Inspection and Monitoring of Fabrication and Construction for the West Halls River Road Bridge Replacement

Contract Number BDV30-706-01
FSU Project ID 038971

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TASK 3 Deliverable: One-year Report
(Part B – Durability Tests at 18 Months)

Draft 1 submitted June 22, 2020

Inspection and Monitoring of Fabrication and Construction for the West Halls River Road Bridge Replacement

Research Report

Deliverable 3 (Task 3: Durability Tests Referenced in Task 1-C after extraction of Test Blocks)

FDOT Contract Number: BDV30 TWO 706-01

University Subcontract No.: R01871

Subcontract Period of Performance: January 1, 2017 – January 9, 2021

Submitted to: FAMU-FSU College of Engineering

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Submitted on: June 20, 2020

Controls:	
Superseded Report	New Report
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Effective Date	June 20, 2020

Test Report Approval Signature:	
Quality review Approval	I indicate that I have reviewed this Test Report and agree with the contents it presents as it meets all applicable laboratory requirements and policies. I approve for its release to the interested party. Name: Guillermo Claure Signature: Date: June 20, 2020
Technical review Approval	I indicate that I have reviewed this Test Report and agree with the contents it presents as it meets all applicable laboratory requirements and policies. I approve for its release to the interested party. Name: Antonio Nanni Signature: Date: June 20, 2020

Quality System: The Structures and Materials Laboratory (SML) maintains a quality system in compliance with ISO 17025-2017, accredited under International Accreditation Service (IAS), testing laboratory TL-478 and is a qualified laboratory by the Florida Department of Transportation (FDOT) number ISM028. All the test results presented herein are linked through unbroken chain data. Analyzed data is obtained directly from the recorded raw data during testing, from which the test results are presented. This report contains analyzed tabulated data results.

Procedures: All tests and services are conducted in accordance with the SML Quality Manual (Version 3.0) revised January 31, 2017; relevant standard operating procedures (SOPs); and with the applicable requirements of the reference standard test methods, unless otherwise stated.

Disclosure: This document may contain confidential information; please contact an authorized entity prior to distributing. Conclusions reached and opinions offered in this document are based upon the data and information available to at the time of its issue, and may be subject to revision as additional information or data becomes available.

EXECUTIVE SUMMARY

This certified test report for the durability program of the West Halls River Road Bridge Replacement project provides experimental results to evaluate fundamental physio-mechanical and more importantly durability properties of concrete and nominal #5 BFRP, CFRP and GFRP rebars exposed to site conditions as per TASK 3 ‘Durability Tests – after Test Block extraction’.

All experimental tests are conducted in accordance with ISO standards, ASTM and/or FDOT Specifications. Sections 2 of this document reports summary of test results as well as information regarding concrete and rebar samples.

Based on the results presented herein, the following preliminary conclusions can be inferred based on the data presented:

Overall as indicated quantitatively herein, the thermal/mechanical properties evaluation of aged/exposed BFRP, CFRP, and GFRP rebars result in equivalent or higher magnitudes than respective reference ASTM and/or FDOT specifications. In terms of results after eighteen-month exposure, test values tend to be lower that benchmark counterparts; but in all cases, test values still show to be higher than respective reference ASTM and /or FDOT specification.

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1. INTRODUCTION

1.1. BACKGROUND

The aim of the work is to inspect properties of materials exposed in seawater for 18 months as part of the Halls River Bridge Replacement Project and assess if these alternatives are suitable for applications in presence of chlorides.
The deliverables from the research will be submitted to Florida Department of Transportation (FDOT) and Federal Highway Administration (FHWA) to be shared with States that wish to consider implementing these material systems in bridge component with fiber reinforced polymer (FRP) rebars used as primary reinforcement.

1.2. OBJECTIVE

This report presents experimental physio-mechanical test results on Glass FRP (GFRP), Basalt FRP (BFRP) and Carbon FRP (CFRP) as well as concrete composition. The report provides results to evaluate fundamental mechanical and durability properties of nominal #5 FRP rebars and Concrete Class V following existing international material specifications (ASTM, ISO, CSA, ICC-ES), federal and state agencies (FHWA, FDOT), and mainly ASTM D7957 - 2017 'Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement' as well as Florida Department of Transportation – FDOT Specifications 932 and 933 'Nonmetallic Accessory Materials for Concrete Pavement and Concrete Structures'. For that, Section 2 of this report provides description of tests and summary tables with average results corresponding to tests referenced to TASK 1-C of TASK 3 'Durability Tests – after Test Block extraction' for concrete and each rebar type.

1.3. REFERENCE CRITERIA

Reference criteria: ASTM D7957 and FDOT Specifications 932 & 933.
ASTM D7957 covers the requirements for GFRP rebars; and, FDOT Specs. 932 & 933 were taken as reference for specific requirements for BFRP rebars and CFRP strands.

2. DELIVERABLE 3 - TASK 3

After Test Block Extraction (tests referenced to Task 1-C after eighteen-month exposure)

2.1. CONCRETE SAMPLE INFORMATION

The test results that are presented provide the eighteen-month-aged physio-mechanical properties for the samples under valuation. The extracted test blocks come from the portion of seawall technically called wall-3B (see Figure 1).

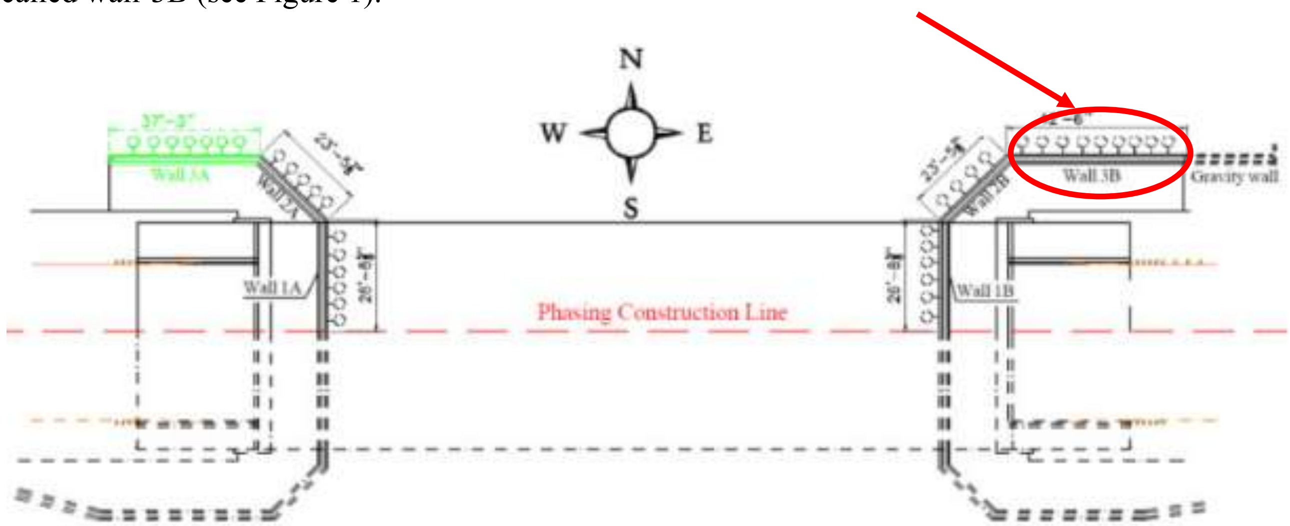


Figure 1 – Aerial picture of the bridge with Wall 3B blocks identification

The wall 3B is situated on the North-eastern seawall cast on the first of February, 2018. It was not until the 26th of the same month that all the temporary sheet piles confining such area were removed and the intended test blocks were exposed to natural environment. For this reason, the research team adopted 26th of February as day-zero.

The eighteen-month extraction activities were scheduled and started on 28th of September 2019. After removal was successfully completed, a total of 3 5-foot concrete blocks and 10 2.5-foot concrete blocks were shipped to Miami.

The thirteen test blocks from wall 3B were successfully delivered at SML where the research team at SML conducted the following activities on the third of October.

The research team at SML initially stored the blocks in a control environment, as shown in Figure 7. The blocks were carefully moved and placed with the aim of a forklift and measured to confirm actual sizes and make sure that during extraction and shipping activities there was no loss of material. The measured cross-section blocks confirmed site-geometry of the original test blocks: 12.25”x7.5” as previously shown in Figure 2.

Figure 2 – Initial storing at SML of the wall-3A test blocks

On the 10th of October the activities of bars extraction started on the thirteen samples using a sledge hammer and a Hilti DD 30. Block after block, the concrete was carefully crushed to extract the internal rebars (Figure 3).

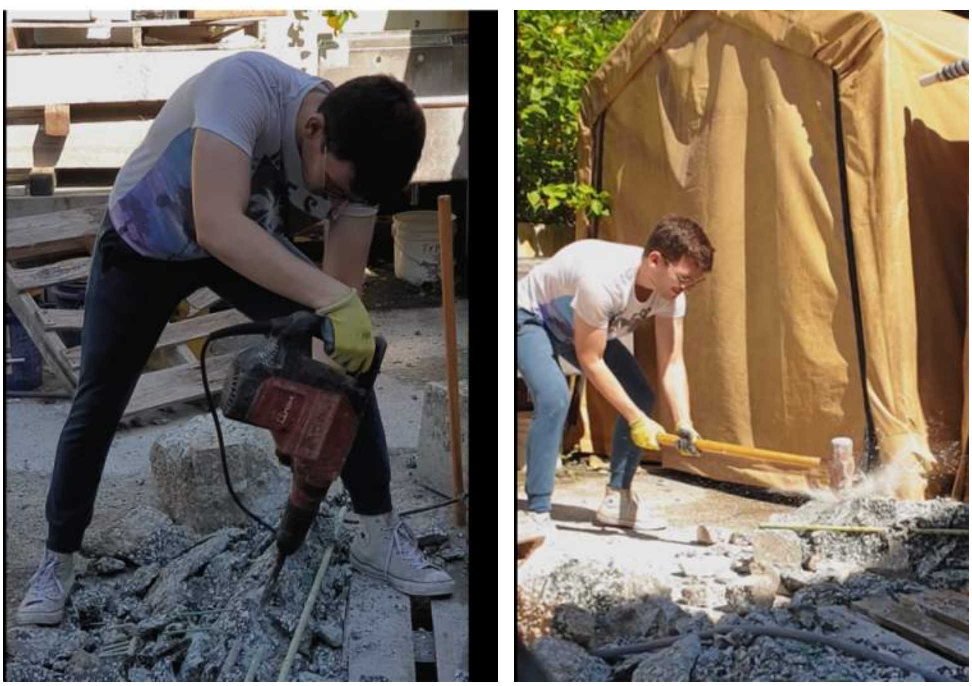


Figure 3 – Rebar extraction

Additionally, from each of the blocks, twelve cores 2”x4” were drilled with a rotary 2” by 4” drilling machine and shipped to FDOT as shown in Figure 4.

