51	169	0.193	4.90
300	7pH	SeaWater	TypeA	2	3	2	21.76	150	0.196	4.99
300	7pH	SeaWater	TypeA	2	3	3	24.01	166	0.163	4.14
300	7pH	SeaWater	TypeA	2	3	4	24.12	166	0.192	4.87
300	7pH	SeaWater	TypeA	2	3	5	26.37	182	0.179	4.55
300	7pH	SeaWater	TypeA	2	5	1	29.07	200	0.149	3.80
300	7pH	SeaWater	TypeA	2	5	2	28.34	195	0.199	5.05
300	7pH	SeaWater	TypeA	2	5	3	28.55	197	0.187	4.75
300	7pH	SeaWater	TypeA	2	5	4	30.17	208	0.163	4.13
300	7pH	SeaWater	TypeB	1	3	1	26.69	184	0.127	3.22
300	7pH	SeaWater	TypeB	1	3	2	29.78	205	0.135	3.44
300	7pH	SeaWater	TypeB	1	3	3	28.90	199	0.127	3.23
300	7pH	SeaWater	TypeB	1	3	4	30.66	211	0.112	2.84
300	7pH	SeaWater	TypeB	1	3	5	29.38	203	0.133	3.37
300	7pH	SeaWater	TypeB	1	5	1	25.85	178	0.172	4.36
300	7pH	SeaWater	TypeB	1	5	2	26.85	185	0.166	4.22
300	7pH	SeaWater	TypeB	1	5	3	28.98	200	0.164	4.17
300	7pH	SeaWater	TypeB	1	5	4	28.48	196	0.165	4.20
300	7pH	SeaWater	TypeB	1	5	5	26.91	186	0.167	4.25
300	7pH	SeaWater	TypeB	2	3	1	35.60	245	0.122	3.10
300	7pH	SeaWater	TypeB	2	3	2	33.56	231	0.130	3.31
300	7pH	SeaWater	TypeB	2	3	3	34.52	238	0.124	3.14
300	7pH	SeaWater	TypeB	2	3	4	32.20	222	0.128	3.26
300	7pH	SeaWater	TypeB	2	3	5	35.01	241	0.132	3.35
300	7pH	SeaWater	TypeB	2	5	1	27.96	193	0.175	4.46
300	7pH	SeaWater	TypeB	2	5	2	29.30	202	0.176	4.47
300	7pH	SeaWater	TypeB	2	5	3	28.66	198	0.177	4.49
300	7pH	SeaWater	TypeB	2	5	4	28.14	194	0.171	4.35
300	7pH	SeaWater	TypeB	2	5	5	28.17	194	0.170	4.32
300	7pH	SeaWater	TypeC	1	3	1	29.87	206	0.129	3.27
300	7pH	SeaWater	TypeC	1	3	2	31.76	219	0.127	3.23
300	7pH	SeaWater	TypeC	1	3	3	28.65	198	0.134	3.41
300	7pH	SeaWater	TypeC	1	3	4	29.53	204	0.131	3.32
300	7pH	SeaWater	TypeC	1	3	5	29.74	205	0.130	3.30
300	7pH	SeaWater	TypeC	1	5	1	13.41	92	0.074	1.87
300	7pH	SeaWater	TypeC	1	5	2	16.43	113	0.064	1.63
300	7pH	SeaWater	TypeC	1	5	3	13.52	93	0.059	1.49
300	7pH	SeaWater	TypeC	1	5	4	13.86	96	0.048	1.22
300	7pH	SeaWater	TypeC	1	5	5	16.02	110	0.067	1.70
300	7pH	SeaWater	TypeC	2	3	1	26.16	180	0.157	3.99
300	7pH	SeaWater	TypeC	2	3	2	24.49	169	0.149	3.79
300	7pH	SeaWater	TypeC	2	3	3	26.46	182	0.131	3.32

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Table A.3: Continued										
Specimen							Transverse Shear Strength		Displacement at Shear Strength	
Age Day	pH	Cl^{-} ppm	Type	Lot No.	Size #	Spec No.	ksi	MPa	in.	mm
300	7pH	SeaWater	TypeC	2	3	5	27.02	186	0.154	3.91
300	7pH	SeaWater	TypeC	2	5	1	14.48	100	0.057	1.44
300	7pH	SeaWater	TypeC	2	5	2	13.11	90	0.050	1.27
300	7pH	SeaWater	TypeC	2	5	3	13.45	93	0.041	1.03
300	7pH	SeaWater	TypeC	2	5	4	11.59	80	0.038	0.97
300	7pH	SeaWater	TypeC	2	5	5	12.88	89	0.039	0.98
600	4pH	0Cl	TypeA	1	3	1	30.56	211	0.133	3.39
600	4pH	0Cl	TypeA	1	3	2	30.85	213	0.126	3.20
600	4pH	0Cl	TypeA	1	3	3	30.63	211	0.147	3.73
600	4pH	0Cl	TypeA	1	5	1	29.69	205	0.171	4.33
600	4pH	0Cl	TypeA	1	5	2	29.22	201	0.181	4.60
600	4pH	0Cl	TypeA	1	5	3	27.40	189	0.167	4.25
600	4pH	0Cl	TypeA	2	3	1	15.19	105	0.165	4.19
600	4pH	0Cl	TypeA	2	3	2	14.56	100	0.160	4.08
600	4pH	0Cl	TypeA	2	3	3	12.51	86	0.167	4.24
600	4pH	0Cl	TypeA	2	5	1	27.96	193	0.202	5.12
600	4pH	0Cl	TypeA	2	5	2	27.52	190	0.194	4.94
600	4pH	0Cl	TypeA	2	5	3	30.13	208	0.222	5.65
600	4pH	0Cl	TypeB	1	3	1	28.89	199	0.120	3.04
600	4pH	0Cl	TypeB	1	3	2	29.02	200	0.123	3.13
600	4pH	0Cl	TypeB	1	3	3	29.14	201	0.126	3.19
600	4pH	0Cl	TypeB	1	5	1	26.39	182	0.161	4.09
600	4pH	0Cl	TypeB	1	5	2	25.70	177	0.149	3.80
600	4pH	0Cl	TypeB	1	5	3	25.99	179	0.157	3.98
600	4pH	0Cl	TypeB	2	3	1	29.90	206	0.118	2.99
600	4pH	0Cl	TypeB	2	3	2	27.84	192	0.105	2.67
600	4pH	0Cl	TypeB	2	3	3	31.73	219	0.107	2.72
600	4pH	0Cl	TypeB	2	5	1	25.93	179	0.172	4.37
600	4pH	0Cl	TypeB	2	5	2	26.03	179	0.163	4.13
600	4pH	0Cl	TypeB	2	5	3	25.75	178	0.170	4.32
600	4pH	0Cl	TypeC	1	3	1	24.29	167	0.147	3.74
600	4pH	0Cl	TypeC	1	3	2	25.12	173	0.150	3.81
600	4pH	0Cl	TypeC	1	3	3	23.78	164	0.162	4.11
600	4pH	0Cl	TypeC	1	5	1	24.34	168	0.203	5.17
600	4pH	0Cl	TypeC	1	5	2	24.36	168	0.205	5.20
600	4pH	0Cl	TypeC	1	5	3	26.68	184	0.184	4.67
600	4pH	0Cl	TypeC	2	3	1	26.50	183	0.123	3.11
600	4pH	0Cl	TypeC	2	3	2	26.04	180	0.132	3.36
600	4pH	0Cl	TypeC	2	3	3	24.37	168	0.131	3.32
600	4pH	0Cl	TypeC	2	5	1	26.52	183	0.188	4.77
600	4pH	0Cl	TypeC	2	5	2	26.16	180	0.205	5.19
600	4pH	0Cl	TypeC	2	5	3	27.11	187	0.178	4.53
600	7pH	0Cl	TypeA	1	3	1	28.52	197	0.137	3.49
600	7pH	0Cl	TypeA	1	3	2	30.11	208	0.152	3.87
600	7pH	0Cl	TypeA	1	3	3	28.37	196	0.137	3.47
600	7pH	0Cl	TypeA	1	5	1	28.38	196	0.188	4.77
600	7pH	0Cl	TypeA	1	5	2	30.68	212	0.236	6.00
600	7pH	0Cl	TypeA	1	5	3	30.28	209	0.199	5.07
600	7pH	0Cl	TypeA	2	3	1	22.20	153	0.178	4.51
600	7pH	0Cl	TypeA	2	3	2	20.69	143	0.183	4.64
600	7pH	0Cl	TypeA	2	3	3	18.74	129	0.199	5.06
600	7pH	0Cl	TypeA	2	5	1	27.84	192	0.236	5.99
600	7pH	0Cl	TypeA	2	5	2	25.61	177	0.229	5.82

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Table A.3: Continued										
Specimen							Transverse		Displacement	
Age	pH	Cl^-	Type	Lot	Size	Spec	Shear Strength		at Shear Strength	
Day		ppm		No.	#	No.	ksi	MPa	in.	mm
600	7pH	0Cl	TypeA	2	5	3	29.53	204	0.151	3.83
600	7pH	0Cl	TypeB	1	3	1	26.40	182	0.140	3.57
600	7pH	0Cl	TypeB	1	3	2	26.20	181	0.115	2.92
600	7pH	0Cl	TypeB	1	3	3	25.99	179	0.132	3.36
600	7pH	0Cl	TypeB	1	5	1	26.92	186	0.157	4.00
600	7pH	0Cl	TypeB	1	5	2	27.03	186	0.151	3.82
600	7pH	0Cl	TypeB	1	5	3	26.92	186	0.150	3.81
600	7pH	0Cl	TypeB	2	3	1	27.06	187	0.126	3.19
600	7pH	0Cl	TypeB	2	3	2	30.00	207	0.124	3.15
600	7pH	0Cl	TypeB	2	3	3	30.06	207	0.129	3.27
600	7pH	0Cl	TypeB	2	5	1	26.76	185	0.165	4.20
600	7pH	0Cl	TypeB	2	5	2	25.22	174	0.159	4.05
600	7pH	0Cl	TypeB	2	5	3	28.60	197	0.157	3.99
600	7pH	0Cl	TypeC	1	3	1	26.35	182	0.139	3.53
600	7pH	0Cl	TypeC	1	3	2	22.51	155	0.149	3.77
600	7pH	0Cl	TypeC	1	3	3	27.63	191	0.126	3.21
600	7pH	0Cl	TypeC	1	5	1	26.97	186	0.179	4.54
600	7pH	0Cl	TypeC	1	5	2	23.17	160	0.220	5.59
600	7pH	0Cl	TypeC	1	5	3	25.55	176	0.201	5.09
600	7pH	0Cl	TypeC	2	3	1	29.81	206	0.134	3.41
600	7pH	0Cl	TypeC	2	3	2	28.75	198	0.134	3.39
600	7pH	0Cl	TypeC	2	3	3	28.50	197	0.145	3.69
600	7pH	0Cl	TypeC	2	5	1	27.73	191	0.203	5.15
600	7pH	0Cl	TypeC	2	5	2	27.37	189	0.198	5.03
600	7pH	0Cl	TypeC	2	5	3	26.94	186	0.200	5.09
600	4pH	20000Cl	TypeA	1	3	1	29.02	200	0.145	3.68
600	4pH	20000Cl	TypeA	1	3	2	26.63	184	0.135	3.43
600	4pH	20000Cl	TypeA	1	3	3	26.40	182	0.148	3.77
600	4pH	20000Cl	TypeA	1	5	1	25.60	176	0.187	4.74
600	4pH	20000Cl	TypeA	1	5	2	28.35	195	0.179	4.54
600	4pH	20000Cl	TypeA	1	5	3	30.98	214	0.186	4.71
600	4pH	20000Cl	TypeA	2	3	1	12.72	88	0.134	3.39
600	4pH	20000Cl	TypeA	2	3	2	11.23	77	0.142	3.61
600	4pH	20000Cl	TypeA	2	3	3	11.53	80	0.146	3.72
600	4pH	20000Cl	TypeA	2	5	1	30.34	209	0.205	5.20
600	4pH	20000Cl	TypeA	2	5	2	30.66	211	0.131	3.32
600	4pH	20000Cl	TypeA	2	5	3	27.99	193	0.148	3.76
600	4pH	20000Cl	TypeB	1	3	1	26.09	180	0.109	2.78
600	4pH	20000Cl	TypeB	1	3	2	25.05	173	0.113	2.88
600	4pH	20000Cl	TypeB	1	3	3	27.22	188	0.118	2.99
600	4pH	20000Cl	TypeB	1	5	1	27.31	188	0.161	4.09
600	4pH	20000Cl	TypeB	1	5	2	26.78	185	0.161	4.09
600	4pH	20000Cl	TypeB	1	5	3	26.82	185	0.147	3.73
600	4pH	20000Cl	TypeB	2	3	1	27.27	188	0.118	3.01
600	4pH	20000Cl	TypeB	2	3	2	29.00	200	0.118	2.99
600	4pH	20000Cl	TypeB	2	3	3	29.99	207	0.115	2.92
600	4pH	20000Cl	TypeB	2	5	1	27.17	187	0.160	4.07
600	4pH	20000Cl	TypeB	2	5	2	27.47	189	0.157	4.00
600	4pH	20000Cl	TypeB	2	5	3	26.91	186	0.155	3.93
600	4pH	20000Cl	TypeC	1	3	1	24.48	169	0.150	3.81
600	4pH	20000Cl	TypeC	1	3	2	25.11	173	0.147	3.73
600	4pH	20000Cl	TypeC	1	3	3	22.47	155	0.167	4.25
600	4pH	20000Cl	TypeC	1	5	1	26.38	182	0.236	6.00

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Table A.3: Continued

Specimen							Transverse Shear Strength		Displacement at Shear Strength	
Age Day	pH	Cl^{-} ppm	Type	Lot No.	Size #	Spec No.	ksi	MPa	in.	mm
600	4pH	20000Cl	TypeC	1	5	2	25.33	175	0.225	5.70
600	4pH	20000Cl	TypeC	1	5	3	24.31	168	0.236	6.00
600	4pH	20000Cl	TypeC	2	3	1	22.56	156	0.156	3.97
600	4pH	20000Cl	TypeC	2	3	2	25.27	174	0.145	3.67
600	4pH	20000Cl	TypeC	2	3	3	24.53	169	0.142	3.61
600	4pH	20000Cl	TypeC	2	5	1	26.71	184	0.227	5.77
600	4pH	20000Cl	TypeC	2	5	2	25.60	177	0.236	6.00
600	4pH	20000Cl	TypeC	2	5	3	26.65	184	0.232	5.88
600	7pH	20000Cl	TypeA	1	3	1	29.34	202	0.128	3.24
600	7pH	20000Cl	TypeA	1	3	2	30.66	211	0.122	3.11
600	7pH	20000Cl	TypeA	1	3	3	27.61	190	0.135	3.43
600	7pH	20000Cl	TypeA	1	5	1	27.68	191	0.174	4.41
600	7pH	20000Cl	TypeA	1	5	2	29.41	203	0.212	5.39
600	7pH	20000Cl	TypeA	1	5	3	26.42	182	0.172	4.38
600	7pH	20000Cl	TypeA	2	3	1	9.94	69	0.134	3.39
600	7pH	20000Cl	TypeA	2	3	2	11.07	76	0.138	3.51
600	7pH	20000Cl	TypeA	2	3	3	11.61	80	0.131	3.32
600	7pH	20000Cl	TypeA	2	5	1	26.74	184	0.137	3.49
600	7pH	20000Cl	TypeA	2	5	2	29.68	205	0.200	5.07
600	7pH	20000Cl	TypeA	2	5	3	29.39	203	0.191	4.85
600	7pH	20000Cl	TypeB	1	3	1	29.46	203	0.119	3.02
600	7pH	20000Cl	TypeB	1	3	2	27.27	188	0.109	2.77
600	7pH	20000Cl	TypeB	1	3	3	27.65	191	0.116	2.95
600	7pH	20000Cl	TypeB	1	5	1	27.43	189	0.166	4.22
600	7pH	20000Cl	TypeB	1	5	2	27.94	193	0.153	3.89
600	7pH	20000Cl	TypeB	1	5	3	27.04	186	0.153	3.89
600	7pH	20000Cl	TypeB	2	3	1	30.25	209	0.115	2.91
600	7pH	20000Cl	TypeB	2	3	2	28.66	198	0.110	2.80
600	7pH	20000Cl	TypeB	2	3	3	31.06	214	0.112	2.85
600	7pH	20000Cl	TypeB	2	5	1	27.26	188	0.158	4.00
600	7pH	20000Cl	TypeB	2	5	2	28.14	194	0.167	4.23
600	7pH	20000Cl	TypeB	2	5	3	27.71	191	0.163	4.13
600	7pH	20000Cl	TypeC	1	3	1	29.59	204	0.122	3.09
600	7pH	20000Cl	TypeC	1	3	2	29.02	200	0.125	3.19
600	7pH	20000Cl	TypeC	1	3	3	30.29	209	0.124	3.15
600	7pH	20000Cl	TypeC	1	5	1	27.06	187	0.181	4.59
600	7pH	20000Cl	TypeC	1	5	2	28.63	197	0.181	4.60
600	7pH	20000Cl	TypeC	1	5	3	29.75	205	0.181	4.60
600	7pH	20000Cl	TypeC	2	3	1	26.76	185	0.145	3.69
600	7pH	20000Cl	TypeC	2	3	2	28.04	193	0.138	3.51
600	7pH	20000Cl	TypeC	2	3	3	24.51	169	0.157	3.98
600	7pH	20000Cl	TypeC	2	5	1	27.81	192	0.195	4.95
600	7pH	20000Cl	TypeC	2	5	2	27.11	187	0.213	5.41
600	7pH	20000Cl	TypeC	2	5	3	27.76	191	0.179	4.55
600	4pH	SeaWater	TypeA	1	3	1	29.43	203	0.144	3.65
600	4pH	SeaWater	TypeA	1	3	2	26.81	185	0.132	3.36
600	4pH	SeaWater	TypeA	1	3	3	27.94	193	0.168	4.28
600	4pH	SeaWater	TypeA	1	5	1	26.35	182	0.195	4.94
600	4pH	SeaWater	TypeA	1	5	2	27.09	187	0.173	4.40
600	4pH	SeaWater	TypeA	1	5	3	27.77	191	0.192	4.88
600	4pH	SeaWater	TypeA	2	3	1	8.87	61	0.148	3.76
600	4pH	SeaWater	TypeA	2	3	2	8.23	57	0.115	2.91
600	4pH	SeaWater	TypeA	2	3	3	8.75	60	0.146	3.71

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Table A.3: Continued										
Specimen							Transverse Shear Strength		Displacement at Shear Strength	
Age Day	pH	Cl^{-} ppm	Type	Lot No.	Size #	Spec No.	ksi	MPa	in.	mm
600	4pH	SeaWater	TypeA	2	5	1	23.63	163	0.227	5.77
600	4pH	SeaWater	TypeA	2	5	2	23.95	165	0.220	5.58
600	4pH	SeaWater	TypeA	2	5	3	23.33	161	0.236	5.99
600	4pH	SeaWater	TypeB	1	3	1	27.09	187	0.118	3.01
600	4pH	SeaWater	TypeB	1	3	2	26.39	182	0.128	3.24
600	4pH	SeaWater	TypeB	1	3	3	28.40	196	0.118	3.01
600	4pH	SeaWater	TypeB	1	5	1	26.72	184	0.153	3.89
600	4pH	SeaWater	TypeB	1	5	2	27.35	189	0.158	4.01
600	4pH	SeaWater	TypeB	1	5	3	26.03	179	0.147	3.73
600	4pH	SeaWater	TypeB	2	3	1	29.03	200	0.105	2.67
600	4pH	SeaWater	TypeB	2	3	2	34.37	237	0.122	3.10
600	4pH	SeaWater	TypeB	2	3	3	30.16	208	0.115	2.91
600	4pH	SeaWater	TypeB	2	5	1	26.37	182	0.152	3.85
600	4pH	SeaWater	TypeB	2	5	2	27.22	188	0.156	3.96
600	4pH	SeaWater	TypeB	2	5	3	27.08	187	0.161	4.10
600	4pH	SeaWater	TypeC	1	3	1	31.58	218	0.127	3.23
600	4pH	SeaWater	TypeC	1	3	2	30.45	210	0.131	3.31
600	4pH	SeaWater	TypeC	1	3	3	28.01	193	0.134	3.40
600	4pH	SeaWater	TypeC	1	5	1	24.62	170	0.188	4.76
600	4pH	SeaWater	TypeC	1	5	2	27.35	189	0.174	4.42
600	4pH	SeaWater	TypeC	1	5	3	28.43	196	0.178	4.53
600	4pH	SeaWater	TypeC	2	3	1	27.89	192	0.127	3.23
600	4pH	SeaWater	TypeC	2	3	2	27.68	191	0.135	3.44
600	4pH	SeaWater	TypeC	2	3	3	27.85	192	0.143	3.62
600	4pH	SeaWater	TypeC	2	5	1	27.77	191	0.189	4.80
600	4pH	SeaWater	TypeC	2	5	2	26.86	185	0.193	4.91
600	4pH	SeaWater	TypeC	2	5	3	26.94	186	0.204	5.18
600	7pH	SeaWater	TypeA	1	3	1	30.60	211	0.131	3.32
600	7pH	SeaWater	TypeA	1	3	2	25.93	179	0.144	3.67
600	7pH	SeaWater	TypeA	1	3	3	28.59	197	0.146	3.72
600	7pH	SeaWater	TypeA	1	5	1	25.01	172	0.164	4.18
600	7pH	SeaWater	TypeA	1	5	2	26.32	181	0.203	5.16
600	7pH	SeaWater	TypeA	1	5	3	27.86	192	0.208	5.29
600	7pH	SeaWater	TypeA	2	3	1	9.27	64	0.139	3.52
600	7pH	SeaWater	TypeA	2	3	2	8.44	58	0.125	3.19
600	7pH	SeaWater	TypeA	2	3	3	11.08	76	0.125	3.19
600	7pH	SeaWater	TypeA	2	5	1	29.11	201	0.195	4.96
600	7pH	SeaWater	TypeA	2	5	2	23.44	162	0.234	5.95
600	7pH	SeaWater	TypeA	2	5	3	25.80	178	0.215	5.45
600	7pH	SeaWater	TypeB	1	3	1	30.93	213	0.119	3.02
600	7pH	SeaWater	TypeB	1	3	2	29.19	201	0.131	3.31
600	7pH	SeaWater	TypeB	1	3	3	29.10	201	0.128	3.25
600	7pH	SeaWater	TypeB	1	5	1	28.08	194	0.158	4.01
600	7pH	SeaWater	TypeB	1	5	2	27.76	191	0.163	4.14
600	7pH	SeaWater	TypeB	1	5	3	27.63	190	0.158	4.01
600	7pH	SeaWater	TypeB	2	3	1	26.79	185	0.126	3.20
600	7pH	SeaWater	TypeB	2	3	2	25.74	177	0.126	3.21
600	7pH	SeaWater	TypeB	2	3	3	27.99	193	0.123	3.13
600	7pH	SeaWater	TypeB	2	5	1	27.58	190	0.150	3.81
600	7pH	SeaWater	TypeB	2	5	2	29.69	205	0.155	3.93
600	7pH	SeaWater	TypeB	2	5	3	28.91	199	0.158	4.02
600	7pH	SeaWater	TypeC	1	3	1	29.27	202	0.124	3.15
600	7pH	SeaWater	TypeC	1	3	2	30.40	210	0.128	3.26

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Table A.3: Continued										
Specimen							Transverse Shear Strength		Displacement at Shear Strength	
Age Day	pH	Cl^- ppm	Type	Lot No.	Size #	Spec No.	ksi	MPa	in.	mm
600	7pH	SeaWater	TypeC	1	3	3	28.36	196	0.130	3.30
600	7pH	SeaWater	TypeC	1	5	1	28.46	196	0.171	4.33
600	7pH	SeaWater	TypeC	1	5	2	25.96	179	0.200	5.08
600	7pH	SeaWater	TypeC	1	5	3	27.50	190	0.171	4.34
600	7pH	SeaWater	TypeC	2	3	1	25.28	174	0.144	3.67
600	7pH	SeaWater	TypeC	2	3	2	22.75	157	0.141	3.59
600	7pH	SeaWater	TypeC	2	3	3	25.81	178	0.148	3.77
600	7pH	SeaWater	TypeC	2	5	1	25.67	177	0.236	6.00
600	7pH	SeaWater	TypeC	2	5	3	28.68	198	0.167	4.25

A.4 Horizontal Shear Test

Similar to the previous section, the following Table A.4 lists the maximum measured data for all specimens that were tested for horizontal shear strength. The given strength values were determined based on the measured maximum loads and the nominal (not measured) cross-sectional dimensions. The displacement at shear strength represents the cross-head extension that was measured at the instant in time at which the maximum failure load was recorded. Accordingly, this value is indicative of the ultimate defection of the shear specimen that lead to resin failure and slip between the fibers.

