Final Report

BFRP Rebar Characterization and Performance

Testing Protocol and Material Specifications
for Basalt Fiber Reinforced Polymer Bars

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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	$\frac{9}{5}\text{C} + 32$	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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alternative concrete reinforcement, material performance,

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Specifically, the project manager Steven Nolan (Senior Structures Design Engineer) provided excellent resources and expertise throughout this study. His dedication and support were key aspects that aided the success of this project. Steven Nolan did not just professionally manage the project, he also invested his personal time and effort to go above and beyond. In fact, his personal interest and dedication lead to significant contribution to the body of knowledge in the FRP rebar society, and his enthusiasm for the subject matter was contagious to all participating researchers.

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.

Contents

Disclaimer . . . i
Unit Conversion to SI Units . . . ii
Unit Conversion to imperial Units . . . iii
Technical Report Documentation Page . . . iv
Acknowledgements . . . v
Executive Summary . . . vi
Table of Contents . . . viii
List of Figures . . . xiii
List of Tables . . . xxi

1 Introduction **1**
1.1 Introduction . . . 1
1.2 Problem Statement . . . 2
1.3 Research Objective . . . 3
1.4 Research Scope . . . 3

2 Background **4**
2.1 Introduction . . . 4
2.2 Fiber Types . . . 5
  2.2.1 Carbon Fibers . . . 5
  2.2.2 Aramid Fibers . . . 5
  2.2.3 Glass Fibers . . . 5
  2.2.4 Basalt Fibers . . . 6
  2.2.5 Summary of Fiber Types . . . 6
2.3 Source Material for Basalt Fibers . . . 8
  2.3.1 Acidity Modulus (M_a) . . . 9
  2.3.2 Viscosity Modulus (M_v) . . . 10
2.4 Basalt Fiber Production . . . 12
2.5 Chemical Durability Studies on Basalt Fibers . . . 12
2.6 Sizing . . . 18
2.7 Chemical Durability Studies on Sizing . . . 18
2.8 Binder Materials and Types . . . 19
  2.8.1 Epoxy . . . 19
  2.8.2 Vinyl-Ester . . . 20
  2.8.3 Polyester . . . 20
2.9 Chemical Durability Studies on Resins . . . 21
2.10 BFRP Rebar Production . . . 25

    2.10.1 Wet-Layup 25
    2.10.2 Pultrusion 26
  2.11 Chemical Durability Studies on FRP Rebar 26

3 Existing Standards for FRP Rebars 28
  3.1 Typical Fiber Properties 28
  3.2 Typical Resin Properties 29
  3.3 Cross Sectional Properties of Rebar 30
  3.4 Minimum Guaranteed Tensile Strength of Rebar 33
  3.5 Physical and Mechanical Properties of Rebar 34
  3.6 Required Chemical Durability of Rebar 34

4 Experimental Program 36
  4.1 Introduction 36
  4.2 Experimental Concept Overview 37
    4.2.1 Characterization of BFRP Constituent Materials 37
    4.2.2 Characterization of BFRP Rebar Specimens 39
    4.2.3 Characterization of Exposure Solutions 40

5 Aggressive Environments — Solution Properties 42
  5.1 Introduction 42
  5.2 Results 42

6 Chemical, Material and Physical Properties of Rebar and Components Before Exposure to Aggressive Environments 45
  6.1 Virgin Component Properties 45
    6.1.1 Resin Moisture Absorption 45
    6.1.2 X-Ray Fluorescence (XRF) Analysis on Fibers 46
    6.1.3 Diameter of Fibers 46
    6.1.4 SEM Images of Fibers, Unsized Fibers, and Resins 47
  6.2 Chemical Properties of Exposure Environments 51
    6.2.1 Introduction 51
    6.2.2 Aggressive Environments — Solution Properties 51
  6.3 Physical Properties of Rebars 52
    6.3.1 Introduction 52
    6.3.2 Cross-Sectional Properties 53
    6.3.3 Fiber Content 53
    6.3.4 Moisture Absorption 53
    6.3.5 X-Ray Fluorescence (XRF) Analysis on Rebars 54
  6.4 Mechanical Properties 57
    6.4.1 Transverse Shear Test 57
    6.4.2 Modes of Failure 59
    6.4.3 Summary of Transverse Shear Properties 60
    6.4.4 Apparent Horizontal Shear Test 62
    6.4.5 Modes of Failure 68
    6.4.6 Summary of Horizontal Shear Strength Properties 69
    6.4.7 Tensile Test 75

6.4.8 Modes of Failure . . . 76
6.4.9 Summary of Tensile Properties . . . 77
6.5 Bond-to-Concrete Strength . . . 84
6.6 Bond Stress vs. Slip at Free End . . . 84

7 Chemical, Physical, and Material Properties of Rebar and Components After Exposure to Aggressive Environments for 300 Days 88
7.1 Introduction . . . 88
7.2 Properties of Exposure Environments after 300 Day Exposure . . . 88
7.2.1 pH . . . 88
7.2.2 Salinity . . . 91
7.2.3 Dissolved oxygen (DO) . . . 106
7.2.4 Alkalinity . . . 115
7.2.5 Anions . . . 128
7.2.6 Metals . . . 151
7.3 Corrosion Behavior of Solid Samples after 300 Days of Exposure under SEM . . . 236
7.3.1 Type A Lot 1 Rebars at day 300 . . . 236
7.3.2 Type B Lot 1 Rebars at day 300 . . . 237
7.3.3 Type C Lot 1 Rebars at day 300 . . . 237
7.3.4 Type A Sized Fibers at day 300 . . . 238
7.3.5 Type A Unsized Fibers at day 300 . . . 238
7.3.6 Type B Sized Fibers at day 300 . . . 239
7.3.7 Type B Unsized Fibers at day 300 . . . 239
7.3.8 Type C Sized Fibers at day 300 . . . 240
7.3.9 Type A Resins at day 300 . . . 240
7.3.10 Type B Resins at day 300 . . . 241
7.4 Mechanical Properties of Components After Exposure to Aggressive Environments . . . 267
7.4.1 Resin Tensile Test . . . 267
7.5 Rebar Mechanical Properties . . . 272
7.5.1 Transverse Shear Test . . . 272
7.5.2 Summary of Transverse Shear Properties . . . 285
7.5.3 Apparent Horizontal Shear Test . . . 287
7.5.4 Summary of Horizontal Shear Strength Properties . . . 300
7.5.5 Tensile Test . . . 302
7.5.6 Summary of Tensile Properties . . . 304
7.5.7 Bond-to-Concrete Strength . . . 318

8 Chemical, Physical, and Material Properties of Rebar and Components After Exposure to Aggressive Environments for 600 Days 325
8.1 Introduction . . . 325
8.2 Properties of Exposure Environments after 600 Day Exposure . . . 325
8.2.1 pH . . . 325
8.2.2 Salinity . . . 335
8.2.3 Dissolved oxygen (DO) . . . 347
8.2.4 Alkalinity . . . 356
8.2.5 Anions . . . 369
8.2.6 Metals . . . 392