Figure 4 – Coring activities on test blocks

2.1.1. SUMMARY OF TEST RESULTS ON CONCERE SAMPLE – 18-MONTH EXPOSURE

Test ID	Standard Test Method	Test Description	Benchmark**	Test Value	Comparing to Benchmark**	Comparing to Reference*
CONCRETE SAMPLE						
CS	ASTM C39/ASTM C496	Concrete Compressive Strength	7,428 psi	7,078psi	95%	129%
PC	ASTM C1202	Penetration of chloride ion into concrete	Pending	Pending	Pending	N/A
PH	N/A	PH concrete test	12.22	12.32	100.8%	N/A
S	N/A	Stiffness test	5,033,333 psi-in	4,800,000 psi-in	95%	143%
FTIR	N/A	Fourier Transform Infrared (FTIR) spectroscopy test	N/A	Pending	N/A	N/A

**FDOT Class V with strength of 5,500 psi and stiffness of 3,400 ksi-in.*
***Benchmark values from Deliverable 1 test results*
N/A: Not Applicable as no standard test or minimum requirements are available

2.1.1.1. CONCRETE COMPRESSIVE STRENGTH RESULTS

Test Standard Method: ASTM C39, Standard test method for concrete compressive strength.
Test Description: A compressive axial load is applied to molded cylinders or cores until failure occurs. The compressive strength of the specimen is calculated by dividing the maximum load achieved during the test by the cross-sectional area of the specimen. The results of this test method are used as a basis for quality control of concrete.
Technician/s: Guillermo Claure, Salvatore Caruso, Roger Solis
Specimen Preparation: Concrete cylinders with dimensions of 100 x 200 mm were cast and cured in the field per ASTM C31. After being collected and brought to the laboratory, sulfur capping was applied on all the specimens per ASTM C617. Compressive strength of each specimen was measured per ASTM C39.
Reference TDS: Technical Data Sheet: TDS-CS-HRB-18M
Test Data:

Specimen ID	Peak force P_{max}		Compressive Strength f'_c		Benchmark** f'_c		Compressive Strength Retention	Comparing to Reference*
	kN	lbf	MPa	psi	MPa	psi	%	%
HRB-18M-CS-001	391.9	88,100	48.6	7,048			95%	128%
HRB-18M-CS-002	396.8	89,200	49.6	7,194	51.2	7,428	97%	131%
HRB-18M-CS-003	395.0	88,800	48.2	6,992			94%	127%
Average	394.6	88,700	48.8	7,078			95%	129%
S_{n-1}	2.48	557	0.72	104				
CV (%)	0.63	0.63	1.47	1.47				

**FDOT Class V with strength of 5,500 psi*
***Benchmark values from Deliverable 1 test results*

2.1.1.1. PENETRATION OF CHLORIDE ION INTO CONCRETE

Test Standard Method: ASTM C1202, Standard test method for penetration of chloride ion into concrete.

Test Description: This test method covers the determination of the electrical conductance of concrete to provide a rapid indication of its resistance to the penetration of chloride ions. This test method is applicable to types of concrete where correlations have been established between this test procedure and long-term chloride ponding procedures

Technician/s: Guillermo Claure, Thomas Cadenazzi, Roger Solis

Specimen Preparation: Concrete cylinders with the diameter of 100 mm were cured for 56 days in accordance with the standard curing procedure of Practice C31/C31M for specimens prepared in the field. a 50 ± 3 mm slice from the top of the cylinder was cut using the water-cooled diamond saw. Side surface of the specimens were covered with rapid setting coating. Specimens were vacuum saturated with both end faces exposed. After mounting specimen in the Cell Test, a potential difference of 60 V dc is maintained across the ends of the specimen, one of which is immersed in a sodium chloride solution, the other in a sodium hydroxide solution. The total charge passed after 6 hours, in coulombs, will be recorded.

Reference TDS: Technical Data Sheet: TDS-PC-HRB-18M

Test Data:

Specimen ID	Charge Passed (coulombs)	Benchmark** (coulombs)	Comparing to Benchmark** %
HRB-18M_PC-001	0		
HRB-18M_PC-002	0	Test results pending	
HRB-18M_PC-003	0		
Average	0.00		
S_{n-1}	0.00		
CV (%)			

***Benchmark values from Deliverable 1 test results*

2.1.1.2. PH CONCRETE TEST

Test Standard Method: Laboratory Method
Test Description: To measure the pH of solid materials such concrete, an aqueous solution of the powdered material is created. The pH is then calculated using a pH strip. The pH scale measures 0 to 14; the lower the number, the more acidic a substance is. A neutral pH value is 7. A value less than 7 is acidic, while a value greater than 7 is basic.
Technician/s: Guillermo Claure, Thomas Cadenazzi, Roger Solis
Specimen Preparation: Concrete was ground at different depth using sand paper. Few grams of the collected powder will be diluted in distilled water with a 1:1 ratio which will be tested using pH strip.
Reference TDS: Technical Data Sheet: TDS-PH-HRB-18M
Test Data:

Specimen ID	**pH**	**Benchmark****	**Comparing to Benchmark****
		pH	**%**
HRB-18M_PH-001	12.30		100.7%
HRB-18M_PH-002	12.33	12.22	100.9%
HRB-18M_PH-003	12.32		100.8%
Average	12.32		100.8%
S_{n-1}	0.02		
CV (%)	0.12		

***Benchmark values from Deliverable 1 test results*

2.1.1.3. STIFFNESS

Test Standard Method: Laboratory Method
Test Description: A compressive axial load is applied to molded cylinders or cores until failure occurs. The stiffness of the specimen is calculated by dividing the maximum load achieved during the test by the displacement produced by the force along the same degree of freedom. The results of this test method are used as a basis for quality control of concrete.
Technician/s: Guillermo Claure, Thomas Cadenazzi, Roger Solis
Specimen Preparation: Concrete cylinders with the dimensions of 100 x 200 mm, cast and cured in the field per ASTM C31, were tested in order to measure the Static Modulus of Elasticity of the concrete per ASTM C469. These values will be used to calculate the stiffness.
Reference TDS: Technical Data Sheet: TDS-S-HRB-18M
Test Data:

Specimen ID	**Stiffness E**		**Benchmark** Stiffness E**		**Stiffness Retention**	**Comparing to Reference***
	MPa.mm	**Psi-in**	**MPa.mm**	**Psi-in**	**%**	**%**
HRB-18M-CS-001	21,574	4,850,000			96%	143%
HRB-18M-CS-002	21,129	4,750,000	22,389	5,033,333	94%	140%
HRB-18M-CS-003	21,351	4,800,000			95%	141%
Average	21,351	4,800,000			95%	143%
S_{n-1}	222	50,000				
CV (%)	1.04	1.04				

**FDOT Class V with stiffness of 3,400 ksi-in.*
***Benchmark values from Deliverable 1 test results*

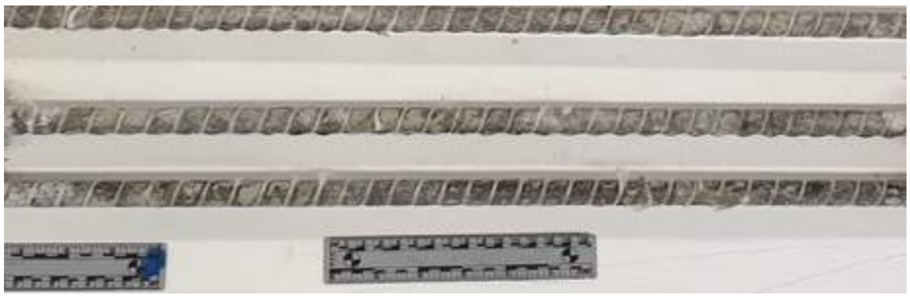
2.1.1.4. FOURIER TRANSFORM INFRARED SPECTROSCOPY

Test Standard Method:	Laboratory Method
Test Description:	Fourier-transform infrared spectroscopy (FTIR) is a well-established spectroscopic method in the analysis of small molecules and protein secondary structure. This technique is used to obtain an infrared spectrum of absorption, emission, photoconductivity or Raman scattering of a solid, liquid or gas. An FTIR spectrometer simultaneously collects spectral data in a wide spectral range.
Technician/s:	Guillermo Claure, Thomas Cadenazzi, Roger Solis
Specimen Preparation:	Concrete was ground at different depth of the cylinders using sand paper. Collected powder was tested using Fourier Transform Infrared spectroscopy in order to study the chemical changes in the concrete due to exposure conditions. IR spectra of the detected hydration phases will provide a qualitative method for microstructural evaluation.
Reference TDS:	Technical Data Sheet: TDS-FTIR-HRB-18M
Test Graphs:	

Results Pending

2.2. REBAR SAMPLE INFORMATION

The research team at SML extracted the six #5 (two CFRP, two GFRP, and two BFRP) rebars from each concrete block received.

Sample No.	Location Reference / Position	Nominal Rebar Denomination	Material type
1	TEST BLOCK BULKHEAD CAP 3B – POSITION I, II	#5	BFRP rebar
			
2	TEST BLOCK BULKHEAD CAP 3B – POSITION III, IV	#5	CFRP rebar
			
3	TEST BLOCK BULKHEAD CAP 3B – POSITION V, VI	#5	GFRP rebar
			

ID/Ref. is given based on their position in the blocks as shown in Figure 5. BFRP bars were located in position I and II, CFRP bars were located in position III and IV, and GFRP bars were located in position V and VI.