Table A.4: Horizontal shear test results (ultimate values) for each individual specimen

Specimen							Horizontal Shear Strength		Displacement at Shear Strength	
Age Day	pH	Cl^- ppm	Type	Lot No.	Size #	Spec No.	ksi	MPa	in.	mm
0	-	-	TypeA	1	3	1	7.53	52	0.078	1.97
0	-	-	TypeA	1	3	2	7.39	51	0.090	2.28
0	-	-	TypeA	1	3	3	7.31	50	0.072	1.84
0	-	-	TypeA	1	3	4	7.26	50	0.095	2.42
0	-	-	TypeA	1	3	5	7.99	55	0.093	2.35
0	-	-	TypeA	1	5	1	7.04	49	0.099	2.51
0	-	-	TypeA	1	5	2	6.67	46	0.112	2.83
0	-	-	TypeA	1	5	3	7.46	51	0.120	3.04
0	-	-	TypeA	1	5	4	7.54	52	0.117	2.96
0	-	-	TypeA	1	5	5	7.44	51	0.146	3.70
0	-	-	TypeA	2	3	1	7.09	49	0.076	1.92
0	-	-	TypeA	2	3	2	6.78	47	0.069	1.76
0	-	-	TypeA	2	3	3	7.68	53	0.084	2.14
0	-	-	TypeA	2	3	4	8.01	55	0.090	2.28
0	-	-	TypeA	2	3	5	6.88	47	0.105	2.66
0	-	-	TypeA	2	5	1	6.22	43	0.123	3.12
0	-	-	TypeA	2	5	2	6.57	45	0.166	4.21
0	-	-	TypeA	2	5	3	7.22	50	0.148	3.77
0	-	-	TypeA	2	5	4	6.32	44	0.134	3.39
0	-	-	TypeA	2	5	5	6.62	46	0.128	3.26

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Table A.4: Continued										
Specimen							Horizontal Shear Strength		Displacement at Shear Strength	
Age	pH	Cl^{-}	Type	Lot	Size	Spec				
Day		ppm		No.	#	No.	ksi	MPa	in.	mm
0	-	-	TypeB	1	3	1	6.18	43	0.064	1.62
0	-	-	TypeB	1	3	2	6.93	48	0.078	1.98
0	-	-	TypeB	1	3	3	6.14	42	0.073	1.85
0	-	-	TypeB	1	3	4	6.84	47	0.081	2.05
0	-	-	TypeB	1	3	5	6.31	43	0.075	1.92
0	-	-	TypeB	1	5	1	6.53	45	0.090	2.28
0	-	-	TypeB	1	5	2	6.44	44	0.084	2.13
0	-	-	TypeB	1	5	3	6.21	43	0.086	2.19
0	-	-	TypeB	1	5	4	6.44	44	0.086	2.19
0	-	-	TypeB	1	5	5	6.17	43	0.082	2.08
0	-	-	TypeB	2	3	1	6.02	41	0.072	1.82
0	-	-	TypeB	2	3	2	6.92	48	0.070	1.79
0	-	-	TypeB	2	3	3	6.78	47	0.075	1.91
0	-	-	TypeB	2	3	4	6.82	47	0.077	1.97
0	-	-	TypeB	2	3	5	6.44	44	0.076	1.93
0	-	-	TypeB	2	5	1	6.19	43	0.079	2.01
0	-	-	TypeB	2	5	2	6.56	45	0.092	2.34
0	-	-	TypeB	2	5	3	6.60	45	0.091	2.30
0	-	-	TypeB	2	5	4	6.59	45	0.085	2.16
0	-	-	TypeB	2	5	5	6.16	42	0.094	2.39
0	-	-	TypeC	1	3	1	7.69	53	0.101	2.56
0	-	-	TypeC	1	3	2	8.06	56	0.097	2.46
0	-	-	TypeC	1	3	3	8.63	60	0.088	2.23
0	-	-	TypeC	1	3	4	7.60	52	0.054	1.38
0	-	-	TypeC	1	3	5	8.37	58	0.127	3.24
0	-	-	TypeC	1	5	1	8.66	60	0.151	3.84
0	-	-	TypeC	1	5	2	7.54	52	0.128	3.25
0	-	-	TypeC	1	5	3	6.90	48	0.147	3.72
0	-	-	TypeC	1	5	4	7.07	49	0.142	3.61
0	-	-	TypeC	1	5	5	8.91	61	0.177	4.49
0	-	-	TypeC	2	3	1	7.53	52	0.110	2.79
0	-	-	TypeC	2	3	2	8.74	60	0.071	1.80
0	-	-	TypeC	2	3	3	8.30	57	0.104	2.65
0	-	-	TypeC	2	3	4	7.60	52	0.101	2.58
0	-	-	TypeC	2	3	5	7.28	50	0.113	2.87
0	-	-	TypeC	2	5	1	8.48	58	0.250	6.35
0	-	-	TypeC	2	5	2	8.79	61	0.185	4.70
0	-	-	TypeC	2	5	3	6.37	44	0.125	3.17
0	-	-	TypeC	2	5	4	7.62	53	0.164	4.17
0	-	-	TypeC	2	5	5	8.80	61	0.153	3.89
300	13pH	0Cl	TypeA	1	5	1	5.56	38	0.136	3.45
300	13pH	0Cl	TypeA	1	5	2	7.01	48	0.079	1.99
300	13pH	0Cl	TypeA	1	5	3	7.18	49	0.090	2.28
300	13pH	0Cl	TypeA	1	5	4	7.24	50	0.092	2.35
300	13pH	0Cl	TypeA	1	5	5	7.28	50	0.089	2.27
300	13pH	0Cl	TypeA	2	5	1	7.23	50	0.111	2.82
300	13pH	0Cl	TypeA	2	5	2	8.22	57	0.124	3.16
300	13pH	0Cl	TypeA	2	5	3	8.03	55	0.113	2.86
300	13pH	0Cl	TypeA	2	5	4	8.41	58	0.140	3.55
300	13pH	0Cl	TypeA	2	5	5	8.29	57	0.116	2.95
300	13pH	0Cl	TypeB	1	3	1	5.84	40	0.073	1.87
300	13pH	0Cl	TypeB	1	3	2	3.61	25	0.056	1.41
300	13pH	0Cl	TypeB	1	3	3	6.03	42	0.063	1.61

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Table A.4: Continued										
Specimen							Horizontal Shear Strength		Displacement at Shear Strength	
Age Day	pH	Cl^- ppm	Type	Lot No.	Size #	Spec No.	ksi	MPa	in.	mm
300	13pH	0Cl	TypeB	1	3	4	5.82	40	0.068	1.73
300	13pH	0Cl	TypeB	1	3	5	6.06	42	0.069	1.75
300	13pH	0Cl	TypeB	1	5	1	2.63	18	0.063	1.59
300	13pH	0Cl	TypeB	1	5	2	3.28	23	0.093	2.36
300	13pH	0Cl	TypeB	1	5	3	2.01	14	0.051	1.30
300	13pH	0Cl	TypeB	1	5	4	4.13	28	0.117	2.97
300	13pH	0Cl	TypeB	1	5	5	1.35	9	0.047	1.19
300	13pH	0Cl	TypeB	2	3	1	6.65	46	0.069	1.75
300	13pH	0Cl	TypeB	2	3	2	4.58	32	0.051	1.30
300	13pH	0Cl	TypeB	2	3	3	6.71	46	0.064	1.63
300	13pH	0Cl	TypeB	2	3	4	6.42	44	0.061	1.56
300	13pH	0Cl	TypeB	2	3	5	6.09	42	0.071	1.80
300	13pH	0Cl	TypeB	2	5	1	6.13	42	0.088	2.22
300	13pH	0Cl	TypeB	2	5	2	5.76	40	0.120	3.05
300	13pH	0Cl	TypeB	2	5	3	5.39	37	0.089	2.26
300	13pH	0Cl	TypeB	2	5	4	5.74	40	0.121	3.07
300	13pH	0Cl	TypeB	2	5	5	5.44	38	0.100	2.55
300	13pH	0Cl	TypeC	1	5	1	6.16	42	0.113	2.88
300	13pH	0Cl	TypeC	1	5	2	5.52	38	0.152	3.85
300	13pH	0Cl	TypeC	1	5	3	0.18	1	0.208	5.29
300	13pH	0Cl	TypeC	1	5	4	6.26	43	0.163	4.13
300	13pH	0Cl	TypeC	1	5	5	4.03	28	0.099	2.52
300	13pH	0Cl	TypeC	2	5	1	6.89	48	0.100	2.53
300	13pH	0Cl	TypeC	2	5	2	6.60	46	0.089	2.27
300	13pH	0Cl	TypeC	2	5	3	7.53	52	0.105	2.66
300	13pH	0Cl	TypeC	2	5	4	7.75	53	0.127	3.22
300	13pH	0Cl	TypeC	2	5	5	7.30	50	0.107	2.72
300	4pH	0Cl	TypeA	1	3	1	7.10	49	0.044	1.12
300	4pH	0Cl	TypeA	1	3	2	7.47	52	0.058	1.48
300	4pH	0Cl	TypeA	1	3	3	7.89	54	0.097	2.47
300	4pH	0Cl	TypeA	1	3	4	6.78	47	0.126	3.19
300	4pH	0Cl	TypeA	1	3	5	7.69	53	0.072	1.82
300	4pH	0Cl	TypeA	1	5	1	5.86	40	0.061	1.55
300	4pH	0Cl	TypeA	1	5	2	4.89	34	0.078	1.99
300	4pH	0Cl	TypeA	2	3	1	9.50	65	0.046	1.18
300	4pH	0Cl	TypeA	2	3	2	5.33	37	0.106	2.68
300	4pH	0Cl	TypeA	2	3	3	6.05	42	0.112	2.85
300	4pH	0Cl	TypeA	2	3	4	4.92	34	0.162	4.12
300	4pH	0Cl	TypeA	2	5	1	3.91	27	0.186	4.71
300	4pH	0Cl	TypeA	2	5	2	2.93	20	0.364	9.25
300	4pH	0Cl	TypeB	1	3	1	5.52	38	0.056	1.41
300	4pH	0Cl	TypeB	1	3	2	5.68	39	0.064	1.63
300	4pH	0Cl	TypeB	1	3	3	6.22	43	0.082	2.09
300	4pH	0Cl	TypeB	1	3	4	6.07	42	0.045	1.13
300	4pH	0Cl	TypeB	1	3	5	6.35	44	0.075	1.91
300	4pH	0Cl	TypeB	1	5	1	6.82	47	0.095	2.42
300	4pH	0Cl	TypeB	1	5	2	6.09	42	0.087	2.20
300	4pH	0Cl	TypeB	1	5	3	6.23	43	0.088	2.24
300	4pH	0Cl	TypeB	2	3	1	5.29	37	0.043	1.10
300	4pH	0Cl	TypeB	2	3	2	5.82	40	0.063	1.60
300	4pH	0Cl	TypeB	2	3	3	7.23	50	0.074	1.88
300	4pH	0Cl	TypeB	2	3	4	6.82	47	0.076	1.93
300	4pH	0Cl	TypeB	2	3	5	5.54	38	0.074	1.87

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Table A.4: Continued										
Specimen							Horizontal Shear Strength		Displacement at Shear Strength	
Age Day	pH	Cl^{-} ppm	Type	Lot No.	Size #	Spec No.	ksi	MPa	in.	mm
300	4pH	0Cl	TypeB	2	5	1	6.55	45	0.093	2.35
300	4pH	0Cl	TypeB	2	5	2	6.34	44	0.083	2.12
300	4pH	0Cl	TypeB	2	5	3	6.89	47	0.088	2.24
300	4pH	0Cl	TypeC	1	3	1	9.01	62	0.058	1.46
300	4pH	0Cl	TypeC	1	3	2	8.59	59	0.077	1.95
300	4pH	0Cl	TypeC	1	3	3	9.21	64	0.071	1.80
300	4pH	0Cl	TypeC	1	3	4	8.54	59	0.081	2.06
300	4pH	0Cl	TypeC	1	3	5	8.47	58	0.080	2.04
300	4pH	0Cl	TypeC	1	5	1	8.53	59	0.137	3.48
300	4pH	0Cl	TypeC	1	5	2	9.58	66	0.141	3.59
300	4pH	0Cl	TypeC	1	5	3	8.99	62	0.107	2.72
300	4pH	0Cl	TypeC	2	3	1	4.11	28	0.083	2.11
300	4pH	0Cl	TypeC	2	3	2	9.21	63	0.091	2.31
300	4pH	0Cl	TypeC	2	3	3	9.60	66	0.084	2.13
300	4pH	0Cl	TypeC	2	3	4	9.05	62	0.063	1.60
300	4pH	0Cl	TypeC	2	3	5	9.55	66	0.093	2.36
300	4pH	0Cl	TypeC	2	3	6	9.72	67	0.086	2.18
300	4pH	0Cl	TypeC	2	5	1	8.47	58	0.136	3.45
300	4pH	0Cl	TypeC	2	5	2	7.73	53	0.109	2.76
300	4pH	0Cl	TypeC	2	5	3	7.60	52	0.109	2.76
300	7pH	0Cl	TypeA	1	3	1	7.86	54	0.085	2.17
300	7pH	0Cl	TypeA	1	3	2	8.27	57	0.092	2.33
300	7pH	0Cl	TypeA	1	3	3	9.21	63	0.090	2.29
300	7pH	0Cl	TypeA	1	3	4	8.52	59	0.093	2.36
300	7pH	0Cl	TypeA	1	3	5	7.87	54	0.087	2.22
300	7pH	0Cl	TypeA	1	5	1	8.37	58	0.097	2.45
300	7pH	0Cl	TypeA	1	5	2	8.83	61	0.122	3.11
300	7pH	0Cl	TypeA	1	5	3	8.15	56	0.104	2.64
300	7pH	0Cl	TypeA	1	5	4	8.00	55	0.097	2.46
300	7pH	0Cl	TypeA	1	5	5	8.24	57	0.111	2.81
300	7pH	0Cl	TypeA	2	3	1	4.22	29	0.130	3.31
300	7pH	0Cl	TypeA	2	3	2	4.30	30	0.107	2.72
300	7pH	0Cl	TypeA	2	3	3	4.26	29	0.100	2.54
300	7pH	0Cl	TypeA	2	3	4	4.40	30	0.096	2.44
300	7pH	0Cl	TypeA	2	3	5	3.24	22	0.119	3.02
300	7pH	0Cl	TypeA	2	5	1	8.39	58	0.117	2.97
300	7pH	0Cl	TypeA	2	5	2	7.72	53	0.118	3.00
300	7pH	0Cl	TypeA	2	5	3	8.05	56	0.114	2.90
300	7pH	0Cl	TypeA	2	5	4	8.58	59	0.100	2.53
300	7pH	0Cl	TypeA	2	5	5	7.40	51	0.098	2.50
300	7pH	0Cl	TypeB	1	3	1	6.21	43	0.065	1.65
300	7pH	0Cl	TypeB	1	3	2	4.80	33	0.059	1.51
300	7pH	0Cl	TypeB	1	3	3	3.87	27	0.053	1.36
300	7pH	0Cl	TypeB	1	3	4	6.23	43	0.059	1.49
300	7pH	0Cl	TypeB	1	3	5	6.20	43	0.066	1.68
300	7pH	0Cl	TypeB	1	5	1	6.84	47	0.079	2.01
300	7pH	0Cl	TypeB	1	5	2	6.96	48	0.084	2.14
300	7pH	0Cl	TypeB	1	5	3	6.97	48	0.098	2.48
300	7pH	0Cl	TypeB	1	5	4	7.28	50	0.087	2.22
300	7pH	0Cl	TypeB	1	5	5	6.89	48	0.075	1.92
300	7pH	0Cl	TypeB	2	3	1	5.63	39	0.062	1.56
300	7pH	0Cl	TypeB	2	3	2	6.48	45	0.069	1.74
300	7pH	0Cl	TypeB	2	3	3	6.65	46	0.065	1.65

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Table A.4: Continued										
Specimen							Horizontal Shear Strength		Displacement at Shear Strength	
Age Day	pH	Cl^{-} ppm	Type	Lot No.	Size #	Spec No.	ksi	MPa	in.	mm
300	7pH	0Cl	TypeB	2	3	4	7.01	48	0.075	1.90
300	7pH	0Cl	TypeB	2	3	5	6.78	47	0.066	1.68
300	7pH	0Cl	TypeB	2	5	1	7.14	49	0.098	2.48
300	7pH	0Cl	TypeB	2	5	2	6.46	45	0.086	2.19
300	7pH	0Cl	TypeB	2	5	3	6.07	42	0.075	1.91
300	7pH	0Cl	TypeB	2	5	4	6.78	47	0.096	2.44
300	7pH	0Cl	TypeB	2	5	5	7.33	51	0.099	2.51
300	7pH	0Cl	TypeC	1	3	1	7.70	53	0.059	1.49
300	7pH	0Cl	TypeC	1	3	2	9.10	63	0.078	1.98
300	7pH	0Cl	TypeC	1	3	3	6.47	45	0.051	1.30
300	7pH	0Cl	TypeC	1	3	4	7.51	52	0.081	2.06
300	7pH	0Cl	TypeC	1	3	5	8.34	58	0.071	1.80
300	7pH	0Cl	TypeC	1	5	1	9.19	63	0.118	3.00
300	7pH	0Cl	TypeC	1	5	2	8.14	56	0.138	3.49
300	7pH	0Cl	TypeC	1	5	3	9.25	64	0.126	3.21
300	7pH	0Cl	TypeC	1	5	4	7.17	49	0.102	2.58
300	7pH	0Cl	TypeC	1	5	5	9.39	65	0.126	3.21
300	7pH	0Cl	TypeC	2	3	1	8.92	62	0.069	1.75
300	7pH	0Cl	TypeC	2	3	2	7.37	51	0.072	1.82
300	7pH	0Cl	TypeC	2	3	3	9.17	63	0.086	2.18
300	7pH	0Cl	TypeC	2	3	4	9.23	64	0.062	1.59
300	7pH	0Cl	TypeC	2	3	5	8.90	61	0.081	2.07
300	7pH	0Cl	TypeC	2	5	1	7.98	55	0.136	3.46
300	7pH	0Cl	TypeC	2	5	2	7.70	53	0.108	2.74
300	7pH	0Cl	TypeC	2	5	3	7.96	55	0.099	2.52
300	7pH	0Cl	TypeC	2	5	4	7.72	53	0.121	3.09
300	7pH	0Cl	TypeC	2	5	5	7.41	51	0.109	2.77
300	13pH	20000Cl	TypeA	1	5	1	6.72	46	0.121	3.08
300	13pH	20000Cl	TypeA	1	5	2	6.12	42	0.118	3.00
300	13pH	20000Cl	TypeA	1	5	3	6.12	42	0.098	2.50
300	13pH	20000Cl	TypeA	1	5	4	6.22	43	0.106	2.69
300	13pH	20000Cl	TypeA	1	5	5	6.77	47	0.126	3.21
300	13pH	20000Cl	TypeA	2	5	1	4.57	32	0.182	4.63
300	13pH	20000Cl	TypeA	2	5	2	2.63	18	0.236	5.99
300	13pH	20000Cl	TypeA	2	5	3	2.81	19	0.233	5.92
300	13pH	20000Cl	TypeA	2	5	4	0.19	1	0.228	5.79
300	13pH	20000Cl	TypeA	2	5	5	3.81	26	0.226	5.73
300	13pH	20000Cl	TypeB	1	3	1	5.29	37	0.077	1.96
300	13pH	20000Cl	TypeB	1	3	2	1.64	11	0.038	0.96
300	13pH	20000Cl	TypeB	1	3	3	5.06	35	0.055	1.41
300	13pH	20000Cl	TypeB	1	3	4	5.35	37	0.061	1.55
300	13pH	20000Cl	TypeB	1	3	5	4.88	34	0.059	1.50
300	13pH	20000Cl	TypeB	1	5	1	6.85	47	0.103	2.60
300	13pH	20000Cl	TypeB	1	5	2	6.51	45	0.101	2.57
300	13pH	20000Cl	TypeB	1	5	3	6.25	43	0.113	2.86
300	13pH	20000Cl	TypeB	1	5	4	3.39	23	0.134	3.41
300	13pH	20000Cl	TypeB	1	5	5	6.73	46	0.096	2.43
300	13pH	20000Cl	TypeB	2	3	1	6.03	42	0.056	1.42
300	13pH	20000Cl	TypeB	2	3	2	6.08	42	0.059	1.50
300	13pH	20000Cl	TypeB	2	3	3	2.06	14	0.041	1.03
300	13pH	20000Cl	TypeB	2	3	4	6.40	44	0.063	1.60
300	13pH	20000Cl	TypeB	2	3	5	6.56	45	0.067	1.69
300	13pH	20000Cl	TypeB	2	5	1	1.46	10	0.045	1.15