8.3 Corrosion Behavior of Solid Samples after 600 Day Exposure under SEM 477
8.3.1 Type A Lot 1 Rebars at day 600 477
8.3.2 Type B Lot 1 Rebars at day 600 478
8.3.3 Type C Lot 1 Rebars at day 600 478
8.3.4 Type A Sized Fibers at day 600 479
8.3.5 Type A Unsized Fibers at day 600 479
8.3.6 Type B Sized Fibers at day 600 480
8.3.7 Type B Unsized Fibers at day 600 480
8.3.8 Type C Sized Fibers at day 600 481
8.3.9 Type A Resins at day 600 482
8.3.10 Type B Resins at day 600 482
8.4 Mechanical Properties of Components After Exposure to Aggressive Environments 510
8.4.1 Resin Tensile Test 510
8.5 Rebar Mechanical Properties 515
8.5.1 Transverse Shear Test 515
8.5.2 Summary of Transverse Shear Properties 528
8.5.3 Apparent Horizontal Shear Test 529
8.5.4 Summary of Horizontal Shear Strength Properties 542
8.5.5 Tensile Test 543
8.5.6 Summary of Tensile Properties 545
8.5.7 Bond-to-Concrete Strength 559

9 BFRP Rebar Characterization and Performance 566
9.1 Research Significance 566
9.2 Significant Findings 567
9.2.1 pH 567
9.2.2 Salinity 567
9.2.3 Dissolved Oxygen (DO) 568
9.2.4 Alkalinity 568
9.2.5 Anions 568
9.2.6 Metals 569
9.2.7 Scanning Electron Microscopic (SEM) Image Analysis 572
9.2.8 Transverse Shear Strength 572
9.2.9 Apparent Horizontal Shear Strength 573
9.2.10 Tensile Properties 573
9.2.11 Bond-to-Concrete Strength 575
9.2.12 BFRP Design Specifications 575
9.3 Supplementary Findings 583
9.3.1 Cross-Sectional Property 583
9.3.2 Fiber Content 583
9.3.3 Moisture Absorption of BFRP Rebar 584
9.4 Limitations 584
9.5 Further Directions 585

10 Proposed BFRP Rebar Specifications 587

11 Long-Term Durability Prediction 588

11.1 Introduction 588
11.2 Previous Durability Studies on BFRP Bars 588
11.3 fib Bulletin 40 Model 589
  11.3.1 FRP Design Strength Equation 590
  11.3.2 Environmental Strength Reduction Factor ($\eta_{env,t}$) 590
  11.3.3 Long-Term Strength 592
11.4 Durability Prediction 594
11.5 Validation of Prediction Model 601
  11.5.1 Long-Term Strength Prediction 603
11.6 Direct comparison to previous FDOT GFRP test results 606
11.7 Durability evaluation using a modified ASTM D7957 Alkaline Resistance Test 607

12 Conclusions **608**
12.1 Summary 608
12.2 Conclusions 609
12.3 Further Recommendations 613

References **615**

Appendices **624**

A Individual Specimen Results **625**
A.1 Density and Cross-Sectional Dimension Test 625
A.2 Fiber Content Test 627
A.3 Transverse Shear Test 628
A.4 Horizontal Shear Test 642
A.5 Tensile Test 656
A.6 Bond-to-Concrete Test 666
A.7 Resin Tensile Test 672

List of Figures

2.1 (a) Basalt rock, (b) Fiber, and (c) Rebar 4
2.2 Total alkali silica 10
2.3 Basalt fiber production process (Ipbüker et al., 2014) 12
2.4 Tensile strength retention of water treated fibers (up to 24 h) 13
2.5 Tensile strength of fibers in 1mol/L HCl for 24 h 13
2.6 Tensile strength of fibers exposed to NaOH solution for 24 h at 100 °C 13
2.7 Quantitative result of basalt fiber (Shi, 2012) 15
2.8 The X-ray diffraction spectroscopy of basalt fiber (Shi, 2012) 15
2.9 The X-ray diffraction spectroscopy of basalt fiber (Iorio et al., 2018) 16
2.10 The X-ray diffraction spectroscopy of basalt fiber (Lipatov et al., 2015) 16
2.11 The X-ray diffraction spectroscopy of basalt fiber (Gutnikov et al., 2013) 17
2.12 Thermoset resin used in FRP 19
2.13 Structure of a vinyl-ester 21
2.14 Schematic of wet-layup process (Banibayat and Patnaik, 2014) 25
2.15 Schematic representation of the pultrusion process (Borges et al., 2015) 26

4.1 Test concept for chemical exposure 38

6.1 Moisture absorption results of all types of resin 46
6.2 All types of sized fibers at different magnifications 48
6.3 All types of unsized fibers at different magnifications 49
6.4 All types of resins at different magnifications 50
6.5 Fiber content percentage of rebars from all manufacturers 54
6.6 Fiber content specimen of rebars after test 54
6.7 Moisture absorption results of rebars from all manufacturers 55
6.8 Extension-transverse shear load behavior of Type A rebars Lot 1 size 3 and 5 58
6.9 Extension-transverse shear load behavior of Type B rebars Lot 1 size 3 and 5 58
6.10 Extension-transverse shear load behavior of Type C rebars Lot 1 size 3 and 5 59
6.11 Extension-transverse shear load behavior of Type A rebars Lot 2 size 3 and 5 59
6.12 Extension-transverse shear load behavior of Type B rebars Lot 2 size 3 and 5 60
6.13 Extension-transverse shear load behavior of Type C rebars Lot 2 size 3 and 5 60
6.14 Transverse shear stress-extension behavior of rebar Type A Lot 1 size 3 and 5 61
6.15 Transverse shear stress-extension results of rebar Type B Lot 1 size 3 and 5 61
6.16 Transverse shear stress-extension results of Type C rebar Lot 1 size 3 and 5 62
6.17 Transverse shear stress-extension behavior of rebar Type A Lot 2 size 3 and 5 62
6.18 Transverse shear stress-extension results of rebar Type B Lot 2 size 3 and 5 63
6.19 Transverse shear stress-extension results of Type C rebar Lot 2 size 3 and 5 63