The research team at SML extracted the six #5 (two CFRP, two GFRP, and two BFRP) rebars from each concrete block. The concrete blocks were extracted with a Hilti DD 30-W and a sledgehammer. The task was accomplished smoothly and all the rebars were extracted with minimal damage as shown in Figure 5.

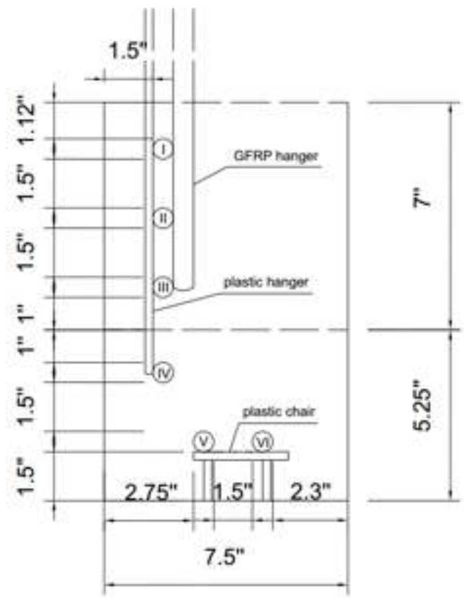


Figure 5. Test blocks cross-section view

All blocks of wall 3B confirmed field-scheme of Figure 5, where BFRP bars were located in position I and II, CFRP bars were located in position III and IV, and GFRP bars were located in position V and VI of scheme in Figure 5. Aside from rebar extraction, on the same day, twelve 2” x 4” cylindrical concrete specimens were cored with a rotary 2” x 4” core drilling machine for respective concrete testing.

2.2.1. SUMMARY OF TEST RESULTS ON REBAR SAMPLES

Test ID	Standard Test Method	Test Description	Benchmark**	Test Value	Comparing to Benchmark**	Comparing to Reference*
		SAMPLE No. 1 BFRP				
TSS	ASTM D7617	Transverse shear strength	29.86 ksi	56.84 ksi	190.34 %	299.13 %
HSS	ASTM D4475	Horizontal shear strength	5.72 ksi	5.69 ksi	99.55 %	N/A
FC	ASTM D2584	Fiber Content (by weight)	81.75 %	80.49 %	98.46 %	115.00 %
DMA	ASTM E1640	Glass transition temperature by Dynamic Mechanical Analysis	101 °C	112 °C	110.23 %	111.70 %
TNS	ASTM D7205	Guar. Tensile Force	33.1 kip	35.9 kip	108.27 %	122.69 %
		Tensile Modulus of Elasticity	≥ 6.5 Msi	8.2 Msi		
		Strain	≥ 1.1 %	3.24 %		
MXA	ASTM D792	Measured Cross Sectional Area	0.292 in^2	0.318 in^2	108.80 %	86.56 %
MAS	ASTM D570	Moisture Absorption Short Term	0.17 %	0.11 %	-35.5 %	55.35 %
DSC	ASTM E2160	Grass transition temperature	283 ^{o}F	225 ^{o}F	79.70 %	106.22 %
		Degree of cure by differential scanning calorimetry	≥ 95% of Total enthalpy polymerization	96.78 %		
SEM	N/A	Scanning electron microscope			see images	N/A
EDX	N/A	Elemental analysis via Energy Dispersive X-ray			see graphs	N/A
FTIR	N/A	Fourier Transform Infrared (FTIR) spectroscopy			see graphs	N/A
		SAMPLE No. 2 CFRP				
TSS	ASTM D7617	Transverse shear strength	42.37 ksi	52.15 ksi	123.09 %	174.49 %
HSS	ASTM D4475	Horizontal shear strength	1.65 ksi	1.73 ksi	105.14	N/A
FC	ASTM D2584	Fiber Content (by weight)	82.58 %	75.24 %	91.12 %	107.49 %
DMA	ASTM E1640	Glass transition temperature by Dynamic Mechanical Analysis	118 °C	128 °C	108.59 %	116.17 %
TNS	ASTM D7205	Guar. Tensile Force	75.8 kip	65.7 kip	86.74 %	124.92 %
		Tensile Modulus of Elasticity	≥ 18 Msi	18.8 Msi		
		Strain	≥ 1.1 %	1.66 %		
MXA	ASTM D792	Measured Cross Sectional Area	0.183 in^2	0.255 in^2	139.43 %	69.52 %
MAS	ASTM D570	Moisture Absorption Short Term	0.21 %	0.08 %	-61.25 %	-67.93 %

DSC	ASTM E2160	Grass transition temperature	224 °F	227 °F	101.30 %	106.91 %
		Degree of cure by differential scanning calorimetry	≥ 95% of Total enthalpy polymerization	99.64 %		
SEM	N/A	Scanning electron microscope			see images	N/A
EDX	N/A	Elemental analysis via Energy Dispersive X-ray			see graphs	N/A
FTIR	N/A	Fourier Transform Infrared (FTIR) spectroscopy			N/A	N/A
SAMPLE No. 3 GFRP						
TSS	ASTM D7617	Transverse shear strength	24.66 ksi	52.98 ksi	214.84 %	278.84 %
HSS	ASTM D4475	Horizontal shear strength	5.72 ksi	6.64 ksi	116.14 %	N/A
FC	ASTM D2584	Fiber Content (by weight)	80.17 %	81.75 %	101.98 %	116.79 %
DMA	ASTM E1640	Glass transition temperature by Dynamic Mechanical Analysis	117 °C	168 °C	143.68 %	168.11%
TNS	ASTM D7205	Guar. Tensile Force	34.1 kip	37.09 kip	108.77 %	126.93 %
		Tensile Modulus of Elasticity	≥ 6.5 Msi	7.54 Msi		
		Strain	≥ 1.1 %	3.56 %		
MXA	ASTM D792	Measured Cross Sectional Area	0.335 in^2	0.300 in^2	89.6 %	81.76 %
MAS	ASTM D570	Moisture Absorption Short Term	0.086 %	0.11 %	29.28 %	-55.34 %
DSC	ASTM E2160	Grass transition temperature	234 °F	241 °F	102.78 %	113.46 %
		Degree of cure by differential scanning calorimetry	≥ 95% of Total enthalpy polymerization	99.48%		
SEM	N/A	Scanning electron microscope			see images	N/A
EDX	N/A	Elemental analysis via Energy Dispersive X-ray			see graphs	N/A
FTIR	N/A	Fourier Transform Infrared (FTIR) spectroscopy			see graphs	N/A

**ASTM D7957 & FDOT SPEC 932*
***Benchmark values from Deliverable 1 test results*
N/A: Not Applicable as no standard test or minimum requirements are available

2.2.1.1. TRANSVERSE SHEAR STRENGTH (TSS)

Test Standard Method: ASTM D7617, Standard test method for Transverse Shear Strength. ASTM D7705, Standard test method for Alkali Resistance of Fiber Reinforced Polymer (FRP) Matrix Composite Bars used in Concrete Construction.

Test Description: This test method specifies the test requirements for (FRP) composite smooth round rods and textured bars for determining the transverse shear strength via a double shear fixture. FRP rods and bars are often loaded in transverse shear when these elements are used as dowels in concrete pavements, as stirrups in concrete beams, or as shear reinforcements in glued-laminated wood beams, for example.

Technician/s: Guillermo Claure, Salvatore Caruso and Roger Solis

Specimen Preparation: The specimens were cut to the prescribed dimensions with ends sealed with epoxy coating.

Reference TDS: TDS-TSS-HRB-18M

Test Data:

Specimen ID	Peak Load P_{max}		Measured Area A_{exp}		Transverse Shear Strength τ_u		Benchmark** Transverse Shear Strength	Comparing to Benchmark**	Comparing to Reference*
	kN	lbs	mm^2	in^2	MPa	ksi	ksi	%	%
HRB_B_18M_TSS_01	75.07	16875			406.83	59.01		197.61	310.55
HRB_B_18M_TSS_02	69.55	15635			376.93	54.67		183.09	287.73
HRB_B_18M_TSS_03	73.12	16438	92.26	0.143	396.28	57.48	29.86	192.48	302.50
HRB_B_18M_TSS_04	70.13	15765			380.06	55.12		184.60	290.12
HRB_B_18M_TSS_05	73.66	16560			399.22	57.90		193.91	304.75
Average	**72.31**	**16255**			**391.86**	**56.84**		190.34	299.13
S_{n-1}	2.37	533			12.84	1.86			
CV (%)	3.3	3.3			3.3	3.3			
HRB_C_18M_TSS_01	65.82	14796			356.70	51.73		122.10	272.29
HRB_C_18M_TSS_02	68.59	15420			371.73	53.92		127.25	283.77
HRB_C_18M_TSS_03	66.34	14914	92.26	0.143	359.54	52.15	42.37	123.07	274.45
HRB_C_18M_TSS_04	64.44	14486			349.23	50.65		119.55	266.59
HRB_C_18M_TSS_05	66.56	14963			360.72	52.32		123.48	275.35
Average	**66.35**	**14916**			**359.58**	**52.15**		**123.09**	**274.49**
S_{n-1}	1.50	337			8.13	1.18			
CV (%)	2.3	2.3			2.3	2.3			
HRB_G_18M_TSS_01	67.00	15063			363.13	52.67		213.57	277.19
HRB_G_18M_TSS_02	69.65	15657			377.46	54.75		222.00	288.13
HRB_G_18M_TSS_03	63.75	14332	92.26	0.143	345.50	50.11	24.66	203.21	263.74
HRB_G_18M_TSS_04	67.53	15182			366.00	53.08		215.26	279.39
HRB_G_18M_TSS_05	69.07	15527			374.31	54.29		220.15	285.73
Average	**67.40**	**15152**			**365.28**	**52.98**		214.84	278.84
S_{n-1}	2.31	519			12.51	1.81			
CV (%)	3.4	3.4			3.4	3.4			

**ASTM D7957 & FDOT SPEC 932, guaranteed value of 19 ksi*
***Benchmark values from Deliverable 1 test results*

Test Setup:

Representative Failure Mode:

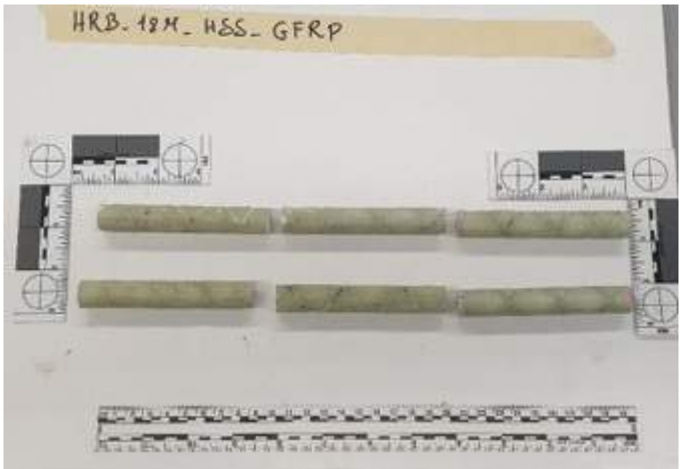
2.2.1.2. HORIZONTAL SHEAR STRENGTH (HSS)

Test Standard Method:	ASTM D4475, Standard test method for Horizontal Shear Strength.
Test Description:	This test method covers the determination of the apparent horizontal shear strength of fiber reinforced plastic rods. The specimen is a short beam in the form of lengths of pultruded rods. This test method is applicable to all types of parallel-fiber-reinforced plastic rod samples.
Technician/s:	Guillermo Claure, Salvatore Caruso, Roger Solis
Specimen Size:	4.5 in. length
Reference TDS:	TDS-HSS-HRB-18M
Test Data:	

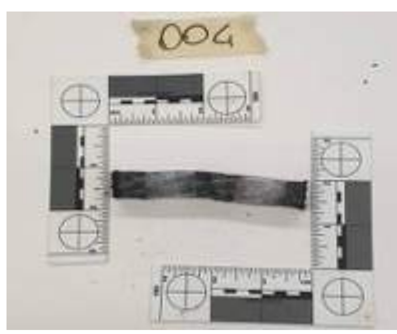
Specimen ID	**Peak Load** P_{max}		**Measured Diameter** $\varnothing_{exp}$		**Experimental Horizontal Shear Strength** τ_u		**Benchmark** Horizontal Shear Strength**	**Horizontal Shear Strength Retention**
	kN	**lbs**	**mm**	**in**	**MPa**	**ksi**	**ksi**	**%**
HRB_B_18M_HSS_01	13.091	2943			40.73	5.91		103.26
HRB_B_18M_HSS_02	12.802	2878			39.83	5.78		100.98
HRB_B_18M_HSS_03	12.553	2822	16.52	0.630	39.05	5.66	5.72	99.02
HRB_B_18M_HSS_04	12.709	2857			39.54	5.73		100.25
HRB_B_18M_HSS_05	11.948	2686			37.17	5.39		94.25
Average	**12.62**	**2837**			**39.26**	**5.69**		99.55
S_{n-1}	0.42	95			1.32	0.19		
CV (%)	3.4	3.4			3.4	3.4		
HRB_C_18M_HSS_01	3.358	755			11.80	1.71		103.76
HRB_C_18M_HSS_02	3.496	786			12.29	1.78		108.05
HRB_C_18M_HSS_03	3.278	737	15.54	0.612	11.53	1.67	1.65	101.31
HRB_C_18M_HSS_04	3.419	769			12.02	1.74		105.66
HRB_C_18M_HSS_05	3.461	778			12.17	1.76		106.95
Average	**3.40**	**765**			**11.96**	**1.73**		105.14
S_{n-1}	0.09	19			0.30	0.04		
CV (%)	2.5	2.5			2.5	2.5		
HRB_G_18M_HSS_01	13.794	3101			47.85	6.94		121.33
HRB_G_18M_HSS_02	13.500	3035			46.83	6.79		118.75
HRB_G_18M_HSS_03	13.202	2968	15.64	0.630	45.80	6.64	5.72	116.13
HRB_G_18M_HSS_04	12.542	2820			43.51	6.31		110.32
HRB_G_18M_HSS_05	12.980	2918			45.03	6.53		114.17
Average	**13.20**	**2968**			**45.80**	**6.64**		116.14
S_{n-1}	0.48	108			1.67	0.24		
CV (%)	3.6	3.6			3.6	3.6		

***Benchmark values from Deliverable 1 test results*

Test Setup:



Representative Failure Mode:

2.2.1.3. FIBER CONTENT (FC)

Test Standard Method: ASTM D2584-11, Standard Test Method for Ignition Loss of Cured Reinforced Resins
Test Description: The specimen contained in a crucible is ignited and allowed to burn until only ash and carbon remain. The carbonaceous residue is reduced to an ash by heating in a muffle furnace at 565°C (1050°F), cooled in a desiccator, and weighed. The basic concept of burning off of the organic matrix of a reinforced polymer composite has also been shown to be a useful method for enabling a visual examination of the fiber architecture or laminate structure of some reinforcements.
Technician/s: Guillermo Claure, Salvatore Caruso, Roger Solis
Specimen Size: 25.0 mm (1.0 in.) long segment cut at different locations from the rebar
Reference TDS: TDS-FC-HRB-18M
Test data:

Specimen ID	Weight of Crucible Wc	Weight prior burnout Wi	Weight post burnout Wf	W1 (Wc-Wi)	W2 (Wf-Wc)	Fiber Content FC=W2/W1	Benchmark** Fiber Content	Comparing to Benchmark**	Comparing to Reference*
	g	g	g	g	g	%	%	%	%
HRB-B-18M-FC-001	42.43	52.84	50.80	10.41	8.37	79.94		98.36	114.87
HRB-B-18M-FC-002	42.45	55.14	52.65	12.69	10.20	80.34		98.32	114.82
HRB-B-18M-FC-003	40.27	50.40	48.44	10.13	8.17	80.24	81.75	98.65	115.21
HRB-B-18M-FC-004	39.68	51.50	49.19	11.82	9.51	79.99		98.42	114.95
HRB-B-18M-FC-005	41.26	51.38	49.41	10.12	8.16	80.33		98.56	115.11
					Average	**80.49**		**98.46**	**115.00**
					Sn-1	19.17			
					CV (%)	0.24			
HRB-G-18M-FC-001	28.68	38.35	36.70	9.67	8.02	82.94		103.45	118.48
HRB-G-18M-FC-002	29.79	41.09	39.16	11.30	9.37	82.92		103.43	118.46
HRB-G-18M-FC-003	29.85	40.49	38.53	10.64	8.68	81.58	80.17	101.76	116.54
HRB-G-18M-FC-004	28.12	39.14	37.08	11.02	8.96	81.31		101.42	116.15
HRB-G-18M-FC-005	30.64	41.70	39.49	11.06	8.85	80.02		99.81	114.31
					Average	**81.75**		**101.98**	**116.79**
					Sn-1	122.51			
					CV (%)	1.50			

**ASTM D7957 & FDOT SPEC 932, SPEC 933*
***Benchmark values from Deliverable 1 test results*

Test Standard Method: ASTM D2584-11, Standard Test Method for Fiber content by acid digestion

Test Description: The specimen are cut to ¼” in discs. The mass of the beaker and the initial mass of the specimen are measured before pouring the acid inside the beaker. The samples are placed under a fume hood and nitric acid is poured allowing it to digest the matrix, the process will take 1 hour and 45 minutes at 80^{o}C. After the acid is cooled, coffee filters are cut at 8cm and weighted. The evaporating dish is weighted as well. With a vacuum pump the fibers are filtered out and baking soda is used to neutralize the acid. After rinsing out the beaker, fibers, coffee filter and evaporating dish are placed in an oven to dry, then the mass of fibers, coffee filter and evaporating dish is measure. At the end it’s evaluated the percentage of fibers with and without wrapping.

Technician/s: Salvatore Caruso, Guillermo Claure, Thomas Cadenazzi, Roger Solis

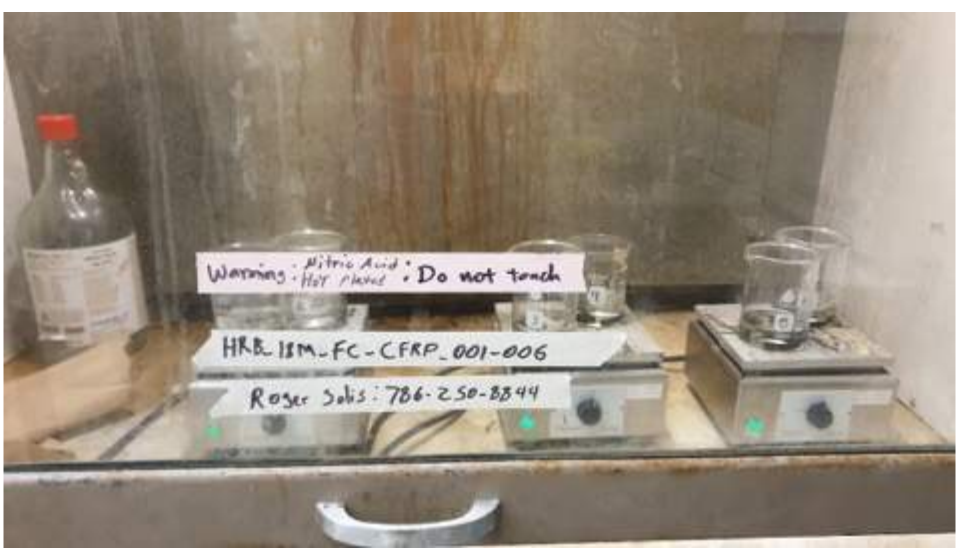
Specimen Size: 25.0 mm (1.0 in.) long segment cut at different locations from the rebar

Reference TDS: TDS-FC-HRB-18M

Test data:

Specimen ID	specimen	dry fibers + wrapping	dry fibers no wrapping	fiber w/out wrapping	fiber w/ wrapping	Benchmark** Fiber Content	Comparing to Benchmark**	Comparing to Reference*
	g	g	g	%	%	%	%	%
HRB-C-18M-FC-001	5.531	5.47	4.27	77.16	98.87	82.58	93.43	110.22
HRB-C-18M-FC-002	6.116	5.97	4.49	73.40	97.60		88.89	104.85
HRB-C-18M-FC-003	5.9007	5.78	4.30	72.84	97.95		88.21	104.06
HRB-C-18M-FC-004	6.4955	6.46	5.13	78.90	99.46		95.54	112.72
HRB-C-18M-FC-005	6.0603	5.96	4.48	73.93	98.40		89.52	105.61
Average	**6.02**	**5.93**	**4.53**	**75.24**	**98.46**		**91.12**	**107.49**
S_{n-1}	0.35	0.36	0.35	2.64	0.73			
CV (%)	5.82	6.08	7.65	3.51	0.75			

Test Setup up:



2.2.1.4. GLASS TRANSITION TEMPERATURE BY DYNAMIC MECHANICAL ANALYSIS

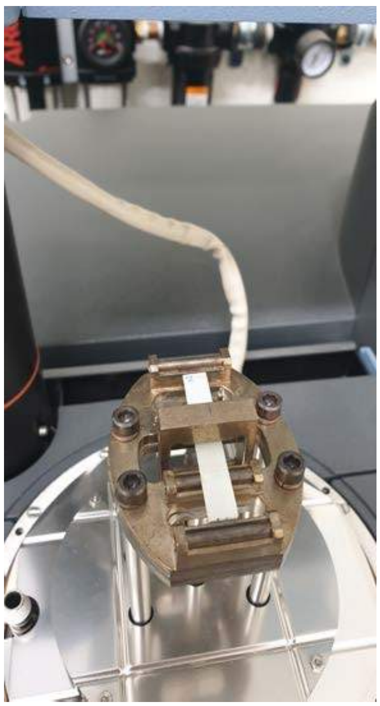
Test Standard Method: ASTM E1640
Test Description: This test method can be used to locate the glass transition region and assign a glass transition temperature of amorphous and semi-crystalline materials.
Technician/s: Guillermo Claure, Salvatore Caruso
Specimen Preparation: It is important to select a specimen size appropriate for both the material and the testing apparatus. Samples may be any uniform size or shape analyzed in rectangular form.
Reference TDS: TDS-DMA-HRB-18M

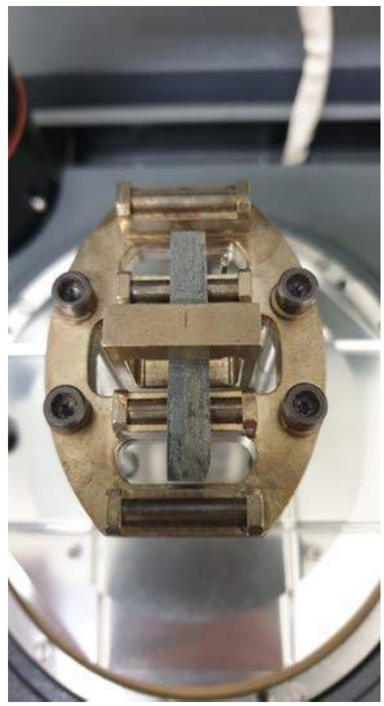
Test Data:

Specimen ID	T_g		Benchmark** T_g	Comparing to Benchmark**	Comparing to Reference*
	°C	°F	°C	%	%
HRB_B_18M_TG_01	113	236		111.91	113.40
HRB_B_18M_TG_02	110	229	101	108.16	109.60
HRB_B_18M_TG_03	112	234		110.62	112.09
Average	**112**	**233**		**110.23**	**111.70**
S_{n-1}	2	3			
CV (%)	1.7	1.5			
HRB_C_18M_TG_01	125	257		105.77	113.64
HRB_C_18M_TG_02	131	268	118	110.85	119.09
HRB_C_18M_TG_03	129	264		109.15	117.27
Average	**128**	**263**		**108.59**	**116.67**
S_{n-1}	3	5			
CV (%)	2.4	2.1			
HRB_G_18M_TG_01	176	349		150.68	176.29
HRB_G_18M_TG_02	164	328	117	140.36	164.22
HRB_G_18M_TG_03	164	327		140.01	163.81
Average	**168**	**335**		**143.68**	**168.11**
S_{n-1}	7	13			
CV (%)	4.2	3.8			

**ASTM D7957 & FDOT SPEC 932, SPEC 933*
***Benchmark values from Deliverable 1 test results*

Test Setup up:





2.2.1.5. TENSILE PROPERTIES (TNS)

Test Standard Method: ASTM D7205 Standard test method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars
Test Description: Determine the ultimate tensile load carrying capacity, tensile modulus of elasticity and computed ultimate strain based on nominal area and an assumed linear elastic behavior
Technician/s: Guillermo Claure, Salvatore Caruso, Roger Solis
Specimen Preparation: The specimens were cut to the prescribed dimensions. Steel pipe type anchors were installed as indicated in ASTM D7205 using expansive grout after machining the ends of the rebar as to center the bars in the anchors.
Reference TDS: TDS-TNS-HRB-18M
Test Data:

SPECIMEN ID	Peak Load P_{max}		Modulus of Elasticity E		Strain ε_u	Benchmark** Tensile Load	Comparing to Benchmark**	Comparing to Reference*
	kN	lbs	GPa	Msi	%	lbs	%	%
HRB-B-TNS-18M-001	165.32	37165.41	49.36	7.16	4.39		112.22	127.17
HRB-B-TNS-18M-002	188.68	42416.95	58.10	8.43	5.14		128.08	145.14
HRB-B-TNS-18M-003	183.74	41306.39	55.84	8.10	4.50	33117.00	124.73	141.34
HRB-B-TNS-18M-004	118.88	26725.29	56.79	8.24	1.06		80.70	91.45
HRB-B-TNS-18M-005	140.88	31671.08	62.45	9.06	1.13		95.63	108.37
Average	**159.50**	**35857.02**	**56.51**	**8.20**	**3.24**		**108.27**	**122.69**
S_{n-1}	29.45	6621.00	4.73	0.69	1.98		19.99	22.66
CV (%)	18.0	18.0	8.0	8.0	61.1		18.0	18.0
HRB-C-TNS-18M-001	285.12	64097.52	73.5	18.9	1.83		84.58	119.32
HRB-C-TNS-18M-002	291.08	65437.38	77.7	18.7	1.97	75786.00	86.34	123.91
HRB-C-TNS-18M-003	301.00	67667.48	77.3	18.8	1.17		89.29	131.54
Average	**292.40**	**65734.13**	**7.62**	**18.80**	**1.66**		**86.74**	**124.92**
S_{n-1}	8.02	1803.39	0.23	0.10	0.43		2.38	6.17
CV (%)	3.0	3.0	3.00	0.5	25.8		0.03	4.9
HRB-G-TNS-18M-001	163.28	36706.80	55.22	8.01	1.50		107.76	125.60
HRB-G-TNS-18M-002	162.64	36562.92	31.40	4.55	4.90		107.34	125.11
HRB-G-TNS-18M-003	166.62	37457.66	57.51	8.34	4.23	34063.00	109.97	128.17
HRB-G-TNS-18M-004	166.14	37349.75	51.32	7.44	4.51		109.65	127.80
HRB-G-TNS-18M-005	166.34	37394.72	64.62	9.37	2.39		109.78	127.95
Average	**165.00**	**37094.37**	**52.01**	**7.54**	**3.5**		**108.90**	**126.93**
S_{n-1}	1.89	424.28	12.50	1.81	1.48		1.25	1.45
CV (%)	1	1	24.0	24.0	42		0.01	0.01

**ASTM D7957 & FDOT SPEC 932, SPEC 933*
***Benchmark values from Deliverable 1 test results*

Test Setup:

Representative Failure Mode:

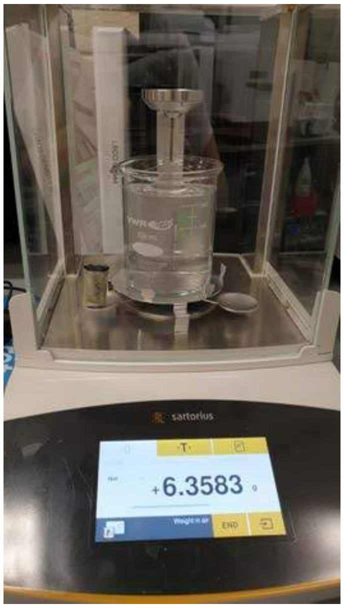
2.2.1.6. CROSS-SECTIONAL AREA (MXA)

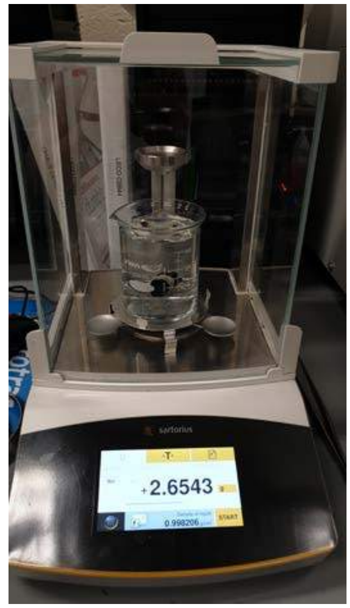
Test Standard Method:	ASTM D7205 Standard test method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars. ASTM D792 Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement.
Test Description:	Measurement of cross-sectional area by volume of water displacement method.
Technician/s:	Guillermo Claure, Salvatore Caruso, Roger Solis.
Specimen Size:	Specimen length dimensions were 50 mm (2.0 in.).
Reference TDS:	Technical Data Sheet: TDS-MXA-HRB-18M
Test Data::	