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Table A.4: Continued										
Specimen							Horizontal Shear Strength		Displacement at Shear Strength	
Age Day	pH	Cl^{-} ppm	Type	Lot No.	Size #	Spec No.	ksi	MPa	in.	mm
300	13pH	20000Cl	TypeB	2	5	2	4.00	28	0.103	2.61
300	13pH	20000Cl	TypeB	2	5	3	2.86	20	0.125	3.17
300	13pH	20000Cl	TypeB	2	5	4	3.73	26	0.120	3.06
300	13pH	20000Cl	TypeB	2	5	5	4.28	30	0.119	3.02
300	13pH	20000Cl	TypeC	1	5	1	6.97	48	0.114	2.90
300	13pH	20000Cl	TypeC	1	5	2	6.91	48	0.109	2.77
300	13pH	20000Cl	TypeC	1	5	3	6.65	46	0.107	2.72
300	13pH	20000Cl	TypeC	1	5	4	7.44	51	0.128	3.24
300	13pH	20000Cl	TypeC	1	5	5	7.49	52	0.113	2.87
300	13pH	20000Cl	TypeC	2	5	1	3.20	22	0.201	5.12
300	13pH	20000Cl	TypeC	2	5	2	3.69	25	0.180	4.58
300	13pH	20000Cl	TypeC	2	5	3	0.34	2	0.236	5.98
300	13pH	20000Cl	TypeC	2	5	4	2.88	20	0.193	4.90
300	13pH	20000Cl	TypeC	2	5	5	6.01	41	0.151	3.83
300	4pH	20000Cl	TypeA	1	3	1	8.25	57	0.086	2.18
300	4pH	20000Cl	TypeA	1	3	2	9.49	65	0.091	2.30
300	4pH	20000Cl	TypeA	1	3	3	8.49	59	0.094	2.40
300	4pH	20000Cl	TypeA	1	3	4	9.32	64	0.082	2.09
300	4pH	20000Cl	TypeA	1	3	5	9.59	66	0.089	2.26
300	4pH	20000Cl	TypeA	1	5	1	2.93	20	0.315	8.01
300	4pH	20000Cl	TypeA	1	5	2	2.93	20	0.504	12.80
300	4pH	20000Cl	TypeA	1	5	3	2.93	20	0.356	9.04
300	4pH	20000Cl	TypeA	1	5	4	2.93	20	0.284	7.21
300	4pH	20000Cl	TypeA	1	5	5	2.93	20	0.312	7.92
300	4pH	20000Cl	TypeA	1	5	6	2.93	20	0.269	6.83
300	4pH	20000Cl	TypeA	2	3	1	1.82	13	0.112	2.85
300	4pH	20000Cl	TypeA	2	3	2	1.53	11	0.127	3.23
300	4pH	20000Cl	TypeA	2	3	3	1.70	12	0.189	4.81
300	4pH	20000Cl	TypeA	2	3	4	1.70	12	0.120	3.06
300	4pH	20000Cl	TypeA	2	3	5	1.73	12	0.113	2.88
300	4pH	20000Cl	TypeA	2	5	1	2.93	20	0.326	8.28
300	4pH	20000Cl	TypeA	2	5	2	2.93	20	0.248	6.30
300	4pH	20000Cl	TypeA	2	5	3	2.93	20	0.339	8.61
300	4pH	20000Cl	TypeA	2	5	4	2.93	20	0.451	11.46
300	4pH	20000Cl	TypeA	2	5	5	2.93	20	0.249	6.33
300	4pH	20000Cl	TypeB	1	3	1	6.03	42	0.067	1.71
300	4pH	20000Cl	TypeB	1	3	2	6.44	44	0.076	1.93
300	4pH	20000Cl	TypeB	1	3	3	4.93	34	0.054	1.37
300	4pH	20000Cl	TypeB	1	3	4	6.09	42	0.055	1.39
300	4pH	20000Cl	TypeB	1	3	5	6.15	42	0.068	1.72
300	4pH	20000Cl	TypeB	1	5	1	6.60	45	0.067	1.70
300	4pH	20000Cl	TypeB	1	5	2	6.77	47	0.075	1.90
300	4pH	20000Cl	TypeB	1	5	3	7.28	50	0.068	1.73
300	4pH	20000Cl	TypeB	1	5	4	7.10	49	0.081	2.07
300	4pH	20000Cl	TypeB	1	5	5	6.89	47	0.079	2.01
300	4pH	20000Cl	TypeB	2	3	1	6.92	48	0.065	1.64
300	4pH	20000Cl	TypeB	2	3	2	6.47	45	0.086	2.18
300	4pH	20000Cl	TypeB	2	3	3	6.42	44	0.064	1.62
300	4pH	20000Cl	TypeB	2	3	4	7.31	50	0.067	1.71
300	4pH	20000Cl	TypeB	2	3	5	6.61	46	0.075	1.92
300	4pH	20000Cl	TypeB	2	5	1	6.27	43	0.074	1.88
300	4pH	20000Cl	TypeB	2	5	2	6.83	47	0.090	2.28
300	4pH	20000Cl	TypeB	2	5	3	6.84	47	0.084	2.14

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Table A.4: Continued										
Specimen							Horizontal		Displacement	
Age	pH	Cl^-	Type	Lot	Size	Spec	Shear Strength		at Shear Strength	
Day		ppm		No.	#	No.	ksi	MPa	in.	mm
300	4pH	20000Cl	TypeB	2	5	4	6.88	47	0.085	2.17
300	4pH	20000Cl	TypeB	2	5	5	6.40	44	0.076	1.94
300	4pH	20000Cl	TypeC	1	3	1	8.02	55	0.076	1.92
300	4pH	20000Cl	TypeC	1	3	2	8.04	55	0.080	2.03
300	4pH	20000Cl	TypeC	1	3	3	8.01	55	0.067	1.71
300	4pH	20000Cl	TypeC	1	3	4	7.59	52	0.088	2.24
300	4pH	20000Cl	TypeC	1	3	5	7.26	50	0.081	2.05
300	4pH	20000Cl	TypeC	1	5	1	9.23	64	0.122	3.11
300	4pH	20000Cl	TypeC	1	5	2	8.34	57	0.132	3.35
300	4pH	20000Cl	TypeC	1	5	3	8.16	56	0.122	3.10
300	4pH	20000Cl	TypeC	1	5	4	3.32	23	0.168	4.28
300	4pH	20000Cl	TypeC	1	5	5	8.06	56	0.121	3.07
300	4pH	20000Cl	TypeC	1	5	6	8.31	57	0.112	2.86
300	4pH	20000Cl	TypeC	2	3	1	9.52	66	0.076	1.93
300	4pH	20000Cl	TypeC	2	3	2	8.82	61	0.073	1.85
300	4pH	20000Cl	TypeC	2	3	3	9.30	64	0.092	2.34
300	4pH	20000Cl	TypeC	2	3	4	8.70	60	0.078	1.99
300	4pH	20000Cl	TypeC	2	3	5	8.80	61	0.081	2.07
300	4pH	20000Cl	TypeC	2	5	1	7.29	50	0.107	2.73
300	4pH	20000Cl	TypeC	2	5	2	7.30	50	0.119	3.02
300	4pH	20000Cl	TypeC	2	5	3	7.72	53	0.115	2.93
300	4pH	20000Cl	TypeC	2	5	5	7.56	52	0.098	2.49
300	7pH	20000Cl	TypeA	1	3	1	8.95	62	0.091	2.32
300	7pH	20000Cl	TypeA	1	3	2	8.03	55	0.088	2.25
300	7pH	20000Cl	TypeA	1	3	3	7.85	54	0.090	2.28
300	7pH	20000Cl	TypeA	1	3	4	9.30	64	0.096	2.43
300	7pH	20000Cl	TypeA	1	3	5	8.11	56	0.121	3.08
300	7pH	20000Cl	TypeA	1	5	1	8.62	59	0.124	3.15
300	7pH	20000Cl	TypeA	1	5	2	7.90	54	0.111	2.82
300	7pH	20000Cl	TypeA	1	5	3	7.89	54	0.121	3.08
300	7pH	20000Cl	TypeA	1	5	4	8.42	58	0.125	3.18
300	7pH	20000Cl	TypeA	1	5	5	7.64	53	0.102	2.60
300	7pH	20000Cl	TypeA	2	3	1	3.44	24	0.117	2.97
300	7pH	20000Cl	TypeA	2	3	2	3.94	27	0.099	2.50
300	7pH	20000Cl	TypeA	2	3	3	3.76	26	0.098	2.49
300	7pH	20000Cl	TypeA	2	3	4	3.96	27	0.115	2.91
300	7pH	20000Cl	TypeA	2	3	5	4.03	28	0.098	2.49
300	7pH	20000Cl	TypeA	2	5	1	7.80	54	0.118	3.00
300	7pH	20000Cl	TypeA	2	5	2	8.35	58	0.113	2.87
300	7pH	20000Cl	TypeA	2	5	3	8.03	55	0.108	2.74
300	7pH	20000Cl	TypeA	2	5	4	6.94	48	0.133	3.38
300	7pH	20000Cl	TypeA	2	5	5	7.10	49	0.093	2.37
300	7pH	20000Cl	TypeB	1	3	1	5.85	40	0.069	1.76
300	7pH	20000Cl	TypeB	1	3	2	5.90	41	0.063	1.61
300	7pH	20000Cl	TypeB	1	3	3	6.10	42	0.066	1.69
300	7pH	20000Cl	TypeB	1	3	4	4.76	33	0.064	1.61
300	7pH	20000Cl	TypeB	1	3	5	5.09	35	0.070	1.77
300	7pH	20000Cl	TypeB	1	5	1	6.49	45	0.077	1.94
300	7pH	20000Cl	TypeB	1	5	2	7.14	49	0.080	2.03
300	7pH	20000Cl	TypeB	1	5	3	6.63	46	0.092	2.35
300	7pH	20000Cl	TypeB	1	5	4	6.25	43	0.078	1.97
300	7pH	20000Cl	TypeB	1	5	5	6.78	47	0.075	1.90
300	7pH	20000Cl	TypeB	2	3	1	7.27	50	0.073	1.85

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Table A.4: Continued										
Specimen							Horizontal Shear Strength		Displacement at Shear Strength	
Age Day	pH	Cl^{-} ppm	Type	Lot No.	Size #	Spec No.	ksi	MPa	in.	mm
300	7pH	20000Cl	TypeB	2	3	2	7.17	49	0.067	1.70
300	7pH	20000Cl	TypeB	2	3	3	7.20	50	0.067	1.70
300	7pH	20000Cl	TypeB	2	3	4	5.31	37	0.056	1.42
300	7pH	20000Cl	TypeB	2	3	5	6.89	48	0.072	1.82
300	7pH	20000Cl	TypeB	2	5	1	6.63	46	0.084	2.15
300	7pH	20000Cl	TypeB	2	5	2	6.39	44	0.078	1.99
300	7pH	20000Cl	TypeB	2	5	3	6.56	45	0.084	2.13
300	7pH	20000Cl	TypeB	2	5	4	7.21	50	0.088	2.23
300	7pH	20000Cl	TypeB	2	5	5	6.60	46	0.094	2.40
300	7pH	20000Cl	TypeC	1	3	1	8.15	56	0.075	1.90
300	7pH	20000Cl	TypeC	1	3	2	8.41	58	0.070	1.78
300	7pH	20000Cl	TypeC	1	3	3	8.81	61	0.088	2.23
300	7pH	20000Cl	TypeC	1	3	4	6.92	48	0.064	1.63
300	7pH	20000Cl	TypeC	1	3	5	8.05	55	0.063	1.59
300	7pH	20000Cl	TypeC	1	5	1	8.73	60	0.113	2.88
300	7pH	20000Cl	TypeC	1	5	2	9.04	62	0.126	3.21
300	7pH	20000Cl	TypeC	1	5	3	9.36	65	0.123	3.13
300	7pH	20000Cl	TypeC	1	5	4	9.49	65	0.120	3.06
300	7pH	20000Cl	TypeC	1	5	5	8.30	57	0.103	2.62
300	7pH	20000Cl	TypeC	2	3	1	8.83	61	0.092	2.34
300	7pH	20000Cl	TypeC	2	3	2	8.73	60	0.099	2.52
300	7pH	20000Cl	TypeC	2	3	3	8.23	57	0.081	2.07
300	7pH	20000Cl	TypeC	2	3	4	9.55	66	0.091	2.32
300	7pH	20000Cl	TypeC	2	3	5	9.20	63	0.090	2.28
300	7pH	20000Cl	TypeC	2	5	1	8.08	56	0.124	3.15
300	7pH	20000Cl	TypeC	2	5	2	7.08	49	0.097	2.46
300	7pH	20000Cl	TypeC	2	5	3	6.06	42	0.108	2.74
300	7pH	20000Cl	TypeC	2	5	4	6.15	42	0.104	2.63
300	7pH	20000Cl	TypeC	2	5	5	6.20	43	0.103	2.62
300	13pH	SeaWater	TypeA	1	5	1	0.70	5	0.236	6.00
300	13pH	SeaWater	TypeA	1	5	2	0.86	6	0.236	6.00
300	13pH	SeaWater	TypeA	1	5	3	0.01	0	0.027	0.70
300	13pH	SeaWater	TypeA	1	5	4	0.79	5	0.236	5.99
300	13pH	SeaWater	TypeA	1	5	5	0.64	4	0.236	5.99
300	13pH	SeaWater	TypeA	2	5	1	0.99	7	0.236	6.00
300	13pH	SeaWater	TypeA	2	5	2	1.21	8	0.236	5.99
300	13pH	SeaWater	TypeA	2	5	3	0.04	0	0.218	5.54
300	13pH	SeaWater	TypeA	2	5	4	1.01	7	0.236	6.00
300	13pH	SeaWater	TypeA	2	5	5	1.05	7	0.236	6.00
300	13pH	SeaWater	TypeB	1	3	1	1.21	8	0.034	0.87
300	13pH	SeaWater	TypeB	1	3	2	1.09	7	0.026	0.65
300	13pH	SeaWater	TypeB	1	3	3	1.12	8	0.028	0.70
300	13pH	SeaWater	TypeB	1	3	4	1.20	8	0.037	0.95
300	13pH	SeaWater	TypeB	1	3	5	1.11	8	0.040	1.02
300	13pH	SeaWater	TypeB	1	5	1	1.88	13	0.051	1.30
300	13pH	SeaWater	TypeB	1	5	2	1.45	10	0.033	0.85
300	13pH	SeaWater	TypeB	1	5	3	1.58	11	0.056	1.43
300	13pH	SeaWater	TypeB	1	5	4	1.37	9	0.046	1.16
300	13pH	SeaWater	TypeB	1	5	5	1.77	12	0.037	0.95
300	13pH	SeaWater	TypeB	2	3	1	1.68	12	0.039	0.98
300	13pH	SeaWater	TypeB	2	3	2	1.43	10	0.044	1.11
300	13pH	SeaWater	TypeB	2	3	3	1.55	11	0.041	1.05
300	13pH	SeaWater	TypeB	2	3	4	1.44	10	0.032	0.82

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Table A.4: Continued										
Specimen							Horizontal Shear Strength		Displacement at Shear Strength	
Age	pH	Cl^-	Type	Lot	Size	Spec	ksi	MPa	in.	mm
Day		ppm		No.	#	No.				
300	13pH	SeaWater	TypeB	2	3	5	1.48	10	0.038	0.97
300	13pH	SeaWater	TypeB	2	5	1	1.60	11	0.039	0.98
300	13pH	SeaWater	TypeB	2	5	2	3.59	25	0.106	2.70
300	13pH	SeaWater	TypeB	2	5	3	3.46	24	0.108	2.74
300	13pH	SeaWater	TypeB	2	5	4	3.52	24	0.121	3.07
300	13pH	SeaWater	TypeB	2	5	5	3.57	25	0.124	3.16
300	13pH	SeaWater	TypeC	1	5	1	0.86	6	0.236	6.00
300	13pH	SeaWater	TypeC	1	5	2	1.52	10	0.236	6.00
300	4pH	SeaWater	TypeA	1	3	1	8.65	60	0.068	1.74
300	4pH	SeaWater	TypeA	1	3	2	9.36	65	0.097	2.48
300	4pH	SeaWater	TypeA	1	3	3	8.87	61	0.091	2.31
300	4pH	SeaWater	TypeA	1	3	4	8.38	58	0.101	2.56
300	4pH	SeaWater	TypeA	1	3	5	7.80	54	0.075	1.90
300	4pH	SeaWater	TypeA	1	5	1	7.57	52	0.110	2.79
300	4pH	SeaWater	TypeA	1	5	2	8.04	55	0.089	2.26
300	4pH	SeaWater	TypeA	1	5	3	8.49	59	0.112	2.83
300	4pH	SeaWater	TypeA	1	5	4	8.23	57	0.109	2.77
300	4pH	SeaWater	TypeA	1	5	5	7.09	49	0.090	2.29
300	4pH	SeaWater	TypeA	2	3	1	2.79	19	0.115	2.93
300	4pH	SeaWater	TypeA	2	3	2	2.43	17	0.114	2.90
300	4pH	SeaWater	TypeA	2	3	3	2.34	16	0.129	3.27
300	4pH	SeaWater	TypeA	2	3	4	2.42	17	0.107	2.72
300	4pH	SeaWater	TypeA	2	3	5	2.32	16	0.100	2.53
300	4pH	SeaWater	TypeA	2	5	1	8.11	56	0.127	3.22
300	4pH	SeaWater	TypeA	2	5	2	8.06	56	0.142	3.61
300	4pH	SeaWater	TypeA	2	5	3	7.80	54	0.132	3.36
300	4pH	SeaWater	TypeA	2	5	4	7.43	51	0.115	2.93
300	4pH	SeaWater	TypeA	2	5	5	7.53	52	0.119	3.03
300	4pH	SeaWater	TypeB	1	3	1	4.59	32	0.065	1.64
300	4pH	SeaWater	TypeB	1	3	2	4.07	28	0.078	1.97
300	4pH	SeaWater	TypeB	1	3	3	4.55	31	0.064	1.62
300	4pH	SeaWater	TypeB	1	3	4	5.05	35	0.064	1.62
300	4pH	SeaWater	TypeB	1	3	5	4.34	30	0.055	1.39
300	4pH	SeaWater	TypeB	1	5	1	6.66	46	0.090	2.29
300	4pH	SeaWater	TypeB	1	5	2	6.91	48	0.081	2.05
300	4pH	SeaWater	TypeB	1	5	3	6.85	47	0.077	1.97
300	4pH	SeaWater	TypeB	1	5	4	6.93	48	0.076	1.93
300	4pH	SeaWater	TypeB	1	5	5	6.90	48	0.079	2.01
300	4pH	SeaWater	TypeB	2	3	1	6.97	48	0.071	1.79
300	4pH	SeaWater	TypeB	2	3	2	6.86	47	0.069	1.76
300	4pH	SeaWater	TypeB	2	3	3	7.00	48	0.081	2.06
300	4pH	SeaWater	TypeB	2	3	4	6.55	45	0.070	1.79
300	4pH	SeaWater	TypeB	2	3	5	7.16	49	0.062	1.57
300	4pH	SeaWater	TypeB	2	5	1	6.50	45	0.088	2.24
300	4pH	SeaWater	TypeB	2	5	2	6.51	45	0.081	2.06
300	4pH	SeaWater	TypeB	2	5	3	6.49	45	0.088	2.24
300	4pH	SeaWater	TypeB	2	5	4	6.93	48	0.093	2.36
300	4pH	SeaWater	TypeB	2	5	5	6.61	46	0.084	2.14
300	4pH	SeaWater	TypeC	1	3	1	7.64	53	0.065	1.65
300	4pH	SeaWater	TypeC	1	3	2	9.17	63	0.081	2.05
300	4pH	SeaWater	TypeC	1	3	3	8.92	61	0.088	2.24
300	4pH	SeaWater	TypeC	1	3	4	7.06	49	0.066	1.67
300	4pH	SeaWater	TypeC	1	3	5	8.12	56	0.062	1.57

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Table A.4: Continued										
Specimen							Horizontal		Displacement	
Age	pH	Cl^{-}	Type	Lot	Size	Spec	Shear Strength		at Shear Strength	
Day		ppm		No.	#	No.	ksi	MPa	in.	mm
300	4pH	SeaWater	TypeC	1	5	1	8.64	60	0.113	2.86
300	4pH	SeaWater	TypeC	1	5	2	8.68	60	0.121	3.07
300	4pH	SeaWater	TypeC	1	5	3	8.77	61	0.122	3.09
300	4pH	SeaWater	TypeC	1	5	4	7.93	55	0.100	2.55
300	4pH	SeaWater	TypeC	1	5	5	9.03	62	0.142	3.61
300	4pH	SeaWater	TypeC	2	3	1	9.94	69	0.079	2.00
300	4pH	SeaWater	TypeC	2	3	2	9.72	67	0.080	2.03
300	4pH	SeaWater	TypeC	2	3	3	9.39	65	0.068	1.73
300	4pH	SeaWater	TypeC	2	3	4	8.06	56	0.074	1.88
300	4pH	SeaWater	TypeC	2	3	5	8.83	61	0.066	1.69
300	4pH	SeaWater	TypeC	2	5	1	7.49	52	0.128	3.25
300	4pH	SeaWater	TypeC	2	5	2	8.16	56	0.138	3.51
300	4pH	SeaWater	TypeC	2	5	3	6.81	47	0.092	2.34
300	4pH	SeaWater	TypeC	2	5	4	8.21	57	0.179	4.55
300	4pH	SeaWater	TypeC	2	5	5	7.87	54	0.121	3.06
300	7pH	SeaWater	TypeA	1	3	1	7.71	53	0.080	2.04
300	7pH	SeaWater	TypeA	1	3	2	7.52	52	0.096	2.44
300	7pH	SeaWater	TypeA	1	3	3	8.65	60	0.091	2.32
300	7pH	SeaWater	TypeA	1	3	4	8.10	56	0.110	2.80
300	7pH	SeaWater	TypeA	1	3	5	9.18	63	0.097	2.46
300	7pH	SeaWater	TypeA	1	5	1	8.70	60	0.122	3.11
300	7pH	SeaWater	TypeA	1	5	2	7.46	51	0.114	2.89
300	7pH	SeaWater	TypeA	1	5	3	7.96	55	0.104	2.63
300	7pH	SeaWater	TypeA	1	5	4	7.30	50	0.090	2.28
300	7pH	SeaWater	TypeA	1	5	5	7.96	55	0.113	2.86
300	7pH	SeaWater	TypeA	2	3	1	2.56	18	0.101	2.56
300	7pH	SeaWater	TypeA	2	3	2	2.57	18	0.148	3.75
300	7pH	SeaWater	TypeA	2	3	3	2.59	18	0.109	2.76
300	7pH	SeaWater	TypeA	2	3	4	2.52	17	0.115	2.92
300	7pH	SeaWater	TypeA	2	3	5	2.80	19	0.134	3.41
300	7pH	SeaWater	TypeA	2	5	1	7.62	53	0.110	2.80
300	7pH	SeaWater	TypeA	2	5	2	7.15	49	0.105	2.66
300	7pH	SeaWater	TypeA	2	5	3	7.76	53	0.107	2.72
300	7pH	SeaWater	TypeA	2	5	4	7.90	54	0.100	2.55
300	7pH	SeaWater	TypeA	2	5	5	7.92	55	0.099	2.53
300	7pH	SeaWater	TypeB	1	3	1	5.99	41	0.060	1.53
300	7pH	SeaWater	TypeB	1	3	2	4.83	33	0.057	1.44
300	7pH	SeaWater	TypeB	1	3	3	5.01	35	0.042	1.06
300	7pH	SeaWater	TypeB	1	3	4	4.16	29	0.051	1.31
300	7pH	SeaWater	TypeB	1	3	5	4.36	30	0.056	1.43
300	7pH	SeaWater	TypeB	1	5	1	6.57	45	0.089	2.25
300	7pH	SeaWater	TypeB	1	5	2	7.10	49	0.085	2.15
300	7pH	SeaWater	TypeB	1	5	3	6.57	45	0.084	2.13
300	7pH	SeaWater	TypeB	1	5	4	6.71	46	0.074	1.88
300	7pH	SeaWater	TypeB	1	5	5	6.99	48	0.086	2.18
300	7pH	SeaWater	TypeB	2	3	1	7.00	48	0.068	1.71
300	7pH	SeaWater	TypeB	2	3	2	7.39	51	0.089	2.25
300	7pH	SeaWater	TypeB	2	3	3	6.69	46	0.066	1.68
300	7pH	SeaWater	TypeB	2	3	4	6.17	43	0.077	1.95
300	7pH	SeaWater	TypeB	2	3	5	6.28	43	0.071	1.79
300	7pH	SeaWater	TypeB	2	5	1	6.32	44	0.075	1.90
300	7pH	SeaWater	TypeB	2	5	2	7.16	49	0.092	2.35
300	7pH	SeaWater	TypeB	2	5	3	6.93	48	0.097	2.46