6.20 Failure pattern for tested rebar after transverse shear test 64
6.21 Extension-horizontal shear load behavior of rebar Type A Lot 1 size 3 and 5 68
6.22 Extension-horizontal shear load behavior of rebar Type B Lot 1 size 3 and 5 69
6.23 Extension-horizontal shear load behavior of Type C rebar Lot 1 size 3 and 5 69
6.24 Extension-horizontal shear load behavior of rebar Type A Lot 2 size 3 and 5 70
6.25 Extension-horizontal shear load behavior of rebar Type B Lot 2 size 3 and 5 70
6.26 Extension-horizontal shear load behavior of Type C rebar Lot 2 size 3 and 5 71
6.27 Horizontal shear stress - extension behavior of rebar Type A Lot 1 size 3 and 5 71
6.28 Horizontal shear stress - extension behavior of rebar Type B Lot 1 size 3 and 5 72
6.29 Horizontal shear stress-extension behavior of Type C rebar Lot 1 size 3 and 5 72
6.30 Horizontal shear stress - extension behavior of rebar Type A Lot 2 size 3 and 5 73
6.31 Horizontal shear stress - extension behavior of rebar Type B Lot 2 size 3 and 5 73
6.32 Horizontal shear stress-extension behavior of Type C rebar Lot 2 size 3 and 5 74
6.33 Failure pattern for tested rebar after horizontal shear test 74
6.34 Tensile strength-displacement behavior of rebar Type A Lot 1 size 3 and 5 76
6.35 Tensile strength-displacement behavior of rebar Type B Lot 1 size 3 and 5 77
6.36 Tensile strength-displacement behavior of Type C rebar Lot 1 size 3 and 5 77
6.37 Tensile strength-displacement behavior of rebar Type A Lot 2 size 3 and 5 78
6.38 Tensile strength-displacement behavior of rebar Type B Lot 2 size 3 and 5 78
6.39 Tensile strength-displacement behavior of Type C rebar Lot 2 size 3 and 5 79
6.40 Tensile stress-strain behavior of rebar Type A Lot 1 rebar size 3 and 5 79
6.41 Tensile stress-strain behavior of rebar Type B Lot 1 rebar size 3 and 5 80
6.42 Tensile stress-strain behavior of Type C rebar Lot 1 rebar size 3 and 5 80
6.43 Tensile stress-strain behavior of rebar Type A Lot 2 rebar size 3 and 5 81
6.44 Tensile stress-strain behavior of rebar Type B Lot 2 rebar size 3 and 5 81
6.45 Tensile stress-strain behavior of Type C rebar Lot 2 size 3 and 5 82
6.46 # 3 rebar final failure pattern after tensile test 82
6.47 # 5 rebar final failure pattern after tensile test 83
6.48 Free end slip behavior of the tested rebar Type A Lot 1 84
6.49 Free end slip behavior of the tested rebar Type B Lot 1 85
6.50 Free end slip behavior of the tested rebar Type C Lot 1 85
6.51 Free end slip behavior of the tested rebar Type A Lot 2 86
6.52 Free end slip behavior of the tested rebar Type B Lot 2 86
6.53 Free end slip behavior of the tested rebar Type C Lot 2 87

7.1 pH of environments after exposure of rebars 92
7.2 pH of environments after exposure of resins 93
7.3 pH of environments after exposure of sized and unsized fibers 94
7.4 Salinity of environments after exposure of rebars 103
7.5 Salinity of environments after exposure of resins 104
7.6 Salinity of environments after exposure of sized and unsized fibers 105
7.7 Dissolved oxygen concentration of environments after exposure of rebars 112
7.8 Dissolved oxygen concentration of environments after exposure of resins 113
7.9 Dissolved oxygen concentration of environments after exposure of sized and unsized fibers . 114
7.10 Alkalinity of environments after exposure of rebars 125
7.11 Alkalinity of environments after exposure of resins 126

7.12 Alkalinity of environments after exposure of sized and unsized fibers 127
7.13 Chloride concentration of all environments after exposure of rebars 137
7.14 Chloride concentration of all environments after exposure of resins 138
7.15 Chloride concentration of all environments after exposure of sized and unsized fibers 139
7.16 Sulfate concentration of all environments after exposure of rebars 148
7.17 Sulfate concentration of all environments after exposure of resins 149
7.18 Sulfate concentration of all environments after exposure of sized and unsized fibers 150
7.19 Aluminum concentration of all environments after exposure of rebars 158
7.20 Aluminum concentration of all environments after exposure of resins 159
7.21 Aluminum concentration of all environments after exposure of sized and unsized fibers . . . 160
7.22 Calcium concentration of all environments after exposure of rebars 168
7.23 Calcium concentration of all environments after exposure of resins 169
7.24 Calcium concentration of all environments after exposure of sized and unsized fibers 170
7.25 Chromium concentration of all environments after exposure of rebars 181
7.26 Chromium concentration of all environments after exposure of resins 182
7.27 Chromium concentration of all environments after exposure of sized and unsized fibers . . . 183
7.28 Iron concentration of all environments after exposure of rebars 191
7.29 Iron concentration of all environments after exposure of resins 192
7.30 Iron concentration of all environments after exposure of sized and unsized fibers 193
7.31 Magnesium concentration of all environments after exposure of rebars 203
7.32 Magnesium concentration of all environments after exposure of resins 204
7.33 Magnesium concentration of all environments after exposure of sized and unsized fibers . . . 205
7.34 Potassium concentration of all environments after exposure of rebars 212
7.35 Potassium concentration of all environments after exposure of resins 213
7.36 Potassium concentration of all environments after exposure of sized and unsized fibers . . . 214
7.37 Silicon concentration of all environments after exposure of rebars 222
7.38 Silicon concentration of all environments after exposure of resins 223
7.39 Silicon concentration of all environments after exposure of sized and unsized fibers 224
7.40 Sodium concentration of all environments after exposure of rebars 233
7.41 Sodium concentration of all environments after exposure of resins 234
7.42 Sodium concentration of all environments after exposure of sized and unsized fibers 235
7.43 Type A Lot 1 rebars at day 300 under 200x magnification 236
7.44 Type A Lot 1 rebars at day 300 under 1000x magnification 237
7.45 Type A Lot 1 rebars at day 300 under 2000x magnification 238
7.46 Type A Lot 1 rebars at day 300 under 5000x magnification 239
7.47 Type B Lot 1 rebars at day 300 under 200x magnification 240
7.48 Type B Lot 1 rebars at day 300 under 1000x magnification 241
7.49 Type B Lot 1 rebars at day 300 under 2000x magnification 242
7.50 Type B Lot 1 rebars at day 300 under 5000x magnification 243
7.51 Type C Lot 1 rebars at day 300 under 200x magnification 244
7.52 Type C Lot 1 rebars at day 300 under 1000x magnification 245
7.53 Type C Lot 1 rebars at day 300 under 2000x magnification 246
7.54 Type C Lot 1 rebars at day 300 under 5000x magnification 247
7.55 Type A sized fibers at day 300 under 200x magnification 248
7.56 Type A sized fibers at day 300 under 2000x magnification 249
7.57 Type A unsized fibers at day 300 under 200x magnification 250