Specimen ID	Measured Area A		Benchmark** Measured Area	Comparing to Benchmark**	Comparing to Reference*
	mm^2	in^2	in^2	%	%
HRB_B_MXA_18M_01	205.88	0.319		109.29	86.95
HRB_B_MXA_18M_02	205.00	0.318		108.82	86.58
HRB_B_MXA_18M_03	202.80	0.314	0.292	107.65	85.65
HRB_B_MXA_18M_04	205.21	0.318		108.93	86.67
HRB_B_MXA_18M_05	205.93	0.319		109.31	86.97
Average	**204.96**	**0.318**		**108.80**	**86.56**
S_{n-1}	1.28	0.002			
CV (%)	0.62	0.62			
HRB_C_MXA_18M_01	161.40	0.250		136.71	68.17
HRB_C_MXA_18M_02	155.44	0.241		131.66	65.65
HRB_C_MXA_18M_03	168.85	0.262	0.183	143.02	71.31
HRB_C_MXA_18M_04	165.47	0.256		140.16	69.89
HRB_C_MXA_18M_05	171.90	0.266		145.60	72.60
Average	**164.61**	**0.255**		**139.43**	**69.52**
S_{n-1}	7	0.011			
CV (%)	4.8	4.8			
HRB_G_MXA_18M_01	194.16	0.301		89.8	82.00
HRB_G_MXA_18M_02	193.55	0.300		89.6	81.75
HRB_G_MXA_18M_03	193.43	0.300	0.335	89.5	81.69
HRB_G_MXA_18M_04	193.63	0.300		89.6	81.78
HRB_G_MXA_18M_05	193.19	0.299		89.4	81.59
Average	**193.59**	**0.300**		**89.6**	**81.76**
S_{n-1}	0.36	0.001			
CV (%)	0.18	0.18			

**ASTM D7957 & FDOT SPEC 932, SPEC 933*
***Benchmark values from Deliverable 1 test results*

Test Setup:





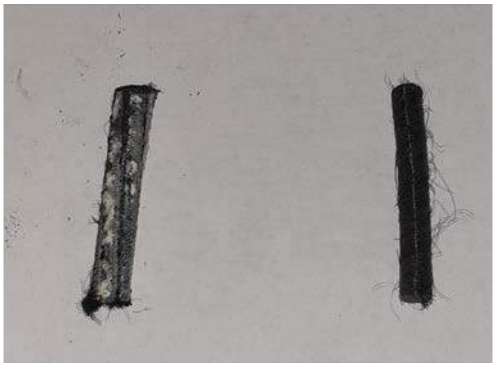
2.2.1.7. WATER ABSORPTION (MA)

Test Standard Method:	ASTM D570, Standard Test Method for Water Absorption of Plastics. ASTM D5229D/D229M - 12, Standard Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials (Procedure B). ASTM D7957/D7957M – 17, Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement.
Test Description:	Short term (24hr) level of moisture absorption when immersed in distilled water at 50^{o}C temperature.
Technician/s:	Guillermo Claure, Salvatore Caruso, Roger Solis.
Specimen Size:	25.0 mm (1.0 in.) long segment cut at different locations from the rebar.
Reference TDS:	TDS-MA-HRB-18M
Test Data:	

Specimen ID	Moisture Absorption W_i	W_{24}	W_{24}	Benchmark**	Comparing to Benchmark**	Comparing to Reference*
	g	g	%	in^2	%	%
HRB_B_MA_18M_01	9.1550	9.1640	0.10		-43.19	-60.68
HRB_B_MA_18M_02	10.2550	10.2670	0.12		-32.38	-53.19
HRB_B_MA_18M_03	10.7250	10.7360	0.10	0.173	-40.73	-58.97
HRB_B_MA_18M_04	10.0550	10.0675	0.12		-28.16	-50.27
HRB_B_MA_18M_05	10.3550	10.3670	0.12		-33.04	-53.65
Average	**10.1090**	**10.1203**	**0.11**		**-35.50**	**-55.35**
S_{n-1}	0.59	0.59	0.01			
CV (%)	5.80	5.80	9.7			
HRB_C_MA_18M_01	5.1734	5.1791	0.11		-46.75	-55.93
HRB_C_MA_18M_02	5.1130	5.1174	0.09		-58.41	-65.58
HRB_C_MA_18M_03	5.0690	5.0732	0.08	0.207	-59.95	-66.86
HRB_C_MA_18M_04	5.0846	5.0872	0.05		-75.29	-79.55
HRB_C_MA_18M_05	5.0951	5.0987	0.07		-65.85	-71.74
Average	**5.1070**	**5.1111**	**0.08**		**-61.25**	**-67.93**
S_{n-1}	0.0404	0.0413	0.02			
CV (%)	0.8	0.8	27.0			
HRB_G_MA_18M_01	10.0765	10.0880	0.11		32.16	-54.35
HRB_G_MA_18M_02	9.4890	9.5010	0.13		46.45	-49.42
HRB_G_MA_18M_03	10.3890	10.4010	0.12	0.086	33.76	-53.80
HRB_G_MA_18M_04	9.7560	9.7654	0.10		11.58	-61.46
HRB_G_MA_18M_05	9.4570	9.4670	0.11		22.45	-57.70
Average	**9.8335**	**9.8445**	**0.11**		**29.28**	**-55.34**
S_{n-1}	0.3981	0.3987	0.01			
CV (%)	4.0	4.0	10.1			

**ASTM D7957 & FDOT SPEC 932, SPEC 933*
***Benchmark values from Deliverable 1 test results*

Test Setup:



2.2.1.8. DEGREE OF CURE BY DIFFERENTIAL SCANNING CALORIMETRY

Test Standard Method: ASTM E2160, Standard test method for heat of reaction of thermally reactive materials by differential scanning calorimetry (DSC).
ASTM E1356, Standard test method for assignment of the glass transition temperatures by differential scanning calorimetry.

Test Description: Degree of cure as a reference value and corresponding glass transition temperature by DSC. The exothermic heat flow produced by the reaction is recorded as a function of temperature and time by a differential scanning calorimeter. Integration of the exothermic heat flow over time yields the heat of reaction.

Technician/s: Guillermo Claure, Thomas Cadenazzi, Roger Solis.

Specimen Size: 5.0 ±0.5 mg and /or 2-mm thick specimen is cut/extracted from the geometrical center of the rebar sample.

Reference TDS: TDS-TEP-HRB-18M

Test Data:

Specimen ID	Heat Reaction H	Degree of Cure DC	Glass Transition Temperature Tg		Benchmark**	Comparing to Benchmark**	Comparing to Reference*
	J/g	%	°C	°F	°F	%	%
HRB_B_DSC_18M_01	3.7560	96.24	106.50	224		79.17	105.52
HRB_B_DSC_18M_02	3.0130	96.99	107.30	225		79.68	106.20
HRB_B_DSC_18M_03	3.1100	96.89	107.90	226	283	80.06	106.71
HRB_B_DSC_18M_04	3.2550	96.75	106.95	225		79.46	105.90
HRB_B_DSC_18M_05	2.9900	97.01	107.99	226		80.12	106.78
Average		**96.78**	**107.33**	**225**		**79.70**	**106.22**
S_{n-1}		0.31	0.63	1			
CV (%)		0.3	0.6	0.5			
HRB_C_DSC_18M_01	0.27200	99.73	108.50	227		101.60	107.22
HRB_C_DSC_18M_02	0.38800	99.61	107.89	226		101.11	106.70
HRB_C_DSC_18M_03	0.35670	99.64	107.45	225	224	100.75	106.33
HRB_C_DSC_18M_04	0.41390	99.59	109.45	229		102.36	108.02
HRB_C_DSC_18M_05	0.38800	99.61	107.39	225		100.70	106.27
Average		**99.64**	**108.14**	**227**		**101.30**	**106.91**
S_{n-1}		0.06	0.86	2			
CV (%)		0.1	0.8	0.7			
HRB_G_DSC_18M_01	0.5548	99.45	115.90	241		102.81	113.50
HRB_G_DSC_18M_02	0.5333	99.47	116.30	241		103.12	113.84
HRB_G_DSC_18M_03	0.4999	99.50	114.99	239	234	102.12	112.73
HRB_G_DSC_18M_04	0.4789	99.52	116.11	241		102.98	113.68
HRB_G_DSC_18M_05	0.5123	99.49	115.99	241		102.88	113.58
Average		**99.48**	**115.86**	**241**		**102.78**	**113.46**
S_{n-1}		0.03	0.51	1			
CV (%)		0.0	0.4	0.4			

**ASTM D7957 & FDOT SPEC 932, SPEC 933*
***Benchmark values from Deliverable 1 test results*

Test Setup:

2.2.1.9. SCANNING ELECTRON MICROSCOPY IMAGING (SEM)

Test Method: Laboratory Method

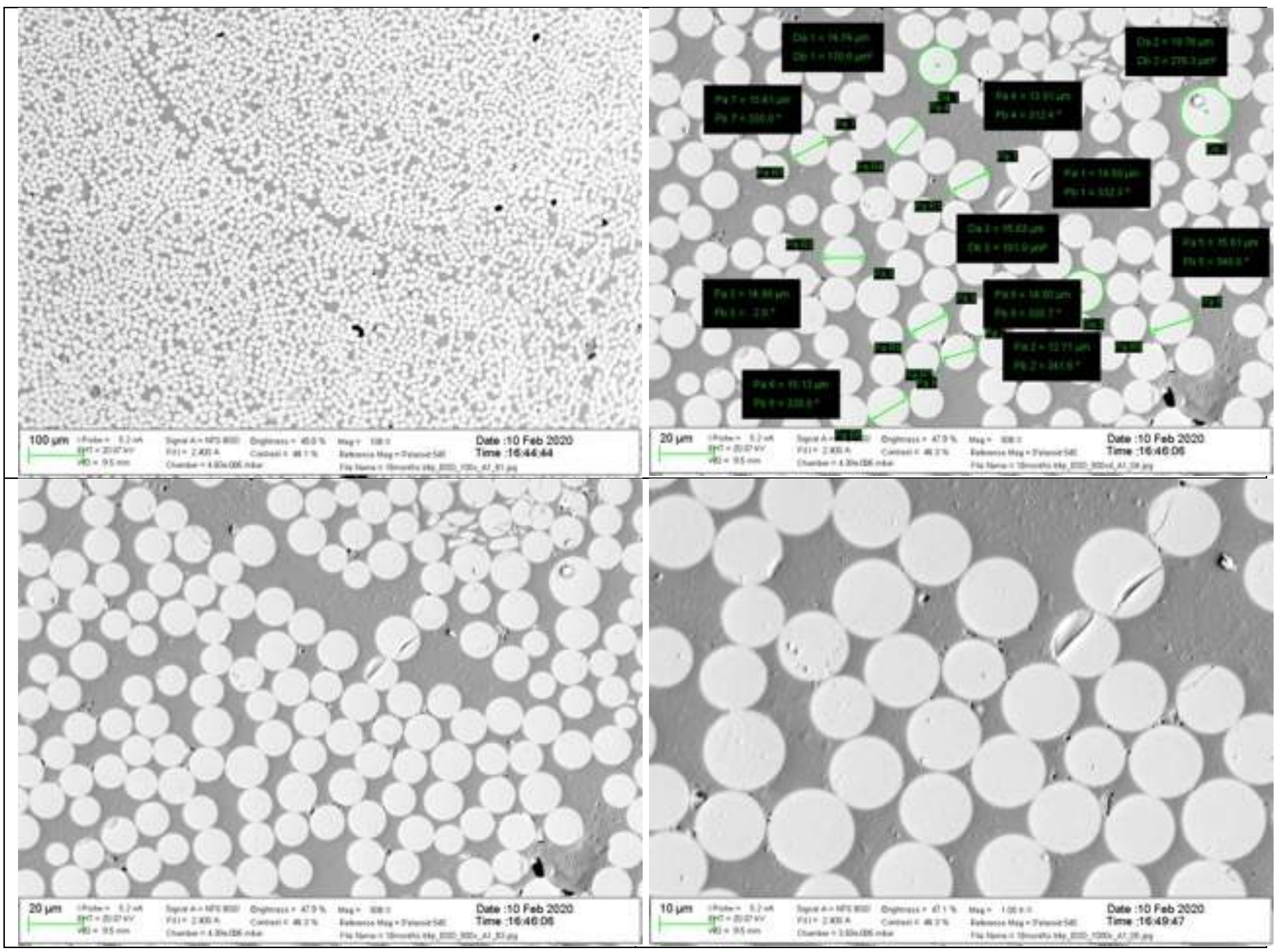
Test Description: Imaging to observe microscopic features of the cross-section of the bars up to 50 nm in size accomplished with SEM. SEM is used to qualitatively evaluate the cross-section and determine the 'finger-print' for the manufactured rebar, the void and fiber dispersion, cross-sectional pattern of manufactured product can be parametrically measured.

