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

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TASK 1 Deliverable: End of Construction Report
(Part B – Initial Durability Tests)
TASK 2 Deliverable: Six-Month Report
(Part B – Durability Tests at 9 months)

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

Research Report

Deliverable 1 (Task 1: End of Construction of Bulk-head Caps and Test Blocks)

Deliverable 2 (Task 2: Durability Tests Referenced in Task 1-C after extraction of Test Blocks)

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Submitted on: July 31, 2019

Controls:	
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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: July 31, 2019
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: July 31, 2019

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 1 'End of Construction of Bulk-head Caps and Test Blocks' and TASK 2 'Durability Tests – after Test Block extraction'.

All experimental tests are conducted in accordance with ISO standards, ASTM and/or FDOT Specifications. Sections 2 and 3 of this document report 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 benchmark and aged BFRP, CFRP, and GFRP rebars result in equivalent or higher magnitudes than respective reference ASTM and/or FDOT specifications. In terms of results after nine-month exposure, test values tend to be lower that benchmark counterparts; but in all cases, test values after nine-month exposure still show to be higher than respective reference ASTM and /or FDOT specification.

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1. INTRODUCTION

1.1. BACKGROUND

As part of the Inspection and Monitoring of Fabrication and Construction of the West Halls River Road Bridge (HRB) Replacement project, this research program evaluates properties of materials exposed to an aggressive environment as part of the efforts to increase the overall life of the bridge along with decreasing the associated maintenance costs; and to prove validity of material properties for future use. 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 Basalt FRP (BFRP), Carbon FRP (CFRP), and Glass FRP (GFRP) rebars, 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 1 'End of Construction of Bulk-head Caps and Test Blocks' for concrete and each rebar type for each different physio-mechanical rebar property. Section 3 provides description of tests and summary tables with average results corresponding to tests referenced to TASK 1-C of TASK 2 '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 1 - TASK 1
End of Construction of Bulk-head Caps and Test Blocks (tests referenced to TASK 1-C)

2.1. CONCRETE SAMPLE INFORMATION

CASTING OF CONTROL SPECIMENS: All control specimens were prepared simultaneously from one batch of concrete made with seawater (green concrete) on Thursday, December 21, 2017 following ASTM C192/C192M-13a 'Practice for Making and Curing Concrete Test Specimens in the Laboratory'. Collection activities of specimens are shown in Figure 1.

(a) (b)

Figure 1 – (a) truck delivering green concrete to site and (b) concrete specimens preparation activities

The 28-day concrete compressive strength was then tested as per ASTM C39, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, to ensure it met the requirements of Concrete Class V with strength of 5,500 psi and stiffness of 3,400 ksi-in.
Figure 2 shows the concrete casting activities. The green concrete was poured through a 4 in. pump. Placement of concrete was aided by the rubber-tipped vibrator on site, already used for the previous concrete pours. Approximately 16.5 cubic yard (3 trucks) of green concrete were poured for the 3 sections of wall; After each wall section form was filled, the top was then smoothly finished.

(a) (b)
Figure 2 – (a) bulkhead cap casting activities, and (b) test blocks demolded and stripped

2.1.1. SUMMARY OF TEST RESULTS ON CONCRETE SAMPLE

Test ID	Standard Test Method	Test Description	Reference*	Test Value	Comparing to Reference*
CONCRETE SAMPLE					
CS	ASTM C39/ASTM C496	Concrete Compressive Strength	5,500 psi	7,428 psi	132%
PC	ASTM C1202	Penetration of chloride ion into concrete	N/A	pending	N/A
PH	N/A	PH concrete test	N/A	12.22	
S	N/A	Stiffness test	3,400 ksi-in	5,033 ksi-in	162%
FTIR	N/A	Fourier Transform Infrared (FTIR) spectroscopy test	N/A	pending	N/A

**FDOT Class V with strength of 5,500 psi and stiffness of 3,400 ksi-in.*
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, Thomas Cadenazzi, 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-ASTM-C39-HRB

Test Data:

Specimen ID	Cylinder diameter		Area		Peak force		Compressive Strength		Reference*	Comparing to Reference*
	d		A		P_{max}		f'c		f'c	
	mm	in	mm²	in²	kN	lbf	MPa	psi	psi	%
HRB-CS-001	102	4.000	8110	12.570	405	90,940	49.9	7,235		132%
HRB-CS-002	102	4.020	8142	12.620	421	94,660	51.4	7,459	5,500	136%
HRB-CS-003	101	3.990	8064	12.500	422	94,870	52.3	7,590		138%
Average	**102**	**4.00**	**8105**	**12.563**	**416**	**93,490**	**51.2**	**7,428**		**132%**
S_{n-1}	0.40	0.02	39	0.06	10	2,211	1.2	180		
CV (%)	0.40	0.38	0.48	0.48	2.36	2.36	2.42	2.42		

**FDOT Class V with strength of 5,500 psi*

Test Setup:

Representative Failure Mode:

2.1.1.2. 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

Test Data:

Specimen ID	Charge Passed (coulombs)
HRB-PC-001	Tests results pending
HRB-PC-002	
HRB-PC-003	
Average	
S_{n-1}	
CV (%)	

2.1.1.3. 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
Test Data:

Specimen ID	pH
HRB-PH-001	12.21
HRB-PH-002	12.23
HRB-PH-003	12.22
Average	**12.22**
S_{n-1}	0.01
CV (%)	0.08

Test Setup:

2.1.1.4. 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

Test Data:

Specimen ID	Cylinder Diameter d		Stiffness E		Reference* E	Comparing to Reference*
	mm	in	MPa.mm	Psi-in	Psi-in	%
HRB-9M-CS-001	101.6	4.000	24,465	5,500,000		162%
HRB-9M-CS-002	102.1	4.020	22,019	4,950,000	3,400,000	146%
HRB-9M-CS-003	101.3	3.990	20,684	4,650,000		137%
Average			**22,389**	**5,033,333**		**162%**
S_{n-1}			1,918	431,084		
CV (%)			8.56	8.56		

**FDOT Class V with stiffness of 3,400 ksi-in.*

Test Setup:

Representative Failure Mode:

2.1.1.5. 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
Test Graphs:	

Tests results pending.

2.2. REBAR SAMPLE INFORMATION

This section includes information, details and results with regards to the three types of rebars deployed in the bulkhead cap test blocks.

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

The Northwestern sea-wall of HRB is composed by three wall sections, wall 1A (25-ft long), 2A (20-ft long), and 3A (35 ft. long), respectively. These wall sections, along with the rest of the sea-wall, include beam-like independent portions "test blocks" to be periodically extracted to assess FRP durability in chloride-exposed sea water concrete. Test blocks cross-section is built with 6 #5-rebars made of BFRP/CFRP/GFRP placed in interchange location along the length of the different wall sections following layout in Table 1. Wall 1B, 2B, 3B refer to the Northeastern sea-wall portion, while wall 4A, 5A, 6A, 4B, 5B, and 6B are part of the Southwestern and Southeastern seawall portions. During construction activities for the wall 3A, due to the geometry reasons and ease of installation, a plastic chair has been set on the bottom of the test block in order to hold both bars in position V and VI. ID/Ref. is assigned based on location of rebars in Figure 3. BFRP bars are located in position I and II, CFRP bars are located in position III and IV, and GFRP bars are located in position V and VI.

Table 1 – Test blocks rebars along wall sections

Wall	Rebar position in test block					
	I	II	III	IV	V	VI
1A	CFRP 0.6"		GFRP #5		BFRP #5	
2A	GFRP #5		BFRP #5		CFRP 0.6"	
3A	BFRP #5		CFRP 0.6"		GFRP #5	
1B	BFRP #5		CFRP 0.6"		GFRP #5	
2B	CFRP 0.6"		GFRP #5		BFRP #5	
3B	GFRP #5		BFRP #5		CFRP 0.6"	
4A	CFRP 0.6"		GFRP #5		BFRP #5	
5A	GFRP #5		BFRP #5		CFRP 0.6"	
6A	BFRP #5		CFRP 0.6"		GFRP #5	
4B	BFRP #5		CFRP 0.6"		GFRP #5	
5B	CFRP 0.6"		GFRP #5		BFRP #5	
6B	GFRP #5		BFRP #5		CFRP 0.6"	

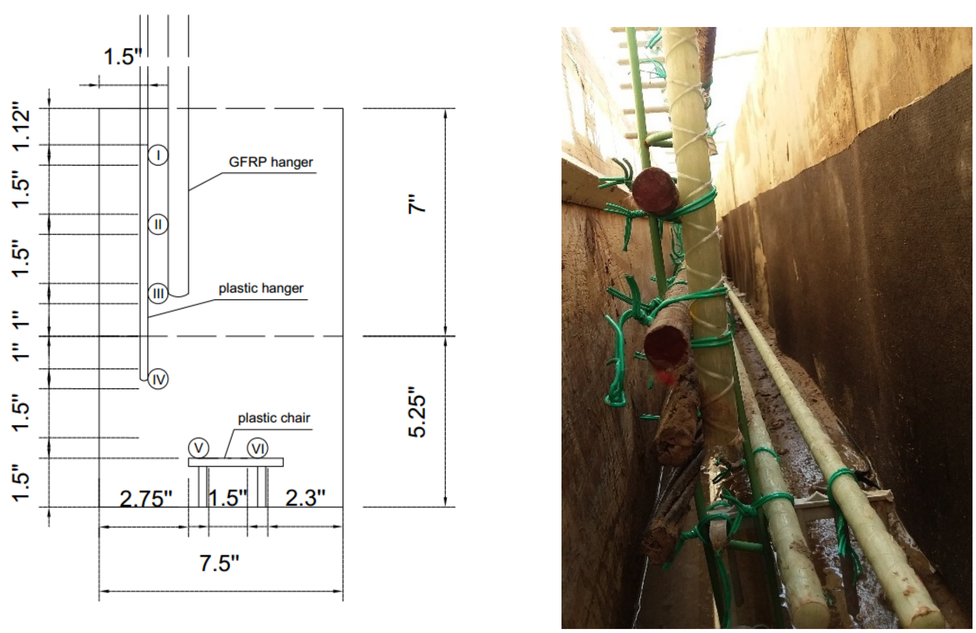


Figure 3 - Test blocks cross-section view

2.2.1. SUMMARY OF TEST RESULTS ON REBAR SAMPLES

Test ID	Standard Test Method	Test Description	Reference*	Test Value	Comparing to Reference*
SAMPLE No. 1					
TSS	ASTM D7617	Transverse shear strength	22.00 ksi	29.86 ksi	135.72%
HSS	ASTM D4475	Horizontal shear strength	N/A	5.72 ksi	N/A
FC	ASTM D2584	Fiber Content (by weight)	>70%	81.75%	116.79%
DMA	ASTM E1640	Glass transition temperature by Dynamic Mechanical Analysis	≥ 100 °C	101 °C	101.33%
TNS	ASTM D7205	Guaranteed Tensile Force	29.1 kip	33.1 kip	113.81%
		Tensile Modulus of Elasticity	≥ 6.5 Msi	7.3 Msi	
		Strain	≥ 1.1%	1.74%	
MXA	ASTM D792	Measured Cross Sectional Area	0.288 in^2 to 0.388 in^2	0.292 in^2	75.15%
MAS	ASTM D570	Moisture Absorption Short Term	≤ 0.25 %	0.17%	-30.78%
DSC	ASTM E2160	Grass transition temperature	≥ 212 ºF	283 ºF	133.28%
		Degree of cure by differential scanning calorimetry	≥ 95% of Total enthalpy polymerization	99.05%	
SEM	N/A	Scanning electron microscope	N/A	see images	N/A
EDX	N/A	Elemental analysis via Energy Dispersive X-ray	N/A	see graphs	N/A
FTIR	N/A	Fourier Transform Infrared (FTIR) spectroscopy	N/A	pending	N/A
SAMPLE No. 2					
TSS	ASTM D7617	Transverse shear strength	>22 ksi	42.37	192.61%
HSS	ASTM D4475	Horizontal shear strength	N/A	1.65 ksi	N/A
FC	ASTM D2584	Fiber Content (by weight)	>70%	82.58%	117.97%
DMA	ASTM E1640	Glass transition temperature by Dynamic Mechanical Analysis	≥ 110 °C	130 °C	118.18%
TNS	ASTM D7205	Guaranteed Tensile Force	49.1 kip	75.8 kip	154.35%
		Tensile Modulus of Elasticity	≥ 18 Msi	23.1 Msi	
		Strain	≥ 1.1%	1.87%	
MXA	ASTM D792	Measured Cross Sectional Area	0.185 in^2 to 0.263 in^2	0.183 in^2	69.48%
MAS	ASTM D570	Moisture Absorption Short Term	≤ 0.25 %	0.21%	-17.24%
DSC	ASTM E2160	Grass transition temperature	≥ 212 ºF	224 ºF	105.53%
		Degree of cure by differential scanning calorimetry	≥ 95% of Total enthalpy polymerization	99.99%	
SEM	N/A	Scanning electron microscope	N/A	see images	N/A
EDX	N/A	Elemental analysis via Energy Dispersive X-ray	N/A	see graphs	N/A
FTIR	N/A	Fourier Transform Infrared (FTIR) spectroscopy	N/A	pending	N/A
SAMPLE No. 3					
TSS	ASTM D7617	Transverse shear strength	>22 ksi	24.66	112.08%
HSS	ASTM D4475	Horizontal shear strength	N/A	5.72 ksi	N/A

FC	ASTM D2584	Fiber Content (by weight)	>70%	80.17%	114.53%
DMA	ASTM E1640	Glass transition temperature by Dynamic Mechanical Analysis	≥ 100 °C	117 °C	117%
TNS	ASTM D7205	Guaranteed Tensile Force	29.1 kip	34.1 kip	117.05%
		Tensile Modulus of Elasticity	≥ 6.5 Msi	7.7 Msi	
		Strain	≥ 1.1%	1.66%	
MXA	ASTM D792	Measured Cross Sectional Area	0.288 in^2 to 0.388 in^2	0.335 in^2	86.38%
MAS	ASTM D570	Moisture Absorption Short Term	≤ 0.25 %	0.09%	-65.46%
DSC	ASTM E2160	Grass transition temperature	≥ 212 ºF	234 ºF	110.39%
		Degree of cure by differential scanning calorimetry	≥ 95% of Total enthalpy polymerization	99.99%	
SEM	N/A	Scanning electron microscope	N/A	see images	N/A
EDX	N/A	Elemental analysis via Energy Dispersive X-ray	N/A	see graphs	N/A
FTIR	N/A	Fourier Transform Infrared (FTIR) spectroscopy	N/A	pending	N/A

**ASTM D7957 & FDOT SPEC 932, SPEC 933*

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, Thomas Cadenazzi and Roger Solis
Specimen Preparation: The specimens were cut to the prescribed dimensions with ends sealed with epoxy coating.
Reference TDS: Technical Data Sheet: TDS-TSS-HRB
Test Data:

Specimen ID	Peak Load P_{max}		Measured Area A_{exp}		Transverse Shear Strength τ_u		Reference* Transverse Shear Strength	Comparing to Reference*
	kN	lbs	mm²	ksi	%	lbs	ksi	%
HRB_B_TSS_01	77.89	17510			206.72	29.98		136.29
HRB_B_TSS_02	77.78	17485			206.43	29.94		136.09
HRB_B_TSS_03	77.07	17326	188.39	0.292	204.55	29.67	22.00	134.85
HRB_B_TSS_04	76.79	17263			203.80	29.56		134.36
HRB_B_TSS_05	78.31	17605			207.85	30.15		137.03
Average	**77.57**	**17438**			**205.87**	**29.86**		**135.72**
S_{n-1}	0.62	140			1.66	0.24		
CV (%)	0.8	0.8			0.8	0.8		
HRB_C_TSS_01	82.09	18455			291.84	42.33		192.40
HRB_C_TSS_02	81.78	18385			290.73	42.17		191.67
HRB_C_TSS_03	82.96	18650	140.64	0.218	294.92	42.78	22.00	194.43
HRB_C_TSS_04	82.00	18435			291.52	42.28		192.19
HRB_C_TSS_05	82.07	18450			291.76	42.32		192.35
Average	**82.18**	**18475**			**292.16**	**42.37**		**192.61**
S_{n-1}	0.45	102			1.61	0.23		
CV (%)	0.6	0.6			0.6	0.6		
HRB_G_TSS_01	73.51	16525			170.05	24.66		112.11
HRB_G_TSS_02	73.44	16510			169.90	24.64		112.01
HRB_G_TSS_03	73.88	16609	216.13	0.335	170.92	24.79	22.00	112.68
HRB_G_TSS_04	73.05	16423			169.00	24.51		111.42
HRB_G_TSS_05	73.55	16535			170.16	24.68		112.18
Average	**73.49**	**16520**			**170.01**	**24.66**		**112.08**
S_{n-1}	0.30	66			0.68	0.10		
CV (%)	0.4	0.4			0.4	0.4		