7.58 Type A unsized fibers at day 300 under 2000x magnification 251
7.59 Type B sized fibers at day 300 under 200x magnification 252
7.60 Type B sized fibers at day 300 under 2000x magnification 253
7.61 Type B sized fibers at day 300 under 5000x magnification 254
7.62 Type B unsized fibers at day 300 under 200x magnification 255
7.63 Type B unsized fibers at day 300 under 2000x magnification 256
7.64 Type B unsized fibers at day 300 under 5000x magnification 257
7.65 Type C sized fibers at day 300 under 200x magnification 258
7.66 Type C sized fibers at day 300 under 2000x magnification 259
7.67 Type C sized fibers at day 300 under 5000x magnification 260
7.68 Type A resins at day 300 under 150x magnification 261
7.69 Type A resins at day 300 under 500x magnification 262
7.70 Type A resins at day 300 under 1500x magnification 263
7.71 Type B resins at day 300 under 150x magnification 264
7.72 Type B resins at day 300 under 500x magnification 265
7.73 Type B resins at day 300 under 1500x magnification 266
7.74 300Day Tensile strength-displacement behavior of Type A Resin 268
7.75 300Day Tensile strength-displacement behavior of Type B Resin 269
7.76 300Day Tensile stress - Strain behavior of rebar Type A Resin 270
7.77 300Day Tensile stress - Strain behavior of rebar Type B Resin 271
7.78 300Day Transverse shear force - displacement behavior of Type A Lot1 tested rebars 273
7.79 300Day Transverse shear force - displacement behavior of Type B Lot1 tested rebars 274
7.80 300Day Transverse shear force - displacement behavior of Type C Lot1 tested rebars 275
7.81 300Day Transverse shear force - displacement behavior of Type A Lot2 tested rebars 276
7.82 300Day Transverse shear force - displacement behavior of Type B Lot2 tested rebars 277
7.83 300Day Transverse shear force - displacement behavior of Type C Lot2 tested rebars 278
7.84 300Day Transverse shear stress - displacement behavior of Type A Lot1 tested rebars 279
7.85 300Day Transverse shear stress - displacement behavior of Type B Lot1 tested rebars 280
7.86 300Day Transverse shear stress - displacement behavior of Type C Lot1 tested rebars 281
7.87 300Day Transverse shear stress - displacement behavior of Type A Lot2 tested rebars 282
7.88 300Day Transverse shear stress - displacement behavior of Type B Lot2 tested rebars 283
7.89 300Day Transverse shear stress - displacement behavior of Type C Lot2 tested rebars 284
7.90 300Day Horizontal shear force - displacement behavior of Type A Lot1 tested rebars 288
7.91 300Day Horizontal shear force - displacement behavior of Type B Lot1 tested rebars 289
7.92 300Day Horizontal shear force - displacement behavior of Type C Lot1 tested rebars 290
7.93 300Day Horizontal shear force - displacement behavior of Type A Lot2 tested rebars 291
7.94 300Day Horizontal shear force - displacement behavior of Type B Lot2 tested rebars 292
7.95 300Day Horizontal shear force - displacement behavior of Type C Lot2 tested rebars 293
7.96 300Day Horizontal shear stress - displacement behavior of Type A Lot1 tested rebars 294
7.97 300Day Horizontal shear stress - displacement behavior of Type B Lot1 tested rebars 295
7.98 300Day Horizontal shear stress - displacement behavior of Type C Lot1 tested rebars 296
7.99 300Day Horizontal shear stress - displacement behavior of Type A Lot2 tested rebars 297
7.100 300Day Horizontal shear stress - displacement behavior of Type B Lot2 tested rebars 298
7.101 300Day Horizontal shear stress - displacement behavior of Type C Lot2 tested rebars 299
7.102 300Day Tensile strength-displacement behavior of rebar Type A Lot 1 size 3 and 5 303
7.103 300Day Tensile strength-displacement behavior of rebar Type B Lot 1 size 3 and 5 304

7.104 300Day Tensile strength-displacement behavior of rebar Type C Lot 1 size 3 and 5 305
7.105 300Day Tensile strength-displacement behavior of rebar Type A Lot 2 size 3 and 5 306
7.106 300Day Tensile strength-displacement behavior of rebar Type B Lot 2 size 3 and 5 307
7.107 300Day Tensile strength-displacement behavior of rebar Type C Lot 2 size 3 and 5 308
7.108 300Day Tensile stress - Strain behavior of rebar Type A Lot 1 size 3 and 5 309
7.109 300Day Tensile stress - Strain behavior of rebar Type B Lot 1 size 3 and 5 310
7.110 300Day Tensile stress - Strain behavior of rebar Type C Lot 1 size 3 and 5 311
7.111 300Day Tensile stress - Strain behavior of rebar Type A Lot 2 size 3 and 5 312
7.112 300Day Tensile stress - Strain behavior of rebar Type B Lot 2 size 3 and 5 313
7.113 300Day Tensile stress - Strain behavior of rebar Type C Lot 2 size 3 and 5 314
7.114 Bond stress - slippage behavior of rebar Type A Lot 1 rebars 319
7.115 Bond stress - slippage behavior of rebar Type B Lot 1 rebars 320
7.116 Bond stress - slippage behavior of rebar Type C Lot 1 rebars 321
7.117 Bond stress - slippage behavior of rebar Type A Lot 2 rebars 322
7.118 Bond stress - slippage behavior of rebar Type B Lot 2 rebars 323
7.119 Bond stress - slippage behavior of rebar Type C Lot 2 rebars 324

8.1 pH of environments after exposure of rebars 332
8.2 pH of environments after exposure of resins 333
8.3 pH of environments after exposure of sized and unsized fibers 334
8.4 Salinity of environments after exposure of rebars 344
8.5 Salinity of environments after exposure of resins 345
8.6 Salinity of environments after exposure of sized and unsized fibers 346
8.7 Dissolved oxygen concentration of environments after exposure of rebars 353
8.8 Dissolved oxygen concentration of environments after exposure of resins 354
8.9 Dissolved oxygen concentration of environments after exposure of sized and unsized fibers . 355
8.10 Alkalinity of environments after exposure of rebars 366
8.11 Alkalinity of environments after exposure of resins 367
8.12 Alkalinity of environments after exposure of sized and unsized fibers 368
8.13 Chloride concentration of all environments after exposure of rebars 378
8.14 Chloride concentration of all environments after exposure of resins 379
8.15 Chloride concentration of all environments after exposure of sized and unsized fibers 380
8.16 Sulfate concentration of all environments after exposure of rebars 389
8.17 Sulfate concentration of all environments after exposure of resins 390
8.18 Sulfate concentration of all environments after exposure of sized and unsized fibers 391
8.19 Aluminum concentration of all environments after exposure of rebars 399
8.20 Aluminum concentration of all environments after exposure of resins 400
8.21 Aluminum concentration of all environments after exposure of sized and unsized fibers . . . 401
8.22 Calcium concentration of all environments after exposure of rebars 409
8.23 Calcium concentration of all environments after exposure of resins 410
8.24 Calcium concentration of all environments after exposure of sized and unsized fibers 411
8.25 Chromium concentration of all environments after exposure of rebars 422
8.26 Chromium concentration of all environments after exposure of resins 423
8.27 Chromium concentration of all environments after exposure of sized and unsized fibers . . . 424
8.28 Iron concentration of all environments after exposure of rebars 432
8.29 Iron concentration of all environments after exposure of resins 433