Technician/s: Guillermo Claure and Salvatore Caruso

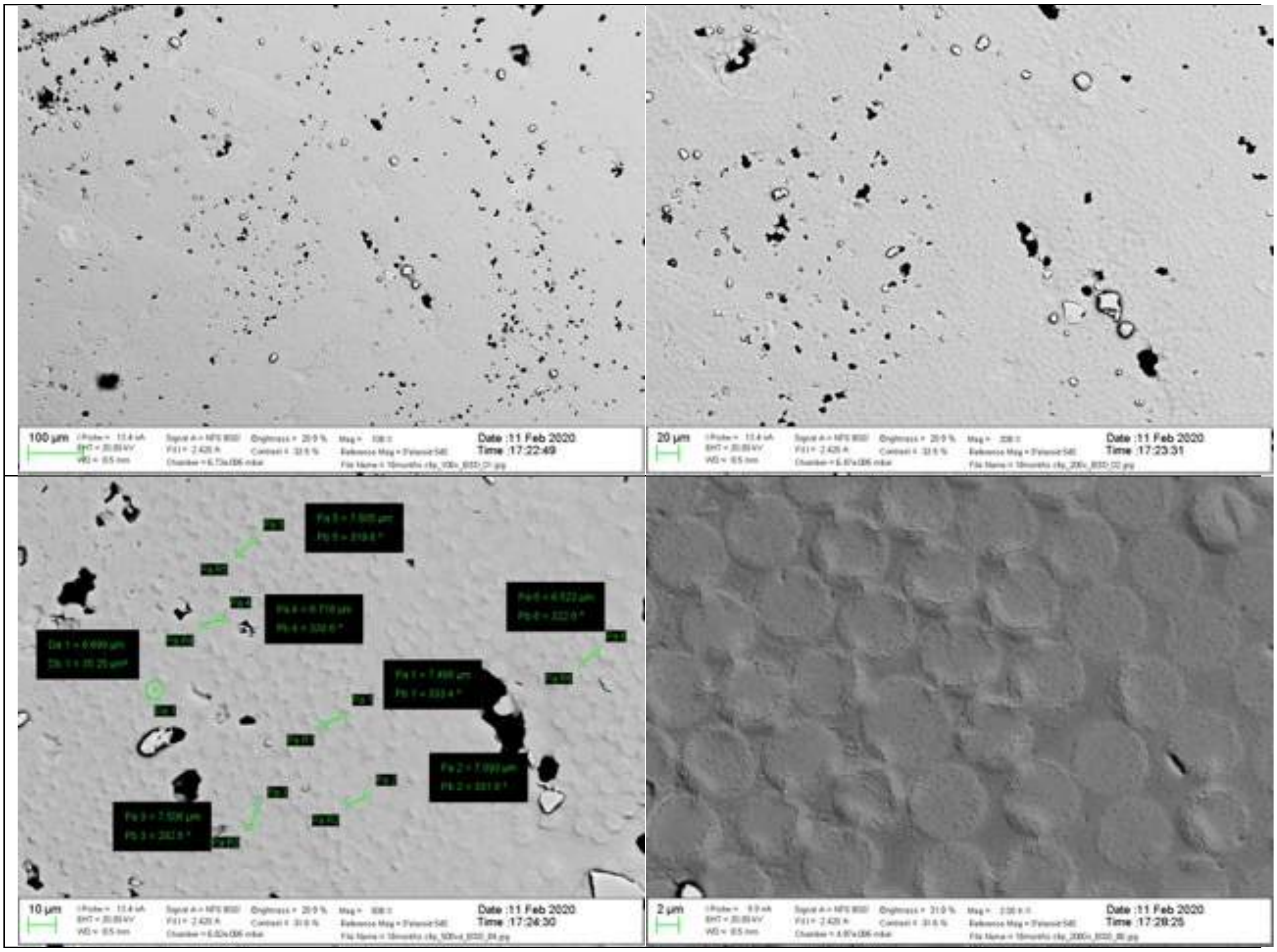
Specimen Preparation: The specimens included acquisition of a sample that will fit into the SEM chamber and some accommodation to prevent charge build-up on electrically insulating samples. Electrically insulating samples were coated with a thin layer of conducting material, commonly metal/alloy. Metal coatings are most effective for high resolution electron imaging applications.

Reference TDS: TDS-SEM-HRB-18M

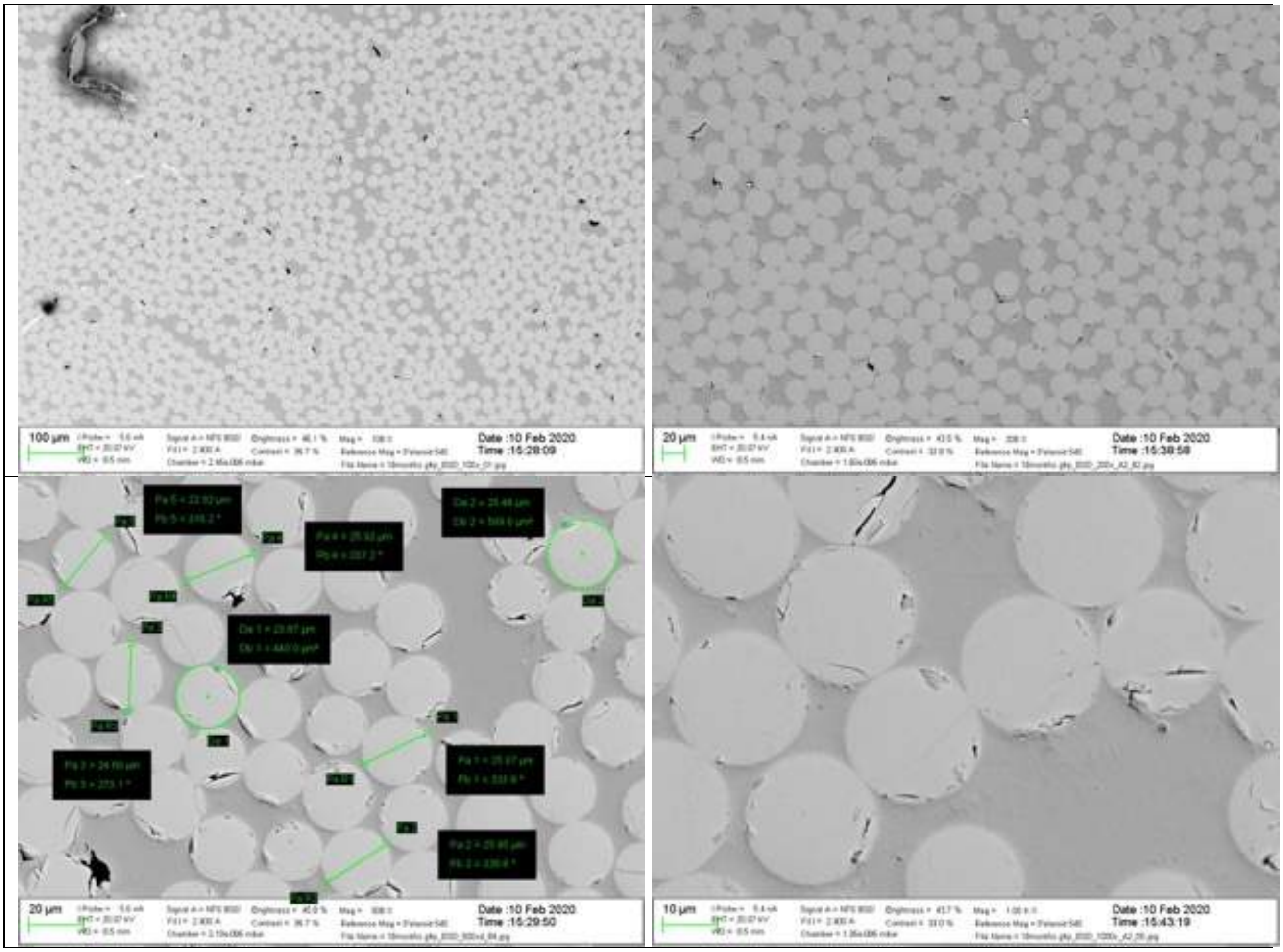
Test Imaging:



Representative SEM image BFRP sample



Representative SEM image CFRP sample



Representative SEM image GFRP sample

Test Preparation and Setup:

2.2.1.10. ELEMENTAL ANALYSIS VIA ENERGY DISPERSIVE X-RAY

Test Standard Method: Laboratory Method

Test Description: Standard method for identifying and quantifying elemental compositions in a very small sample of material.