** ASTM D7957 & FDOT SPEC 932, SPEC 933*

Test Setup:

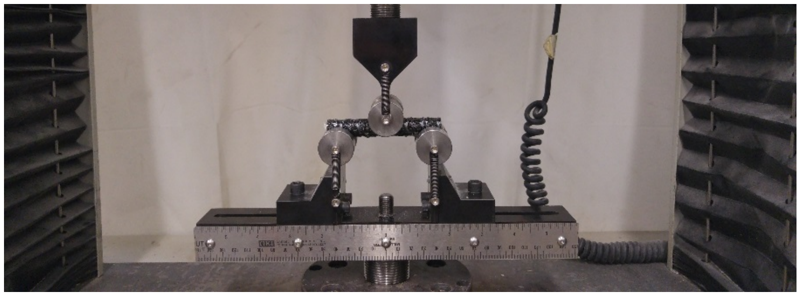
Representative Failure Mode:

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, Thomas Cadenazzi, Roger Solis
Specimen Size: 4.5 in. length
Reference TDS: TDS-HSS-HRB
Test Data:

Specimen ID	Peak Load		Measured Diameter		Experimental Horizontal Shear Strength	
	P_{max}		$\varnothing_{exp}$		τ_u	
	kN	lbs	mm	in	MPa	ksi
HRB_B_HSS_01	11.850	2664			43.17	6.26
HRB_B_HSS_02	10.342	2325			37.68	5.47
HRB_B_HSS_03	9.521	2140	15.27	0.601	34.69	5.03
HRB_B_HSS_04	11.835	2661			43.12	6.25
HRB_B_HSS_05	10.541	2370			38.40	5.57
Average	**10.82**	**2432**			**39.41**	**5.72**
S_{n-1}	1.01	227			3.68	0.53
CV (%)	9.3	9.3			9.3	9.3
HRB_C_HSS_01	3.470	780			11.74	1.70
HRB_C_HSS_02	3.447	775			11.67	1.69
HRB_C_HSS_03	3.318	746	15.84	0.624	11.23	1.63
HRB_C_HSS_04	3.287	739			11.13	1.61
HRB_C_HSS_05	3.296	741			11.16	1.62
Average	**3.36**	**756**			**11.39**	**1.65**
S_{n-1}	0.09	20			0.30	0.04
CV (%)	2.6	2.6			2.6	2.6
HRB_G_HSS_01	13.462	3026			41.04	5.95
HRB_G_HSS_02	13.650	3069			41.61	6.04
HRB_G_HSS_03	13.130	2952	16.69	0.657	40.03	5.81
HRB_G_HSS_04	13.206	2969			40.26	5.84
HRB_G_HSS_05	11.270	2533			34.36	4.98
Average	**12.94**	**2910**			**39.46**	**5.72**
S_{n-1}	0.96	215			2.92	0.42
CV (%)	7.4	7.4			7.4	7.4

Test Setup:



Representative Failure Mode:

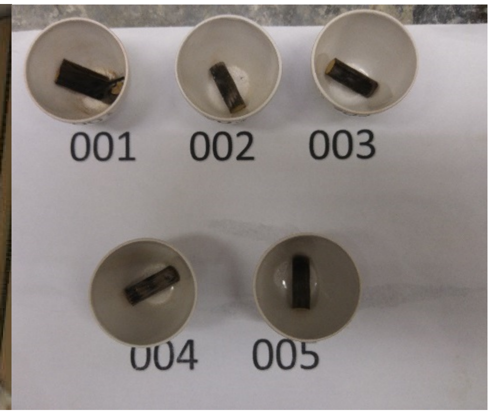
2.2.1.3. FIBER CONTENT (FC)

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, 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
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	Reference* Fiber Content	Comparing to Reference*
	g	g	g	g	g	%	%	%
HRB_B_FC_01	28.68	38.35	36.70	9.67	8.02	82.94		118.48
HRB_B_FC_02	29.79	41.09	39.16	11.30	9.37	82.92		118.46
HRB_B_FC_03	29.85	40.49	38.53	10.64	8.68	81.58	70.00	116.54
HRB_B_FC_04	28.12	39.14	37.08	11.02	8.96	81.31		116.15
HRB_B_FC_05	30.64	41.70	39.49	11.06	8.85	80.02		114.31
					Average	**81.75**		**116.79**
					Sn-1	122.51		
					CV (%)	1.50		
HRB_C_FC_01	54.03	55.76	30.42	1.73	1.41	81.74		116.77
HRB_C_FC_02	53.01	55.01	31.58	2.00	1.41	70.37		100.53
HRB_C_FC_03	58.11	59.94	31.52	1.83	1.68	91.93	70.00	131.33
HRB_C_FC_04	54.06	55.60	29.55	1.54	1.32	85.95		122.79
HRB_C_FC_05	53.19	54.75	32.27	1.56	1.30	82.92		118.45
					Average	**82.58**		**117.97**
					Sn-1	788.67		
					CV (%)	9.55		
HRB_G_FC_01	28.68	39.72	37.51	11.04	8.83	79.94		114.20
HRB_G_FC_02	26.87	37.75	35.61	10.88	8.74	80.34		114.77
HRB_G_FC_03	29.85	40.14	38.11	10.29	8.26	80.24	70.00	114.62
HRB_G_FC_04	28.12	39.80	37.46	11.68	9.34	79.99		114.27
HRB_G_FC_05	30.64	41.39	39.28	10.75	8.64	80.33		114.76
					Average	**80.17**		**114.53**
					Sn-1	19.17		
					CV (%)	0.24		

** ASTM D7957 & FDOT SPEC 932, SPEC 933*

Test Setup:



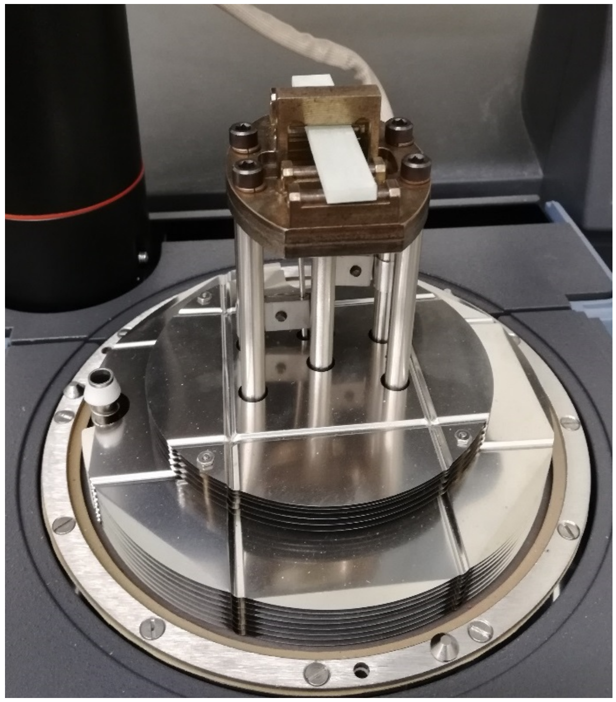
2.2.1.4. GLASS TRANSITION TEMPERATURE BY DYNAMIC MECHANICAL ANALYSIS

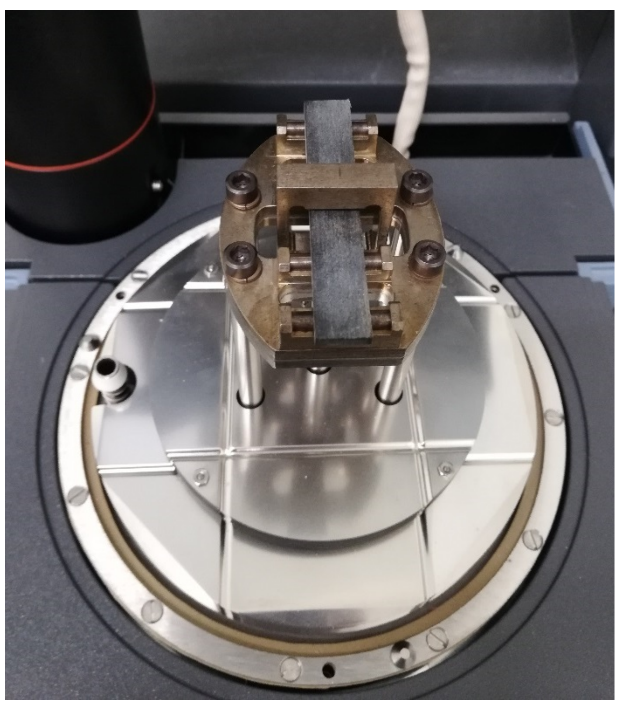
Test Standard Method: ASTM E1640
Test Description: This test method can be used to locate the glass transition region and assign a glass transition temperature of amorphous and semi-crystalline materials.
Technician/s: Guillermo Claure, Thomas Cadenazzi, Guan Wang
Specimen Preparation: It is important 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
Test Data:

Specimen ID	T_g		Reference* T_g	Comparing to Reference*
	°C	°F	°C	%
HRB_B_TG_01	100	212		100.00
HRB_B_TG_02	105	221	100.00	105.00
HRB_B_TG_03	99	210		99.00
Average	**101**	**214**		**101.33**
S_{n-1}	3	6		
CV (%)	3.2	2.7		
HRB_C_TG_01	128	262		116.36
HRB_C_TG_02	133	271	110.00	120.91
HRB_C_TG_03	129	264		117.27
Average	**130**	**266**		**118.18**
S_{n-1}	3	5		
CV (%)	2.0	1.8		
HRB_G_TG_01	114	237		114.00
HRB_G_TG_02	120	248	100.00	120.00
HRB_G_TG_03	117	243		117.00
Average	**117**	**243**		**117.00**
S_{n-1}	3	5		
CV (%)	2.6	2.2		

** ASTM D7957 & FDOT SPEC 932, SPEC 933*

Test Setup:





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, Thomas Cadenazzi, 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
Test Data:

SPECIMEN ID	Peak Load P_{max}		Tensile Strength f_{fu}		Modulus of Elasticity E		Strain ε_u	Reference* Tensile Load	Comparing to Reference*
	kN	lbs	MPa	ksi	GPa	Msi	%	lbs	%
HRB_B_TNS_001	172	38694	914	133	53.57	7.77	1.71		132.97
HRB_B_TNS_002	158	35624	841	122	48.77	7.07	1.72		122.42
HRB_B_TNS_003	159	35792	845	123	50.18	7.28	1.68	29100	123.00
HRB_B_TNS_004	167	37514	886	128	49.80	7.22	1.78		128.92
HRB_B_TNS_005	167	37643	889	129	49.27	7.15	1.80		129.36
Average	**165**	**37054**	**875**	**127**	**50.32**	**7.30**	**1.74**		**127.33**
S_{n-1}	6	1312	31	4	1.90	0.28	0.05		4.51
CV (%)	3.5	3.5	3.5	3.5	3.8	3.8	2.9		3.5
Guar. Tensile Force	**147**	**33117**							**113.81**
HRB_C_TNS_001	346	77878	2950	428	147.02	21.32	2.01		158.61
HRB_C_TNS_002	345	77529	2937	426	161.55	23.43	1.82		157.90
HRB_C_TNS_003	353	79370	3007	436	175.96	25.52	1.71	49100	161.65
HRB_C_TNS_004	345	77502	2936	426	153.17	22.21	1.92		157.84
HRB_C_TNS_005	349	78519	2975	431	158.67	23.01	1.87		159.92
Average	**348**	**78159**	**2961**	**429**	**159.27**	**23.10**	**1.87**		**159.18**
S_{n-1}	4	791	30	4	10.86	1.57	0.11		1.61
CV (%)	1.0	1.0	1.0	1.0	6.8	6.8	6.0		1.0
Guar. Tensile Force	**337**	**75786**							**154.35**
HRB_G_TNS_001	196	43959	916	133	52.60	7.63	1.74		151.06
HRB_G_TNS_002	204	45759	953	138	54.37	7.89	1.75		157.25
HRB_G_TNS_003	171	38513	802	116	53.23	7.72	1.51	29100	132.35
HRB_G_TNS_004	183	41036	855	124	52.40	7.60	1.63		141.02
HRB_G_TNS_005	190	42628	888	129	52.83	7.66	1.68		146.49
Average	**189**	**42379**	**883**	**128**	**53.09**	**7.70**	**1.66**		**145.63**
S_{n-1}	12	2772	58	8	0.78	0.11	0.10		9.53
CV (%)	6.5	6.5	6.5	6.5	1.5	1.5	6.0		6.5
Guar. Tensile Force	**152**	**34063**							**117.05**

** ASTM D7957 & FDOT SPEC 932, SPEC 933*

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, Thomas Cadenazzi, Roger Solis.
Specimen Size: Specimen length dimensions were 50 mm (2.0 in.).
Reference TDS: Technical Data Sheet: TDS-MXA-HRB
Test Data:

Specimen ID	Measured Area A		Reference* Maximum Area	Comparing to Reference*
	mm^2	in^2	in^2	%
HRB_B_MXA_01	186	0.288		74.28
HRB_B_MXA_02	190	0.295		75.93
HRB_B_MXA_03	192	0.297	0.388	76.57
HRB_B_MXA_04	185	0.286		73.77
HRB_B_MXA_05	188	0.292		75.21
Average	**188**	**0.292**		**75.15**
S_{n-1}	3	0.004		
CV (%)	1.5	1.5		
HRB_C_MXA_01	118	0.182		69.27
HRB_C_MXA_02	117	0.181		69.01
HRB_C_MXA_03	120	0.185	0.263	70.44
HRB_C_MXA_04	118	0.182		69.34
HRB_C_MXA_05	118	0.182		69.34
Average	**118**	**0.183**		**69.48**
S_{n-1}	1	0.001		
CV (%)	0.8	0.8		
HRB_G_MXA_01	221	0.343		88.29
HRB_G_MXA_02	219	0.340		87.60
HRB_G_MXA_03	206	0.320	0.388	82.44
HRB_G_MXA_04	217	0.337		86.85
HRB_G_MXA_05	217	0.336		86.72
Average	**216**	**0.335**		**86.38**
S_{n-1}	6	0.009		
CV (%)	2.6	2.6		

**ASTM D7957 & FDOT SPEC 932, SPEC 933*

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 50ºC temperature.
Technician/s: 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-MA-HRB
Test Data:

Specimen ID	Moisture Absorption			Reference* Moisture Absorption	Comparing to Reference*
	W_i	W_{24}	W_{24}		
	g	g	%	%	%
HRB_B_MA_01	8.4651	8.4808	0.19	0.25	-25.81
HRB_B_MA_02	9.6544	9.6694	0.16		-37.85
HRB_B_MA_03	9.1223	9.1400	0.19		-22.39
HRB_B_MA_04	9.3691	9.3830	0.15		-40.66
HRB_B_MA_05	9.9416	9.9597	0.18		-27.17
Average	**9.3105**	**9.3266**	**0.17**		**-30.78**
S_{n-1}	0.56	0.56	0.02		
CV (%)	6.05	6.05	11.5		
HRB_C_MA_01	5.1265	5.1372	0.21	0.25	-16.51
HRB_C_MA_02	5.0620	5.0726	0.21		-16.24
HRB_C_MA_03	5.2725	5.2834	0.21		-17.31
HRB_C_MA_04	5.2330	5.2433	0.20		-21.27
HRB_C_MA_05	5.6380	5.6500	0.21		-14.86
Average	**5.2664**	**5.2773**	**0.21**		**-17.24**
S_{n-1}	0.2239	0.2245	0.01		
CV (%)	4.3	4.3	2.9		
HRB_G_MA_01	10.6448	10.6535	0.08	0.25	-67.31
HRB_G_MA_02	11.0548	11.0643	0.09		-65.63
HRB_G_MA_03	10.6352	10.6437	0.08		-68.03
HRB_G_MA_04	10.9056	10.9152	0.09		-64.79
HRB_G_MA_05	10.9197	10.9302	0.10		-61.54
Average	**10.8320**	**10.8414**	**0.09**		**-65.46**
S_{n-1}	0.1847	0.1853	0.01		
CV (%)	1.7	1.7	7.4		

**ASTM D7957 & FDOT SPEC 932, SPEC 933*

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-TPE-HRB

Test Data:

Specimen ID	Normalized Heat of Reaction H	Degree of Cure DC	Glass Transition Temperature Tg		Reference* Glass Transition Temperature	Comparing to Reference*
	J/g	%	°C	°F	°F	%
HRB_B_DSC_01	0.7658	99.23	141.08	286		134.88
HRB_B_DSC_02	0.7755	99.22	138.78	282		132.93
HRB_B_DSC_03	1.1830	98.82	137.42	279	212	131.77
HRB_B_DSC_04	1.0880	98.91	140.04	284		134.00
HRB_B_DSC_05	0.9202	99.08	138.66	282		132.82
Average		**99.05**	**139.20**	**283**		**133.28**
S_{n-1}		0.19	1.40	3		
CV (%)		0.2	1.0	0.9		
HRB_C_DSC_01	0.010	99.99	110.51	231		108.92
HRB_C_DSC_02	0.010	99.99	106.52	224		105.54
HRB_C_DSC_03	0.010	99.99	104.67	220	212	103.97
HRB_C_DSC_04	0.020	99.98	106.70	224		105.69
HRB_C_DSC_05	0.020	99.98	104.18	220		103.55
Average		**99.99**	**106.52**	**224**		**105.53**
S_{n-1}		0.01	2.49	4		
CV (%)		0.0	2.3	2.0		
HRB_G_DSC_01	0.010	99.99	110.57	231		108.97
HRB_G_DSC_02	0.010	99.99	111.44	233		109.71
HRB_G_DSC_03	0.020	99.98	112.74	235	212	110.82
HRB_G_DSC_04	0.010	99.99	114.41	238		112.23
HRB_G_DSC_05	0.020	99.98	112.04	234		110.22
Average		**99.99**	**112.24**	**234**		**110.39**
S_{n-1}		0.01	1.45	3		
CV (%)		0.0	1.3	1.1		

**ASTM D7957 & FDOT SPEC 932, SPEC 933*

Test Setup:

2.2.1.9. SCANNING ELECTRON MICROSCOPY IMAGING (SEM)

Test Method: Laboratory Method

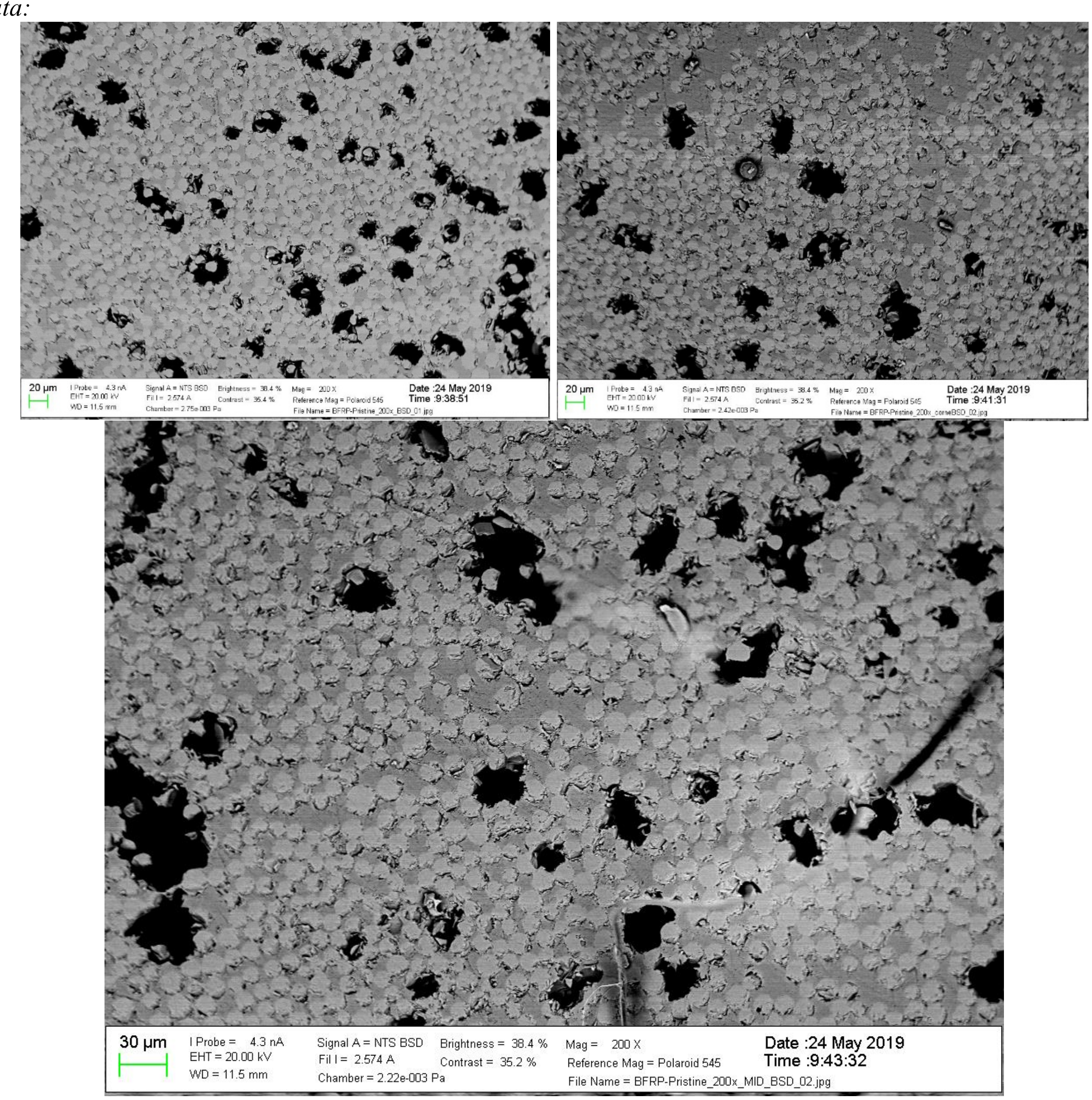
Test Description: Imaging to observe microscopic features of the cross-section of the bars up to 50 nm in size accomplished with SEM. SEM is used to qualitatively evaluate the cross-section and determine the 'finger-print' for the manufactured rebar, the void and fiber dispersion, cross-sectional pattern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

Technician/s: Guillermo Claure and Guan Wang

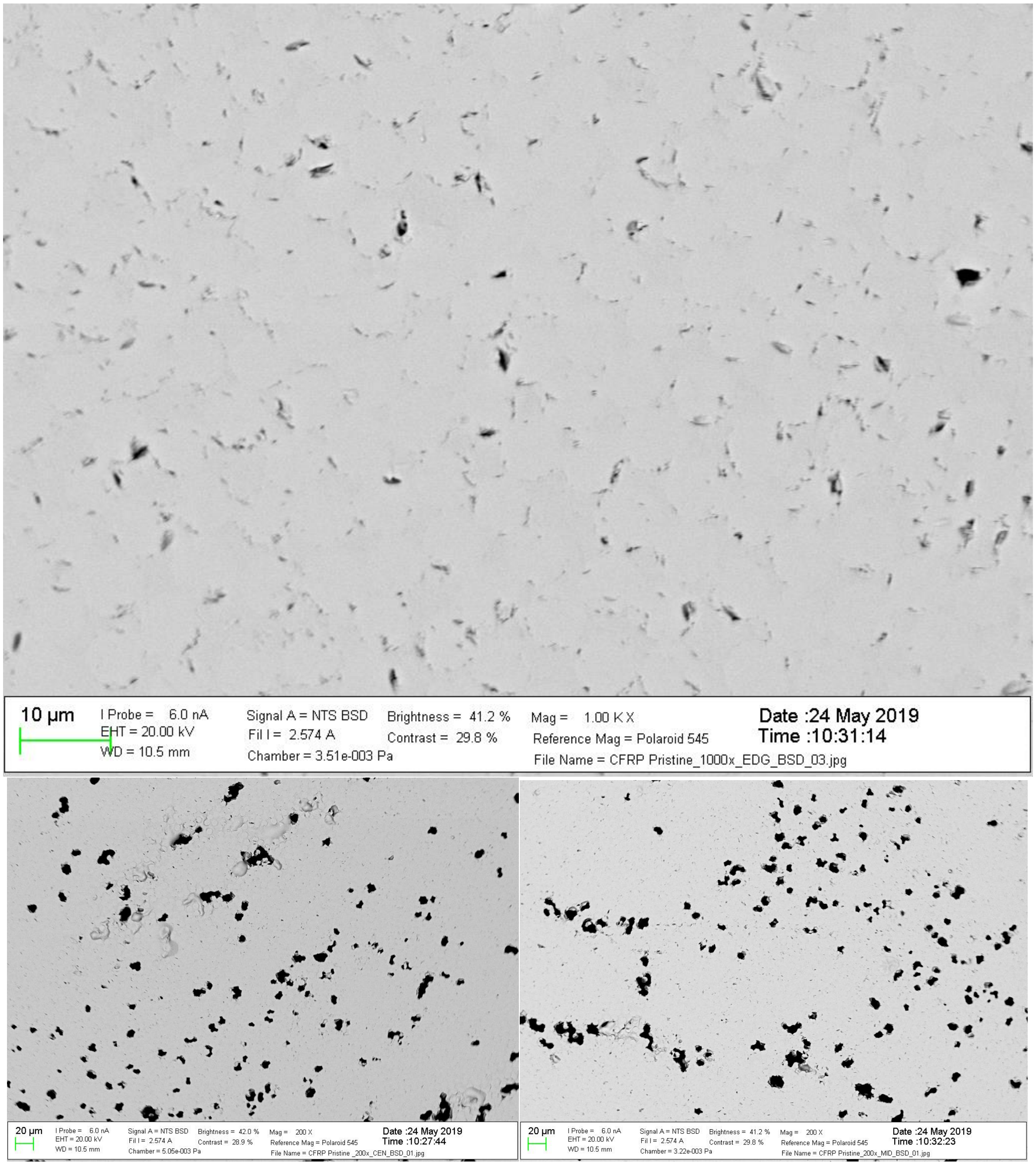
Specimen Preparation: The specimens included acquisition of a sample that will fit into the SEM chamber and some accommodation to prevent charge build-up on electrically insulating samples. Electrically insulating samples were coated with a thin layer of conducting material, commonly metal/alloy. Metal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

Reference TDS: TDS-SEM-HRB

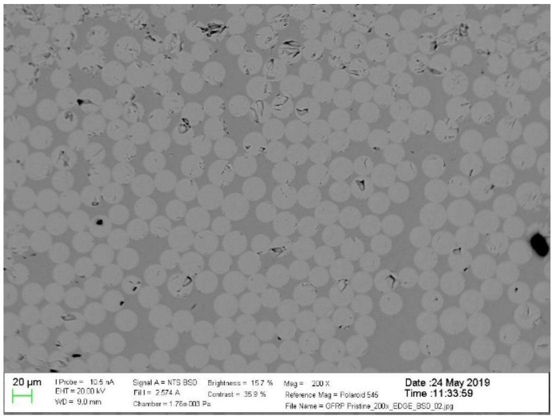
Test Data:

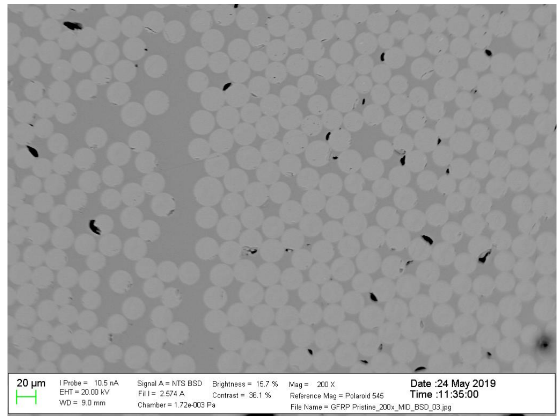


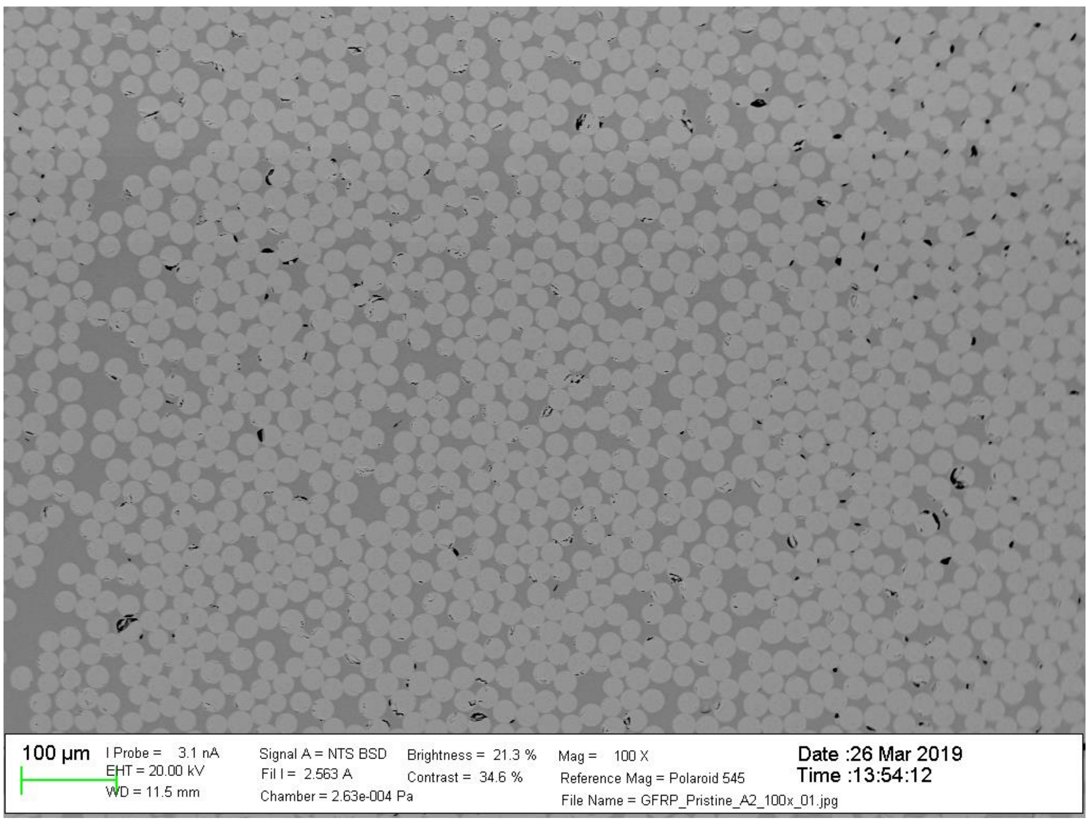
Representative SEM image of BFRP sample



Representative SEM image of CFRP sample



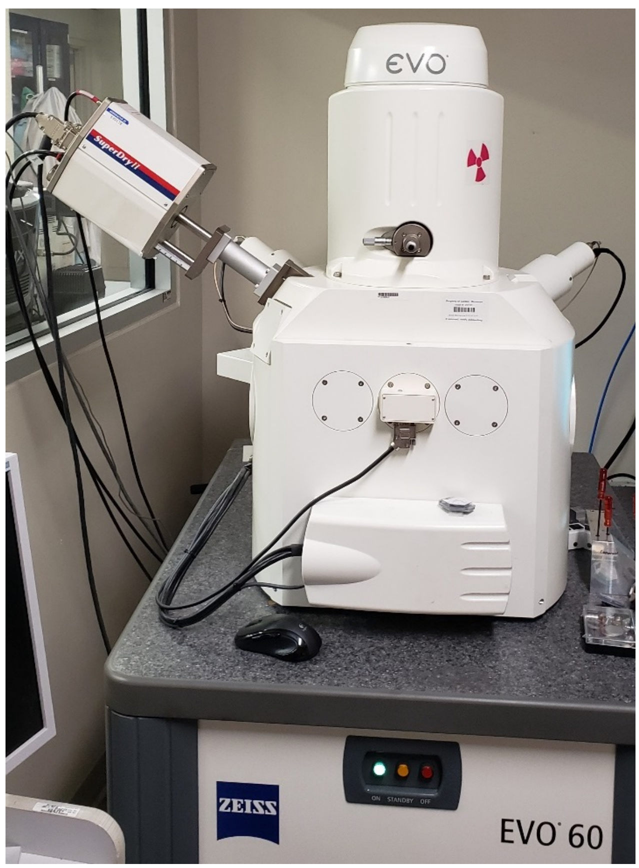




Representative SEM image of GFRP sample

Test Preparation:

Test 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, Thomas Cadenazzi and Roger Solis

Specimen Preparation: Specimen are gold coated. 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

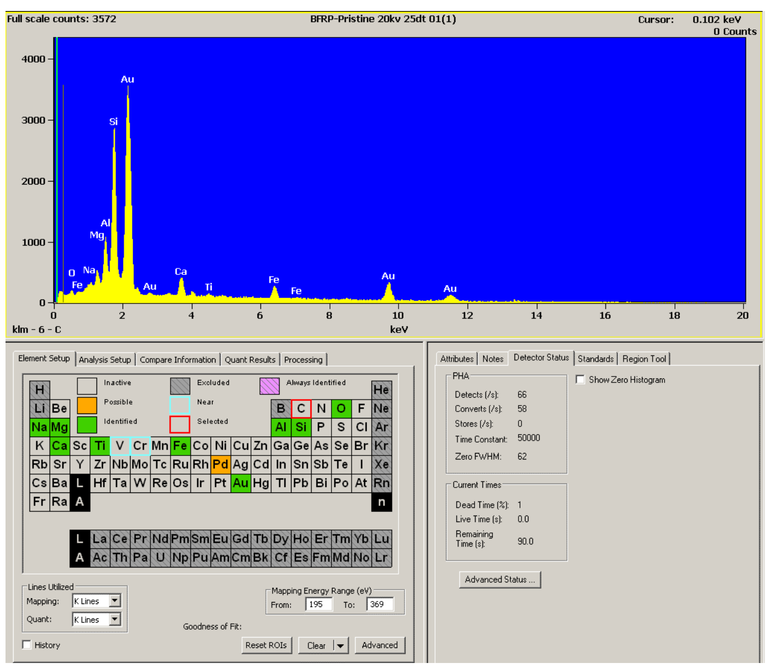
Test Data:

BFRP	Fe	Ca	Na	Mg	Al	Si
Quant. detected	200	300	400	300	1100	2900

CFRP	Si	Ca	Na	Al	Cl
Quant. detected	250	7600	200	200	300

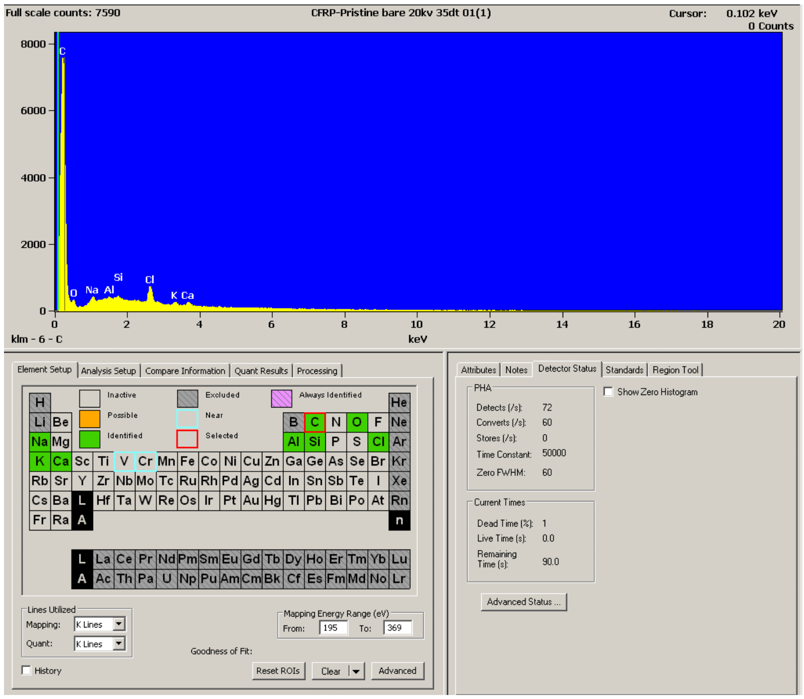
GFRP	Ti	Ca	O	Mg	Al	Si
Quant. detected	150	1900	150	300	1200	5300

Graphs:



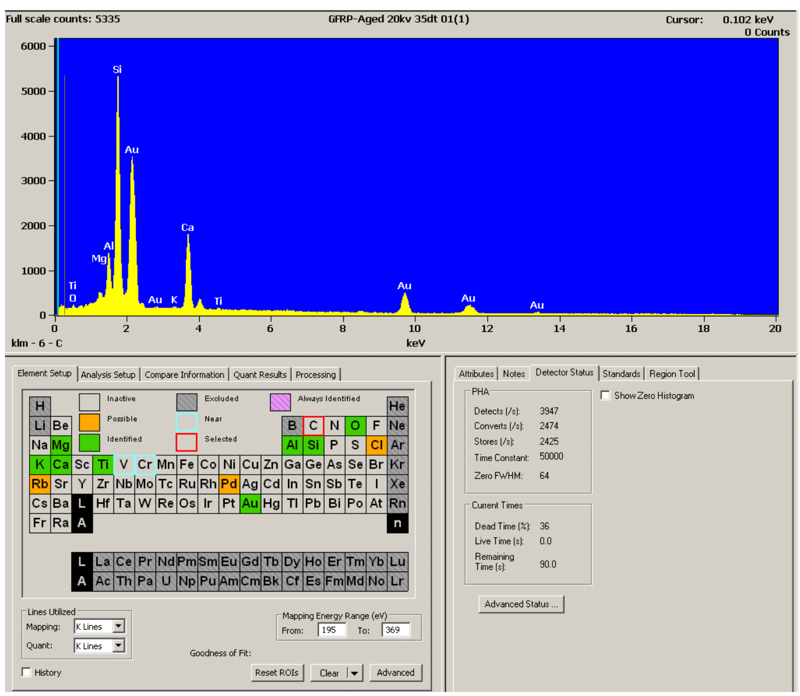
Representative EDX image of BFRP sample

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



Representative EDX image of CFRP sample

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



Representative EDX image of 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
Test Graphs:	

Tests results pending.

3. DELIVERABLE 2 - TASK 2
After Test Block Extraction (tests referenced to Task 1-C after nine-month exposure)

3.1. CONCRETE SAMPLE INFORMATION

The test results presented herein provides the nine-month-aged physio-mechanical properties for the samples under valuation. The extracted test blocks come from the portion of seawall technically called wall-3A (see Figure 4).

Figure 4 – Aerial picture of the bridge with Wall 3A blocks identification

The wall 3A was cast as part of the North-western seawall on Thursday, December 21, 2017. As all test blocks of the north-western seawall were cast, they were not immediately exposed to seawater, and thus the intended corrosive environment. It was not until February 18th 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 February 18th as day-zero.
The nine-month extraction activities were scheduled for November 18th. On that day, the extraction crew initially started operating by land since the first set of wall-3A blocks were located in shallow water. However, as parallel activities on bridge ramped up, and the bridge eventually opened to traffic, it became more convenient to work from boat. The blocks were held up while cutting, and subsequently picked up. For the wall 3A set, the extraction crew installed heavy duty eye bolts prior to cutting (see Figure 5).

Figure 5 - Wall 3A test blocks

Afterwards, through the aim of a crane, able to drag the blocks out from under the bulkhead section, the crew was able to get some strapping around prior to further lifting and loading by crane.
The crew used concrete chain saws which required water. The crew did vertical cuts first and then the horizontal cuts. In most cases after the cutting was complete, the blocks needed some additional force to break free (through wedge and sledge).
After removal was successfully completed, the resulting four 5-foot and four 2.5-foot test blocks from wall 3-A blocks were loaded on a pick-up and shipped to Miami.
On December 5th, the eight test blocks from wall 3A were successfully delivered at SML where the research team at SML conducted the following activities.


Figure 6 - Shipping and delivering to SML of the wall 3A test blocks

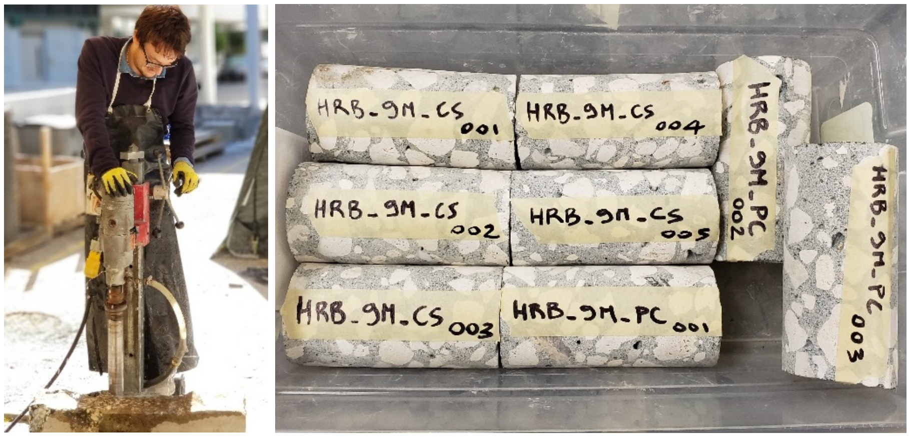
The research team at SML initially stored the blocks in a control environment, as shown in Figure 7. The blocks were carefully moved and placed with the aim of a forklift and measured to confirm actual sizes and make sure that during extraction and shipping activities there was no loss of material. The measured cross-section blocks confirmed site-geometry of the original test blocks: 12.25”x7.5” as previously shown in Figure 3.

Figure 7 – Initial storing at SML of the wall-3A test blocks

On December 7th, the eight concrete blocks were first chipped with a Hilti DD 30-W reducing noise, dust, and vibration throughout the internal rebars. Block after block, the concrete was carefully crushed to extract the internal rebars (Figure 8).

Figure 8 – (b) coring activities on test blocks, and (c) cores extracted

Additionally, from each of the blocks, along the free vertical line 7” long, 2”x4” cylindrical concrete specimens were extracted.
A total of thirty-one (31) 2” x 4” cylindrical concrete specimens were cored from each test block received, with a rotary 2” x 4” core drilling machine, as shown in Figure 9.



(a) (b)

Figure 9 – (a) coring activities on test blocks, and (b) cores extracted

3.1.1. SUMMARY OF TEST RESULTS ON CONCERE SAMPLE – 9-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	6,953 psi	94%	126%
PC	ASTM C1202	Penetration of chloride ion into concrete	Pending	Pending	Pending	N/A
PH	N/A	PH concrete test	12.22	12.33	100.9%	N/A
S	N/A	Stiffness test	5,033,333 psi-in	4,750,000 psi-in	93%	138%
FTIR	N/A	Fourier Transform Infrared (FTIR) spectroscopy test	N/A	see graphs	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

3.1.1.1. 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, Thomas Cadenazzi, 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-9M
Test Data:

Specimen ID	Peak force		Compressive Strength		Benchmark**		Compressive Strength Retention	Comparing to Reference*
	P_{max}		f'_c		f'_c			
	kN	lbf	MPa	psi	MPa	psi	%	%
HRB-9M-CS-001	90.1	20,255	44.5	6,447			87%	117%
HRB-9M-CS-002	107.2	24,104	52.9	7,673	51.2	7,428	103%	140%
HRB-9M-CS-003	94.2	21,175	46.5	6,740			91%	123%
Average	**97.2**	**21,845**	**47.9**	**6,953**			**94%**	**126%**
S_{n-1}	8.94	2,010	4.41	640				
CV (%)	9.20	9.20	9.21	9.21				

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

Test Setup:

Representative Failure Mode:

3.1.1.1. 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-9M
Test Data:

Specimen ID	**Charge Passed**	**Benchmark****	**Comparing to Benchmark****
	(coulombs)	**(coulombs)**	**%**
HRB-9M_PC-001	0		
HRB-9M_PC-002	0	Test results pending	
HRB-9M_PC-003	0		
Average	0.00		
S_{n-1}	0.00		
CV (%)			

***Benchmark values from Deliverable 1 test results*

3.1.1.2. 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-9M
Test Data:

Specimen ID	pH	Benchmark**	Comparing to Benchmark**
		pH	%
HRB-9M_PH-001	12.32		100.8%
HRB-9M_PH-002	12.34	12.22	101.0%
HRB-9M_PH-003	12.33		100.9%
Average	12.33		100.9%
S_{n-1}	0.01		
CV (%)	0.08		

***Benchmark values from Deliverable 1 test results*

Test Setup:

3.1.1.3. 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-9M
Test Data:

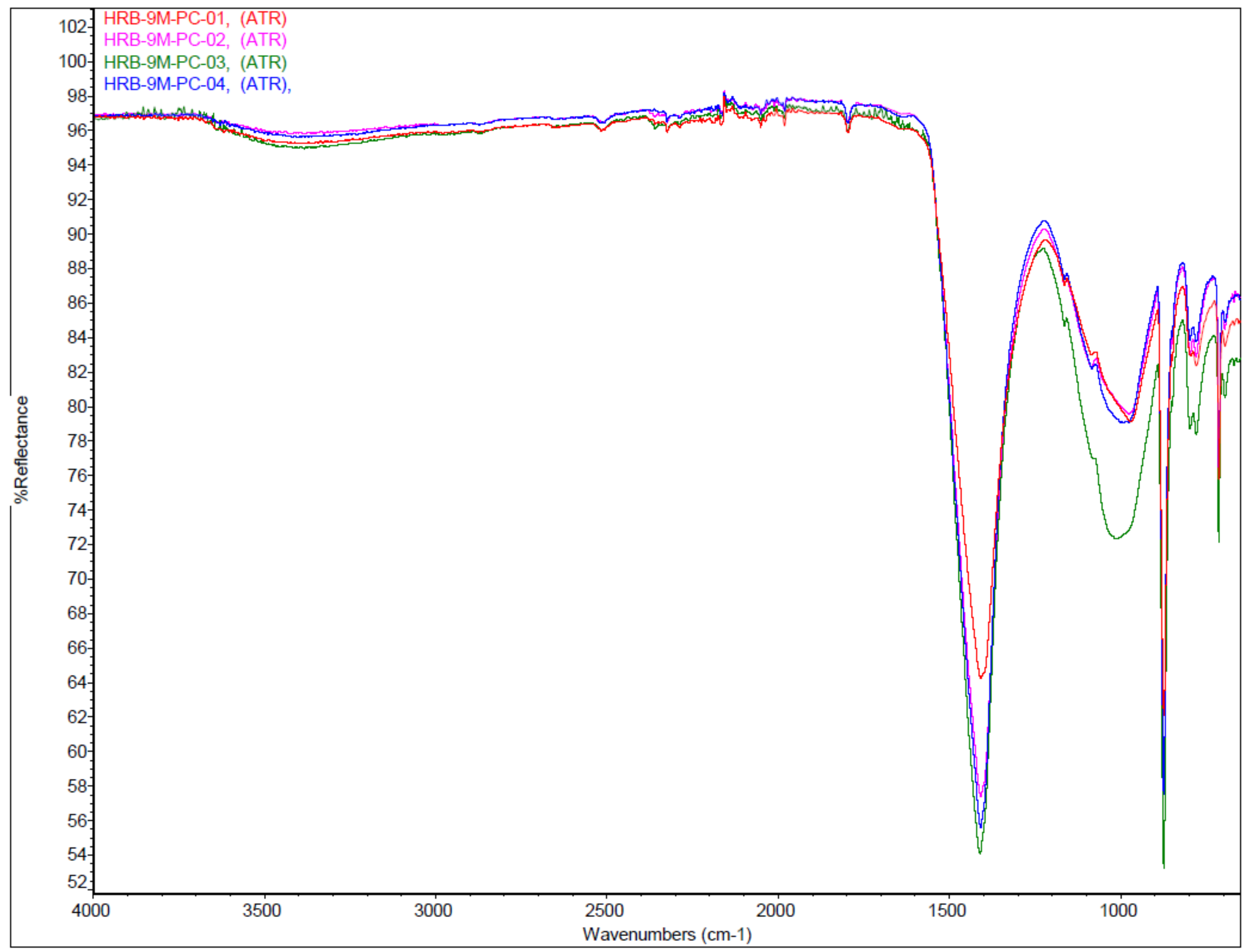
Specimen ID	Stiffness E		Benchmark** Stiffness E		Stiffness Retention	Comparing to Reference*
	MPa.mm	psi-in	MPa.mm	psi-in	%	%
HRB-9M-CS-002	20,907	4,700,000			93%	138%
HRB-9M-CS-004	22,019	4,950,000	22,389	5,033,333	98%	146%
HRB-9M-CS-005	19,795	4,450,000			88%	131%
Average	20,907	4,700,000			93%	138%
S_{n-1}	1,112	250,000				
CV (%)	5.32	5.32				

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

Test Setup & Representative Failure Mode:

3.1.1.4. 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-9M
Test Graphs:	

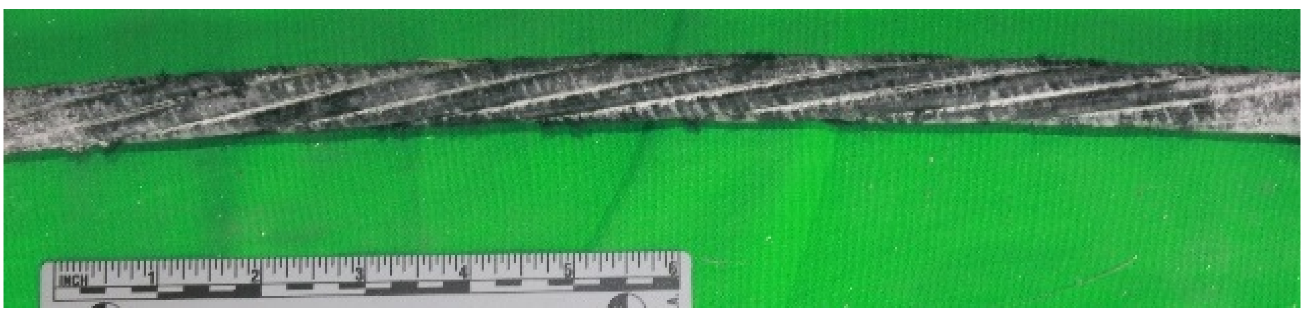


3.2. REBAR SAMPLE INFORMATION

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

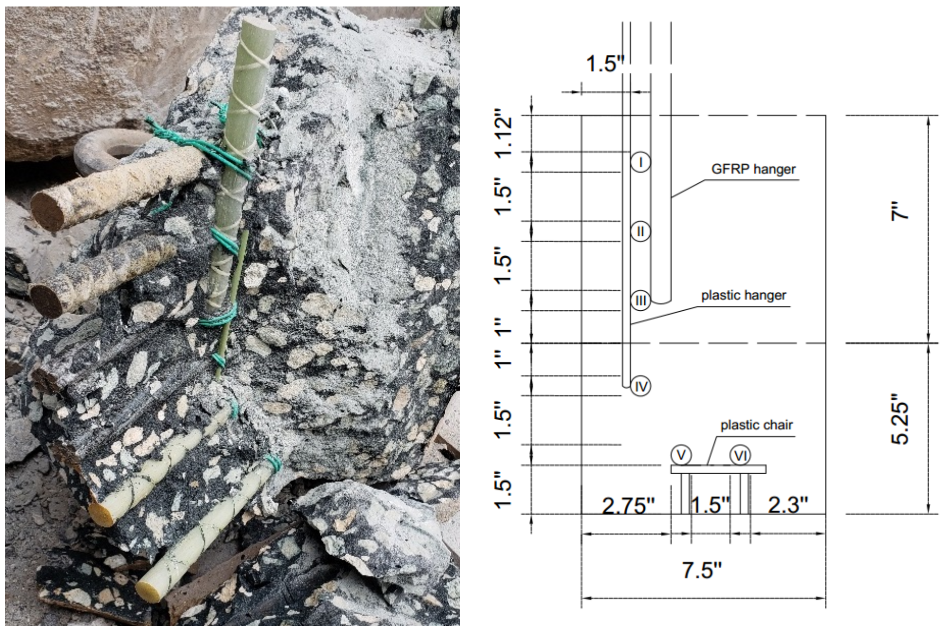
Sample No.	Location Reference / Position	Nominal Rebar Denomination	Material type
1	TEST BLOCK BULKHEAD CAP 3A – POSITION I, II	#5	BFRP rebar

2	TEST BLOCK BULKHEAD CAP 3A – POSITION III, IV	#5	CFRP rebar



3	TEST BLOCK BULKHEAD CAP 3A – POSITION V, VI	#6	GFRP rebar

ID/Ref. is assigned based on location of rebars in Figure 3. All rebars from blocks of wall 3A confirmed field-scheme of Figure 3, 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. Figure 4a shows the bars field scheme during bars extractions activities (Figure 4b).
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 chipped with a Hilti DD 30-W reducing noise, dust, and vibration through rebar specimens. This way, particular care was taken so not to damage the FRP rebars while removing the concrete from their surface. The task was accomplished smoothly and all the rebars were extracted with minimal damage as shown in Figure 3a.



(a) (b)

Figure 3. (a) Bars extraction activities; (b) test blocks cross-section view

All blocks of wall 3A confirmed field-scheme of Figure 3b, 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 3b. Aside from rebar extraction, on the same day, thirty one (31) 2” x 4” cylindrical concrete specimens were cored with a rotary 2” x 4” core drilling machine for respective concrete testing.

3.2.1. 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						
TSS	ASTM D7617	Transverse shear strength	29.86 ksi	24.38 ksi	81.64%	110.80%
HSS	ASTM D4475	Horizontal shear strength	5.72 ksi	5.87 ksi	102.68%	N/A
FC	ASTM D2584	Fiber Content (by weight)	81.75%	80.17%	98.06%	114.53%
DMA	ASTM E1640	Glass transition temperature by Dynamic Mechanical Analysis	101 °C	102 °C	101.07%	102.41%
TNS	ASTM D7205	Guar. Tensile Force	33.1 kip	29.4 kip	88.72%	100.97%
		Tensile Modulus of Elasticity	≥ 6.5 Msi	7.7 Msi		
		Strain	≥ 1.1%	1.48%		
MXA	ASTM D792	Measured Cross Sectional Area	0.292 in^2	0.341 in^2	116.86%	87.82%
MAS	ASTM D570	Moisture Absorption Short Term	0.17 %	0.22%	27.44%	-11.78%
DSC	ASTM E2160	Grass transition temperature	283 ºF	226 ºF	79.82%	106.39%
		Degree of cure by differential scanning calorimetry	≥ 95% of Total enthalpy polymerization	97.09%		
SEM	N/A	Scanning electron microscope		N/A	see images	N/A
EDX	N/A	Elemental analysis via Energy Dispersive X-ray		N/A	see graphs	N/A
FTIR	N/A	Fourier Transform Infrared (FTIR) spectroscopy		N/A	see graphs	N/A
SAMPLE No. 2						
TSS	ASTM D7617	Transverse shear strength	42.37 ksi	37.88 ksi	89.39%	172.17%
HSS	ASTM D4475	Horizontal shear strength	1.65 ksi	1.66	100.70 %	N/A
FC	ASTM D2584	Fiber Content (by weight)	82.58%	85.04%	102.98%	121.49%
DMA	ASTM E1640	Glass transition temperature by Dynamic Mechanical Analysis	118 °C	132 °C	111.92%	120.24%
TNS	ASTM D7205	Guar. Tensile Force	75.8 kip	55.8 kip	73.60%	113.61%
		Tensile Modulus of Elasticity	≥ 18 Msi	18.9 Msi		
		Strain	≥ 1.1%	1.51%		
MXA	ASTM D792	Measured Cross Sectional Area	0.183 in^2	0.224 in^2	122.49%	85.10%
MAS	ASTM D570	Moisture Absorption Short Term	0.21 %	0.18%	-12.36%	-27.47%
DSC		Grass transition temperature	224 ºF	228 ºF	101.78%	107.41%

	ASTM E2160	Degree of cure by differential scanning calorimetry	≥ 95% of Total enthalpy polymerization	99.66%		
SEM	N/A	Scanning electron microscope		N/A	see images	N/A
EDX	N/A	Elemental analysis via Energy Dispersive X-ray		N/A	see graphs	N/A
FTIR	N/A	Fourier Transform Infrared (FTIR) spectroscopy		N/A	N/A	N/A
SAMPLE No. 3						
TSS	ASTM D7617	Transverse shear strength	24.66 ksi	23.10 ksi	93.67%	104.98%
HSS	ASTM D4475	Horizontal shear strength	5.72 ksi	6.51 ksi	113.79%	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	115 °C	98.68%	115.46%
TNS	ASTM D7205	Guar. Tensile Force	34.1 kip	35.5 kip	104.34%	122.14%
		Tensile Modulus of Elasticity	≥ 6.5 Msi	7.1 Msi		
		Strain	≥ 1.1%	1.65%		
MXA	ASTM D792	Measured Cross Sectional Area	0.335 in^2	0.342 in^2	101.96%	88.07%
MAS	ASTM D570	Moisture Absorption Short Term	0.086 %	0.10%	15.61%	-60.07%
DSC	ASTM E2160	Grass transition temperature	234 ºF	241 ºF	103.05%	113.76%
		Degree of cure by differential scanning calorimetry	≥ 95% of Total enthalpy polymerization	99.50%		
SEM	N/A	Scanning electron microscope		N/A	see images	N/A
EDX	N/A	Elemental analysis via Energy Dispersive X-ray		N/A	see graphs	N/A
FTIR	N/A	Fourier Transform Infrared (FTIR) spectroscopy		N/A	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

3.2.1.1. 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, Thomas Cadenazzi and Roger Solis

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

Reference TDS: Technical Data Sheet: TDS-TSS-HRB-9M

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	mm²	in²	MPa	ksi	ksi	%	%
HRB_B_9M_TSS_01	71.65	16108			162.84	23.62		79.10	107.36
HRB_B_9M_TSS_02	74.69	16792			169.76	24.62		82.46	111.91
HRB_B_9M_TSS_03	74.17	16675	220.00	0.341	168.57	24.45	29.86	81.88	111.13
HRB_B_9M_TSS_04	76.79	17263			174.52	25.31		84.77	115.05
HRB_B_9M_TSS_05	72.45	16288			164.66	23.88		79.98	108.56
Average	**73.95**	**16625**			**168.07**	**24.38**		**81.64**	**110.80**
S_{n-1}	2.01	452			4.57	0.66			
CV (%)	2.7	2.7			2.7	2.7			
HRB_C_9M_TSS_01	71.83	16147			248.51	36.04		85.06	163.83
HRB_C_9M_TSS_02	72.96	16402			252.43	36.61		86.40	166.42
HRB_C_9M_TSS_03	76.38	17170	144.52	0.224	264.25	38.33	42.37	90.45	174.21
HRB_C_9M_TSS_04	76.44	17185			264.47	38.36		90.52	174.36
HRB_C_9M_TSS_05	79.80	17941			276.11	40.05		94.51	182.03
Average	**75.48**	**16969**			**261.15**	**37.88**		**89.39**	**172.17**
S_{n-1}	3.17	712			10.96	1.59			
CV (%)	4.2	4.2			4.2	4.2			
HRB_G_9M_TSS_01	69.82	15696			158.22	22.95		93.06	104.31
HRB_G_9M_TSS_02	66.79	15016			151.36	21.95		89.03	99.78
HRB_G_9M_TSS_03	69.93	15720	220.64	0.342	158.46	22.98	24.66	93.21	104.47
HRB_G_9M_TSS_04	71.99	16185			163.14	23.66		95.96	107.55
HRB_G_9M_TSS_05	72.83	16372			165.03	23.94		97.07	108.80
Average	**70.27**	**15798**			**159.24**	**23.10**		**93.67**	**104.98**
S_{n-1}	2.34	526			5.31	0.77			
CV (%)	3.3	3.3			3.3	3.3			

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

Test Setup:

Representative Failure Mode:

3.2.1.2. 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, Thomas Cadenazzi, Roger Solis
Specimen Size:	4.5 in. length
Reference TDS:	TDS-HSS-HRB-9M
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_9M_HSS_01	13.839	3111			43.05	6.24		109.23
HRB_B_9M_HSS_02	12.882	2896			40.08	5.81		101.69
HRB_B_9M_HSS_03	13.055	2935	16.52	0.650	40.61	5.89	5.72	103.05
HRB_B_9M_HSS_04	13.298	2990			41.37	6.00		104.97
HRB_B_9M_HSS_05	11.965	2690			37.22	5.40		94.45
Average	**13.01**	**2924**			**40.47**	**5.87**		**102.68**
S_{n-1}	0.69	154			2.13	0.31		
CV (%)	5.3	5.3			5.3	5.3		
HRB_C_9M_HSS_01	3.341	751			11.75	1.70		103.15
HRB_C_9M_HSS_02	3.345	752			11.76	1.71		103.27
HRB_C_9M_HSS_03	3.208	721	15.54	0.612	11.28	1.64	1.65	99.06
HRB_C_9M_HSS_04	3.229	726			11.35	1.65		99.68
HRB_C_9M_HSS_05	3.185	716			11.20	1.62		98.35
Average	**3.26**	**733**			**11.47**	**1.66**		**100.70**
S_{n-1}	0.08	17			0.27	0.04		
CV (%)	2.3	2.3			2.3	2.3		
HRB_G_9M_HSS_01	13.462	3026			46.70	6.77		118.34
HRB_G_9M_HSS_02	13.650	3069			47.35	6.87		120.00
HRB_G_9M_HSS_03	13.130	2952	15.64	0.616	45.55	6.61	5.72	115.42
HRB_G_9M_HSS_04	13.206	2969			45.81	6.64		116.09
HRB_G_9M_HSS_05	11.270	2533			39.09	5.67		99.07
Average	**12.94**	**2910**			**44.90**	**6.51**		**113.79**
S_{n-1}	0.96	215			3.32	0.48		
CV (%)	7.4	7.4			7.4	7.4		

***Benchmark values from Deliverable 1 test results*

Test Setup:

Representative Failure Mode:

3.2.1.3. 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, Thomas Cadenazzi, Roger Solis