8.30 Iron concentration of all environments after exposure of sized and unsized fibers 434
8.31 Magnesium concentration of all environments after exposure of rebars 444
8.32 Magnesium concentration of all environments after exposure of resins 445
8.33 Magnesium concentration of all environments after exposure of sized and unsized fibers . . . 446
8.34 Potassium concentration of all environments after exposure of rebars 453
8.35 Potassium concentration of all environments after exposure of resins 454
8.36 Potassium concentration of all environments after exposure of sized and unsized fibers . . . 455
8.37 Silicon concentration of all environments after exposure of rebars 463
8.38 Silicon concentration of all environments after exposure of resins 464
8.39 Silicon concentration of all environments after exposure of sized and unsized fibers 465
8.40 Sodium concentration of all environments after exposure of rebars 474
8.41 Sodium concentration of all environments after exposure of resins 475
8.42 Sodium concentration of all environments after exposure of sized and unsized fibers 476
8.43 Type A Lot 1 rebars at day 600 under 200x magnification 477
8.44 Type A Lot 1 rebars at day 600 under 1000x magnification 478
8.45 Type A Lot 1 rebars at day 600 under 2000x magnification 479
8.46 Type A Lot 1 rebars at day 600 under 5000x magnification 480
8.47 Type B Lot 1 rebars at day 600 under 200x magnification 481
8.48 Type B Lot 1 rebars at day 600 under 1000x magnification 482
8.49 Type B Lot 1 rebars at day 600 under 2000x magnification 483
8.50 Type B Lot 1 rebars at day 600 under 5000x magnification 484
8.51 Type C Lot 1 rebars at day 600 under 200x magnification 485
8.52 Type C Lot 1 rebars at day 600 under 1000x magnification 486
8.53 Type C Lot 1 rebars at day 600 under 2000x magnification 487
8.54 Type C Lot 1 rebars at day 600 under 5000x magnification 488
8.55 Type A sized fibers at day 600 under 200x magnification 489
8.56 Type A sized fibers at day 600 under 2000x magnification 490
8.57 Type A sized fibers at day 600 under 5000x magnification 491
8.58 Type A unsized fibers at day 600 under 200x magnification 492
8.59 Type A unsized fibers at day 600 under 2000x magnification 493
8.60 Type A unsized fibers at day 600 under 5000x magnification 494
8.61 Type B sized fibers at day 600 under 200x magnification 495
8.62 Type B sized fibers at day 600 under 2000x magnification 496
8.63 Type B sized fibers at day 600 under 5000x magnification 497
8.64 Type B unsized fibers at day 600 under 200x magnification 498
8.65 Type B unsized fibers at day 600 under 2000x magnification 499
8.66 Type B unsized fibers at day 600 under 5000x magnification 500
8.67 Type C sized fibers at day 600 under 200x magnification 501
8.68 Type C sized fibers at day 600 under 2000x magnification 502
8.69 Type C sized fibers at day 600 under 5000x magnification 503
8.70 Type A resins at day 600 under 150x magnification 504
8.71 Type A resins at day 600 under 500x magnification 505
8.72 Type A resins at day 600 under 1500x magnification 506
8.73 Type B resins at day 600 under 150x magnification 507
8.74 Type B resins at day 600 under 500x magnification 508
8.75 Type B resins at day 600 under 1500x magnification 509

8.76 600Day Tensile strength-displacement behavior of Type A Resin 511
8.77 600Day Tensile strength-displacement behavior of Type B Resin 512
8.78 600Day Tensile stress - Strain behavior of rebar Type A Resin 513
8.79 600Day Tensile stress - Strain behavior of rebar Type B Resin 514
8.80 600Day Transverse shear force - displacement behavior of Type A Lot1 tested rebars 516
8.81 600Day Transverse shear force - displacement behavior of Type B Lot1 tested rebars 517
8.82 600Day Transverse shear force - displacement behavior of Type C Lot1 tested rebars 518
8.83 600Day Transverse shear force - displacement behavior of Type A Lot2 tested rebars 519
8.84 600Day Transverse shear force - displacement behavior of Type B Lot2 tested rebars 520
8.85 600Day Transverse shear force - displacement behavior of Type C Lot2 tested rebars 521
8.86 600Day Transverse shear stress - displacement behavior of Type A Lot1 tested rebars 522
8.87 600Day Transverse shear stress - displacement behavior of Type B Lot1 tested rebars 523
8.88 600Day Transverse shear stress - displacement behavior of Type C Lot1 tested rebars 524
8.89 600Day Transverse shear stress - displacement behavior of Type A Lot2 tested rebars 525
8.90 600Day Transverse shear stress - displacement behavior of Type B Lot2 tested rebars 526
8.91 600Day Transverse shear stress - displacement behavior of Type C Lot2 tested rebars 527
8.92 600Day Horizontal shear force - displacement behavior of Type A Lot1 tested rebars 530
8.93 600Day Horizontal shear force - displacement behavior of Type B Lot1 tested rebars 531
8.94 600Day Horizontal shear force - displacement behavior of Type C Lot1 tested rebars 532
8.95 600Day Horizontal shear force - displacement behavior of Type A Lot2 tested rebars 533
8.96 600Day Horizontal shear force - displacement behavior of Type B Lot2 tested rebars 534
8.97 600Day Horizontal shear force - displacement behavior of Type C Lot2 tested rebars 535
8.98 600Day Horizontal shear stress - displacement behavior of Type A Lot1 tested rebars 536
8.99 600Day Horizontal shear stress - displacement behavior of Type B Lot1 tested rebars 537
8.100 600Day Horizontal shear stress - displacement behavior of Type C Lot1 tested rebars 538
8.101 600Day Horizontal shear stress - displacement behavior of Type A Lot2 tested rebars 539
8.102 600Day Horizontal shear stress - displacement behavior of Type B Lot2 tested rebars 540
8.103 600Day Horizontal shear stress - displacement behavior of Type C Lot2 tested rebars 541
8.104 600Day Tensile strength-displacement behavior of rebar Type A Lot 1 size 3 and 5 544
8.105 600Day Tensile strength-displacement behavior of rebar Type B Lot 1 size 3 and 5 545
8.106 600Day Tensile strength-displacement behavior of rebar Type C Lot 1 size 3 and 5 546
8.107 600Day Tensile strength-displacement behavior of rebar Type A Lot 2 size 3 and 5 547
8.108 600Day Tensile strength-displacement behavior of rebar Type B Lot 2 size 3 and 5 548
8.109 600Day Tensile strength-displacement behavior of rebar Type C Lot 2 size 3 and 5 549
8.110 600Day Tensile stress - Strain behavior of rebar Type A Lot 1 size 3 and 5 550
8.111 600Day Tensile stress - Strain behavior of rebar Type B Lot 1 size 3 and 5 551
8.112 600Day Tensile stress - Strain behavior of rebar Type C Lot 1 size 3 and 5 552
8.113 600Day Tensile stress - Strain behavior of rebar Type A Lot 2 size 3 and 5 553
8.114 600Day Tensile stress - Strain behavior of rebar Type B Lot 2 size 3 and 5 554
8.115 600Day Tensile stress - Strain behavior of rebar Type C Lot 2 size 3 and 5 555
8.116 Bond stress - slippage behavior of rebar Type A Lot 1 rebars 560
8.117 Bond stress - slippage behavior of rebar Type B Lot 1 rebars 561
8.118 Bond stress - slippage behavior of rebar Type C Lot 1 rebars 562
8.119 Bond stress - slippage behavior of rebar Type A Lot 2 rebars 563
8.120 Bond stress - slippage behavior of rebar Type B Lot 2 rebars 564
8.121 Bond stress - slippage behavior of rebar Type C Lot 2 rebars 565

9.1 Gaussian distribution for tensile strength of # 5 rebars 577
9.2 Gaussian distribution for tensile strength of # 3 rebars 578

11.1 Environmental strength reduction factor and 1000h strength for two different GFRP materials with different durability (International Federation for Structural Concrete, 2007) . . . 591
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) 592
11.3 Long-term tensile strength retention of all tested bars (log-log scale) for 60 °C average environment temperature 595
11.4 Long-term transverse shear strength retention of all tested bars (log-log scale) for 60 °C average environment temperature 596
11.5 Long-term horizontal shear strength retention of all tested bars (log-log scale) for 60 °C average environment temperature 597
11.6 Long-term tensile strength retention of all tested bars (semi-log scale) for 60 °C average environment temperature 598
11.7 Long-term transverse shear strength retention of all tested bars (semi-log scale) for 60 °C average environment temperature 599
11.8 Long-term horizontal shear strength retention of all tested bars (semi-log scale) for 60 °C average environment temperature 600
11.9 Tensile strength retention after exposure period 601
11.10 Transverse shear strength retention after exposure period 602
11.11 Horizontal shear strength retention after exposure period 603
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) 604
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) 604
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) 605
11.15 Interpolation of ASTM D7957-17 Alkaline Resistance limit to BFRP Rebar 607