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Table A.4: Continued										
Specimen							Horizontal Shear Strength		Displacement at Shear Strength	
Age Day	pH	Cl^- ppm	Type	Lot No.	Size #	Spec No.	ksi	MPa	in.	mm
300	7pH	SeaWater	TypeB	2	5	4	6.59	45	0.094	2.39
300	7pH	SeaWater	TypeB	2	5	5	7.19	50	0.095	2.41
300	7pH	SeaWater	TypeC	1	3	1	8.86	61	0.082	2.07
300	7pH	SeaWater	TypeC	1	3	2	8.17	56	0.079	2.01
300	7pH	SeaWater	TypeC	1	3	3	8.10	56	0.066	1.67
300	7pH	SeaWater	TypeC	1	3	4	8.50	59	0.079	2.01
300	7pH	SeaWater	TypeC	1	3	5	8.61	59	0.073	1.84
300	7pH	SeaWater	TypeC	1	5	1	9.11	63	0.114	2.90
300	7pH	SeaWater	TypeC	1	5	2	8.84	61	0.134	3.40
300	7pH	SeaWater	TypeC	1	5	3	8.93	62	0.114	2.90
300	7pH	SeaWater	TypeC	1	5	4	7.19	50	0.118	3.00
300	7pH	SeaWater	TypeC	1	5	5	9.03	62	0.112	2.86
300	7pH	SeaWater	TypeC	2	3	1	7.72	53	0.069	1.75
300	7pH	SeaWater	TypeC	2	3	2	7.90	54	0.078	1.98
300	7pH	SeaWater	TypeC	2	3	3	7.46	51	0.083	2.10
300	7pH	SeaWater	TypeC	2	3	4	7.36	51	0.077	1.95
300	7pH	SeaWater	TypeC	2	3	5	7.15	49	0.058	1.47
300	7pH	SeaWater	TypeC	2	5	1	7.70	53	0.094	2.40
300	7pH	SeaWater	TypeC	2	5	2	7.12	49	0.100	2.54
300	7pH	SeaWater	TypeC	2	5	3	7.23	50	0.109	2.77
300	7pH	SeaWater	TypeC	2	5	4	8.06	56	0.104	2.63
300	7pH	SeaWater	TypeC	2	5	5	6.89	48	0.086	2.20
600	4pH	0Cl	TypeA	1	3	1	8.04	55	0.091	2.32
600	4pH	0Cl	TypeA	1	3	2	9.14	63	0.117	2.97
600	4pH	0Cl	TypeA	1	3	3	7.99	55	0.085	2.17
600	4pH	0Cl	TypeA	1	5	1	6.41	44	0.124	3.15
600	4pH	0Cl	TypeA	1	5	2	7.51	52	0.133	3.38
600	4pH	0Cl	TypeA	1	5	3	6.90	48	0.129	3.27
600	4pH	0Cl	TypeA	2	3	1	0.48	3	0.235	5.98
600	4pH	0Cl	TypeA	2	3	2	0.51	4	0.234	5.94
600	4pH	0Cl	TypeA	2	3	3	0.37	3	0.224	5.70
600	4pH	0Cl	TypeA	2	5	1	7.77	54	0.141	3.58
600	4pH	0Cl	TypeA	2	5	2	7.34	51	0.119	3.03
600	4pH	0Cl	TypeA	2	5	3	6.59	45	0.124	3.15
600	4pH	0Cl	TypeB	1	3	1	3.84	26	0.057	1.46
600	4pH	0Cl	TypeB	1	3	2	4.16	29	0.062	1.58
600	4pH	0Cl	TypeB	1	3	3	4.96	34	0.069	1.75
600	4pH	0Cl	TypeB	1	5	1	6.27	43	0.078	1.97
600	4pH	0Cl	TypeB	1	5	2	6.04	42	0.103	2.62
600	4pH	0Cl	TypeB	1	5	3	5.78	40	0.092	2.32
600	4pH	0Cl	TypeB	2	3	1	5.06	35	0.062	1.59
600	4pH	0Cl	TypeB	2	3	2	6.41	44	0.077	1.96
600	4pH	0Cl	TypeB	2	3	3	5.65	39	0.064	1.62
600	4pH	0Cl	TypeB	2	5	1	6.44	44	0.103	2.60
600	4pH	0Cl	TypeB	2	5	2	6.44	44	0.112	2.85
600	4pH	0Cl	TypeB	2	5	3	5.94	41	0.100	2.55
600	4pH	0Cl	TypeC	1	3	1	6.40	44	0.064	1.63
600	4pH	0Cl	TypeC	1	3	2	7.40	51	0.082	2.08
600	4pH	0Cl	TypeC	1	3	3	7.24	50	0.077	1.96
600	4pH	0Cl	TypeC	1	5	1	8.03	55	0.128	3.26
600	4pH	0Cl	TypeC	1	5	2	7.41	51	0.113	2.88
600	4pH	0Cl	TypeC	1	5	3	7.70	53	0.140	3.57
600	4pH	0Cl	TypeC	2	3	1	7.13	49	0.074	1.88

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Table A.4: Continued

Specimen							Horizontal Shear Strength		Displacement at Shear Strength	
Age Day	pH	Cl^{-} ppm	Type	Lot No.	Size #	Spec No.	ksi	MPa	in.	mm
600	4pH	0Cl	TypeC	2	3	2	8.31	57	0.087	2.21
600	4pH	0Cl	TypeC	2	3	3	7.98	55	0.077	1.95
600	4pH	0Cl	TypeC	2	5	1	7.90	54	0.130	3.30
600	4pH	0Cl	TypeC	2	5	2	7.58	52	0.143	3.63
600	4pH	0Cl	TypeC	2	5	3	7.86	54	0.153	3.90
600	7pH	0Cl	TypeA	1	3	1	8.36	58	0.097	2.47
600	7pH	0Cl	TypeA	1	3	2	8.58	59	0.085	2.16
600	7pH	0Cl	TypeA	1	3	3	4.12	28	0.053	1.34
600	7pH	0Cl	TypeA	1	5	1	7.62	53	0.128	3.25
600	7pH	0Cl	TypeA	1	5	2	7.08	49	0.143	3.63
600	7pH	0Cl	TypeA	1	5	3	7.76	53	0.136	3.45
600	7pH	0Cl	TypeA	2	3	1	3.92	27	0.082	2.08
600	7pH	0Cl	TypeA	2	3	2	4.36	30	0.103	2.62
600	7pH	0Cl	TypeA	2	3	3	4.64	32	0.103	2.61
600	7pH	0Cl	TypeA	2	5	1	6.65	46	0.131	3.33
600	7pH	0Cl	TypeA	2	5	2	7.12	49	0.186	4.73
600	7pH	0Cl	TypeA	2	5	3	7.87	54	0.129	3.27
600	7pH	0Cl	TypeB	1	3	1	7.90	54	0.094	2.38
600	7pH	0Cl	TypeB	1	3	2	4.01	28	0.062	1.57
600	7pH	0Cl	TypeB	1	3	3	3.71	26	0.075	1.90
600	7pH	0Cl	TypeB	1	5	1	5.54	38	0.096	2.43
600	7pH	0Cl	TypeB	1	5	2	6.00	41	0.104	2.64
600	7pH	0Cl	TypeB	1	5	3	6.20	43	0.108	2.73
600	7pH	0Cl	TypeB	2	3	1	6.72	46	0.077	1.95
600	7pH	0Cl	TypeB	2	3	2	6.73	46	0.071	1.80
600	7pH	0Cl	TypeB	2	3	3	5.14	35	0.048	1.23
600	7pH	0Cl	TypeB	2	5	1	5.96	41	0.107	2.72
600	7pH	0Cl	TypeB	2	5	2	6.53	45	0.108	2.73
600	7pH	0Cl	TypeB	2	5	3	6.15	42	0.111	2.81
600	7pH	0Cl	TypeC	1	3	1	8.12	56	0.082	2.09
600	7pH	0Cl	TypeC	1	3	2	7.24	50	0.057	1.45
600	7pH	0Cl	TypeC	1	3	3	8.23	57	0.065	1.66
600	7pH	0Cl	TypeC	1	5	1	7.38	51	0.143	3.62
600	7pH	0Cl	TypeC	1	5	2	7.83	54	0.138	3.52
600	7pH	0Cl	TypeC	1	5	3	7.77	54	0.130	3.31
600	7pH	0Cl	TypeC	2	3	1	9.23	64	0.077	1.96
600	7pH	0Cl	TypeC	2	3	2	9.09	63	0.093	2.37
600	7pH	0Cl	TypeC	2	3	3	9.03	62	0.089	2.25
600	7pH	0Cl	TypeC	2	5	1	6.09	42	0.115	2.93
600	7pH	0Cl	TypeC	2	5	2	7.07	49	0.141	3.58
600	7pH	0Cl	TypeC	2	5	3	7.17	49	0.132	3.35
600	4pH	20000Cl	TypeA	1	3	1	7.57	52	0.101	2.57
600	4pH	20000Cl	TypeA	1	3	2	7.95	55	0.084	2.13
600	4pH	20000Cl	TypeA	1	3	3	8.49	59	0.088	2.24
600	4pH	20000Cl	TypeA	1	5	1	7.00	48	0.128	3.25
600	4pH	20000Cl	TypeA	1	5	2	7.45	51	0.145	3.70
600	4pH	20000Cl	TypeA	1	5	3	7.01	48	0.128	3.25
600	4pH	20000Cl	TypeA	2	3	1	0.18	1	0.244	6.19
600	4pH	20000Cl	TypeA	2	3	2	0.19	1	0.235	5.97
600	4pH	20000Cl	TypeA	2	3	3	0.26	2	0.188	4.77
600	4pH	20000Cl	TypeA	2	5	1	6.82	47	0.126	3.21
600	4pH	20000Cl	TypeA	2	5	2	7.35	51	0.145	3.69
600	4pH	20000Cl	TypeA	2	5	3	6.34	44	0.103	2.61

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Table A.4: Continued										
Specimen							Horizontal Shear Strength		Displacement at Shear Strength	
Age Day	pH	Cl^- ppm	Type	Lot No.	Size #	Spec No.	ksi	MPa	in.	mm
600	4pH	20000Cl	TypeB	1	3	1	5.12	35	0.070	1.78
600	4pH	20000Cl	TypeB	1	3	2	3.84	27	0.055	1.40
600	4pH	20000Cl	TypeB	1	3	3	5.27	36	0.064	1.63
600	4pH	20000Cl	TypeB	1	5	1	6.45	44	0.107	2.72
600	4pH	20000Cl	TypeB	1	5	2	6.32	44	0.100	2.55
600	4pH	20000Cl	TypeB	1	5	3	6.12	42	0.093	2.36
600	4pH	20000Cl	TypeB	2	3	1	4.85	33	0.064	1.63
600	4pH	20000Cl	TypeB	2	3	2	6.11	42	0.074	1.88
600	4pH	20000Cl	TypeB	2	3	3	6.22	43	0.077	1.96
600	4pH	20000Cl	TypeB	2	5	1	5.75	40	0.095	2.40
600	4pH	20000Cl	TypeB	2	5	2	5.67	39	0.095	2.43
600	4pH	20000Cl	TypeB	2	5	3	5.84	40	0.109	2.76
600	4pH	20000Cl	TypeC	1	3	1	5.66	39	0.071	1.79
600	4pH	20000Cl	TypeC	1	3	2	2.85	20	0.058	1.46
600	4pH	20000Cl	TypeC	1	3	3	2.96	20	0.066	1.68
600	4pH	20000Cl	TypeC	1	5	1	8.37	58	0.134	3.41
600	4pH	20000Cl	TypeC	1	5	2	7.75	53	0.121	3.07
600	4pH	20000Cl	TypeC	1	5	3	7.21	50	0.129	3.28
600	4pH	20000Cl	TypeC	2	3	1	7.56	52	0.080	2.03
600	4pH	20000Cl	TypeC	2	3	2	7.33	51	0.074	1.89
600	4pH	20000Cl	TypeC	2	3	3	7.28	50	0.072	1.84
600	4pH	20000Cl	TypeC	2	5	1	7.06	49	0.124	3.15
600	4pH	20000Cl	TypeC	2	5	2	6.06	42	0.225	5.71
600	4pH	20000Cl	TypeC	2	5	3	7.88	54	0.137	3.48
600	7pH	20000Cl	TypeA	1	3	1	8.17	56	0.088	2.24
600	7pH	20000Cl	TypeA	1	3	2	8.19	56	0.079	2.01
600	7pH	20000Cl	TypeA	1	3	3	8.96	62	0.094	2.39
600	7pH	20000Cl	TypeA	1	5	1	7.08	49	0.128	3.24
600	7pH	20000Cl	TypeA	1	5	2	6.99	48	0.132	3.34
600	7pH	20000Cl	TypeA	1	5	3	7.70	53	0.123	3.13
600	7pH	20000Cl	TypeA	2	3	1	0.73	5	0.236	6.00
600	7pH	20000Cl	TypeA	2	3	2	1.74	12	0.148	3.77
600	7pH	20000Cl	TypeA	2	3	3	1.24	9	0.236	6.00
600	7pH	20000Cl	TypeA	2	5	1	6.79	47	0.112	2.84
600	7pH	20000Cl	TypeA	2	5	2	7.14	49	0.140	3.55
600	7pH	20000Cl	TypeA	2	5	3	6.87	47	0.124	3.15
600	7pH	20000Cl	TypeB	1	3	1	5.61	39	0.071	1.80
600	7pH	20000Cl	TypeB	1	3	2	3.86	27	0.042	1.06
600	7pH	20000Cl	TypeB	1	3	3	4.92	34	0.060	1.53
600	7pH	20000Cl	TypeB	1	5	1	6.38	44	0.108	2.74
600	7pH	20000Cl	TypeB	1	5	2	6.09	42	0.099	2.51
600	7pH	20000Cl	TypeB	1	5	3	6.25	43	0.103	2.62
600	7pH	20000Cl	TypeB	2	3	1	5.75	40	0.062	1.58
600	7pH	20000Cl	TypeB	2	3	2	6.44	44	0.067	1.69
600	7pH	20000Cl	TypeB	2	3	3	6.13	42	0.071	1.81
600	7pH	20000Cl	TypeB	2	5	1	6.10	42	0.104	2.64
600	7pH	20000Cl	TypeB	2	5	2	5.93	41	0.109	2.76
600	7pH	20000Cl	TypeB	2	5	3	6.23	43	0.116	2.95
600	7pH	20000Cl	TypeC	1	3	1	5.17	36	0.101	2.57
600	7pH	20000Cl	TypeC	1	3	2	8.80	61	0.084	2.13
600	7pH	20000Cl	TypeC	1	3	3	8.94	62	0.082	2.07
600	7pH	20000Cl	TypeC	1	5	1	7.27	50	0.126	3.20
600	7pH	20000Cl	TypeC	1	5	2	8.17	56	0.136	3.45

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Table A.4: Continued										
Specimen							Horizontal Shear Strength		Displacement at Shear Strength	
Age Day	pH	Cl^{-} ppm	Type	Lot No.	Size #	Spec No.	ksi	MPa	in.	mm
600	7pH	20000Cl	TypeC	1	5	3	7.89	54	0.129	3.27
600	7pH	20000Cl	TypeC	2	3	1	7.51	52	0.079	2.02
600	7pH	20000Cl	TypeC	2	3	2	7.69	53	0.075	1.90
600	7pH	20000Cl	TypeC	2	3	3	6.86	47	0.070	1.77
600	7pH	20000Cl	TypeC	2	5	1	7.65	53	0.154	3.92
600	7pH	20000Cl	TypeC	2	5	2	6.64	46	0.137	3.47
600	7pH	20000Cl	TypeC	2	5	3	6.42	44	0.135	3.42
600	4pH	SeaWater	TypeA	1	3	1	8.85	61	0.079	2.02
600	4pH	SeaWater	TypeA	1	3	2	8.73	60	0.092	2.35
600	4pH	SeaWater	TypeA	1	3	3	8.77	61	0.080	2.03
600	4pH	SeaWater	TypeA	1	5	1	6.34	44	0.090	2.30
600	4pH	SeaWater	TypeA	1	5	2	7.52	52	0.157	3.99
600	4pH	SeaWater	TypeA	1	5	3	7.84	54	0.120	3.04
600	4pH	SeaWater	TypeA	2	3	1	0.61	4	0.236	5.99
600	4pH	SeaWater	TypeA	2	3	2	0.86	6	0.137	3.49
600	4pH	SeaWater	TypeA	2	3	3	1.46	10	0.172	4.37
600	4pH	SeaWater	TypeA	2	5	1	4.68	32	0.146	3.70
600	4pH	SeaWater	TypeA	2	5	2	4.63	32	0.153	3.90
600	4pH	SeaWater	TypeA	2	5	3	5.07	35	0.152	3.87
600	4pH	SeaWater	TypeB	1	3	1	5.96	41	0.066	1.68
600	4pH	SeaWater	TypeB	1	3	2	4.27	29	0.066	1.67
600	4pH	SeaWater	TypeB	1	3	3	5.77	40	0.066	1.66
600	4pH	SeaWater	TypeB	1	5	1	6.49	45	0.106	2.69
600	4pH	SeaWater	TypeB	1	5	2	6.49	45	0.105	2.67
600	4pH	SeaWater	TypeB	1	5	3	6.26	43	0.107	2.71
600	4pH	SeaWater	TypeB	2	3	1	5.11	35	0.060	1.53
600	4pH	SeaWater	TypeB	2	3	2	6.55	45	0.086	2.17
600	4pH	SeaWater	TypeB	2	3	3	6.25	43	0.066	1.68
600	4pH	SeaWater	TypeB	2	5	1	5.48	38	0.101	2.58
600	4pH	SeaWater	TypeB	2	5	2	6.38	44	0.104	2.64
600	4pH	SeaWater	TypeB	2	5	3	6.25	43	0.107	2.71
600	4pH	SeaWater	TypeC	1	3	1	7.29	50	0.084	2.14
600	4pH	SeaWater	TypeC	1	3	2	6.84	47	0.064	1.62
600	4pH	SeaWater	TypeC	1	3	3	7.55	52	0.072	1.82
600	4pH	SeaWater	TypeC	1	5	1	7.34	51	0.138	3.50
600	4pH	SeaWater	TypeC	1	5	2	8.77	60	0.143	3.63
600	4pH	SeaWater	TypeC	1	5	3	7.96	55	0.139	3.53
600	4pH	SeaWater	TypeC	2	3	1	9.08	63	0.084	2.13
600	4pH	SeaWater	TypeC	2	3	2	8.48	58	0.080	2.02
600	4pH	SeaWater	TypeC	2	3	3	5.32	37	0.104	2.64
600	4pH	SeaWater	TypeC	2	5	1	7.03	48	0.161	4.10
600	4pH	SeaWater	TypeC	2	5	2	8.20	57	0.149	3.78
600	4pH	SeaWater	TypeC	2	5	3	7.88	54	0.132	3.36
600	7pH	SeaWater	TypeA	1	3	1	0.19	1	0.230	5.83
600	7pH	SeaWater	TypeA	1	3	2	0.15	1	0.236	5.99
600	7pH	SeaWater	TypeA	1	3	3	0.20	1	0.235	5.96
600	7pH	SeaWater	TypeA	1	5	1	7.13	49	0.117	2.96
600	7pH	SeaWater	TypeA	1	5	2	7.09	49	0.122	3.09
600	7pH	SeaWater	TypeA	1	5	3	7.07	49	0.119	3.02
600	7pH	SeaWater	TypeA	2	3	1	8.45	58	0.092	2.33
600	7pH	SeaWater	TypeA	2	3	2	7.68	53	0.076	1.93
600	7pH	SeaWater	TypeA	2	3	3	9.10	63	0.102	2.59
600	7pH	SeaWater	TypeA	2	5	1	7.03	48	0.125	3.17

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Table A.4: Continued										
Specimen							Horizontal Shear Strength		Displacement at Shear Strength	
Age Day	pH	Cl^- ppm	Type	Lot No.	Size #	Spec No.	ksi	MPa	in.	mm
600	7pH	SeaWater	TypeA	2	5	2	6.34	44	0.135	3.43
600	7pH	SeaWater	TypeA	2	5	3	7.47	51	0.176	4.48
600	7pH	SeaWater	TypeB	1	3	1	5.84	40	0.064	1.62
600	7pH	SeaWater	TypeB	1	3	2	6.45	44	0.067	1.70
600	7pH	SeaWater	TypeB	1	3	3	5.93	41	0.064	1.64
600	7pH	SeaWater	TypeB	1	5	1	6.66	46	0.106	2.70
600	7pH	SeaWater	TypeB	1	5	2	5.93	41	0.096	2.44
600	7pH	SeaWater	TypeB	1	5	3	6.36	44	0.104	2.65
600	7pH	SeaWater	TypeB	2	3	1	5.67	39	0.073	1.85
600	7pH	SeaWater	TypeB	2	3	2	4.85	33	0.067	1.70
600	7pH	SeaWater	TypeB	2	3	3	6.12	42	0.068	1.72
600	7pH	SeaWater	TypeB	2	5	1	6.22	43	0.102	2.60
600	7pH	SeaWater	TypeB	2	5	2	5.91	41	0.104	2.64
600	7pH	SeaWater	TypeB	2	5	3	6.76	47	0.106	2.70
600	7pH	SeaWater	TypeC	1	3	1	8.25	57	0.083	2.12
600	7pH	SeaWater	TypeC	1	3	2	7.56	52	0.078	1.98
600	7pH	SeaWater	TypeC	1	3	3	7.63	53	0.076	1.92
600	7pH	SeaWater	TypeC	1	5	1	7.72	53	0.139	3.53
600	7pH	SeaWater	TypeC	1	5	2	7.22	50	0.127	3.23
600	7pH	SeaWater	TypeC	1	5	3	7.39	51	0.131	3.33
600	7pH	SeaWater	TypeC	2	3	1	7.87	54	0.085	2.17
600	7pH	SeaWater	TypeC	2	3	2	7.40	51	0.078	1.98
600	7pH	SeaWater	TypeC	2	3	3	7.94	55	0.078	1.98
600	7pH	SeaWater	TypeC	2	5	1	8.12	56	0.142	3.61
600	7pH	SeaWater	TypeC	2	5	2	7.17	49	0.132	3.35
600	7pH	SeaWater	TypeC	2	5	3	7.94	55	0.135	3.42

A.5 Tensile Test

The longitudinal tensile properties for all tested specimens are listed in Table A.5. Specifically, the table presents the maximum tensile stresses and the corresponding elastic moduli, both based on the nominal cross-sectional dimensions.