Technician/s: Guillermo Claure, Salvatore Caruso and Roger Solis

Specimen Preparation: By using the SEM equipment, the atoms on the surface are excited by the electron beam, emitting specific wavelengths of X-rays that are characteristic of the atomic structure of the elements. An energy dispersive detector (a solid-state device that discriminates among X-ray energies) can analyze these X-ray emissions. Appropriate elements are assigned, yielding the composition of the atoms on the specimen surface. This procedure is called energy dispersive X-ray spectroscopy (EDS) and is useful for analyzing the composition of the surface of a specimen

Reference TDS: Technical Data Sheet: TDS-EDX-HRB-18M

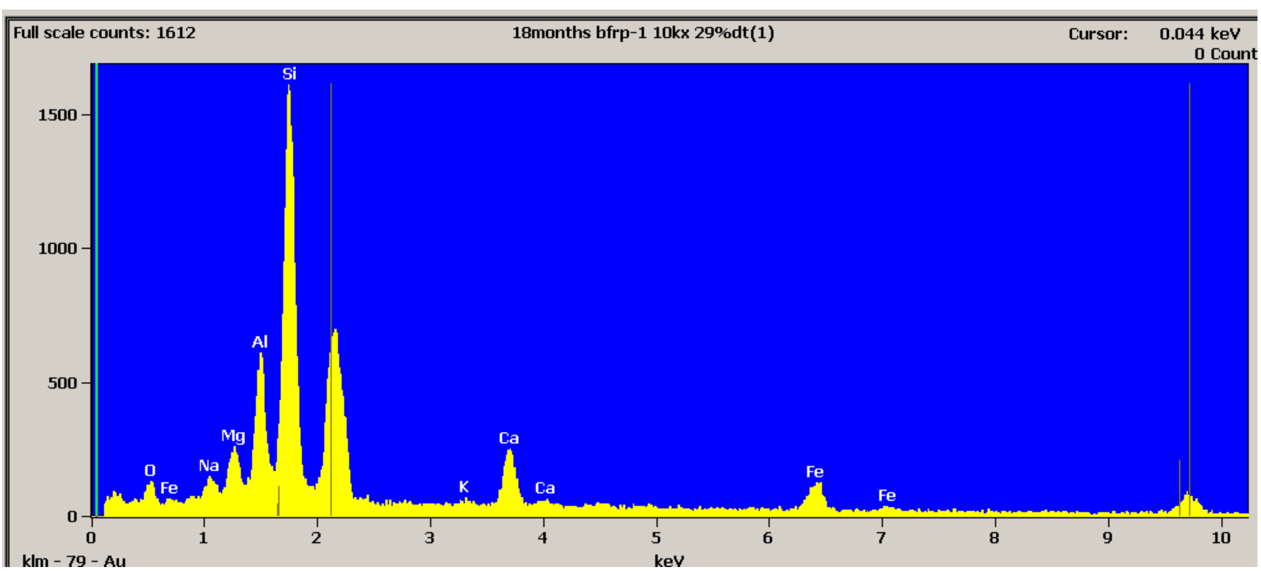
Test Data:

BFRP	Fe	Ca	Na	Mg	Al	Si
Quant. detected	1140	950	330	350	1120	4330

CFRP	Si	Ca	O	Cl
Quant. detected	20	9281	583	96

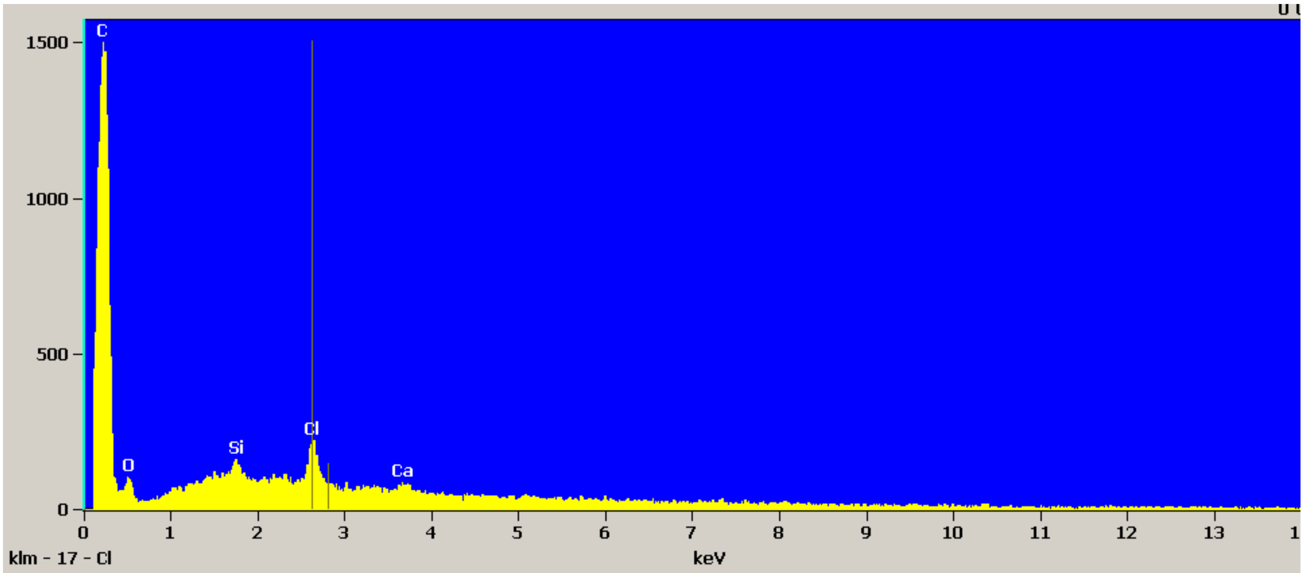
GFRP	Ca	Al	Si
Quant. detected	3340	740	5930

Graphs:



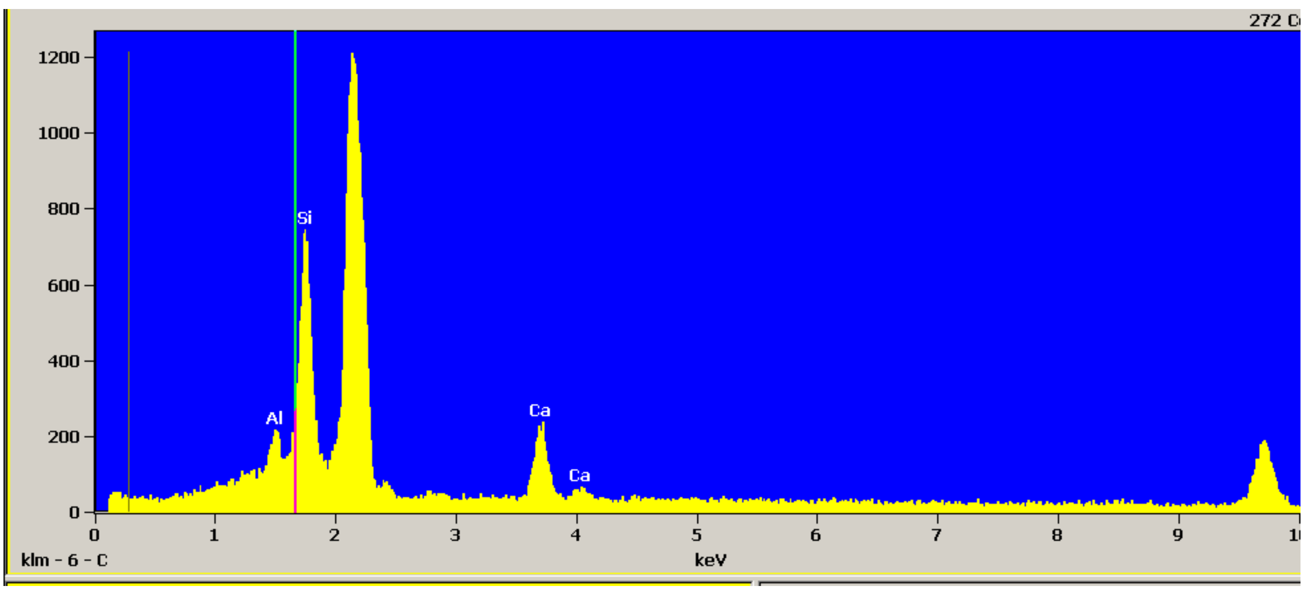
Representative EDX image of a 18M-BFRP sample

Note: AU (Gold) is graphically displayed, since the sample preparation required the specimen to be gold-coated.



Representative EDX image of a 18M-CFRP sample

Note: AU (Gold) is graphically displayed, since the sample preparation required the specimen to be gold-coated.



Representative EDX image of a 18M-GFRP sample

Note: AU (Gold) is graphically displayed, since the sample preparation required the specimen to be gold-coated.

Test setup:

2.2.1.11. FOURIER TRANSFORMATION INFRARED

Test Standard Method:	Laboratory Method
Test Description:	FTIR stands for Fourier transform infrared, the preferred method of infrared spectroscopy. This technique is used to obtain an infrared spectrum of absorption, emission, photoconductivity or Raman scattering of a solid, liquid or gas. An FTIR spectrometer simultaneously collects spectral data in a wide spectral range.
Technician/s:	Guillermo Claure, Thomas Cadenazzi and Roger Solis
Specimen Preparation:	When IR radiation is passed through a sample, some radiation is absorbed by the sample and some passes through (is transmitted). The resulting signal at the detector is a spectrum representing a molecular 'fingerprint' of the sample. The usefulness of infrared spectroscopy arises because different chemical structures (molecules) produce different spectral fingerprints.
Reference TDS:	Technical Data Sheet: TDS-FTIR-HRB-18M
Test Graphs:	

Results Pending

Representative FTIR image of BFRP sample

Representative FTIR image of GFRP sample

♦ END OF REPORT ♦