12.1 Chemical Transfer Direction 610

List of Tables

2.1 Mechanical and physical properties of fibers (Singha, 2012) 6
2.2 Thermal properties of fibers (Singha, 2012) 7
2.3 Typical mechanical properties of fibers (Nanni et al., 2014) 7
2.4 Typical Basalt components 8
2.5 Limits for chemical composition of basalt for CBF production 9
2.6 Classification of acidity modulus (Johannesson et al., 2017) 10
2.7 Composition of basalt used in the viscosity equation (Tatarintseva et al., 2012a) 11
2.8 Typical properties of resins (Nanni et al., 2014) 20
2.9 Effect of liquid media at room temperature on the tensile properties of epoxy neat resin (Kajorncheappunngam et al., 2002) 22
2.10 Effect of liquid media at elevated temperature on the tensile properties of epoxy neat resin (Kajorncheappunngam et al., 2002) 22
2.11 Effect of liquid media at room temperature on the tensile properties of glass/epoxy composite (Kajorncheappunngam et al., 2002) 23
2.12 Effect of liquid media at elevated temperature on the tensile properties of glass/epoxy composite (Kajorncheappunngam et al., 2002) 23
2.13 Chemical composition of accelerated solutions (Guo et al., 2018) 27

3.1 Codes and standards for FRP in different countries 28
3.2 Acceptance criteria for properties of fibers for the production of FRP rebars (Imperial Units) 29
3.3 Acceptance criteria for properties of fibers for the production of FRP rebars (Metric Units) 29
3.4 Acceptance criteria for properties of resins for the production of FRP rebars (Imperial Units) 30
3.5 Acceptance criteria for properties of resins for the production of FRP rebars (Metric Units) 30
3.6 Acceptance criteria for cross section measurements of GFRP rebar (Imperial Units) 31
3.7 Acceptance criteria for cross section measurements of BFRP rebar (Imperial Units) 31
3.8 Acceptance criteria for nominal diameters and cross section measurements of GFRP rebar (Metric Units) 32
3.9 Acceptance criteria for nominal diameters and cross section measurements of BFRP rebar (Metric Units) 32
3.10 Acceptance criteria for tensile strength (Imperial Units) 33
3.11 Acceptance criteria for tensile strength (Metric Units) 33
3.12 Acceptance criteria for physical and mechanical characteristics of GFRP rebar (Imperial Units) 34
3.13 Acceptance criteria for physical and mechanical characteristics of BFRP rebar (Imperial Units) 34
3.14 Acceptance criteria for chemical durability of rebar 35

4.1 Test matrix 38
4.2 Tests on individual components of BFRP rebar 39

4.3 Tests on BFRP rebars 40
4.4 Tests on exposure solutions 41

5.1 pH and Salinity results of exposure solutions 43
5.2 Dissolved oxygen and Anions results of exposure solutions 44

6.1 XRF analysis on virgin naked and sized fibers 46
6.2 Diameter of virgin sized and un-sized fibers 47
6.3 pH and salinity results of exposure solutions 52
6.4 Statistical evaluation of diameter measurements for rebar size # 3 and # 5 53
6.5 XRF results of virgin rebars 56
6.6 Transverse Shear test statistical values for each sample group (US Customary Units) 65
6.6 Transverse Shear test statistical values for each sample group (US Customary Units) 66
6.6 Transverse Shear test statistical values for each sample group (US Customary Units) 67
6.6 Transverse Shear test statistical values for each sample group (US Customary Units) 68
6.7 Horizontal Shear test statistical values for each sample group (US Customary Units) 75
6.8 Tensile strength test statistical values for each sample group (US Customary Units) 83

7.1 pH Test Statistical values for All Rebar Sample Groups 89
7.1 pH Test Statistical values for All Rebar Sample Groups 90
7.1 pH Test Statistical values for All Rebar Sample Groups 91
7.2 Salinity Test Statistical values for All Rebar Sample Groups 95
7.2 Salinity Test Statistical values for All Rebar Sample Groups 96
7.2 Salinity Test Statistical values for All Rebar Sample Groups 97
7.2 Salinity Test Statistical values for All Rebar Sample Groups 98
7.3 Salinity Test Statistical values for All Resin Sample Groups 99
7.3 Salinity Test Statistical values for All Resin Sample Groups 100
7.4 Salinity Test Statistical values for All Fiber Sample Groups 101
7.4 Salinity Test Statistical values for All Fiber Sample Groups 102
7.5 Dissolved Oxygen Test Statistical values for All Rebar Sample Groups 106
7.5 Dissolved Oxygen Test Statistical values for All Rebar Sample Groups 107
7.5 Dissolved Oxygen Test Statistical values for All Rebar Sample Groups 108
7.6 Dissolved Oxygen Test Statistical values for All Resin Sample Groups 108
7.6 Dissolved Oxygen Test Statistical values for All Resin Sample Groups 109
7.7 Dissolved Oxygen Test Statistical values for All Fiber Sample Groups 109
7.7 Dissolved Oxygen Test Statistical values for All Fiber Sample Groups 110
7.7 Dissolved Oxygen Test Statistical values for All Fiber Sample Groups 111
7.8 Alkalinity Test Statistical values for All Rebar Sample Groups 116
7.8 Alkalinity Test Statistical values for All Rebar Sample Groups 117
7.8 Alkalinity Test Statistical values for All Rebar Sample Groups 118
7.8 Alkalinity Test Statistical values for All Rebar Sample Groups 119
7.9 Alkalinity Test Statistical values for All Resin Sample Groups 120
7.9 Alkalinity Test Statistical values for All Resin Sample Groups 121
7.10 Alkalinity Test Statistical values for All Fiber Sample Groups 122
7.10 Alkalinity Test Statistical values for All Fiber Sample Groups 123
7.10 Alkalinity Test Statistical values for All Fiber Sample Groups 124
7.11 Chloride Ion Test Statistical values for All Rebar Sample Groups 129