Table A.5: Tensile strength test results (ultimate values) for each individual specimen

Specimen							Tensile Strength		Elastic Modulus	
Age Day	pH	Cl^- ppm	Type	Lot No.	Size #	Spec No.	ksi	MPa	ksi	GPa
0	-	-	TypeA	1	3	1	167	1154	6358	43.84
0	-	-	TypeA	1	3	2	171	1179	7039	48.53
0	-	-	TypeA	1	3	3	161	1112	8565	59.05
0	-	-	TypeA	1	3	4	149	1030	8339	57.50
0	-	-	TypeA	1	3	5	163	1122	8638	59.55
0	-	-	TypeA	1	5	1	134	925	7318	50.46
0	-	-	TypeA	1	5	2	151	1039	6824	47.05

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Table A.5: Continued										
Specimen							Tensile		Elastic	
Age	pH	Cl^{-}	Type	Lot	Size	Spec	Strength		Modulus	
Day				No.	#	No.	ksi	MPa	ksi	GPa
0	-	-	TypeA	1	5	3	154	1059	7575	52.23
0	-	-	TypeA	1	5	4	144	993	7329	50.53
0	-	-	TypeA	1	5	5	163	1123	7158	49.36
0	-	-	TypeA	2	3	1	181	1251	8100	55.84
0	-	-	TypeA	2	3	2	181	1249	8012	55.24
0	-	-	TypeA	2	3	3	189	1302	8473	58.42
0	-	-	TypeA	2	3	4	187	1291	8744	60.29
0	-	-	TypeA	2	3	5	179	1232	11 461	79.02
0	-	-	TypeA	2	5	1	149	1030	6902	47.59
0	-	-	TypeA	2	5	2	138	955	6980	48.12
0	-	-	TypeA	2	5	3	138	951	6626	45.69
0	-	-	TypeA	2	5	4	166	1148	8036	55.41
0	-	-	TypeA	2	5	5	152	1049	5352	36.90
0	-	-	TypeB	1	3	1	178	1224	7583	52.29
0	-	-	TypeB	1	3	2	175	1203	7050	48.61
0	-	-	TypeB	1	3	3	185	1275	7601	52.41
0	-	-	TypeB	1	3	4	178	1228	7079	48.81
0	-	-	TypeB	1	3	5	177	1218	7888	54.39
0	-	-	TypeB	1	5	1	194	1338	7871	54.27
0	-	-	TypeB	1	5	2	181	1246	8540	58.88
0	-	-	TypeB	1	5	3	184	1271	7562	52.14
0	-	-	TypeB	1	5	4	183	1259	9134	62.98
0	-	-	TypeB	1	5	5	186	1284	8487	58.52
0	-	-	TypeB	2	3	1	198	1362	8542	58.89
0	-	-	TypeB	2	3	2	187	1288	8796	60.64
0	-	-	TypeB	2	3	3	186	1284	8643	59.59
0	-	-	TypeB	2	3	4	198	1367	7938	54.73
0	-	-	TypeB	2	3	5	200	1380	8203	56.56
0	-	-	TypeB	2	5	1	178	1225	7941	54.75
0	-	-	TypeB	2	5	2	190	1311	7769	53.57
0	-	-	TypeB	2	5	3	180	1243	8619	59.43
0	-	-	TypeB	2	5	4	185	1278	7504	51.74
0	-	-	TypeB	2	5	5	186	1282	7938	54.73
0	-	-	TypeC	1	3	1	167	1153	8760	60.40
0	-	-	TypeC	1	3	2	167	1148	8315	57.33
0	-	-	TypeC	1	3	3	183	1259	8273	57.04
0	-	-	TypeC	1	3	4	167	1152	8623	59.46
0	-	-	TypeC	1	3	5	181	1248	8146	56.16
0	-	-	TypeC	1	5	1	142	978	8087	55.76
0	-	-	TypeC	1	5	2	139	956	7377	50.86
0	-	-	TypeC	1	5	3	143	987	7549	52.05
0	-	-	TypeC	1	5	4	140	964	8010	55.23
0	-	-	TypeC	1	5	5	131	904	7981	55.03
0	-	-	TypeC	2	3	1	183	1262	8576	59.13
0	-	-	TypeC	2	3	2	185	1278	7726	53.27
0	-	-	TypeC	2	3	3	190	1310	8145	56.16
0	-	-	TypeC	2	3	4	183	1262	8866	61.13
0	-	-	TypeC	2	3	5	172	1183	8447	58.24
0	-	-	TypeC	2	5	1	140	965	8012	55.24
0	-	-	TypeC	2	5	2	148	1018	7253	50.01
0	-	-	TypeC	2	5	3	145	997	7949	54.81
0	-	-	TypeC	2	5	4	142	976	7782	53.66
0	-	-	TypeC	2	5	5	134	923	7816	53.89

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Table A.5: Continued										
Specimen							Tensile		Elastic	
Age	pH	Cl^{-}	Type	Lot	Size	Spec	Strength		Modulus	
Day				No.	#	No.	ksi	MPa	ksi	GPa
300	13pH	0Cl	TypeA	1	5	1	117	810	8242	56.83
300	13pH	0Cl	TypeA	1	5	2	64	440	7064	48.71
300	13pH	0Cl	TypeA	1	5	3	65	447	7163	49.39
300	13pH	0Cl	TypeA	2	5	1	74	509	7513	51.80
300	13pH	0Cl	TypeA	2	5	2	114	785	7424	51.19
300	13pH	0Cl	TypeA	2	5	3	86	591	7603	52.42
300	13pH	0Cl	TypeB	1	3	1	80	553	8206	56.58
300	13pH	0Cl	TypeB	1	3	2	83	575	8355	57.61
300	13pH	0Cl	TypeB	1	3	3	3	21	NA	NA
300	13pH	0Cl	TypeB	1	5	1	81	556	8815	60.78
300	13pH	0Cl	TypeB	1	5	2	89	615	9267	63.89
300	13pH	0Cl	TypeB	1	5	3	88	609	8443	58.21
300	13pH	0Cl	TypeB	2	3	1	45	310	9218	63.56
300	13pH	0Cl	TypeB	2	3	2	30	208	NA	NA
300	13pH	0Cl	TypeB	2	3	3	26	181	−9659	−66.60
300	13pH	0Cl	TypeB	2	5	1	119	819	8356	57.61
300	13pH	0Cl	TypeB	2	5	2	89	615	8808	60.73
300	13pH	0Cl	TypeB	2	5	3	82	568	8492	58.55
300	13pH	0Cl	TypeC	1	5	1	112	772	7703	53.11
300	13pH	0Cl	TypeC	1	5	2	109	751	7602	52.42
300	13pH	0Cl	TypeC	1	5	3	101	693	7492	51.65
300	13pH	0Cl	TypeC	2	5	1	108	745	7539	51.98
300	13pH	0Cl	TypeC	2	5	2	116	801	7581	52.27
300	13pH	0Cl	TypeC	2	5	3	102	702	7516	51.82
300	4pH	0Cl	TypeA	1	3	1	138	948	8651	59.65
300	4pH	0Cl	TypeA	1	3	2	152	1047	7335	50.57
300	4pH	0Cl	TypeA	1	3	3	142	981	8431	58.13
300	4pH	0Cl	TypeA	1	5	1	121	835	7579	52.26
300	4pH	0Cl	TypeA	1	5	2	124	852	7390	50.95
300	4pH	0Cl	TypeA	1	5	3	123	847	7325	50.50
300	4pH	0Cl	TypeA	2	3	1	151	1042	7043	48.56
300	4pH	0Cl	TypeA	2	3	2	155	1070	6722	46.35
300	4pH	0Cl	TypeA	2	3	3	144	992	8079	55.70
300	4pH	0Cl	TypeA	2	5	1	133	916	7493	51.66
300	4pH	0Cl	TypeA	2	5	2	104	718	7290	50.26
300	4pH	0Cl	TypeA	2	5	3	127	877	7254	50.01
300	4pH	0Cl	TypeB	1	3	2	122	841	8080	55.71
300	4pH	0Cl	TypeB	1	3	3	107	737	8247	56.86
300	4pH	0Cl	TypeB	1	5	1	140	968	8148	56.18
300	4pH	0Cl	TypeB	1	5	2	146	1004	8363	57.66
300	4pH	0Cl	TypeB	1	5	3	145	998	8710	60.05
300	4pH	0Cl	TypeB	2	3	1	135	931	8490	58.53
300	4pH	0Cl	TypeB	2	3	2	138	955	9079	62.59
300	4pH	0Cl	TypeB	2	3	3	143	984	8394	57.88
300	4pH	0Cl	TypeB	2	5	1	150	1032	8219	56.67
300	4pH	0Cl	TypeB	2	5	2	145	997	8418	58.04
300	4pH	0Cl	TypeB	2	5	3	139	959	8549	58.94
300	4pH	0Cl	TypeC	1	3	1	139	958	8083	55.73
300	4pH	0Cl	TypeC	1	3	2	149	1028	9928	68.45
300	4pH	0Cl	TypeC	1	3	3	105	721	8669	59.77
300	4pH	0Cl	TypeC	1	5	1	107	740	7841	54.06
300	4pH	0Cl	TypeC	1	5	2	113	782	6980	48.12
300	4pH	0Cl	TypeC	1	5	3	105	725	7741	53.38

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Table A.5: Continued										
Specimen							Tensile		Elastic	
Age	pH	Cl^{-}	Type	Lot	Size	Spec	Strength		Modulus	
Day				No.	#	No.	ksi	MPa	ksi	GPa
300	4pH	0Cl	TypeC	2	3	1	120	829	8966	61.82
300	4pH	0Cl	TypeC	2	3	2	134	924	7522	51.87
300	4pH	0Cl	TypeC	2	3	3	141	969	8571	59.09
300	4pH	0Cl	TypeC	2	5	1	112	771	7816	53.89
300	4pH	0Cl	TypeC	2	5	2	120	827	7741	53.37
300	4pH	0Cl	TypeC	2	5	3	109	749	7680	52.95
300	7pH	0Cl	TypeA	1	3	1	164	1132	7720	53.22
300	7pH	0Cl	TypeA	1	3	2	158	1092	7581	52.27
300	7pH	0Cl	TypeA	1	3	3	156	1079	8126	56.02
300	7pH	0Cl	TypeA	1	5	1	120	830	7047	48.59
300	7pH	0Cl	TypeA	1	5	2	124	855	7023	48.42
300	7pH	0Cl	TypeA	1	5	3	141	975	7875	54.30
300	7pH	0Cl	TypeA	2	3	1	146	1006	8452	58.27
300	7pH	0Cl	TypeA	2	3	2	143	987	8527	58.79
300	7pH	0Cl	TypeA	2	3	3	155	1068	9082	62.62
300	7pH	0Cl	TypeA	2	5	1	133	917	7500	51.71
300	7pH	0Cl	TypeA	2	5	2	142	980	8250	56.88
300	7pH	0Cl	TypeB	1	3	1	116	800	7314	50.43
300	7pH	0Cl	TypeB	1	3	2	120	824	7488	51.63
300	7pH	0Cl	TypeB	1	3	3	112	773	7139	49.22
300	7pH	0Cl	TypeB	1	5	1	136	936	8897	61.34
300	7pH	0Cl	TypeB	1	5	2	137	944	8527	58.79
300	7pH	0Cl	TypeB	1	5	3	140	966	8699	59.98
300	7pH	0Cl	TypeB	2	3	1	138	953	8349	57.56
300	7pH	0Cl	TypeB	2	3	2	141	975	8181	56.41
300	7pH	0Cl	TypeB	2	3	3	141	974	8190	56.47
300	7pH	0Cl	TypeB	2	5	1	149	1031	8451	58.27
300	7pH	0Cl	TypeB	2	5	2	145	997	8375	57.74
300	7pH	0Cl	TypeB	2	5	3	143	988	8262	56.97
300	7pH	0Cl	TypeC	1	3	1	144	991	8192	56.48
300	7pH	0Cl	TypeC	1	3	2	143	989	8323	57.38
300	7pH	0Cl	TypeC	1	3	3	123	849	7224	49.81
300	7pH	0Cl	TypeC	1	5	1	104	716	7258	50.04
300	7pH	0Cl	TypeC	1	5	2	117	805	7467	51.49
300	7pH	0Cl	TypeC	1	5	3	112	772	7608	52.46
300	7pH	0Cl	TypeC	2	3	1	139	959	8555	58.98
300	7pH	0Cl	TypeC	2	3	2	122	839	8442	58.21
300	7pH	0Cl	TypeC	2	3	3	122	843	8961	61.79
300	7pH	0Cl	TypeC	2	5	1	119	822	7398	51.01
300	7pH	0Cl	TypeC	2	5	2	136	939	7613	52.49
300	7pH	0Cl	TypeC	2	5	3	125	859	8086	55.75
300	13pH	20000Cl	TypeB	1	3	1	28	192	8920	61.50
300	13pH	20000Cl	TypeB	1	3	2	22	150	NA	NA
300	13pH	20000Cl	TypeB	1	3	3	87	602	8390	57.85
300	13pH	20000Cl	TypeB	1	5	1	91	627	8112	55.93
300	13pH	20000Cl	TypeB	1	5	2	92	634	8961	61.78
300	13pH	20000Cl	TypeB	1	5	3	95	655	8292	57.17
300	13pH	20000Cl	TypeB	2	3	1	44	305	8149	56.19
300	13pH	20000Cl	TypeB	2	3	2	55	381	8583	59.18
300	13pH	20000Cl	TypeB	2	3	3	48	328	728	5.02
300	13pH	20000Cl	TypeB	2	5	1	123	846	8441	58.20
300	13pH	20000Cl	TypeB	2	5	2	96	661	8388	57.83
300	13pH	20000Cl	TypeB	2	5	3	98	678	8537	58.86

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Table A.5: Continued										
Specimen							Tensile Strength		Elastic Modulus	
Age Day	pH	Cl^{-}	Type	Lot No.	Size #	Spec No.	ksi	MPa	ksi	GPa
300	4pH	20000Cl	TypeA	1	3	1	149	1027	7529	51.91
300	4pH	20000Cl	TypeA	1	3	2	151	1039	7822	53.93
300	4pH	20000Cl	TypeA	1	3	3	147	1015	7701	53.09
300	4pH	20000Cl	TypeA	1	5	1	131	905	7256	50.03
300	4pH	20000Cl	TypeA	1	5	2	155	1068	7490	51.64
300	4pH	20000Cl	TypeA	1	5	3	131	905	7466	51.48
300	4pH	20000Cl	TypeA	2	3	1	151	1044	8365	57.68
300	4pH	20000Cl	TypeA	2	3	2	164	1129	8746	60.30
300	4pH	20000Cl	TypeA	2	3	3	162	1114	9048	62.39
300	4pH	20000Cl	TypeA	2	5	1	134	922	7395	50.99
300	4pH	20000Cl	TypeA	2	5	2	120	825	7768	53.56
300	4pH	20000Cl	TypeA	2	5	3	149	1026	7458	51.42
300	4pH	20000Cl	TypeB	1	3	1	149	1027	8918	61.49
300	4pH	20000Cl	TypeB	1	3	2	152	1045	8280	57.09
300	4pH	20000Cl	TypeB	1	3	3	152	1048	8466	58.37
300	4pH	20000Cl	TypeB	1	5	1	152	1050	8395	57.88
300	4pH	20000Cl	TypeB	1	5	2	155	1071	8337	57.49
300	4pH	20000Cl	TypeB	1	5	3	139	957	8221	56.68
300	4pH	20000Cl	TypeB	2	3	1	119	822	7115	49.06
300	4pH	20000Cl	TypeB	2	3	2	125	859	7158	49.35
300	4pH	20000Cl	TypeB	2	3	3	122	841	7303	50.35
300	4pH	20000Cl	TypeB	2	5	1	146	1009	8435	58.16
300	4pH	20000Cl	TypeB	2	5	2	145	998	8626	59.48
300	4pH	20000Cl	TypeB	2	5	3	141	974	NA	NA
300	4pH	20000Cl	TypeC	1	3	1	127	877	8583	59.18
300	4pH	20000Cl	TypeC	1	3	2	139	955	8887	61.28
300	4pH	20000Cl	TypeC	1	3	3	148	1020	8274	57.05
300	4pH	20000Cl	TypeC	1	5	1	128	883	7847	54.10
300	4pH	20000Cl	TypeC	1	5	2	120	826	7375	50.85
300	4pH	20000Cl	TypeC	1	5	3	130	896	7528	51.91
300	4pH	20000Cl	TypeC	2	3	1	127	874	8042	55.45
300	4pH	20000Cl	TypeC	2	3	2	137	946	8490	58.54
300	4pH	20000Cl	TypeC	2	3	3	117	808	9853	67.93
300	4pH	20000Cl	TypeC	2	5	1	109	753	7548	52.04
300	4pH	20000Cl	TypeC	2	5	2	105	722	7491	51.65
300	4pH	20000Cl	TypeC	2	5	3	116	797	7116	49.06
300	7pH	20000Cl	TypeA	1	3	1	145	1003	7575	52.23
300	7pH	20000Cl	TypeA	1	3	2	151	1038	7844	54.08
300	7pH	20000Cl	TypeA	1	3	3	153	1052	7692	53.03
300	7pH	20000Cl	TypeA	1	5	1	78	540	8096	55.82
300	7pH	20000Cl	TypeA	1	5	2	120	827	7334	50.57
300	7pH	20000Cl	TypeA	2	3	1	89	616	8439	58.19
300	7pH	20000Cl	TypeA	2	3	2	92	638	8626	59.47
300	7pH	20000Cl	TypeA	2	3	3	88	609	8255	56.92
300	7pH	20000Cl	TypeA	2	5	1	148	1021	7615	52.50
300	7pH	20000Cl	TypeA	2	5	2	125	864	7920	54.60
300	7pH	20000Cl	TypeA	2	5	3	130	893	7447	51.34
300	7pH	20000Cl	TypeB	1	3	1	118	812	7465	51.47
300	7pH	20000Cl	TypeB	1	3	2	125	864	7538	51.97
300	7pH	20000Cl	TypeB	1	3	3	112	775	7586	52.30
300	7pH	20000Cl	TypeB	1	5	1	147	1017	8253	56.90
300	7pH	20000Cl	TypeB	1	5	2	149	1024	8388	57.83
300	7pH	20000Cl	TypeB	1	5	3	136	939	8974	61.87

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Table A.5: Continued										
Specimen							Tensile Strength		Elastic Modulus	
Age Day	pH	Cl^{-}	Type	Lot No.	Size #	Spec No.	ksi	MPa	ksi	GPa
300	7pH	20000Cl	TypeB	2	3	1	151	1040	7809	53.84
300	7pH	20000Cl	TypeB	2	3	2	149	1024	7620	52.54
300	7pH	20000Cl	TypeB	2	3	3	158	1087	8183	56.42
300	7pH	20000Cl	TypeB	2	5	1	150	1032	8502	58.62
300	7pH	20000Cl	TypeB	2	5	2	147	1011	1198	8.26
300	7pH	20000Cl	TypeB	2	5	3	149	1031	8275	57.05
300	7pH	20000Cl	TypeC	1	3	1	126	869	7894	54.42
300	7pH	20000Cl	TypeC	1	3	2	156	1073	8526	58.78
300	7pH	20000Cl	TypeC	1	3	3	119	818	8852	61.03
300	7pH	20000Cl	TypeC	1	5	1	116	798	7274	50.15
300	7pH	20000Cl	TypeC	1	5	2	105	725	7483	51.59
300	7pH	20000Cl	TypeC	1	5	3	93	644	7752	53.45
300	7pH	20000Cl	TypeC	2	3	1	139	959	8672	59.79
300	7pH	20000Cl	TypeC	2	3	2	122	841	8928	61.56
300	7pH	20000Cl	TypeC	2	3	3	127	875	8574	59.12
300	7pH	20000Cl	TypeC	2	5	1	123	846	7726	53.27
300	7pH	20000Cl	TypeC	2	5	2	106	731	7399	51.01
300	7pH	20000Cl	TypeC	2	5	3	130	894	7347	50.65
300	13pH	SeaWater	TypeB	1	3	1	5	34	NA	NA
300	13pH	SeaWater	TypeB	1	3	2	5	32	NA	NA
300	13pH	SeaWater	TypeB	1	3	3	4	27	NA	NA
300	13pH	SeaWater	TypeB	1	5	1	35	241	3084	21.26
300	13pH	SeaWater	TypeB	1	5	2	65	448	11 629	80.18
300	13pH	SeaWater	TypeB	1	5	3	65	448	2356	16.24
300	13pH	SeaWater	TypeB	2	3	1	12	85	0	0.00
300	13pH	SeaWater	TypeB	2	3	2	12	80	NA	NA
300	13pH	SeaWater	TypeB	2	3	3	7	47	0	0.00
300	13pH	SeaWater	TypeB	2	5	1	30	207	6685	46.09
300	13pH	SeaWater	TypeB	2	5	2	36	251	4487	30.94
300	13pH	SeaWater	TypeB	2	5	3	33	225	5922	40.83
300	4pH	SeaWater	TypeA	1	3	1	149	1028	7570	52.19
300	4pH	SeaWater	TypeA	1	3	2	149	1027	8139	56.11
300	4pH	SeaWater	TypeA	1	3	3	150	1032	7636	52.65
300	4pH	SeaWater	TypeA	1	5	1	126	869	7158	49.35
300	4pH	SeaWater	TypeA	1	5	2	142	976	7712	53.17
300	4pH	SeaWater	TypeA	1	5	3	130	895	8230	56.75
300	4pH	SeaWater	TypeA	2	3	1	105	722	6960	47.99
300	4pH	SeaWater	TypeA	2	3	2	101	695	8509	58.67
300	4pH	SeaWater	TypeA	2	3	3	122	840	8476	58.44
300	4pH	SeaWater	TypeA	2	5	1	138	952	7293	50.29
300	4pH	SeaWater	TypeA	2	5	2	146	1004	8037	55.41
300	4pH	SeaWater	TypeA	2	5	3	142	976	7482	51.59
300	4pH	SeaWater	TypeB	1	3	1	138	950	7225	49.81
300	4pH	SeaWater	TypeB	1	3	2	129	890	7300	50.33
300	4pH	SeaWater	TypeB	1	3	3	113	780	7170	49.43
300	4pH	SeaWater	TypeB	1	5	1	143	987	8254	56.91
300	4pH	SeaWater	TypeB	1	5	2	144	994	8269	57.01
300	4pH	SeaWater	TypeB	1	5	3	152	1048	7970	54.95
300	4pH	SeaWater	TypeB	2	3	1	153	1056	7715	53.19
300	4pH	SeaWater	TypeB	2	3	2	147	1015	8724	60.15
300	4pH	SeaWater	TypeB	2	3	3	144	990	8157	56.24
300	4pH	SeaWater	TypeB	2	5	1	144	991	8721	60.13
300	4pH	SeaWater	TypeB	2	5	2	146	1009	8191	56.48

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Table A.5: Continued										
Specimen							Tensile Strength		Elastic Modulus	
Age Day	pH	Cl^{-}	Type	Lot No.	Size #	Spec No.	ksi	MPa	ksi	GPa
300	4pH	SeaWater	TypeB	2	5	3	152	1051	8213	56.63
300	4pH	SeaWater	TypeC	1	3	1	144	996	7938	54.73
300	4pH	SeaWater	TypeC	1	3	2	144	993	8120	55.98
300	4pH	SeaWater	TypeC	1	3	3	148	1023	8361	57.65
300	4pH	SeaWater	TypeC	1	5	1	100	690	7677	52.93
300	4pH	SeaWater	TypeC	1	5	2	104	717	7549	52.05
300	4pH	SeaWater	TypeC	1	5	3	104	717	7921	54.61
300	4pH	SeaWater	TypeC	2	3	1	139	957	8532	58.83
300	4pH	SeaWater	TypeC	2	3	2	141	973	8308	57.28
300	4pH	SeaWater	TypeC	2	3	3	130	899	9059	62.46
300	4pH	SeaWater	TypeC	2	5	1	123	845	7480	51.57
300	4pH	SeaWater	TypeC	2	5	2	117	804	7767	53.55
300	4pH	SeaWater	TypeC	2	5	3	104	717	7921	54.61
300	7pH	SeaWater	TypeA	1	3	1	130	893	8388	57.83
300	7pH	SeaWater	TypeA	1	3	2	128	881	6981	48.13
300	7pH	SeaWater	TypeA	1	3	3	118	815	8076	55.68
300	7pH	SeaWater	TypeA	1	5	1	132	912	7292	50.28
300	7pH	SeaWater	TypeA	1	5	2	139	956	7781	53.65
300	7pH	SeaWater	TypeA	1	5	3	149	1025	7306	50.38
300	7pH	SeaWater	TypeA	2	3	1	144	996	8951	61.72
300	7pH	SeaWater	TypeA	2	3	2	159	1097	8893	61.31
300	7pH	SeaWater	TypeA	2	3	3	151	1041	8633	59.53
300	7pH	SeaWater	TypeA	2	5	1	157	1083	7282	50.21
300	7pH	SeaWater	TypeA	2	5	2	145	1002	7275	50.16
300	7pH	SeaWater	TypeA	2	5	3	130	894	7198	49.63
300	7pH	SeaWater	TypeB	1	3	1	144	996	8951	61.72
300	7pH	SeaWater	TypeB	1	3	2	159	1097	8893	61.31
300	7pH	SeaWater	TypeB	1	3	3	151	1041	8633	59.53
300	7pH	SeaWater	TypeB	1	5	1	154	1065	8354	57.60
300	7pH	SeaWater	TypeB	1	5	2	150	1032	8469	58.39
300	7pH	SeaWater	TypeB	1	5	3	147	1016	8796	60.65
300	7pH	SeaWater	TypeB	2	3	1	131	906	7906	54.51
300	7pH	SeaWater	TypeB	2	3	2	129	888	7393	50.97
300	7pH	SeaWater	TypeB	2	3	3	159	1097	8893	61.31
300	7pH	SeaWater	TypeB	2	5	1	133	915	8435	58.16
300	7pH	SeaWater	TypeB	2	5	2	145	1003	8496	58.58
300	7pH	SeaWater	TypeB	2	5	3	146	1007	8465	58.36
300	7pH	SeaWater	TypeC	1	3	1	123	851	8955	61.74
300	7pH	SeaWater	TypeC	1	3	2	159	1098	8354	57.60
300	7pH	SeaWater	TypeC	1	3	3	139	959	8672	59.79
300	7pH	SeaWater	TypeC	1	5	1	131	902	8483	58.49
300	7pH	SeaWater	TypeC	1	5	2	107	737	7795	53.75
300	7pH	SeaWater	TypeC	1	5	3	128	881	7421	51.16
300	7pH	SeaWater	TypeC	2	3	1	127	875	8574	59.12
300	7pH	SeaWater	TypeC	2	3	2	128	881	9355	64.50
300	7pH	SeaWater	TypeC	2	3	3	128	881	10 700	73.78
300	7pH	SeaWater	TypeC	2	5	1	107	738	7714	53.19
300	7pH	SeaWater	TypeC	2	5	2	102	705	7610	52.47
300	7pH	SeaWater	TypeC	2	5	3	119	821	7616	52.51
600	4pH	0Cl	TypeA	1	3	1	116	797	7803	53.80
600	4pH	0Cl	TypeA	1	3	2	122	840	7920	54.61
600	4pH	0Cl	TypeA	1	3	3	115	796	8257	56.93
600	4pH	0Cl	TypeA	1	5	1	124	857	7910	54.54