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

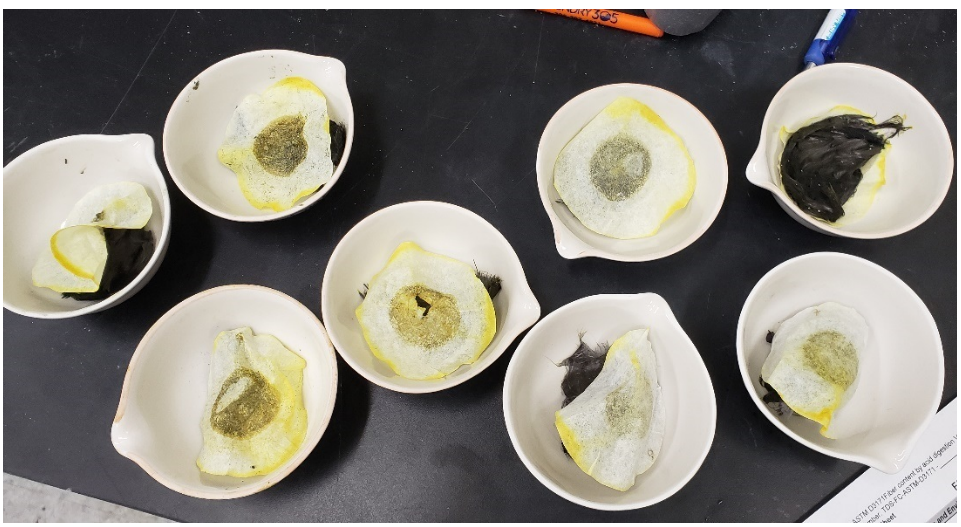
Reference TDS: TDS-FC-HRB-9M

Test data:

Specimen ID	Weight of Crucible Wc g	Weight prior burnout Wi g	Weight post burnout Wf g	W1 (Wc-Wi) g	W2 (Wf-Wc) g	Fiber Content FC=W2/W1 %	Benchmark** Fiber Content %	Comparing to Benchmark** %	Comparing to Reference* %
HRB-B-9M-FC-001	28.68	39.72	37.51	11.04	8.83	79.94		97.78	114.20
HRB-B-9M-FC-002	26.87	37.75	35.61	10.88	8.74	80.34		98.27	114.77
HRB-B-9M-FC-003	29.85	40.14	38.11	10.29	8.26	80.24	81.75	98.14	114.62
HRB-B-9M-FC-004	28.12	39.80	37.46	11.68	9.34	79.99		97.85	114.27
HRB-B-9M-FC-005	30.64	41.39	39.28	10.75	8.64	80.33		98.27	114.76
					Average	**80.17**		**98.06**	**114.53**
					Sn-1	19.17			
					CV (%)	0.24			
HRB-C-9M-FC-001	79.09	84.45	83.70	5.35	4.61	86.05		104.20	122.93
HRB-C-9M-FC-002	78.44	83.66	82.88	5.22	4.44	85.12		103.07	121.60
HRB-C-9M-FC-003	78.37	83.79	82.93	5.42	4.55	84.01	82.58	101.73	120.02
HRB-C-9M-FC-004	72.93	78.31	77.32	5.38	4.39	81.62		98.83	116.60
HRB-C-9M-FC-005	78.22	82.91	82.37	4.70	4.15	88.43		107.08	126.32
					Average	**85.04**		**102.98**	**121.49**
					Sn-1	251.28			
					CV (%)	2.95			
HRB-G-9M-FC-001	28.68	38.35	36.70	9.67	8.02	82.94		103.45	118.48
HRB-G-9M-FC-002	29.79	41.09	39.16	11.30	9.37	82.92		103.43	118.46
HRB-G-9M-FC-003	29.85	40.49	38.53	10.64	8.68	81.58	80.17	101.76	116.54
HRB-G-9M-FC-004	28.12	39.14	37.08	11.02	8.96	81.31		101.42	116.15
HRB-G-9M-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 Setup up:



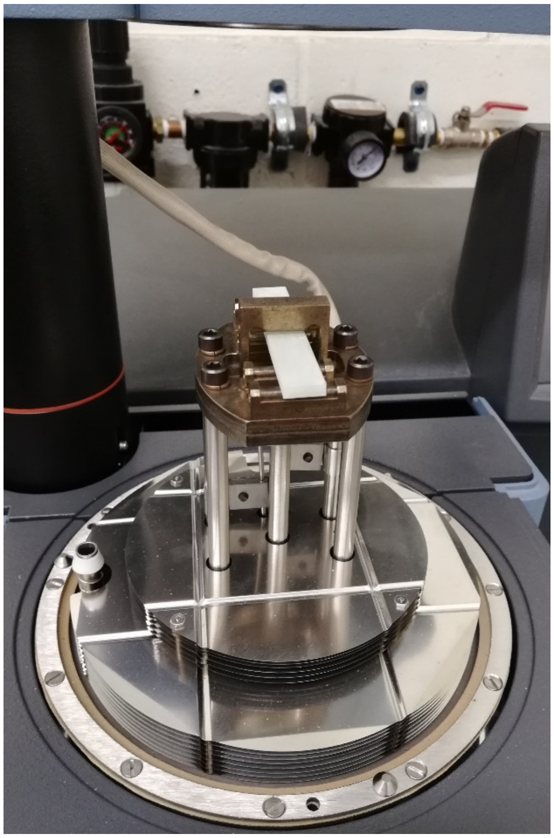
3.2.1.4. GLASS TRANSITION TEMPERATURE BY DYNAMIC MECHANICAL ANALYSIS

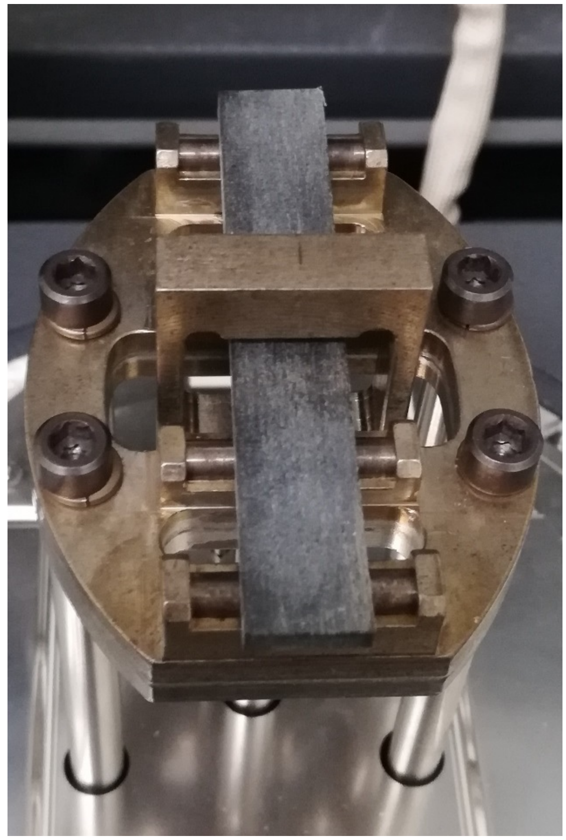
Test Standard Method: ASTM E1640
Test Description: This test method can be used to locate the glass transition region and assign a glass transition temperature of amorphous and semi-crystalline materials.
Technician/s: Guillermo Claure, Thomas Cadenazzi, Guan Wang
Specimen Preparation: It is important 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-9M
Test Data:

Specimen ID	T_g		Benchmark** T_g	Comparing to Benchmark**	Comparing to Reference*
	°C	°F	°C	%	%
HRB_B_9M_TG_01	99	211		98.02	99.33
HRB_B_9M_TG_02	100	212	101.33	98.59	99.90
HRB_B_9M_TG_03	108	226		106.59	108.01
Average	**102**	**216**		**101.07**	**102.41**
S_{n-1}	5	9			
CV (%)	4.7	4.0			
HRB_C_9M_TG_01	129	263		108.77	116.86
HRB_C_9M_TG_02	138	280	118.18	116.57	125.25
HRB_C_9M_TG_03	130	267		110.40	118.61
Average	**132**	**270**		**111.92**	**120.24**
S_{n-1}	5	9			
CV (%)	3.7	3.2			
HRB_G_9M_TG_01	115	238		97.92	114.57
HRB_G_9M_TG_02	117	242	117.00	99.63	116.57
HRB_G_9M_TG_03	115	239		98.50	115.24
Average	**115**	**240**		**98.68**	**115.46**
S_{n-1}	1	2			
CV (%)	0.9	0.8			

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

Test Setup up:





3.2.1.5. 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, Thomas Cadenazzi, 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-9M
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_9M_001	163	36644	46.75	6.78	1.58		110.65	125.92
HRB_B_TNS_9M_002	184	41286	54.11	7.85	1.54		124.67	141.88
HRB_B_TNS_9M_003	164	36852	42.18	6.12	1.77	33117	111.28	126.64
HRB_B_TNS_9M_004	169	38062	75.62	10.97	1.02		114.93	130.80
HRB_B_TNS_9M_005	151	33952	46.85	6.79	1.47		102.52	116.67
Average	**166**	**37359**	**53.10**	**7.70**	**1.48**		**112.81**	**128.38**
S_{n-1}	12	2659	13.29	1.93	0.28		8.03	9.14
CV (%)	7.1	7.1	25.0	25.0	18.9		7.1	7.1
Guar. Tensile Force	**131**	**29381**					**88.72**	**100.97**
HRB_C_TNS_9M_001	285	64177	126.72	18.38	1.56		84.68	130.71
HRB_C_TNS_9M_002	277	62318	124.96	18.12	1.53		82.23	126.92
HRB_C_TNS_9M_003	301	67732	125.74	18.24	1.66	75786	89.37	137.95
HRB_C_TNS_9M_004	288	64715	142.47	20.66	1.40		85.39	131.80
HRB_C_TNS_9M_005	269	60535	131.37	19.05	1.42		79.88	123.29
Average	**284**	**63895**	**130.25**	**18.89**	**1.51**		**84.31**	**130.13**
S_{n-1}	12	2704	7.27	1.05	0.11		3.57	5.51
CV (%)	4.2	4.2	5.6	5.6	7.1		4.2	4.2
Guar. Tensile Force	**248**	**55782**					**73.60**	**113.61**
HRB_G_TNS_9M_001	180	40414	47.40	6.87	1.72		118.64	138.88
HRB_G_TNS_9M_002	176	39471	53.78	7.80	1.48		115.88	135.64
HRB_G_TNS_9M_003	179	40333	42.05	6.10	1.93	34063	118.41	138.60
HRB_G_TNS_9M_004	186	41723	49.82	7.23	1.69		122.49	143.38
HRB_G_TNS_9M_005	168	37747	52.57	7.63	1.45		110.81	129.71
Average	**178**	**39937**	**49.12**	**7.12**	**1.65**		**117.25**	**137.24**
S_{n-1}	7	1465	4.66	0.68	0.20		4.30	5.04
CV (%)	3.7	3.7	9.5	9.5	12.0		3.7	3.7
Guar. Tensile Force	**158**	**35542**					**104.34**	**122.14**

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

Test Setup:

Representative Failure Mode:


INCH
U.S.A.


HRB-9M-C-005

3.2.1.6. 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, Thomas Cadenazzi, Roger Solis.
Specimen Size: Specimen length dimensions were 50 mm (2.0 in.).
Reference TDS: Technical Data Sheet: TDS-MXA-HRB-9M
Test Data:
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_9M_01	220	0.341		116.88	87.84
HRB_B_MXA_9M_02	220	0.341		116.93	87.88
HRB_B_MXA_9M_03	219	0.340	0.292	116.54	87.58
HRB_B_MXA_9M_04	220	0.341		116.91	87.86
HRB_B_MXA_9M_05	220	0.341		117.03	87.95
Average	**220**	**0.341**		**116.86**	**87.82**
S_{n-1}	0	0.001			
CV (%)	0.2	0.2			
HRB_C_MXA_9M_01	147	0.228		124.63	86.59
HRB_C_MXA_9M_02	147	0.228		124.51	86.51
HRB_C_MXA_9M_03	146	0.226	0.183	123.93	86.11
HRB_C_MXA_9M_04	150	0.232		127.19	88.37
HRB_C_MXA_9M_05	132	0.205		112.18	77.94
Average	**144**	**0.224**		**122.49**	**85.10**
S_{n-1}	7	0.011			
CV (%)	4.8	4.8			
HRB_G_MXA_9M_01	217	0.337		100.41	86.73
HRB_G_MXA_9M_02	213	0.330		98.38	84.97
HRB_G_MXA_9M_03	214	0.332	0.335	99.14	85.63
HRB_G_MXA_9M_04	215	0.333		99.33	85.80
HRB_G_MXA_9M_05	243	0.377		112.54	97.21
Average	**220**	**0.342**		**101.96**	**88.07**
S_{n-1}	13	0.020			
CV (%)	5.8	5.8			

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

Test Setup:

3.2.1.7. 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 50ºC temperature.
Technician/s:	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-MA-HRB-9M
Test Data:	

Specimen ID	Moisture Absorption W_i g	W_{24} g	W_{24} %	Benchmark** Moisture Absorption in^2	Comparing to Benchmark** %	Comparing to Reference* %
HRB_B_MA_9M_01	10.1563	10.1831	0.26		52.48	5.55
HRB_B_MA_9M_02	9.9512	9.9698	0.19		8.01	-25.24
HRB_B_MA_9M_03	10.6241	10.6423	0.17	0.173	-1.01	-31.48
HRB_B_MA_9M_04	10.0155	10.0472	0.32		82.89	26.60
HRB_B_MA_9M_05	10.4198	10.4369	0.16		-5.17	-34.36
Average	**10.2334**	**10.2559**	**0.22**		**27.44**	**-11.78**
S_{n-1}	0.28	0.28	0.07			
CV (%)	2.77	2.73	30.3			
HRB_C_MA_9M_01	9.2672	9.2764	0.10		-52.02	-60.29
HRB_C_MA_9M_02	9.3282	9.3462	0.19		-6.74	-22.81
HRB_C_MA_9M_03	9.3652	9.3890	0.25	0.207	22.83	1.65
HRB_C_MA_9M_04	9.3351	9.3448	0.10		-49.78	-58.44
HRB_C_MA_9M_05	9.8291	9.8543	0.26		23.91	2.55
Average	**9.4250**	**9.4421**	**0.18**		**-12.36**	**-27.47**
S_{n-1}	0.2287	0.2339	0.08			
CV (%)	2.4	2.5	42.5			
HRB_G_MA_9M_01	10.0972	10.1055	0.08		-4.81	-67.12
HRB_G_MA_9M_02	9.4400	9.4485	0.09		4.27	-63.98
HRB_G_MA_9M_03	10.8347	10.8475	0.12	0.086	36.81	-52.74
HRB_G_MA_9M_04	9.6646	9.6738	0.10		10.23	-61.92
HRB_G_MA_9M_05	9.1561	9.1665	0.11		31.53	-54.57
Average	**9.8385**	**9.8484**	**0.10**		**15.61**	**-60.07**
S_{n-1}	0.6546	0.6557	0.02			
CV (%)	6.7	6.7	15.5			

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

Test Setup:

3.2.1.8. 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-TPE-HRB-9M

Test Data:

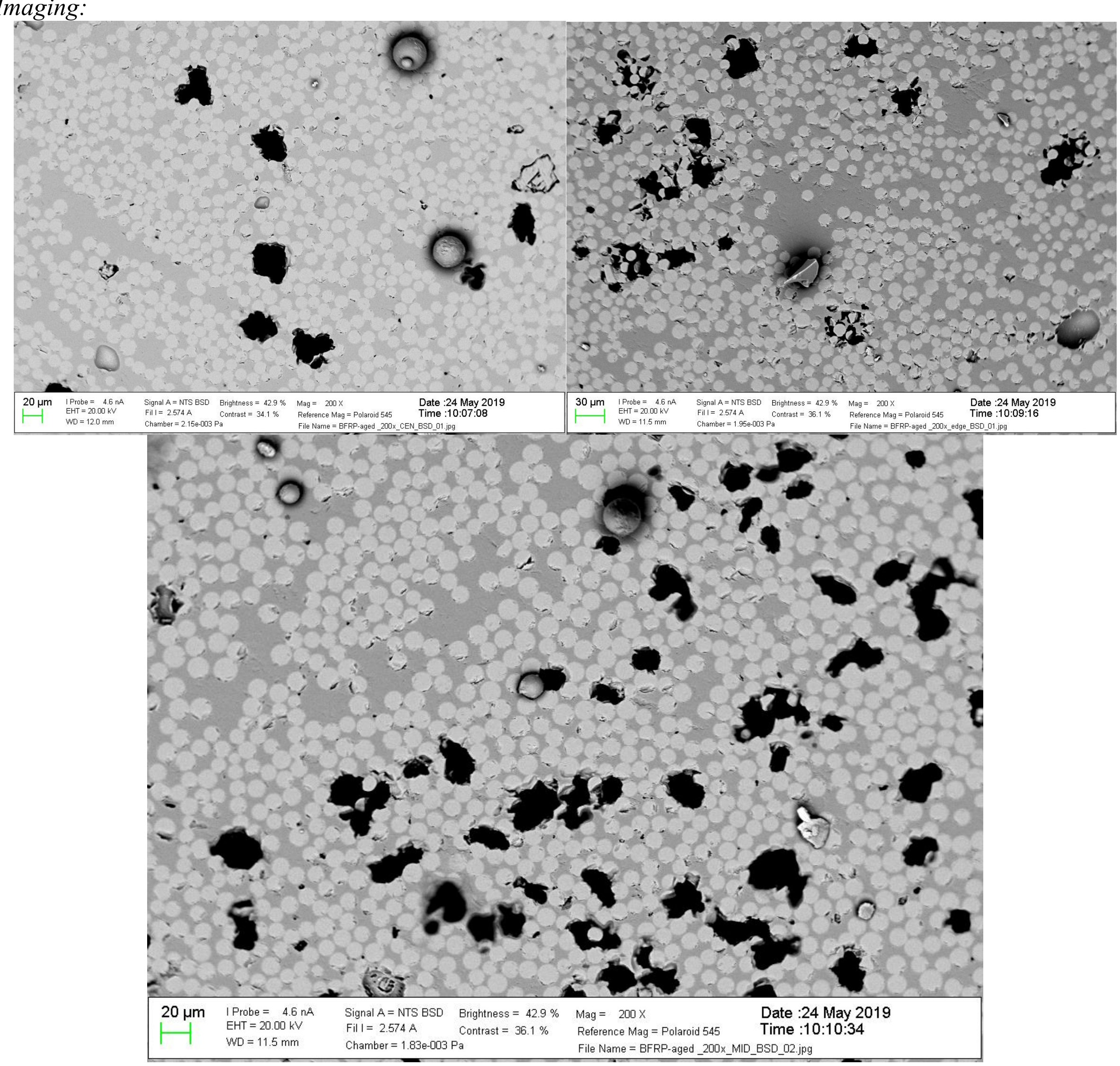
Specimen ID	Normalized Heat of Reaction H	Degree of Cure DC	Glass Transition Temperature Tg		Benchmark** Glass Transition Temperature	Comparing to Benchmark**	Comparing to Reference*
	J/g	%	°C	°F	°F	%	%
HRB_B_DSC_9M_01	3.8460	96.15	107.30	225		79.68	106.20
HRB_B_DSC_9M_02	2.9670	97.03	107.40	225		79.74	106.28
HRB_B_DSC_9M_03	3.1750	96.83	108.98	228	283	80.75	107.62
HRB_B_DSC_9M_04	3.2910	96.71	106.86	224		79.40	105.82
HRB_B_DSC_9M_05	1.2550	98.75	107.08	225		79.54	106.01
Average		**97.09**	**107.52**	**226**		**79.82**	**106.39**
S_{n-1}		0.98	0.84	2			
CV (%)		1.0	0.8	0.7			
HRB_C_DSC_9M_01	0.2610	99.74	109.27	229		102.22	107.87
HRB_C_DSC_9M_02	0.3924	99.61	109.40	229		102.32	107.98
HRB_C_DSC_9M_03	0.3579	99.64	107.18	225	224	100.53	106.10
HRB_C_DSC_9M_04	0.4506	99.55	110.87	232		103.50	109.23
HRB_C_DSC_9M_05	0.2193	99.78	106.90	224		100.31	105.86
Average		**99.66**	**108.72**	**228**		**101.78**	**107.41**
S_{n-1}		0.09	1.66	3			
CV (%)		0.1	1.5	1.3			
HRB_G_DSC_9M_01	0.5352	99.46	116.01	241		102.90	113.59
HRB_G_DSC_9M_02	0.4318	99.57	116.88	242		103.57	114.33
HRB_G_DSC_9M_03	0.5644	99.44	116.21	241	234	103.05	113.76
HRB_G_DSC_9M_04	0.4268	99.57	115.73	240		102.68	113.36
HRB_G_DSC_9M_05	0.5543	99.45	116.18	241		103.03	113.74
Average		**99.50**	**116.20**	**241**		**103.05**	**113.76**
S_{n-1}		0.07	0.42	1			
CV (%)		0.1	0.4	0.3			

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

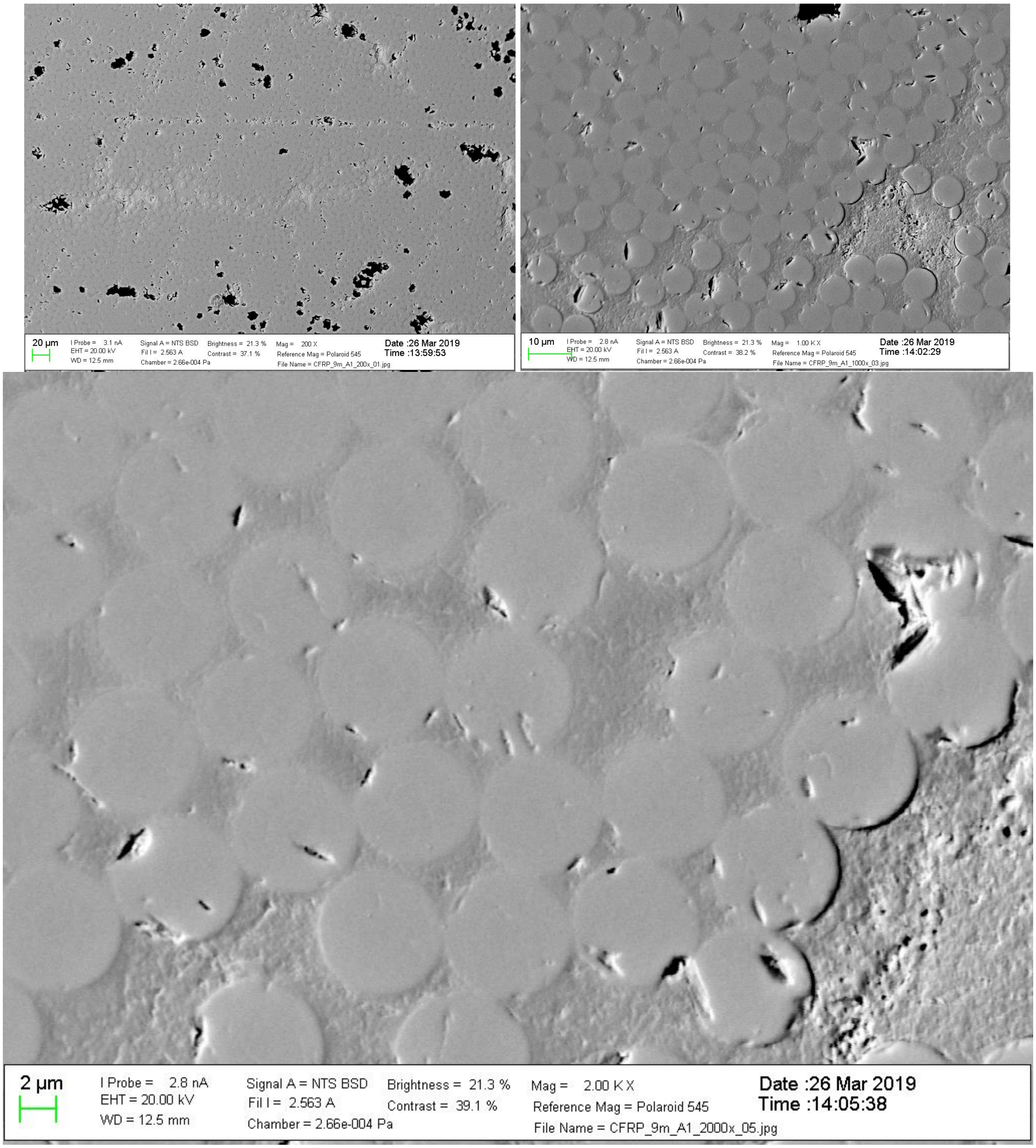
Test Setup:


3.2.1.9. SCANNING ELECTRON MICROSCOPY IMAGING (SEM)

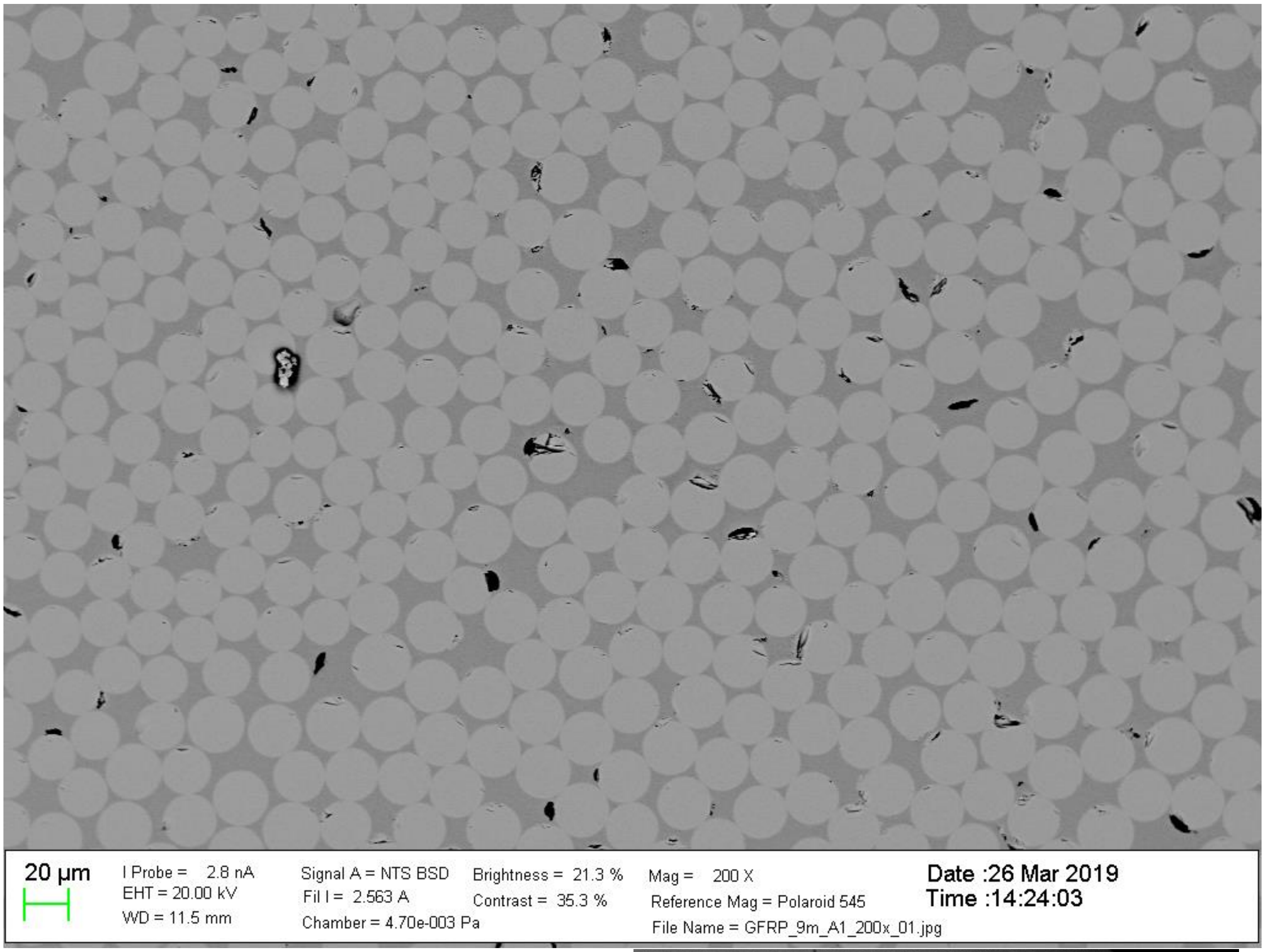
Test Method:	Laboratory Method
Test Description:	Imaging to observe microscopic features of the cross-section of the bars up to 50 nm in size accomplished with SEM. SEM is used to qualitatively evaluate the cross-section and determine the 'finger-print' for the manufactured rebar, the void and fiber dispersion, cross-sectional pattern of manufactured product can be parametrically measured.
Technician/s:	Guillermo Claure and Thomas Cadenazzi
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-9M
Test Imaging:	

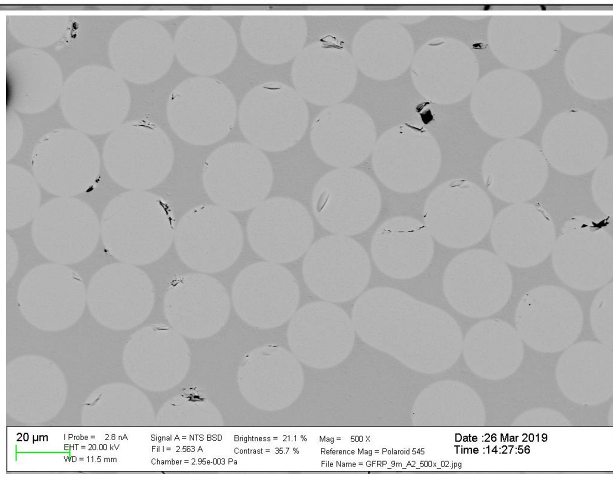


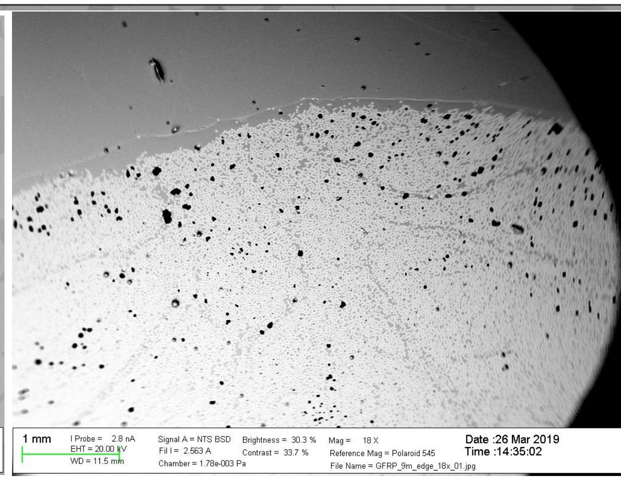
Representative SEM image BFRP sample



Representative SEM image CFRP sample

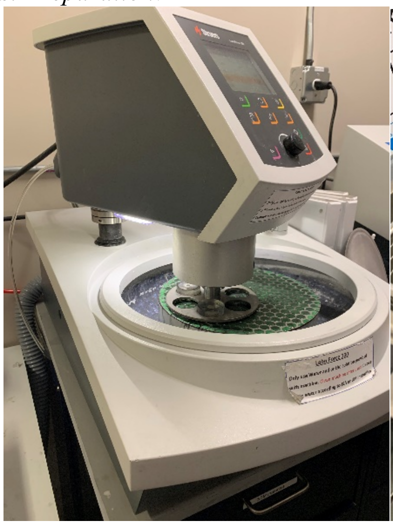




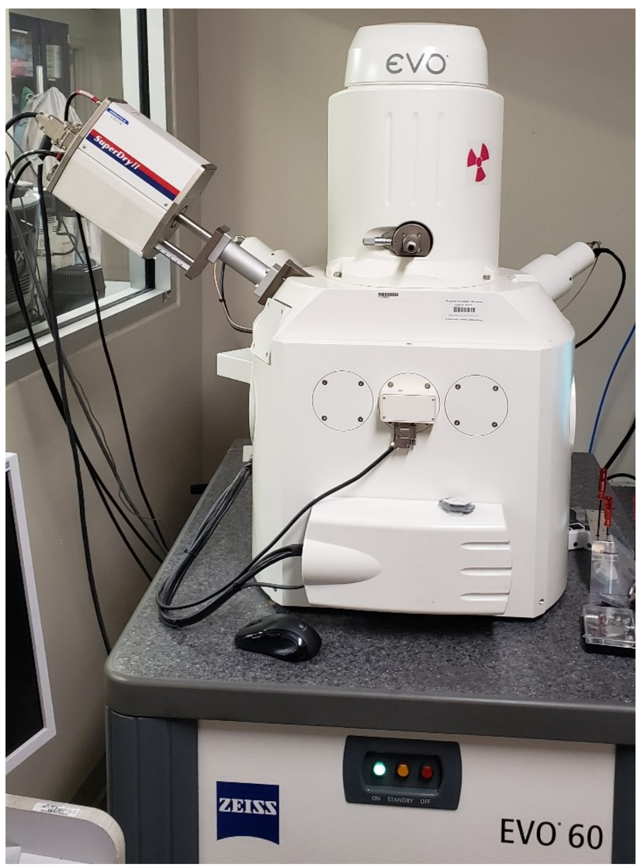


Representative SEM image GFRP sample

Test Preparation:



Test Setup:



3.2.1.10. 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, Thomas Cadenazzi 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-9M

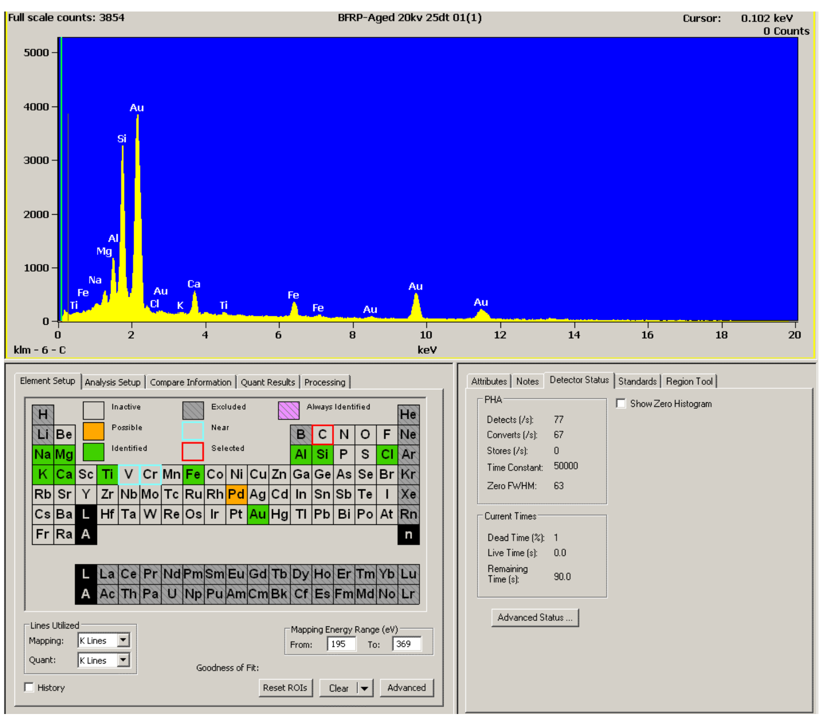
Test Data:

BFRP	Fe	Ca	Na	Mg	Al	Si
Quant. detected	200	300	400	300	1100	3150

CFRP	Si	Ca	Na	Al	Cl
Quant. detected	250	7800	200	200	300

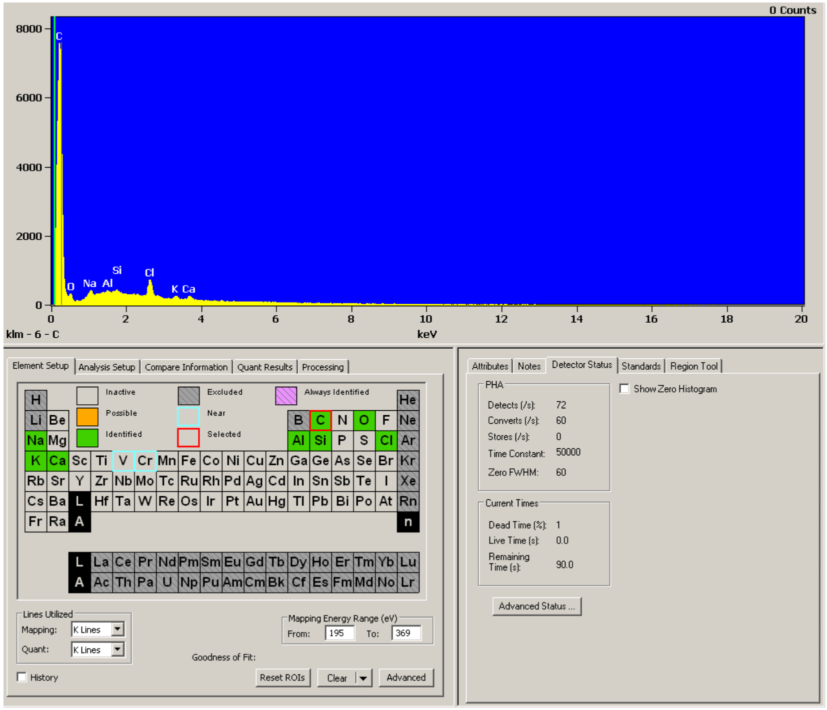
GFRP	Ti	Ca	O	Mg	Al	Si
Quant. detected	150	1900	150	300	1200	5300

Graphs:



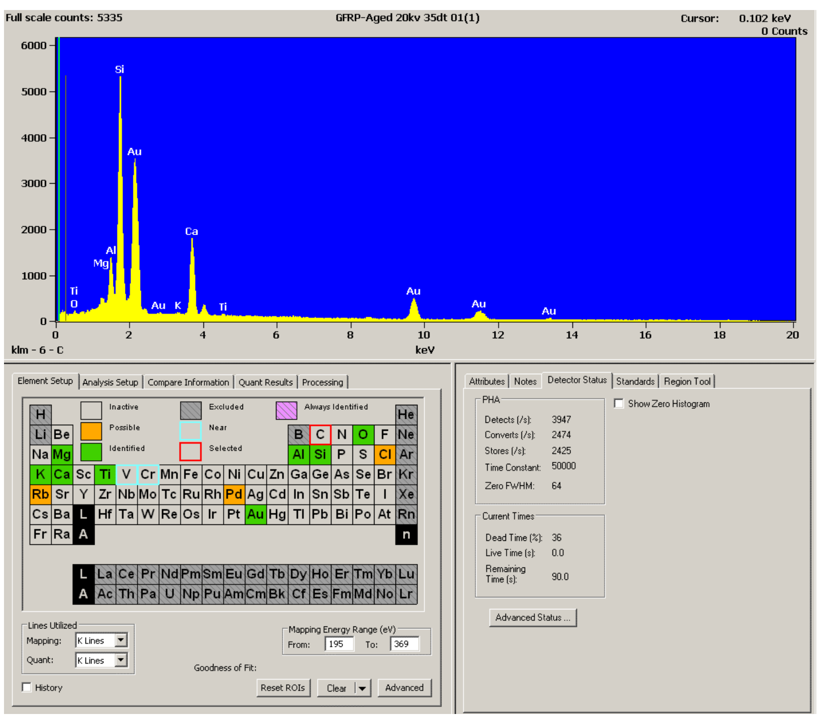
Representative EDX image of a 9M-BFRP sample

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



Representative EDX image of a 9M-CFRP sample

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



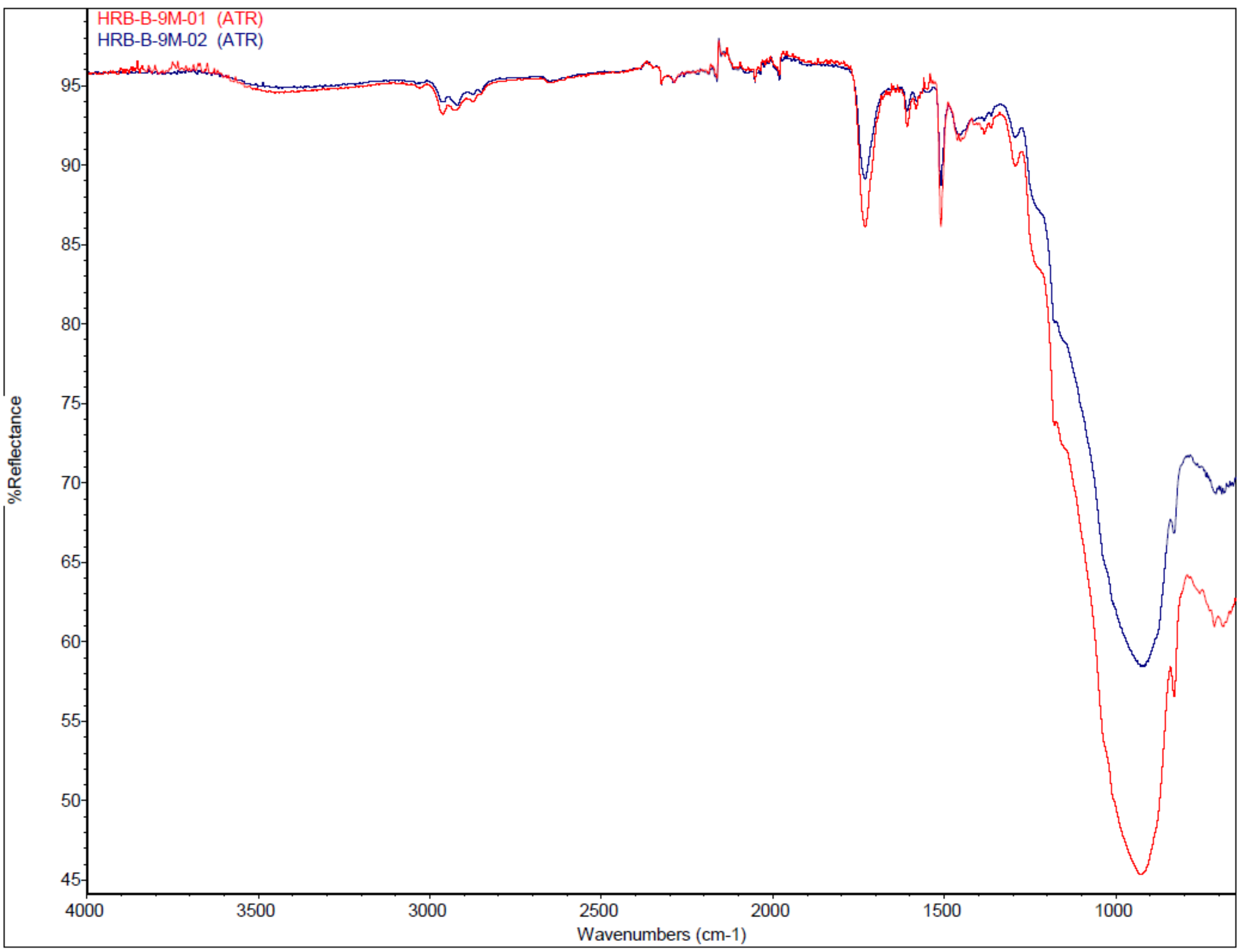
Representative EDX image of a 9M-GFRP sample

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

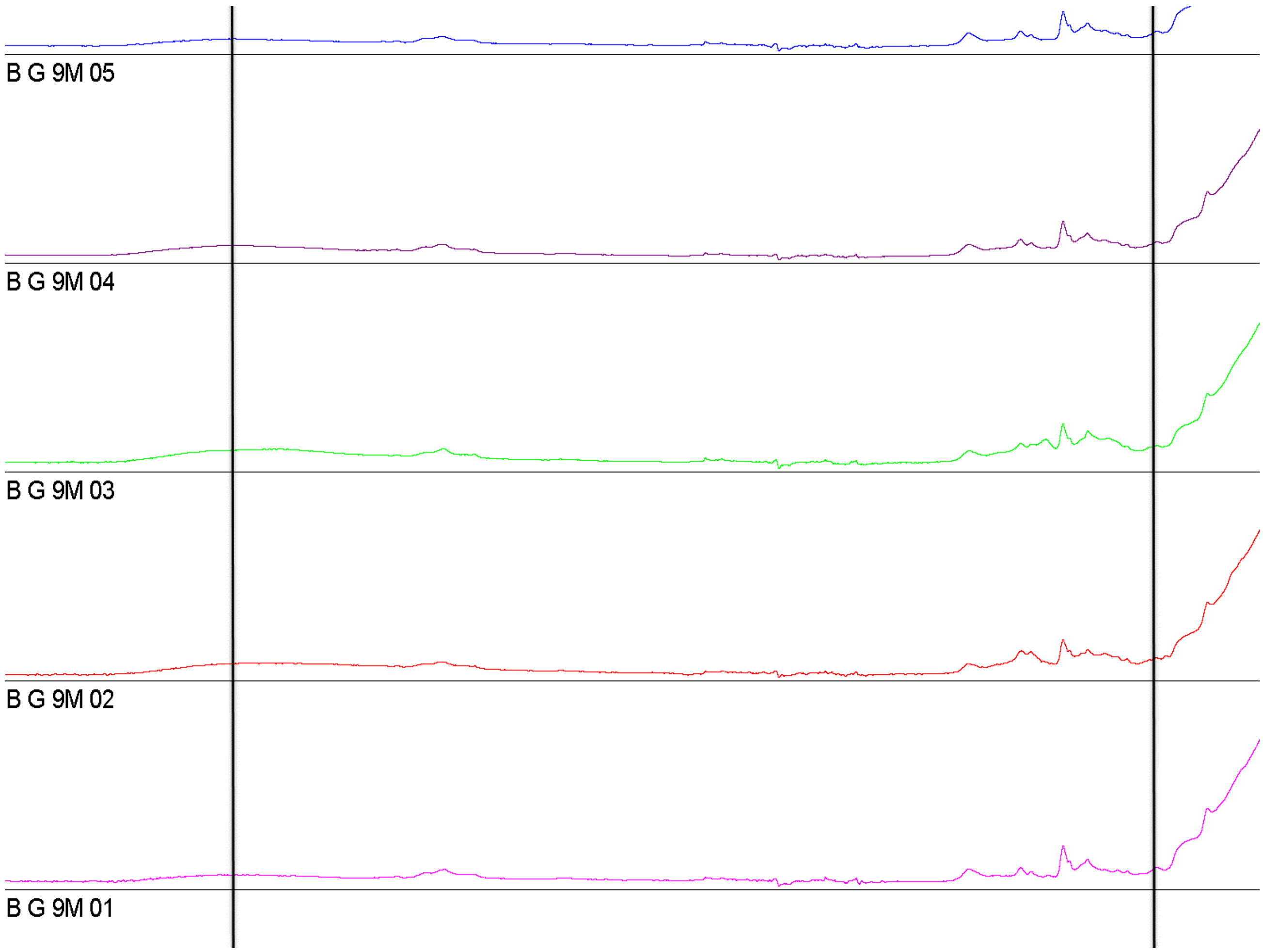
Test setup:

3.2.1.11. 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-9M
Test Graphs:	



Representative FTIR image of BFRP sample



Representative FTIR image of GFRP sample

♦ END OF REPORT ♦