7.11 Chloride Ion Test Statistical values for All Rebar Sample Groups 130
7.11 Chloride Ion Test Statistical values for All Rebar Sample Groups 131
7.11 Chloride Ion Test Statistical values for All Rebar Sample Groups 132
7.12 Chloride Ion Test Statistical values for All Resin Sample Groups 133
7.12 Chloride Ion Test Statistical values for All Resin Sample Groups 134
7.13 Chloride Ion Test Statistical values for All Fiber Sample Groups 135
7.13 Chloride Ion Test Statistical values for All Fiber Sample Groups 136
7.14 Sulfate Ion Test Statistical values for All Rebar Sample Groups 141
7.14 Sulfate Ion Test Statistical values for All Rebar Sample Groups 142
7.14 Sulfate Ion Test Statistical values for All Rebar Sample Groups 143
7.14 Sulfate Ion Test Statistical values for All Rebar Sample Groups 144
7.15 Sulfate Ion Test Statistical values for All Resin Sample Groups 145
7.16 Sulfate Ion Test Statistical values for All Fiber Sample Groups 146
7.16 Sulfate Ion Test Statistical values for All Fiber Sample Groups 147
7.17 Aluminum Test Statistical values for All Rebar Sample Groups 151
7.17 Aluminum Test Statistical values for All Rebar Sample Groups 152
7.17 Aluminum Test Statistical values for All Rebar Sample Groups 153
7.18 Aluminum Test Statistical values for All Resin Sample Groups 154
7.18 Aluminum Test Statistical values for All Resin Sample Groups 155
7.19 Aluminum Test Statistical values for All Fiber Sample Groups 156
7.19 Aluminum Test Statistical values for All Fiber Sample Groups 157
7.20 Calcium Test Statistical values for All Rebar Sample Groups 161
7.20 Calcium Test Statistical values for All Rebar Sample Groups 162
7.20 Calcium Test Statistical values for All Rebar Sample Groups 163
7.21 Calcium Test Statistical values for All Resin Sample Groups 164
7.21 Calcium Test Statistical values for All Resin Sample Groups 165
7.22 Calcium Test Statistical values for All Fiber Sample Groups 166
7.22 Calcium Test Statistical values for All Fiber Sample Groups 167
7.23 Chromium Test Statistical values for All Rebar Sample Groups 172
7.23 Chromium Test Statistical values for All Rebar Sample Groups 173
7.23 Chromium Test Statistical values for All Rebar Sample Groups 174
7.23 Chromium Test Statistical values for All Rebar Sample Groups 175
7.24 Chromium Test Statistical values for All Resin Sample Groups 176
7.24 Chromium Test Statistical values for All Resin Sample Groups 177
7.25 Chromium Test Statistical values for All Fiber Sample Groups 178
7.25 Chromium Test Statistical values for All Fiber Sample Groups 179
7.25 Chromium Test Statistical values for All Fiber Sample Groups 180
7.26 Iron Test Statistical values for All Rebar Sample Groups 184
7.26 Iron Test Statistical values for All Rebar Sample Groups 185
7.26 Iron Test Statistical values for All Rebar Sample Groups 186
7.27 Iron Test Statistical values for All Resin Sample Groups 187
7.27 Iron Test Statistical values for All Resin Sample Groups 188
7.28 Iron Test Statistical values for All Fiber Sample Groups 189
7.28 Iron Test Statistical values for All Fiber Sample Groups 190
7.29 Magnesium Test Statistical values for All Rebar Sample Groups 195
7.29 Magnesium Test Statistical values for All Rebar Sample Groups 196

7.29 Magnesium Test Statistical values for All Rebar Sample Groups 197
7.29 Magnesium Test Statistical values for All Rebar Sample Groups 198
7.30 Magnesium Test Statistical values for All Resin Sample Groups 199
7.31 Magnesium Test Statistical values for All Fiber Sample Groups 200
7.31 Magnesium Test Statistical values for All Fiber Sample Groups 201
7.31 Magnesium Test Statistical values for All Fiber Sample Groups 202
7.32 Potassium Test Statistical values for All Rebar Sample Groups 206
7.32 Potassium Test Statistical values for All Rebar Sample Groups 207
7.32 Potassium Test Statistical values for All Rebar Sample Groups 208
7.33 Potassium Test Statistical values for All Resin Sample Groups 208
7.33 Potassium Test Statistical values for All Resin Sample Groups 209
7.34 Potassium Test Statistical values for All Fiber Sample Groups 209
7.34 Potassium Test Statistical values for All Fiber Sample Groups 210
7.34 Potassium Test Statistical values for All Fiber Sample Groups 211
7.35 Silicon Test Statistical values for All Rebar Sample Groups 215
7.35 Silicon Test Statistical values for All Rebar Sample Groups 216
7.35 Silicon Test Statistical values for All Rebar Sample Groups 217
7.36 Silicon Test Statistical values for All Resin Sample Groups 218
7.36 Silicon Test Statistical values for All Resin Sample Groups 219
7.37 Silicon Test Statistical values for All Fiber Sample Groups 220
7.37 Silicon Test Statistical values for All Fiber Sample Groups 221
7.38 Sodium Test Statistical values for All Rebar Sample Groups 226
7.38 Sodium Test Statistical values for All Rebar Sample Groups 227
7.38 Sodium Test Statistical values for All Rebar Sample Groups 228
7.38 Sodium Test Statistical values for All Rebar Sample Groups 229
7.39 Sodium Test Statistical values for All Resin Sample Groups 230
7.40 Sodium Test Statistical values for All Fiber Sample Groups 231
7.40 Sodium Test Statistical values for All Fiber Sample Groups 232
7.41 Transverse Shear test statistical values for each sample group (US Customary Units) 285
7.41 Transverse Shear test statistical values for each sample group (US Customary Units) 286
7.41 Transverse Shear test statistical values for each sample group (US Customary Units) 287
7.42 Horizontal Shear test statistical values for each sample group (US Customary Units) 300
7.42 Horizontal Shear test statistical values for each sample group (US Customary Units) 301
7.42 Horizontal Shear test statistical values for each sample group (US Customary Units) 302
7.43 300Day Tensile strength test statistical values for each sample group (US Customary Units) 315
7.43 300Day Tensile strength test statistical values for each sample group (US Customary Units) 316
7.43 300Day Tensile strength test statistical values for each sample group (US Customary Units) 317

8.1 pH Test Statistical values for All Rebar Sample Groups 326
8.1 pH Test Statistical values for All Rebar Sample Groups 327
8.1 pH Test Statistical values for All Rebar Sample Groups 328
8.2 pH Test Statistical values for All Resin Sample Groups 328
8.2 pH Test Statistical values for All Resin Sample Groups 329
8.3 pH Test Statistical values for All Fiber Sample Groups 329
8.3 pH Test Statistical values for All Fiber Sample Groups 330
8.3 pH Test Statistical values for All Fiber Sample Groups 331

8.4 Salinity Test Statistical values for All Rebar Sample Groups 336
8.4 Salinity Test Statistical values for All Rebar Sample Groups 337
8.4 Salinity Test Statistical values for All Rebar Sample Groups 338
8.4 Salinity Test Statistical values for All Rebar Sample Groups 339
8.5 Salinity Test Statistical values for All Resin Sample Groups 340
8.5 Salinity Test Statistical values for All Resin Sample Groups 341
8.6 Salinity Test Statistical values for All Fiber Sample Groups 342
8.6 Salinity Test Statistical values for All Fiber Sample Groups 343
8.7 Dissolved Oxygen Test Statistical values for All Rebar Sample Groups 347
8.7 Dissolved Oxygen Test Statistical values for All Rebar Sample Groups 348
8.7 Dissolved Oxygen Test Statistical values for All Rebar Sample Groups 349
8.8 Dissolved Oxygen Test Statistical values for All Resin Sample Groups 349
8.8 Dissolved Oxygen Test Statistical values for All Resin Sample Groups 350
8.9 Dissolved Oxygen Test Statistical values for All Fiber Sample Groups 350
8.9 Dissolved Oxygen Test Statistical values for All Fiber Sample Groups 351
8.9 Dissolved Oxygen Test Statistical values for All Fiber Sample Groups 352
8.10 Alkalinity Test Statistical values for All Rebar Sample Groups 357
8.10 Alkalinity Test Statistical values for All Rebar Sample Groups 358
8.10 Alkalinity Test Statistical values for All Rebar Sample Groups 359
8.10 Alkalinity Test Statistical values for All Rebar Sample Groups 360
8.11 Alkalinity Test Statistical values for All Resin Sample Groups 361
8.11 Alkalinity Test Statistical values for All Resin Sample Groups 362
8.12 Alkalinity Test Statistical values for All Fiber Sample Groups 363
8.12 Alkalinity Test Statistical values for All Fiber Sample Groups 364
8.12 Alkalinity Test Statistical values for All Fiber Sample Groups 365
8.13 Chloride Ion Test Statistical values for All Rebar Sample Groups 370
8.13 Chloride Ion Test Statistical values for All Rebar Sample Groups 371
8.13 Chloride Ion Test Statistical values for All Rebar Sample Groups 372
8.13 Chloride Ion Test Statistical values for All Rebar Sample Groups 373
8.14 Chloride Ion Test Statistical values for All Resin Sample Groups 374
8.14 Chloride Ion Test Statistical values for All Resin Sample Groups 375
8.15 Chloride Ion Test Statistical values for All Fiber Sample Groups 376
8.15 Chloride Ion Test Statistical values for All Fiber Sample Groups 377
8.16 Sulfate Ion Test Statistical values for All Rebar Sample Groups 382
8.16 Sulfate Ion Test Statistical values for All Rebar Sample Groups 383
8.16 Sulfate Ion Test Statistical values for All Rebar Sample Groups 384
8.16 Sulfate Ion Test Statistical values for All Rebar Sample Groups 385
8.17 Sulfate Ion Test Statistical values for All Resin Sample Groups 386
8.18 Sulfate Ion Test Statistical values for All Fiber Sample Groups 387
8.18 Sulfate Ion Test Statistical values for All Fiber Sample Groups 388
8.19 Aluminum Test Statistical values for All Rebar Sample Groups 392
8.19 Aluminum Test Statistical values for All Rebar Sample Groups 393
8.19 Aluminum Test Statistical values for All Rebar Sample Groups 394
8.20 Aluminum Test Statistical values for All Resin Sample Groups 395
8.20 Aluminum Test Statistical values for All Resin Sample Groups 396
8.21 Aluminum Test Statistical values for All Fiber Sample Groups 397