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Table A.5: Continued										
Specimen							Tensile		Elastic	
Age	pH	Cl^{-}	Type	Lot	Size	Spec	Strength		Modulus	
Day				No.	#	No.	ksi	MPa	ksi	GPa
600	4pH	0Cl	TypeA	1	5	2	123	850	7257	50.04
600	4pH	0Cl	TypeA	1	5	3	103	713	6762	46.62
600	4pH	0Cl	TypeA	2	3	1	121	831	7905	54.50
600	4pH	0Cl	TypeA	2	3	2	67	463	7475	51.54
600	4pH	0Cl	TypeA	2	3	3	125	860	7551	52.06
600	4pH	0Cl	TypeA	2	5	1	119	823	7250	49.99
600	4pH	0Cl	TypeA	2	5	2	100	691	7171	49.44
600	4pH	0Cl	TypeA	2	5	3	110	758	7797	53.76
600	4pH	0Cl	TypeB	1	3	1	118	814	8067	55.62
600	4pH	0Cl	TypeB	1	3	2	104	719	7992	55.10
600	4pH	0Cl	TypeB	1	3	3	125	864	7814	53.87
600	4pH	0Cl	TypeB	1	5	1	121	835	7903	54.49
600	4pH	0Cl	TypeB	1	5	2	135	929	8172	56.34
600	4pH	0Cl	TypeB	1	5	3	128	884	7986	55.06
600	4pH	0Cl	TypeB	2	3	1	93	640	7020	48.40
600	4pH	0Cl	TypeB	2	3	2	91	627	7069	48.74
600	4pH	0Cl	TypeB	2	3	3	112	772	7242	49.93
600	4pH	0Cl	TypeB	2	5	1	126	867	8316	57.34
600	4pH	0Cl	TypeB	2	5	2	98	675	7575	52.22
600	4pH	0Cl	TypeB	2	5	3	123	847	8188	56.45
600	4pH	0Cl	TypeC	1	3	1	108	743	8322	57.38
600	4pH	0Cl	TypeC	1	3	2	98	673	8150	56.19
600	4pH	0Cl	TypeC	1	3	3	119	822	7571	52.20
600	4pH	0Cl	TypeC	1	5	1	80	554	6933	47.80
600	4pH	0Cl	TypeC	1	5	2	105	723	7742	53.38
600	4pH	0Cl	TypeC	1	5	3	84	579	7315	50.43
600	4pH	0Cl	TypeC	2	3	1	114	787	8064	55.60
600	4pH	0Cl	TypeC	2	3	2	109	751	8411	57.99
600	4pH	0Cl	TypeC	2	3	3	110	761	8203	56.55
600	4pH	0Cl	TypeC	2	5	1	104	719	6726	46.38
600	4pH	0Cl	TypeC	2	5	2	105	727	7176	49.48
600	4pH	0Cl	TypeC	2	5	3	90	620	7049	48.60
600	7pH	0Cl	TypeA	1	5	1	111	766	7245	49.95
600	7pH	0Cl	TypeA	1	5	2	116	800	7103	48.97
600	7pH	0Cl	TypeA	1	5	3	126	865	8170	56.33
600	7pH	0Cl	TypeA	2	5	1	121	835	7667	52.86
600	7pH	0Cl	TypeA	2	5	2	131	906	8078	55.70
600	7pH	0Cl	TypeA	2	5	3	120	831	8385	57.81
600	7pH	0Cl	TypeB	1	3	1	101	694	7247	49.97
600	7pH	0Cl	TypeB	1	3	2	111	767	6930	47.78
600	7pH	0Cl	TypeB	1	3	3	102	707	7039	48.53
600	7pH	0Cl	TypeB	1	5	1	114	787	7871	54.27
600	7pH	0Cl	TypeB	1	5	2	124	853	8182	56.41
600	7pH	0Cl	TypeB	1	5	3	121	832	7866	54.23
600	7pH	0Cl	TypeB	2	3	1	118	814	8145	56.16
600	7pH	0Cl	TypeB	2	3	2	126	871	8235	56.78
600	7pH	0Cl	TypeB	2	3	3	118	816	7977	55.00
600	7pH	0Cl	TypeB	2	5	1	126	872	8469	58.39
600	7pH	0Cl	TypeB	2	5	2	127	873	8260	56.95
600	7pH	0Cl	TypeB	2	5	3	126	866	8326	57.41
600	7pH	0Cl	TypeC	1	3	1	132	908	7150	49.30
600	7pH	0Cl	TypeC	1	3	2	109	754	7862	54.21
600	7pH	0Cl	TypeC	1	3	3	109	753	7866	54.24

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Table A.5: Continued										
Specimen							Tensile Strength		Elastic Modulus	
Age Day	pH	Cl^{-}	Type	Lot No.	Size #	Spec No.	ksi	MPa	ksi	GPa
600	7pH	0Cl	TypeC	2	3	1	102	704	8442	58.20
600	7pH	0Cl	TypeC	2	3	2	119	821	8061	55.58
600	7pH	0Cl	TypeC	2	3	3	109	749	8076	55.68
600	7pH	0Cl	TypeC	2	5	1	93	640	7652	52.76
600	7pH	0Cl	TypeC	2	5	2	90	621	7198	49.63
600	7pH	0Cl	TypeC	2	5	3	93	644	7448	51.35
600	4pH	20000Cl	TypeA	1	3	1	132	907	8333	57.46
600	4pH	20000Cl	TypeA	1	3	2	145	999	8094	55.80
600	4pH	20000Cl	TypeA	1	3	3	131	900	7548	52.04
600	4pH	20000Cl	TypeA	1	5	1	117	807	6973	48.07
600	4pH	20000Cl	TypeA	1	5	2	122	839	8002	55.17
600	4pH	20000Cl	TypeA	1	5	3	128	881	7951	54.82
600	4pH	20000Cl	TypeA	2	3	1	142	981	7282	50.21
600	4pH	20000Cl	TypeA	2	5	1	131	902	7108	49.01
600	4pH	20000Cl	TypeA	2	5	2	122	839	7080	48.81
600	4pH	20000Cl	TypeA	2	5	3	121	836	7282	50.21
600	4pH	20000Cl	TypeB	1	3	1	115	794	7358	50.73
600	4pH	20000Cl	TypeB	1	3	2	100	690	6567	45.28
600	4pH	20000Cl	TypeB	1	3	3	122	841	7323	50.49
600	4pH	20000Cl	TypeB	1	5	1	111	765	8150	56.20
600	4pH	20000Cl	TypeB	1	5	2	119	818	7793	53.73
600	4pH	20000Cl	TypeB	1	5	3	124	856	7931	54.68
600	4pH	20000Cl	TypeB	2	3	1	122	841	7896	54.44
600	4pH	20000Cl	TypeB	2	3	2	136	939	8019	55.29
600	4pH	20000Cl	TypeB	2	3	3	120	826	8526	58.78
600	4pH	20000Cl	TypeB	2	5	1	128	885	8461	58.34
600	4pH	20000Cl	TypeB	2	5	2	136	937	8433	58.14
600	4pH	20000Cl	TypeC	1	3	1	106	730	8178	56.38
600	4pH	20000Cl	TypeC	1	3	2	121	831	7630	52.61
600	4pH	20000Cl	TypeC	1	3	3	124	854	8614	59.39
600	4pH	20000Cl	TypeC	1	5	1	101	697	7057	48.66
600	4pH	20000Cl	TypeC	1	5	2	90	620	7336	50.58
600	4pH	20000Cl	TypeC	1	5	3	92	633	7415	51.13
600	4pH	20000Cl	TypeC	2	3	1	108	747	8489	58.53
600	4pH	20000Cl	TypeC	2	3	2	121	833	7763	53.52
600	4pH	20000Cl	TypeC	2	3	3	115	795	7816	53.89
600	4pH	20000Cl	TypeC	2	5	1	106	728	7423	51.18
600	4pH	20000Cl	TypeC	2	5	2	104	715	7178	49.49
600	4pH	20000Cl	TypeC	2	5	3	91	628	7525	51.88
600	7pH	20000Cl	TypeA	1	3	1	134	926	7411	51.10
600	7pH	20000Cl	TypeA	1	3	2	125	862	8238	56.80
600	7pH	20000Cl	TypeA	1	3	3	123	847	8201	56.55
600	7pH	20000Cl	TypeA	1	5	1	73	507	6978	48.11
600	7pH	20000Cl	TypeA	1	5	2	85	588	7272	50.14
600	7pH	20000Cl	TypeA	1	5	3	113	778	6569	45.29
600	7pH	20000Cl	TypeA	2	5	1	126	868	7944	54.77
600	7pH	20000Cl	TypeA	2	5	2	132	910	8466	58.37
600	7pH	20000Cl	TypeA	2	5	3	126	868	6755	46.58
600	7pH	20000Cl	TypeB	1	3	1	99	683	7315	50.44
600	7pH	20000Cl	TypeB	1	3	2	118	810	7652	52.76
600	7pH	20000Cl	TypeB	1	3	3	107	738	7139	49.22
600	7pH	20000Cl	TypeB	1	5	1	121	832	8395	57.88
600	7pH	20000Cl	TypeB	1	5	2	117	810	8245	56.85

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Table A.5: Continued										
Specimen							Tensile		Elastic	
Age	pH	Cl^{-}	Type	Lot	Size	Spec	Strength		Modulus	
Day				No.	#	No.	ksi	MPa	ksi	GPa
600	7pH	20000Cl	TypeB	1	5	3	123	846	8288	57.14
600	7pH	20000Cl	TypeB	2	3	1	129	888	7974	54.98
600	7pH	20000Cl	TypeB	2	3	2	125	862	7398	51.01
600	7pH	20000Cl	TypeB	2	3	3	128	883	7714	53.19
600	7pH	20000Cl	TypeB	2	5	1	131	904	7932	54.69
600	7pH	20000Cl	TypeB	2	5	2	108	742	7960	54.88
600	7pH	20000Cl	TypeB	2	5	3	132	913	8054	55.53
600	7pH	20000Cl	TypeC	1	3	1	112	771	7668	52.87
600	7pH	20000Cl	TypeC	1	3	2	120	831	8222	56.69
600	7pH	20000Cl	TypeC	1	3	3	118	816	8025	55.33
600	7pH	20000Cl	TypeC	1	5	1	88	609	6994	48.22
600	7pH	20000Cl	TypeC	1	5	2	103	709	7488	51.63
600	7pH	20000Cl	TypeC	2	3	1	117	809	8552	58.96
600	7pH	20000Cl	TypeC	2	3	2	106	730	7564	52.15
600	7pH	20000Cl	TypeC	2	3	3	108	745	8018	55.28
600	7pH	20000Cl	TypeC	2	5	1	116	798	7489	51.63
600	7pH	20000Cl	TypeC	2	5	2	102	700	7030	48.47
600	7pH	20000Cl	TypeC	2	5	3	117	807	6973	48.07
600	4pH	SeaWater	TypeA	1	3	1	127	878	8681	59.85
600	4pH	SeaWater	TypeA	1	3	2	131	906	7962	54.89
600	4pH	SeaWater	TypeA	1	5	1	73	506	7088	48.87
600	4pH	SeaWater	TypeA	1	5	2	110	758	7469	51.49
600	4pH	SeaWater	TypeA	1	5	3	87	603	7097	48.93
600	4pH	SeaWater	TypeA	2	3	1	61	422	8382	57.79
600	4pH	SeaWater	TypeA	2	3	2	131	904	7594	52.36
600	4pH	SeaWater	TypeA	2	3	3	127	877	7826	53.96
600	4pH	SeaWater	TypeA	2	5	1	98	675	7473	51.53
600	4pH	SeaWater	TypeA	2	5	2	99	686	7095	48.92
600	4pH	SeaWater	TypeA	2	5	3	77	532	6760	46.61
600	4pH	SeaWater	TypeB	1	3	1	99	685	7372	50.83
600	4pH	SeaWater	TypeB	1	3	2	108	744	7303	50.35
600	4pH	SeaWater	TypeB	1	3	3	109	748	7096	48.93
600	4pH	SeaWater	TypeB	1	5	1	86	590	7976	54.99
600	4pH	SeaWater	TypeB	1	5	2	128	886	8199	56.53
600	4pH	SeaWater	TypeB	1	5	3	115	791	8001	55.17
600	4pH	SeaWater	TypeB	2	3	1	125	864	7355	50.71
600	4pH	SeaWater	TypeB	2	3	2	102	705	7605	52.43
600	4pH	SeaWater	TypeB	2	3	3	107	737	7222	49.79
600	4pH	SeaWater	TypeB	2	5	1	111	768	7973	54.97
600	4pH	SeaWater	TypeB	2	5	2	75	519	8572	59.11
600	4pH	SeaWater	TypeB	2	5	3	89	610	8550	58.95
600	4pH	SeaWater	TypeC	1	3	1	129	891	7668	52.87
600	4pH	SeaWater	TypeC	1	3	2	98	673	7828	53.98
600	4pH	SeaWater	TypeC	1	3	3	117	808	7929	54.67
600	4pH	SeaWater	TypeC	1	5	1	67	465	7285	50.23
600	4pH	SeaWater	TypeC	1	5	2	74	512	7600	52.40
600	4pH	SeaWater	TypeC	1	5	3	92	636	7506	51.75
600	4pH	SeaWater	TypeC	2	3	1	117	809	8097	55.83
600	4pH	SeaWater	TypeC	2	3	2	115	795	7856	54.16
600	4pH	SeaWater	TypeC	2	3	3	95	653	7970	54.95
600	4pH	SeaWater	TypeC	2	5	1	74	513	7325	50.50
600	4pH	SeaWater	TypeC	2	5	2	75	516	7421	51.17
600	4pH	SeaWater	TypeC	2	5	3	89	616	7542	52.00

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Table A.5: Continued										
Specimen							Tensile		Elastic	
Age	pH	Cl^{-}	Type	Lot	Size	Spec	Strength		Modulus	
Day				No.	#	No.	ksi	MPa	ksi	GPa
600	7pH	SeaWater	TypeA	1	3	1	76	525	7321	50.47
600	7pH	SeaWater	TypeA	1	3	2	91	624	7548	52.04
600	7pH	SeaWater	TypeA	1	3	3	108	743	7223	49.80
600	7pH	SeaWater	TypeA	1	5	1	75	518	7190	49.58
600	7pH	SeaWater	TypeA	1	5	2	127	872	7513	51.80
600	7pH	SeaWater	TypeA	2	5	1	110	755	7179	49.50
600	7pH	SeaWater	TypeA	2	5	2	108	747	6725	46.37
600	7pH	SeaWater	TypeA	2	5	3	68	466	6870	47.37
600	7pH	SeaWater	TypeB	1	3	1	109	755	7153	49.32
600	7pH	SeaWater	TypeB	1	3	2	105	723	7409	51.08
600	7pH	SeaWater	TypeB	1	3	3	99	685	7586	52.31
600	7pH	SeaWater	TypeB	1	5	1	117	806	2020	13.92
600	7pH	SeaWater	TypeB	1	5	02 2	130	898	7703	53.11
600	7pH	SeaWater	TypeB	1	5	2	130	898	7703	53.11
600	7pH	SeaWater	TypeB	1	5	3	122	840	9157	63.14
600	7pH	SeaWater	TypeB	2	3	1	124	854	7971	54.96
600	7pH	SeaWater	TypeB	2	3	2	120	826	8072	55.65
600	7pH	SeaWater	TypeB	2	3	3	111	763	8631	59.51
600	7pH	SeaWater	TypeB	2	5	1	72	497	8089	55.77
600	7pH	SeaWater	TypeB	2	5	2	51	350	7435	51.27
600	7pH	SeaWater	TypeB	2	5	3	74	513	7806	53.82
600	7pH	SeaWater	TypeC	1	3	1	82	565	7661	52.82
600	7pH	SeaWater	TypeC	1	3	2	104	718	7771	53.58
600	7pH	SeaWater	TypeC	1	3	3	112	774	7491	51.65
600	7pH	SeaWater	TypeC	1	5	1	96	659	7625	52.58
600	7pH	SeaWater	TypeC	1	5	2	66	457	7775	53.61
600	7pH	SeaWater	TypeC	1	5	3	89	614	7036	48.51
600	7pH	SeaWater	TypeC	2	3	1	114	789	7920	54.61
600	7pH	SeaWater	TypeC	2	3	2	114	784	7558	52.11
600	7pH	SeaWater	TypeC	2	5	1	41	284	2851	19.66
600	7pH	SeaWater	TypeC	2	5	2	41	282	2721	18.76
600	7pH	SeaWater	TypeC	2	5	3	80	550	6893	47.52

A.6 Bond-to-Concrete Test

The individual measured bond strength test results are listed in Table A.6 to report both the bond stresses and the rebar bond slippage for each specimen. Because ACI 440.3R suggests documenting the slippage behavior through the bond stress measurements at specific rebar slip instances, the table presents not just the ultimate bond stress (strength) but also the bond stresses that corresponded to slip values of $\frac{2}{1000}$ in., $\frac{4}{1000}$ in., and $\frac{1}{100}$ in. For clarity, the table lists all results in imperial units only.

Table A.6: Bond-to-concrete strength test results for each individual specimen (Imperial Units)

Specimen							Bond Stress at Specific Slippage				Bond Slippage at Maximum Stress
Age Day	pH	Cl^{-} ppm	Type	Lot No.	Size #	Spec No.	$\frac{2}{1000}$ in. ksi	$\frac{4}{1000}$ in. ksi	$\frac{1}{100}$ in. ksi	Ult. ksi	Free End in.
000	-	-	TypeA	1	3	01	2.17	2.57	3.40	3.58	0.022
000	-	-	TypeA	1	3	02	1.65	2.21	3.07	3.52	0.024
000	-	-	TypeA	1	3	03	2.69	3.08	3.62	3.99	0.013
000	-	-	TypeA	1	3	04	2.52	3.27	4.35	4.41	0.014
000	-	-	TypeA	1	3	05	2.22	2.59	2.94	3.24	0.025
000	-	-	TypeA	1	5	01	1.71	2.11	3.01	3.13	0.022
000	-	-	TypeA	1	5	02	1.68	2.26	2.93	3.78	0.055
000	-	-	TypeA	1	5	03	1.40	2.12	2.98	3.57	0.035
000	-	-	TypeA	1	5	04	2.76	2.84	3.17	3.32	0.026
000	-	-	TypeA	1	5	05	0.09	0.09	0.16	3.42	0.073
000	-	-	TypeB	1	3	01	0.07	0.07	0.08	2.90	0.005
000	-	-	TypeB	1	3	02	1.49	2.65	3.02	3.06	0.011
000	-	-	TypeB	1	3	03	3.37	3.37	3.31	3.39	0.002
000	-	-	TypeB	1	3	04	1.79	2.09	2.63	3.07	0.018
000	-	-	TypeB	1	3	05	1.92	2.25	2.89	3.56	0.023
000	-	-	TypeB	1	5	01	2.14	2.35	2.59	2.61	0.011
000	-	-	TypeB	1	5	02	2.74	2.78	2.86	2.87	0.008
000	-	-	TypeB	1	5	03	1.97	2.41	2.71	2.72	0.010
000	-	-	TypeB	1	5	04	1.29	1.44	1.85	2.19	0.020
000	-	-	TypeB	1	5	05	1.84	2.30	2.54	2.56	0.012
300	13	0	TypeB	1	5	01	0.55	1.25	1.24	1.27	−0.004
300	13	0	TypeB	1	5	02	0.12	0.20	1.75	1.93	−0.003
300	13	0	TypeB	1	5	03	0.08	0.10	0.22	0.50	0.023
300	13	20000	TypeB	1	5	01	NA	NA	NA	1.32	−0.022
300	13	20000	TypeB	1	5	02	1.02	1.17	NA	1.32	0.000
300	13	20000	TypeB	1	5	03	1.13	1.18	1.16	1.18	0.004
300	4	0	TypeA	1	3	01	2.75	3.18	3.65	3.82	0.018
300	4	0	TypeA	1	3	02	0.80	1.26	1.92	2.28	0.034
300	4	0	TypeA	1	3	03	2.10	2.87	2.95	2.97	0.008
300	4	0	TypeA	1	5	01	1.64	2.13	2.99	3.56	0.045
300	4	0	TypeA	1	5	02	0.85	1.05	1.45	2.58	0.097
300	4	0	TypeA	1	5	03	1.45	2.09	2.99	3.70	0.059
300	4	20000	TypeA	1	3	01	0.35	0.43	0.58	1.16	0.069
300	4	20000	TypeA	1	3	02	1.77	2.53	3.57	4.06	0.022
300	4	20000	TypeA	1	3	03	4.28	4.27	4.20	4.29	0.001
300	4	20000	TypeA	1	5	01	1.32	1.61	2.06	2.72	0.076
300	4	20000	TypeA	1	5	02	2.31	2.37	2.44	2.57	0.046
300	4	20000	TypeA	1	5	03	2.02	2.21	2.52	2.84	0.039
300	4	SeaWater	TypeA	1	3	01	0.40	0.67	1.69	2.59	0.027
300	4	SeaWater	TypeA	1	3	02	2.09	2.45	2.83	2.92	0.019
300	4	SeaWater	TypeA	1	3	03	2.77	3.20	3.69	3.88	0.018
300	4	SeaWater	TypeA	1	5	01	1.91	2.33	2.93	3.83	0.087
300	4	SeaWater	TypeA	1	5	02	1.89	2.50	3.30	3.64	0.029
300	4	SeaWater	TypeA	1	5	03	1.37	1.80	2.45	3.08	0.061
600	4	0	TypeA	1	5	01	0.49	0.62	0.73	1.68	0.001
600	4	0	TypeA	1	5	02	0.49	0.58	0.70	1.63	0.126
600	4	0	TypeA	1	5	03	0.69	0.83	0.89	1.74	0.060
600	4	20000	TypeA	1	5	01	0.88	1.16	1.85	2.86	0.011
600	4	20000	TypeA	1	5	02	1.95	2.33	2.82	3.27	0.066
600	4	20000	TypeA	1	5	03	0.06	0.06	0.06	2.81	0.051
600	4	SeaWater	TypeA	1	5	01	0.68	0.80	0.98	2.38	0.081
600	4	SeaWater	TypeA	1	5	02	0.76	0.78	0.83	1.71	0.090
600	4	SeaWater	TypeA	1	5	03	0.31	0.43	0.43	0.69	0.158
300	4	0	TypeB	1	3	01	3.23	3.59	3.99	4.02	0.013
300	4	0	TypeB	1	3	02	2.30	2.75	2.94	2.96	0.008
300	4	0	TypeB	1	3	03	2.32	2.85	3.55	3.58	0.012
300	4	0	TypeB	1	5	01	1.02	1.02	1.02	2.64	−0.005
300	4	0	TypeB	1	5	02	2.18	2.41	2.66	2.71	0.006
300	4	0	TypeB	1	5	03	1.58	1.58	1.56	2.60	−0.008
300	4	20000	TypeB	1	3	01	1.63	1.72	1.90	1.96	0.016
300	4	20000	TypeB	1	3	02	3.06	3.08	3.12	3.14	0.008
300	4	20000	TypeB	1	3	03	2.16	2.46	2.71	2.76	0.014
300	4	20000	TypeB	1	5	01	1.85	2.08	1.83	2.59	0.008
300	4	20000	TypeB	1	5	02	1.92	2.15	2.38	2.39	0.011
300	4	20000	TypeB	1	5	03	2.28	2.43	1.19	2.54	0.005
300	4	SeaWater	TypeB	1	3	01	3.00	3.66	4.27	4.43	0.016
300	4	SeaWater	TypeB	1	3	02	2.22	2.78	3.98	4.06	0.015
300	4	SeaWater	TypeB	1	3	03	2.73	3.75	4.35	4.42	0.015
300	4	SeaWater	TypeB	1	5	01	1.70	1.97	2.44	2.46	0.012
300	4	SeaWater	TypeB	1	5	02	1.57	1.79	2.19	2.43	0.038
300	4	SeaWater	TypeB	1	5	03	1.14	1.14	1.12	2.65	−0.040
600	4	0	TypeB	1	5	01	1.64	2.13	2.99	3.56	0.045

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Table A.6: Continued

Specimen							Bond Stress at Specific Slippage				Bond Slippage at Maximum Stress
Age Day	pH	Cl^{-} ppm	Type	Lot No.	Size #	Spec No.	$\frac{2}{1000}$ in. ksi	$\frac{4}{1000}$ in. ksi	$\frac{1}{100}$ in. ksi	Ult. ksi	Free End in.
600	4	0	TypeB	1	5	02	0.85	1.05	1.45	2.58	0.097
600	4	0	TypeB	1	5	03	1.45	2.09	2.99	3.70	0.059
600	4	0	TypeB	1	3	01	NA	NA	NA	1.23	−0.008
600	4	0	TypeB	1	3	02	0.11	1.16	1.27	1.34	0.019
600	4	0	TypeB	1	3	03	0.13	0.13	0.13	0.30	0.145
600	4	20000	TypeB	1	5	01	1.32	1.61	2.06	2.72	0.076
600	4	20000	TypeB	1	5	02	2.31	2.37	2.44	2.57	0.046
600	4	20000	TypeB	1	5	03	2.02	2.21	2.52	2.84	0.039
600	4	20000	TypeB	1	3	01	0.70	0.93	1.29	1.52	0.024
600	4	20000	TypeB	1	3	02	1.11	1.32	1.58	1.78	0.022
600	4	20000	TypeB	1	3	03	0.66	0.73	0.92	1.11	0.027
600	4	SeaWater	TypeB	1	5	01	1.91	2.33	2.93	3.83	0.087
600	4	SeaWater	TypeB	1	5	02	1.89	2.50	3.30	3.64	0.029
600	4	SeaWater	TypeB	1	5	03	1.37	1.80	2.45	3.08	0.061
600	4	SeaWater	TypeB	1	3	01	1.72	1.71	1.70	1.72	0.004
600	4	SeaWater	TypeB	1	3	02	0.64	0.73	1.07	1.22	0.022
600	4	SeaWater	TypeB	1	3	03	1.08	1.17	1.24	1.25	0.012
300	7	0	TypeA	1	3	01	1.48	1.87	2.19	2.21	0.012
300	7	0	TypeA	1	3	02	0.79	1.18	1.88	2.28	0.061
300	7	0	TypeA	1	3	03	3.26	3.80	4.00	4.02	0.009
300	7	0	TypeA	1	5	01	1.47	2.11	2.52	3.02	0.064
300	7	0	TypeA	1	5	02	3.47	3.45	3.42	3.57	−0.005
300	7	0	TypeA	1	5	03	0.94	1.40	2.20	3.02	0.068
300	7	20000	TypeA	1	3	01	0.29	0.42	0.71	1.56	0.129
300	7	20000	TypeA	1	3	02	1.32	2.32	2.85	3.01	0.026
300	7	20000	TypeA	1	5	01	0.19	1.25	2.44	2.55	0.016
300	7	20000	TypeA	1	5	02	1.45	1.79	2.28	3.05	0.076
300	7	20000	TypeA	1	5	03	1.36	1.80	3.02	3.90	0.060
300	7	SeaWater	TypeA	1	3	01	0.46	0.61	0.93	1.56	0.046
300	7	SeaWater	TypeA	1	3	02	2.15	2.27	2.36	2.41	0.021
300	7	SeaWater	TypeA	1	3	03	1.00	1.15	1.42	1.92	0.117
300	7	SeaWater	TypeA	1	5	01	2.83	2.83	2.82	2.84	0.002
300	7	SeaWater	TypeA	1	5	02	0.85	1.19	2.33	3.30	0.035
300	7	SeaWater	TypeA	1	5	03	2.28	2.50	2.83	3.13	0.038
600	7	0	TypeA	1	5	01	1.13	1.62	2.69	3.41	0.035
600	7	0	TypeA	1	5	02	0.98	1.42	2.51	2.99	0.046
600	7	0	TypeA	1	5	03	1.47	2.18	2.96	3.30	0.038
600	7	20000	TypeA	1	5	01	2.46	2.70	2.98	3.00	0.011
600	7	20000	TypeA	1	5	02	3.29	3.33	3.43	3.44	0.008
600	7	20000	TypeA	1	5	03	2.16	2.65	2.98	2.99	0.010
600	7	SeaWater	TypeA	1	5	01	0.68	2.45	2.71	2.73	0.014
300	7	0	TypeB	1	3	01	1.72	1.96	2.23	2.29	0.015
300	7	0	TypeB	1	3	02	2.23	2.76	3.01	3.02	0.009
300	7	0	TypeB	1	5	01	1.36	1.96	2.34	2.81	0.064
300	7	0	TypeB	1	5	02	3.23	3.21	3.18	3.32	−0.005
300	7	0	TypeB	1	5	03	0.87	1.30	2.05	2.81	0.068
300	7	20000	TypeB	1	3	01	2.75	2.94	3.14	3.19	0.016
300	7	20000	TypeB	1	3	02	2.84	3.23	3.62	3.65	0.013
300	7	20000	TypeB	1	3	03	3.03	3.06	3.07	3.09	0.006
300	7	20000	TypeB	1	5	01	0.16	1.06	2.07	2.17	0.016
300	7	20000	TypeB	1	5	02	1.23	1.53	1.94	2.59	0.076
300	7	20000	TypeB	1	5	03	1.15	1.53	2.56	3.31	0.060
300	7	SeaWater	TypeB	1	3	01	2.17	2.50	3.10	3.19	0.015
300	7	SeaWater	TypeB	1	3	02	3.38	3.47	3.50	3.51	0.009
300	7	SeaWater	TypeB	1	3	03	2.83	3.18	3.64	3.81	0.020
300	7	SeaWater	TypeB	1	5	01	2.83	2.83	2.82	2.84	0.002
300	7	SeaWater	TypeB	1	5	02	0.85	1.19	2.33	3.30	0.035
300	7	SeaWater	TypeB	1	5	03	2.28	2.50	2.83	3.13	0.038
600	7	0	TypeB	1	3	01	0.96	1.15	1.71	2.12	0.023
600	7	0	TypeB	1	3	02	2.74	2.73	2.66	2.75	0.002
600	7	0	TypeB	1	3	03	1.40	1.57	2.15	2.18	0.012
600	7	0	TypeB	1	5	01	2.44	3.52	4.19	5.03	0.064
600	7	0	TypeB	1	5	02	5.79	5.75	5.70	5.96	−0.005
600	7	0	TypeB	1	5	03	1.57	2.33	3.67	5.04	0.068
600	7	20000	TypeB	1	3	01	1.46	1.54	1.92	2.45	0.026
600	7	20000	TypeB	1	3	02	1.49	1.68	2.13	2.65	0.025
600	7	20000	TypeB	1	3	03	1.52	1.76	2.26	2.54	0.025
600	7	20000	TypeB	1	5	01	0.31	2.08	4.07	4.25	0.016
600	7	20000	TypeB	1	5	02	2.42	2.99	3.80	5.08	0.076
600	7	20000	TypeB	1	5	03	2.26	3.00	5.03	6.50	0.060
600	7	SeaWater	TypeB	1	5	01	2.83	2.83	2.82	2.84	0.002
600	7	SeaWater	TypeB	1	5	02	0.85	1.19	2.33	3.30	0.035
600	7	SeaWater	TypeB	1	5	03	2.28	2.50	2.83	3.13	0.038

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Table A.6: Continued

Specimen							Bond Stress at Specific Slippage				Bond Slippage at Maximum Stress
Age Day	pH	Cl^{-} ppm	Type	Lot No.	Size #	Spec No.	$\frac{2}{1000}$ in. ksi	$\frac{4}{1000}$ in. ksi	$\frac{1}{100}$ in. ksi	Ult. ksi	Free End in.
600	7	SeaWater	TypeB	1	3	01	0.68	0.74	0.85	1.08	0.029
600	7	SeaWater	TypeB	1	3	02	0.59	0.66	0.79	1.01	0.029
600	7	SeaWater	TypeB	1	3	03	1.10	1.10	1.07	1.46	0.000
000	-	-	TypeA	2	3	01	2.29	2.64	3.95	4.03	0.013
000	-	-	TypeA	2	3	02	1.94	2.41	3.33	3.85	0.019
000	-	-	TypeA	2	3	03	3.05	3.39	3.83	3.91	0.019
000	-	-	TypeA	2	3	04	3.37	3.45	3.57	3.60	0.014
000	-	-	TypeA	2	5	01	1.06	1.88	3.53	5.29	0.042
000	-	-	TypeA	2	5	02	2.93	3.49	4.68	4.91	0.035
000	-	-	TypeA	2	5	03	3.53	3.71	4.81	5.54	0.061
000	-	-	TypeA	2	5	04	0.07	0.07	0.07	6.15	0.053
000	-	-	TypeA	2	5	05	3.24	3.74	4.72	5.58	0.043
000	-	-	TypeB	2	3	01	3.11	3.25	3.47	3.53	0.014
000	-	-	TypeB	2	3	02	3.16	3.34	3.49	3.54	0.013
000	-	-	TypeB	2	3	03	2.60	2.87	3.23	3.24	0.010
000	-	-	TypeB	2	3	04	3.13	3.42	3.55	3.56	0.009
000	-	-	TypeB	2	3	05	5.22	5.23	5.31	5.33	0.009
000	-	-	TypeB	2	5	01	1.87	2.26	2.51	2.60	0.016
000	-	-	TypeB	2	5	02	2.01	2.23	2.75	2.86	0.017
000	-	-	TypeB	2	5	03	1.87	2.22	2.60	2.61	0.012
000	-	-	TypeB	2	5	04	1.88	2.22	2.62	2.72	0.014
000	-	-	TypeB	2	5	05	1.94	2.15	2.39	2.44	0.014
300	13	0	TypeB	2	5	01	0.05	NA	NA	1.32	−0.016
300	13	0	TypeB	2	5	02	0.30	0.67	NA	1.17	0.005
300	13	0	TypeB	2	5	03	1.21	0.13	0.13	1.23	0.003
300	4	0	TypeA	2	3	01	1.36	1.65	2.16	2.43	0.023
300	4	0	TypeA	2	3	02	0.67	0.82	0.85	0.85	0.010
300	4	0	TypeA	2	3	03	1.19	1.28	1.33	1.97	0.099
300	4	0	TypeA	2	5	01	0.93	1.25	2.00	4.72	0.154
300	4	0	TypeA	2	5	02	2.74	3.96	5.24	6.07	0.051
300	4	0	TypeA	2	5	03	2.79	4.07	5.45	6.37	0.054
300	4	20000	TypeA	2	3	01	3.03	3.84	NA	4.11	0.007
300	4	20000	TypeA	2	3	02	2.52	3.10	0.04	3.26	0.006
300	4	20000	TypeA	2	3	03	2.88	3.47	4.00	4.05	0.014
300	4	20000	TypeA	2	5	01	1.46	1.94	3.09	4.76	0.011
300	4	20000	TypeA	2	5	02	3.25	3.88	4.70	5.44	0.066
300	4	20000	TypeA	2	5	03	0.10	0.10	0.10	4.69	0.051
300	4	SeaWater	TypeA	2	3	01	0.82	1.28	2.12	2.94	0.031
300	4	SeaWater	TypeA	2	3	02	2.75	3.18	3.65	3.82	0.018
300	4	SeaWater	TypeA	2	3	03	1.60	2.05	2.20	2.22	0.014
300	4	SeaWater	TypeA	2	5	01	2.39	2.40	2.39	2.40	0.004
300	4	SeaWater	TypeA	2	5	02	2.63	3.31	4.38	5.53	0.055
300	4	SeaWater	TypeA	2	5	03	2.56	3.52	4.57	5.18	0.027
600	4	0	TypeA	2	5	01	0.51	0.64	0.73	1.90	0.161
600	4	0	TypeA	2	5	02	NA	NA	NA	2.53	−0.000
600	4	0	TypeA	2	5	03	1.83	2.03	2.31	2.36	0.015
600	4	20000	TypeA	2	5	01	NA	NA	NA	1.42	−0.034
600	4	20000	TypeA	2	5	02	0.60	0.65	0.73	1.47	0.082
600	4	20000	TypeA	2	5	03	0.43	0.58	0.79	1.88	0.049
600	4	SeaWater	TypeA	2	5	02	0.50	0.65	0.77	1.96	0.165
600	4	SeaWater	TypeA	2	5	03	0.43	0.58	0.79	1.88	0.049
300	4	0	TypeB	2	3	01	1.96	2.14	2.32	2.33	0.010
300	4	0	TypeB	2	3	02	2.87	2.95	3.09	3.10	0.012
300	4	0	TypeB	2	3	03	2.79	3.01	3.33	3.35	0.013
300	4	0	TypeB	2	5	01	2.71	2.70	2.60	2.72	0.001
300	4	0	TypeB	2	5	02	NA	NA	NA	2.53	−0.000
300	4	0	TypeB	2	5	03	1.83	2.03	2.31	2.36	0.015
300	4	20000	TypeB	2	3	01	2.37	2.66	2.94	2.98	0.014
300	4	20000	TypeB	2	3	02	2.75	2.99	3.35	3.40	0.012
300	4	20000	TypeB	2	3	03	1.93	2.31	2.78	2.83	0.013
300	4	20000	TypeB	2	5	01	1.94	2.00	2.04	2.05	0.009
300	4	20000	TypeB	2	5	02	2.33	2.56	2.73	2.74	0.010
300	4	20000	TypeB	2	5	03	NA	NA	NA	2.67	−0.018
300	4	SeaWater	TypeB	2	3	01	0.84	0.84	1.22	2.19	0.121
300	4	SeaWater	TypeB	2	3	02	3.93	4.12	4.20	4.22	0.008
300	4	SeaWater	TypeB	2	3	03	2.00	2.38	3.11	3.30	0.018
300	4	SeaWater	TypeB	2	5	01	2.16	2.64	2.57	2.67	0.005
300	4	SeaWater	TypeB	2	5	02	1.59	1.69	1.81	1.84	0.003
300	4	SeaWater	TypeB	2	5	03	2.53	2.54	1.11	2.67	0.001
600	4	0	TypeB	2	5	01	0.56	0.75	1.20	2.83	0.154
600	4	0	TypeB	2	5	02	1.64	2.38	3.14	3.64	0.051
600	4	0	TypeB	2	5	03	1.67	2.44	3.27	3.82	0.054
600	4	0	TypeB	2	3	01	2.07	2.07	2.09	2.10	0.012

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Table A.6: Continued

Specimen							Bond Stress at Specific Slippage				Bond Slippage at Maximum Stress
Age Day	pH	Cl^- ppm	Type	Lot No.	Size #	Spec No.	$\frac{2}{1000}$ in. ksi	$\frac{4}{1000}$ in. ksi	$\frac{1}{100}$ in. ksi	Ult. ksi	Free End in.
600	4	0	TypeB	2	3	02	1.24	1.57	2.14	2.74	0.027
600	4	0	TypeB	2	3	03	1.53	1.98	2.01	2.02	0.006
600	4	20000	TypeB	2	5	01	0.88	1.16	1.85	2.86	0.011
600	4	20000	TypeB	2	5	02	1.95	2.33	2.82	3.27	0.066
600	4	20000	TypeB	2	5	03	0.06	0.06	0.06	2.81	0.051
600	4	20000	TypeB	2	3	01	1.62	1.69	1.78	1.82	0.016
600	4	20000	TypeB	2	3	02	1.87	2.24	2.39	2.47	0.017
600	4	20000	TypeB	2	3	03	2.04	2.17	2.30	2.30	0.009
600	4	SeaWater	TypeB	2	5	01	1.43	1.44	1.43	1.44	0.004
600	4	SeaWater	TypeB	2	5	02	1.58	1.99	2.63	3.32	0.055
600	4	SeaWater	TypeB	2	5	03	1.54	2.11	2.74	3.11	0.027
600	4	SeaWater	TypeB	2	3	01	1.60	1.98	2.47	2.61	0.018
600	4	SeaWater	TypeB	2	3	02	1.74	2.33	2.95	3.45	0.025
600	4	SeaWater	TypeB	2	3	03	1.74	1.96	2.35	2.91	0.026
300	7	0	TypeA	2	3	01	3.38	3.51	3.55	3.57	0.009
300	7	0	TypeA	2	3	02	1.73	2.33	2.79	2.92	0.018
300	7	0	TypeA	2	3	03	1.75	2.16	2.54	2.81	0.021
300	7	0	TypeA	2	5	01	1.89	2.70	4.48	5.68	0.035
300	7	0	TypeA	2	5	02	1.63	2.37	4.19	4.98	0.046
300	7	0	TypeA	2	5	03	2.45	3.63	4.93	5.50	0.038
300	7	20000	TypeA	2	3	01	3.18	3.81	4.26	4.31	0.013
300	7	20000	TypeA	2	3	02	1.83	2.23	2.85	3.18	0.022
300	7	20000	TypeA	2	3	03	0.50	0.68	1.20	1.94	0.074
300	7	20000	TypeA	2	5	01	4.09	4.49	4.96	5.00	0.011
300	7	20000	TypeA	2	5	02	5.49	5.56	5.71	5.74	0.008
300	7	20000	TypeA	2	5	03	3.60	4.42	4.97	4.98	0.010
300	7	SeaWater	TypeA	2	3	01	2.13	2.69	4.15	4.30	0.016
300	7	SeaWater	TypeA	2	3	02	0.84	1.36	2.28	3.00	0.046
300	7	SeaWater	TypeA	2	3	03	3.98	4.31	4.52	4.55	0.013
300	7	SeaWater	TypeA	2	5	01	5.16	5.18	5.25	5.36	0.038
300	7	SeaWater	TypeA	2	5	02	2.90	3.37	4.13	5.09	0.076
300	7	SeaWater	TypeA	2	5	03	1.60	2.21	3.19	5.32	0.091
600	7	0	TypeA	2	5	01	1.47	2.11	2.52	3.02	0.064
600	7	0	TypeA	2	5	02	3.47	3.45	3.42	3.57	−0.005
600	7	0	TypeA	2	5	03	0.94	1.40	2.20	3.02	0.068
600	7	20000	TypeA	2	5	02	0.76	0.94	1.02	2.03	0.109
600	7	20000	TypeA	2	5	03	0.31	0.58	0.73	2.39	0.113
600	7	SeaWater	TypeA	2	5	01	2.83	2.83	2.82	2.84	0.002
600	7	SeaWater	TypeA	2	5	02	0.85	1.19	2.33	3.30	0.035
600	7	SeaWater	TypeA	2	5	03	2.28	2.50	2.83	3.13	0.038
300	7	0	TypeB	2	3	01	1.57	2.26	2.61	2.62	0.011
300	7	0	TypeB	2	3	02	3.15	3.46	3.57	3.61	0.008
300	7	0	TypeB	2	3	03	3.09	3.25	3.35	3.36	0.010
300	7	0	TypeB	2	5	01	0.98	1.39	2.31	2.93	0.035
300	7	0	TypeB	2	5	02	0.86	1.25	2.21	2.63	0.046
300	7	0	TypeB	2	5	03	1.30	1.91	2.60	2.90	0.038
300	7	20000	TypeB	2	3	01	2.64	2.74	2.75	2.77	0.007
300	7	20000	TypeB	2	3	02	3.08	3.50	3.73	3.74	0.010
300	7	20000	TypeB	2	3	03	2.90	3.38	3.86	3.98	0.016
300	7	20000	TypeB	2	5	01	2.14	2.35	2.59	2.61	0.011
300	7	20000	TypeB	2	5	02	2.74	2.78	2.86	2.87	0.008
300	7	20000	TypeB	2	5	03	1.97	2.41	2.71	2.72	0.010
300	7	SeaWater	TypeB	2	3	01	1.70	2.12	2.85	3.00	0.018
300	7	SeaWater	TypeB	2	3	02	3.25	3.50	3.84	3.90	0.015
300	7	SeaWater	TypeB	2	3	03	2.64	3.39	3.81	3.83	0.012
300	7	SeaWater	TypeB	2	5	01	2.79	2.80	2.84	2.90	0.038
300	7	SeaWater	TypeB	2	5	02	1.67	1.94	2.38	2.93	0.076
300	7	SeaWater	TypeB	2	5	03	0.85	1.16	1.68	2.81	0.091
600	7	0	TypeB	2	3	01	1.84	3.02	3.26	3.31	0.013
600	7	0	TypeB	2	3	02	2.19	2.72	2.85	3.05	0.017
600	7	0	TypeB	2	3	03	2.57	2.68	2.78	2.79	0.009
600	7	0	TypeB	2	5	01	1.89	2.70	4.48	5.68	0.035
600	7	0	TypeB	2	5	02	1.63	2.37	4.19	4.98	0.046
600	7	0	TypeB	2	5	03	2.45	3.63	4.93	5.50	0.038
600	7	20000	TypeB	2	3	01	1.87	2.04	2.46	2.78	0.020
600	7	20000	TypeB	2	5	01	4.09	4.49	4.96	5.00	0.011
600	7	20000	TypeB	2	5	02	5.49	5.56	5.71	5.74	0.008
600	7	20000	TypeB	2	5	03	3.60	4.42	4.97	4.98	0.010
600	7	SeaWater	TypeB	2	5	01	3.10	3.11	3.15	3.22	0.038
600	7	SeaWater	TypeB	2	5	02	1.74	2.02	2.48	3.05	0.076
600	7	SeaWater	TypeB	2	5	03	0.96	1.32	1.91	3.19	0.091
600	7	SeaWater	TypeB	2	3	01	1.41	1.61	1.88	1.99	0.019
600	7	SeaWater	TypeB	2	3	02	1.62	2.01	2.60	2.77	0.020