8.21 Aluminum Test Statistical values for All Fiber Sample Groups 398
8.22 Calcium Test Statistical values for All Rebar Sample Groups 402
8.22 Calcium Test Statistical values for All Rebar Sample Groups 403
8.22 Calcium Test Statistical values for All Rebar Sample Groups 404
8.23 Calcium Test Statistical values for All Resin Sample Groups 405
8.23 Calcium Test Statistical values for All Resin Sample Groups 406
8.24 Calcium Test Statistical values for All Fiber Sample Groups 407
8.24 Calcium Test Statistical values for All Fiber Sample Groups 408
8.25 Chromium Test Statistical values for All Rebar Sample Groups 413
8.25 Chromium Test Statistical values for All Rebar Sample Groups 414
8.25 Chromium Test Statistical values for All Rebar Sample Groups 415
8.25 Chromium Test Statistical values for All Rebar Sample Groups 416
8.26 Chromium Test Statistical values for All Resin Sample Groups 417
8.26 Chromium Test Statistical values for All Resin Sample Groups 418
8.27 Chromium Test Statistical values for All Fiber Sample Groups 419
8.27 Chromium Test Statistical values for All Fiber Sample Groups 420
8.27 Chromium Test Statistical values for All Fiber Sample Groups 421
8.28 Iron Test Statistical values for All Rebar Sample Groups 425
8.28 Iron Test Statistical values for All Rebar Sample Groups 426
8.28 Iron Test Statistical values for All Rebar Sample Groups 427
8.29 Iron Test Statistical values for All Resin Sample Groups 428
8.29 Iron Test Statistical values for All Resin Sample Groups 429
8.30 Iron Test Statistical values for All Fiber Sample Groups 430
8.30 Iron Test Statistical values for All Fiber Sample Groups 431
8.31 Magnesium Test Statistical values for All Rebar Sample Groups 436
8.31 Magnesium Test Statistical values for All Rebar Sample Groups 437
8.31 Magnesium Test Statistical values for All Rebar Sample Groups 438
8.31 Magnesium Test Statistical values for All Rebar Sample Groups 439
8.32 Magnesium Test Statistical values for All Resin Sample Groups 440
8.33 Magnesium Test Statistical values for All Fiber Sample Groups 441
8.33 Magnesium Test Statistical values for All Fiber Sample Groups 442
8.33 Magnesium Test Statistical values for All Fiber Sample Groups 443
8.34 Potassium Test Statistical values for All Rebar Sample Groups 447
8.34 Potassium Test Statistical values for All Rebar Sample Groups 448
8.34 Potassium Test Statistical values for All Rebar Sample Groups 449
8.35 Potassium Test Statistical values for All Resin Sample Groups 449
8.35 Potassium Test Statistical values for All Resin Sample Groups 450
8.36 Potassium Test Statistical values for All Fiber Sample Groups 450
8.36 Potassium Test Statistical values for All Fiber Sample Groups 451
8.36 Potassium Test Statistical values for All Fiber Sample Groups 452
8.37 Silicon Test Statistical values for All Rebar Sample Groups 456
8.37 Silicon Test Statistical values for All Rebar Sample Groups 457
8.37 Silicon Test Statistical values for All Rebar Sample Groups 458
8.38 Silicon Test Statistical values for All Resin Sample Groups 459
8.38 Silicon Test Statistical values for All Resin Sample Groups 460
8.39 Silicon Test Statistical values for All Fiber Sample Groups 461

8.39 Silicon Test Statistical values for All Fiber Sample Groups 462
8.40 Sodium Test Statistical values for All Rebar Sample Groups 467
8.40 Sodium Test Statistical values for All Rebar Sample Groups 468
8.40 Sodium Test Statistical values for All Rebar Sample Groups 469
8.40 Sodium Test Statistical values for All Rebar Sample Groups 470
8.41 Sodium Test Statistical values for All Resin Sample Groups 471
8.42 Sodium Test Statistical values for All Fiber Sample Groups 472
8.42 Sodium Test Statistical values for All Fiber Sample Groups 473
8.43 600Day Transverse Shear test statistical values for each sample group (US Customary Units) 528
8.43 600Day Transverse Shear test statistical values for each sample group (US Customary Units) 529
8.44 600Day Horizontal Shear test statistical values for each sample group (US Customary Units) 542
8.44 600Day Horizontal Shear test statistical values for each sample group (US Customary Units) 543
8.45 600Day Tensile strength test statistical values for each sample group (US Customary Units) 556
8.45 600Day Tensile strength test statistical values for each sample group (US Customary Units) 557
8.45 600Day Tensile strength test statistical values for each sample group (US Customary Units) 558

9.1 Guaranteed tensile strength of tested rebars a day 0 (virgin bars) 579
9.2 Guaranteed tensile strength of tested rebars after 300 d of exposure 580
9.2 Guaranteed tensile strength of tested rebars after 300 d of exposure 581
9.2 Guaranteed tensile strength of tested rebars after 300 d of exposure 582

11.1 Influence factors 593
11.2 Differences in predicted and tested tensile strength retention percentage of all GFRP bars . 605

A.1 Diameter measurements for each individual specimen 625
A.2 Fiber content test results for each individual specimen 627
A.3 Transverse shear test results (ultimate values) for each individual specimen 628
A.4 Horizontal shear test results (ultimate values) for each individual specimen 642
A.5 Tensile strength test results (ultimate values) for each individual specimen 656
A.6 Bond-to-concrete strength test results for each individual specimen (Imperial Units) 667
A.7 Resin tensile strength test results (ultimate values) for each individual specimen 673