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Table A.6: Continued

Specimen							Bond Stress at Specific Slippage				Bond Slippage at Maximum Stress
Age Day	pH	Cl^- ppm	Type	Lot No.	Size #	Spec No.	$\frac{2}{1000}$ in. ksi	$\frac{4}{1000}$ in. ksi	$\frac{1}{100}$ in. ksi	Ult. ksi	Free End in.
600	7	SeaWater	TypeB	2	3	03	1.62	1.79	2.00	2.20	0.024
000	-	-	Type	Lot1	3	01	0.64	0.66	0.66	1.65	0.263
000	-	-	Type	Lot1	3	02	0.48	0.61	0.93	1.84	0.160
000	-	-	Type	Lot1	3	03	0.59	0.62	0.65	1.14	0.177
000	-	-	Type	Lot1	3	04	0.46	0.75	0.89	1.91	0.174
000	-	-	Type	Lot1	3	05	0.59	0.77	1.03	1.45	0.034
000	-	-	Type	Lot1	5	01	0.60	0.65	0.72	1.77	0.256
000	-	-	Type	Lot1	5	02	0.48	0.63	0.90	2.17	0.170
000	-	-	Type	Lot1	5	03	0.55	0.60	0.68	1.70	0.114
000	-	-	Type	Lot1	5	04	0.68	0.82	0.90	1.84	0.253
300	4	0	Type	Lot1	3	01	0.30	0.56	0.83	2.03	0.138
300	4	0	Type	Lot1	3	02	0.59	0.75	NA	1.68	−0.010
300	4	0	Type	Lot1	3	03	0.51	0.54	NA	1.03	−0.014
300	4	0	Type	Lot1	5	01	0.49	0.62	0.73	1.68	0.001
300	4	0	Type	Lot1	5	02	0.49	0.58	0.70	1.63	0.126
300	4	0	Type	Lot1	5	03	0.69	0.83	0.89	1.74	0.060
300	4	20000	Type	Lot1	3	01	0.40	0.56	0.95	1.30	0.203
300	4	20000	Type	Lot1	3	02	0.47	0.60	0.90	1.85	0.195
300	4	SeaWater	Type	Lot1	3	01	0.44	0.45	0.51	0.82	0.218
300	4	SeaWater	Type	Lot1	3	02	1.02	1.03	1.07	1.74	0.146
300	4	SeaWater	Type	Lot1	3	03	0.63	0.74	0.73	1.79	0.144
300	4	SeaWater	Type	Lot1	5	01	0.68	0.80	0.98	2.38	0.081
300	4	SeaWater	Type	Lot1	5	02	0.76	0.78	0.83	1.71	0.090
300	4	SeaWater	Type	Lot1	5	03	0.31	0.43	0.43	0.69	0.158
600	4	0	Type	Lot1	3	01	0.63	0.73	0.94	1.49	0.120
600	4	0	Type	Lot1	3	02	0.62	0.64	0.69	0.81	0.067
600	4	0	Type	Lot1	3	03	0.27	0.25	0.25	1.82	0.120
600	4	0	Type	Lot1	5	01	0.04	0.05	1.02	2.53	0.121
600	4	0	Type	Lot1	5	02	0.07	0.08	0.28	4.63	0.128
600	4	20000	Type	Lot1	3	01	0.68	0.80	0.93	1.92	0.120
600	4	20000	Type	Lot1	3	02	1.35	1.42	1.58	2.32	0.115
600	4	20000	Type	Lot1	3	03	0.41	0.53	0.90	2.59	0.123
600	4	20000	Type	Lot1	5	01	0.63	1.04	1.60	3.93	0.124
600	4	20000	Type	Lot1	5	02	0.48	0.73	1.03	3.09	0.121
600	4	SeaWater	Type	Lot1	3	01	1.03	1.13	1.36	2.75	0.130
600	4	SeaWater	Type	Lot1	3	02	0.55	0.76	0.99	2.91	0.119
600	4	SeaWater	Type	Lot1	5	01	0.88	1.18	1.69	2.85	0.122
600	4	SeaWater	Type	Lot1	5	02	1.13	1.25	1.41	3.43	0.120
300	7	0	Type	Lot1	3	01	0.66	0.71	0.83	1.67	0.211
300	7	0	Type	Lot1	3	02	0.49	0.58	0.68	1.50	0.190
300	7	0	Type	Lot1	3	03	0.50	0.52	0.61	1.58	0.122
300	7	20000	Type	Lot1	3	01	0.40	0.41	0.49	1.28	0.212
300	7	20000	Type	Lot1	3	02	0.56	0.63	0.75	1.32	0.220
300	7	20000	Type	Lot1	3	03	0.51	0.71	0.72	1.15	0.158
300	7	SeaWater	Type	Lot1	3	01	0.65	0.68	0.62	1.59	0.217
300	7	SeaWater	Type	Lot1	3	02	0.37	0.40	0.47	1.52	0.179
300	7	SeaWater	Type	Lot1	5	01	0.68	2.45	2.71	2.73	0.014
600	7	0	Type	Lot1	3	01	0.78	0.93	1.19	2.89	0.120
600	7	0	Type	Lot1	3	02	0.86	1.19	1.49	3.16	0.122
600	7	0	Type	Lot1	3	03	0.70	0.76	0.86	1.97	0.120
600	7	0	Type	Lot1	5	01	1.03	1.15	1.41	3.87	0.122
600	7	0	Type	Lot1	5	02	0.13	0.13	1.50	3.88	0.120
600	7	20000	Type	Lot1	3	01	0.63	0.73	0.84	1.99	0.120
600	7	20000	Type	Lot1	3	02	0.81	0.96	1.07	2.73	0.120
600	7	20000	Type	Lot1	5	01	0.13	0.14	1.36	2.95	0.121
600	7	20000	Type	Lot1	5	02	0.79	0.90	1.14	2.50	0.125
600	7	SeaWater	Type	Lot1	3	01	0.48	0.59	0.70	1.41	0.121
600	7	SeaWater	Type	Lot1	3	02	0.55	0.61	0.86	1.59	0.119
600	7	SeaWater	Type	Lot1	3	03	0.45	0.58	0.90	2.29	0.121
600	7	SeaWater	Type	Lot1	5	01	1.89	1.95	2.11	3.62	0.126
600	7	SeaWater	Type	Lot1	5	02	0.57	0.64	0.76	1.81	0.121
000	-	-	Type	Lot2	3	01	0.42	0.43	0.51	1.50	0.155
000	-	-	Type	Lot2	3	02	0.02	0.02	0.70	1.28	0.215
000	-	-	Type	Lot2	3	03	0.37	0.44	0.62	1.21	0.400
000	-	-	Type	Lot2	3	04	0.01	0.01	0.01	1.48	0.180
000	-	-	Type	Lot2	3	05	0.35	0.46	0.56	1.41	0.504
000	-	-	Type	Lot2	5	01	0.50	0.71	1.00	1.72	0.154
000	-	-	Type	Lot2	5	02	0.43	0.66	0.88	1.81	0.149
000	-	-	Type	Lot2	5	03	0.78	0.88	1.07	2.10	0.213
000	-	-	Type	Lot2	5	04	0.59	0.71	0.74	2.12	0.171
300	4	0	Type	Lot2	3	01	0.48	0.51	0.36	1.28	0.211
300	4	0	Type	Lot2	3	02	0.37	0.46	0.76	1.36	0.231
300	4	0	Type	Lot2	5	01	0.51	0.64	0.73	1.90	0.161

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Table A.6: Continued											
Specimen							Bond Stress				Bond Slippage
							at Specific Slippage				at Maximum Stress
Age Day	pH	Cl^- ppm	Type	Lot No.	Size #	Spec No.	$\frac{2}{1000}$ in. ksi	$\frac{4}{1000}$ in. ksi	$\frac{1}{100}$ in. ksi	Ult. ksi	Free End in.
300	4	20000	Type	Lot2	3	01	0.59	0.60	0.64	1.73	0.204
300	4	20000	Type	Lot2	3	02	NA	NA	NA	1.64	−0.055
300	4	20000	Type	Lot2	3	03	0.37	0.44	0.82	2.07	0.168
300	4	20000	Type	Lot2	5	01	NA	NA	NA	1.42	−0.034
300	4	20000	Type	Lot2	5	02	0.60	0.65	0.73	1.47	0.082
300	4	20000	Type	Lot2	5	03	0.43	0.58	0.79	1.88	0.049
300	4	SeaWater	Type	Lot2	3	01	0.49	0.61	0.61	1.15	0.180
300	4	SeaWater	Type	Lot2	3	02	0.83	0.88	0.98	1.83	0.024
300	4	SeaWater	Type	Lot2	3	03	0.48	0.44	0.44	1.19	0.225
300	4	SeaWater	Type	Lot2	5	01	0.24	0.24	0.29	0.77	0.212
300	4	SeaWater	Type	Lot2	5	02	0.50	0.65	0.77	1.96	0.165
300	4	SeaWater	Type	Lot2	5	03	0.43	0.58	0.79	1.88	0.049
600	4	0	Type	Lot2	3	01	0.40	0.40	0.40	1.39	0.102
600	4	0	Type	Lot2	3	02	0.79	0.89	1.03	1.62	0.122
600	4	0	Type	Lot2	3	03	0.53	0.58	0.66	1.03	0.042
600	4	0	Type	Lot2	5	01	1.05	1.14	1.32	3.36	0.122
600	4	0	Type	Lot2	5	02	0.54	0.72	1.21	3.37	0.134
600	4	20000	Type	Lot2	3	01	0.55	0.71	0.96	3.87	0.120
600	4	20000	Type	Lot2	3	02	0.51	0.73	1.17	3.63	0.121
600	4	20000	Type	Lot2	3	03	0.56	0.65	0.86	2.27	0.122
600	4	20000	Type	Lot2	5	01	0.79	1.08	1.59	3.68	0.124
600	4	20000	Type	Lot2	5	02	0.61	0.78	1.11	3.19	0.120
600	4	SeaWater	Type	Lot2	3	01	0.66	0.76	0.87	2.14	0.123
600	4	SeaWater	Type	Lot2	5	01	1.40	1.48	1.73	3.31	0.121
600	4	SeaWater	Type	Lot2	5	02	0.54	0.87	1.21	3.07	0.120
300	7	0	Type	Lot2	3	01	0.76	0.80	0.84	1.72	0.188
300	7	0	Type	Lot2	3	02	0.65	0.67	0.72	1.23	0.204
300	7	0	Type	Lot2	3	03	0.69	0.78	0.57	2.09	0.197
300	7	20000	Type	Lot2	3	01	1.09	1.11	1.17	1.51	0.166
300	7	20000	Type	Lot2	3	02	0.69	0.72	0.71	1.52	0.183
300	7	20000	Type	Lot2	3	03	0.75	0.62	0.62	1.45	0.236
300	7	20000	Type	Lot2	5	01	1.34	NA	NA	2.09	−0.044
300	7	20000	Type	Lot2	5	02	0.76	0.94	1.02	2.03	0.109
300	7	20000	Type	Lot2	5	03	0.31	0.58	0.73	2.39	0.113
300	7	SeaWater	Type	Lot2	3	01	0.03	0.03	0.03	2.08	0.144
300	7	SeaWater	Type	Lot2	3	02	0.48	0.48	0.49	0.81	0.064
600	7	0	Type	Lot2	3	01	0.46	0.60	0.74	1.88	0.160
600	7	0	Type	Lot2	3	02	0.89	0.95	1.04	1.75	0.120
600	7	0	Type	Lot2	3	03	0.90	1.22	1.48	4.34	0.120
600	7	0	Type	Lot2	5	01	1.12	1.30	1.62	3.24	0.126
600	7	0	Type	Lot2	5	03	0.62	0.86	1.42	3.34	0.120
600	7	20000	Type	Lot2	3	01	0.53	0.63	0.75	2.21	0.120
600	7	20000	Type	Lot2	5	01	0.03	0.67	1.26	3.56	0.130
600	7	SeaWater	Type	Lot2	3	01	0.68	0.73	0.87	2.16	0.086
600	7	SeaWater	Type	Lot2	3	02	0.53	0.75	0.87	2.57	0.119
600	7	SeaWater	Type	Lot2	3	03	2.04	2.18	2.46	4.39	0.128

A.7 Resin Tensile Test

The longitudinal tensile properties for all tested specimens are listed in Table A.7. Specifically, the table presents the maximum tensile stresses and the corresponding elastic moduli, both based on measured dimensions.

Table A.7: Resin tensile strength test results (ultimate values) for each individual specimen

Specimen						Tensile		Elastic	
Age	pH	Cl^{-}	Type	Resin	Spec	Strength		Modulus	
Day		ppm		Type	No.	ksi	MPa	ksi	MPa
0	-	-	A	Epoxy	1	1	9	3	0.02
0	-	-	A	Epoxy	2	1	8	3	0.02
0	-	-	A	Epoxy	3	1	9	3	0.02
0	-	-	A	Epoxy	4	1	8	3	0.02
0	-	-	A	Epoxy	5	2	10	7	0.05
0	-	-	B	Vinylester	1	1	7	3	0.02
0	-	-	B	Vinylester	2	1	8	0	0.00
0	-	-	B	Vinylester	3	1	9	3	0.02
0	-	-	B	Vinylester	4	1	8	3	0.02
0	-	-	B	Vinylester	5	1	9	3	0.02
300	4	0	A	Epoxy	1	1	7	0	0.00
300	4	0	A	Epoxy	2	1	6	3	0.02
300	4	0	A	Epoxy	3	1	4	7	0.05
300	4	0	A	Epoxy	4	1	4	0	0.00
300	4	0	A	Epoxy	5	1	6	3	0.02
300	4	0	B	Vinylester	1	1	7	0	0.00
300	4	0	B	Vinylester	2	1	6	3	0.02
300	4	0	B	Vinylester	3	1	4	7	0.05
300	4	0	B	Vinylester	4	1	4	0	0.00
300	4	0	B	Vinylester	5	1	6	3	0.02
300	4	20000	A	Epoxy	1	1	5	3	0.02
300	4	20000	A	Epoxy	2	1	6	3	0.02
300	4	20000	A	Epoxy	3	0	2	3	0.02
300	4	20000	A	Epoxy	4	0	3	3	0.02
300	4	20000	A	Epoxy	5	1	5	4	0.02
300	4	20000	B	Vinylester	1	1	5	3	0.02
300	4	20000	B	Vinylester	2	1	6	3	0.02
300	4	20000	B	Vinylester	3	0	2	3	0.02
300	4	20000	B	Vinylester	4	0	3	3	0.02
300	4	20000	B	Vinylester	5	1	5	4	0.02
300	4	200	A	Epoxy	1	1	5	4	0.02
300	4	200	A	Epoxy	2	1	4	3	0.02
300	4	200	A	Epoxy	3	1	5	2	0.02
300	4	200	A	Epoxy	4	1	5	3	0.02
300	4	200	A	Epoxy	5	0	3	3	0.02
300	4	200	B	Vinylester	1	1	5	4	0.02
300	4	200	B	Vinylester	2	1	4	3	0.02
300	4	200	B	Vinylester	3	1	5	2	0.02
300	4	200	B	Vinylester	4	1	5	3	0.02
300	4	200	B	Vinylester	5	0	3	3	0.02
300	4	Seawater	A	Epoxy	1	1	6	1	0.01
300	4	Seawater	A	Epoxy	2	1	4	NA	NA
300	4	Seawater	A	Epoxy	3	1	4	3	0.02
300	4	Seawater	A	Epoxy	4	1	6	4	0.02
300	4	Seawater	A	Epoxy	5	1	6	3	0.02
300	4	Seawater	B	Vinylester	1	1	6	1	0.01
300	4	Seawater	B	Vinylester	2	1	4	NA	NA
300	4	Seawater	B	Vinylester	3	1	4	3	0.02
300	4	Seawater	B	Vinylester	4	1	6	4	0.02
300	4	Seawater	B	Vinylester	5	1	6	3	0.02
300	7	0	A	Epoxy	1	1	6	3	0.02
300	7	0	A	Epoxy	2	1	7	3	0.02

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Table A.7: Continued									
Specimen						Tensile		Elastic	
Age	pH	Cl^{-}	Type	Resin	Spec	Strength		Modulus	
Day		ppm		No.	No.	ksi	MPa	ksi	MPa
300	7	0	A	Epoxy	3	1	6	3	0.02
300	7	0	A	Epoxy	4	0	2	3	0.02
300	7	0	A	Epoxy	5	1	6	3	0.02
300	7	0	B	Vinylester	1	1	6	3	0.02
300	7	0	B	Vinylester	2	1	7	3	0.02
300	7	0	B	Vinylester	3	1	6	3	0.02
300	7	0	B	Vinylester	4	0	2	3	0.02
300	7	0	B	Vinylester	5	1	6	3	0.02
300	7	20000	A	Epoxy	1	1	4	4	0.03
300	7	20000	A	Epoxy	2	1	6	4	0.02
300	7	20000	A	Epoxy	3	1	7	4	0.03
300	7	20000	A	Epoxy	4	1	5	3	0.02
300	7	20000	A	Epoxy	5	1	5	3	0.02
300	7	20000	B	Vinylester	1	1	4	4	0.03
300	7	20000	B	Vinylester	2	1	6	4	0.02
300	7	20000	B	Vinylester	3	1	7	4	0.03
300	7	20000	B	Vinylester	4	1	5	3	0.02
300	7	20000	B	Vinylester	5	1	5	3	0.02
300	7	200	A	Epoxy	1	1	5	0	0.00
300	7	200	A	Epoxy	2	1	7	3	0.02
300	7	200	A	Epoxy	3	1	5	3	0.02
300	7	200	A	Epoxy	4	1	5	2	0.01
300	7	200	A	Epoxy	5	0	3	3	0.02
300	7	200	B	Vinylester	1	1	5	0	0.00
300	7	200	B	Vinylester	2	1	7	3	0.02
300	7	200	B	Vinylester	3	1	5	3	0.02
300	7	200	B	Vinylester	4	1	5	2	0.01
300	7	200	B	Vinylester	5	0	3	3	0.02
300	7	Seawater	A	Epoxy	1	1	6	0	0.00
300	7	Seawater	A	Epoxy	2	1	6	3	0.02
300	7	Seawater	A	Epoxy	3	1	5	3	0.02
300	7	Seawater	A	Epoxy	4	1	6	−0	−0.00
300	7	Seawater	A	Epoxy	5	1	5	3	0.02
300	7	Seawater	B	Vinylester	1	1	6	0	0.00
300	7	Seawater	B	Vinylester	2	1	6	3	0.02
300	7	Seawater	B	Vinylester	3	1	5	3	0.02
300	7	Seawater	B	Vinylester	4	1	6	−0	−0.00
300	7	Seawater	B	Vinylester	5	1	5	3	0.02
300	10	0	A	Epoxy	1	1	6	3	0.02
300	10	0	A	Epoxy	2	1	5	3	0.02
300	10	0	A	Epoxy	3	0	0	NA	NA
300	10	0	A	Epoxy	4	0	3	7	0.05
300	10	0	A	Epoxy	5	1	6	3	0.02
300	10	0	B	Vinylester	1	1	6	3	0.02
300	10	0	B	Vinylester	2	1	5	3	0.02
300	10	0	B	Vinylester	3	0	0	NA	NA
300	10	0	B	Vinylester	4	0	3	7	0.05
300	10	0	B	Vinylester	5	1	6	3	0.02
300	10	20000	A	Epoxy	1	1	4	4	0.02
300	10	20000	A	Epoxy	2	1	4	7	0.04
300	10	20000	A	Epoxy	3	1	6	5	0.03
300	10	20000	A	Epoxy	4	1	6	4	0.02
300	10	20000	A	Epoxy	5	1	6	4	0.02

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Table A.7: Continued									
Specimen						Tensile		Elastic	
Age	pH	Cl^{-}	Type	Resin	Spec	Strength		Modulus	
Day		ppm		No.	No.	ksi	MPa	ksi	MPa
300	10	20000	B	Vinylester	1	1	4	4	0.02
300	10	20000	B	Vinylester	2	1	4	7	0.04
300	10	20000	B	Vinylester	3	1	6	5	0.03
300	10	20000	B	Vinylester	4	1	6	4	0.02
300	10	20000	B	Vinylester	5	1	6	4	0.02
300	10	200	A	Epoxy	1	1	6	3	0.02
300	10	200	A	Epoxy	2	1	6	3	0.02
300	10	200	A	Epoxy	3	1	6	4	0.03
300	10	200	A	Epoxy	4	1	5	7	0.05
300	10	200	A	Epoxy	5	1	4	4	0.02
300	10	200	B	Vinylester	1	1	6	3	0.02
300	10	200	B	Vinylester	2	1	6	3	0.02
300	10	200	B	Vinylester	3	1	6	4	0.03
300	10	200	B	Vinylester	4	1	5	7	0.05
300	10	200	B	Vinylester	5	1	4	4	0.02
300	10	Seawater	A	Epoxy	1	1	6	6	0.04
300	10	Seawater	A	Epoxy	2	1	5	3	0.02
300	10	Seawater	A	Epoxy	3	1	5	1	0.01
300	10	Seawater	A	Epoxy	4	1	5	2	0.01
300	10	Seawater	A	Epoxy	5	1	6	−1	−0.00
300	10	Seawater	B	Vinylester	1	1	6	6	0.04
300	10	Seawater	B	Vinylester	2	1	5	3	0.02
300	10	Seawater	B	Vinylester	3	1	5	1	0.01
300	10	Seawater	B	Vinylester	4	1	5	2	0.01
300	10	Seawater	B	Vinylester	5	1	6	−1	−0.00
300	13	0	A	Epoxy	1	1	7	NA	NA
300	13	0	A	Epoxy	2	0	2	3	0.02
300	13	0	A	Epoxy	3	1	5	4	0.03
300	13	0	A	Epoxy	4	1	4	3	0.02
300	13	0	A	Epoxy	5	0	3	3	0.02
300	13	0	B	Vinylester	1	1	7	NA	NA
300	13	0	B	Vinylester	2	0	2	3	0.02
300	13	0	B	Vinylester	3	1	5	4	0.03
300	13	0	B	Vinylester	4	1	4	3	0.02
300	13	0	B	Vinylester	5	0	3	3	0.02
300	13	20000	A	Epoxy	1	1	6	0	0.00
300	13	20000	A	Epoxy	2	1	5	3	0.02
300	13	20000	A	Epoxy	3	1	3	4	0.03
300	13	20000	A	Epoxy	4	1	4	3	0.02
300	13	20000	A	Epoxy	5	1	4	3	0.02
300	13	20000	B	Vinylester	1	1	6	0	0.00
300	13	20000	B	Vinylester	2	1	5	3	0.02
300	13	20000	B	Vinylester	3	1	3	4	0.03
300	13	20000	B	Vinylester	4	1	4	3	0.02
300	13	20000	B	Vinylester	5	1	4	3	0.02
300	13	200	A	Epoxy	1	1	5	1	0.01
300	13	200	A	Epoxy	2	1	6	4	0.02
300	13	200	A	Epoxy	3	0	2	1	0.00
300	13	200	A	Epoxy	4	1	6	6	0.04
300	13	200	A	Epoxy	5	1	6	3	0.02
300	13	200	B	Vinylester	1	1	5	1	0.01
300	13	200	B	Vinylester	2	1	6	4	0.02
300	13	200	B	Vinylester	3	0	2	1	0.00

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Table A.7: Continued									
Specimen						Tensile		Elastic	
Age	pH	Cl^{-}	Type	Resin	Spec	Strength		Modulus	
Day		ppm		No.	No.	ksi	MPa	ksi	MPa
300	13	200	B	Vinylester	4	1	6	6	0.04
300	13	200	B	Vinylester	5	1	6	3	0.02
300	13	Seawater	A	Epoxy	1	1	5	0	0.00
300	13	Seawater	A	Epoxy	2	1	4	6	0.04
300	13	Seawater	A	Epoxy	3	1	5	3	0.02
300	13	Seawater	A	Epoxy	4	1	5	0	0.00
300	13	Seawater	A	Epoxy	5	1	6	3	0.02
300	13	Seawater	B	Vinylester	1	1	5	0	0.00
300	13	Seawater	B	Vinylester	2	1	4	6	0.04
300	13	Seawater	B	Vinylester	3	1	5	3	0.02
300	13	Seawater	B	Vinylester	4	1	5	0	0.00
300	13	Seawater	B	Vinylester	5	1	6	3	0.02