CERTIFIED TEST REPORT

EVALUATION OF CONCRETE STRENGTHENING FIBER-REINFORCED POLYMER COMPOSITE QUAKEWRAP® FRP SYSTEMS
- Per ICC-ES Acceptance Criteria AC125 -

Report Number: R-5.10_QUA_13-09-10
Date: October 4, 2018

REPORT PREPARED FOR:

QuakeWrap

Mo Ehsani, PhD, PE, SE, President, and
Professor Emeritus of Civil Eng., U. of AZ
6840 S. Tucson Blvd. Tucson, AZ 85756
(520) 791-7000 X 122; email: Mo@QuakeWrap.com

REFERENCE:

File No. 13-09-10

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

Procedures: All tests and services are done 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.

Test Data: All the test results presented herein are linked through unbroken chain to the raw data files recorded on the day of the test. 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 of each test.

Controls:	
Superseded Report	New report
Reason for Revision	n/a
Effective Date	October 4, 2018

Test Report Approval Signatures:	
Quality review Approval	I indicate that I have reviewed this Test Report and agree with the contents it presents, and find it meets all applicable laboratory requirements and policies. I approve for its release to the customer. Name: Francisco De Caso Signature: Date: October 4, 2018
Technical review Approval	I indicate that I have reviewed this Test Report and agree with the technical contents it presents, and find it meets all applicable laboratory requirements and policies. I approve for its release to the customer. Name: Antonio Nanni Signature: Date: October 4, 2018

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1. INTRODUCTION

1.1. PURPOSE

The purpose of this document is provide the experimental results per the qualification test plan to develop an ICC-ES Evaluation Report for **file #13-09-10** for the applicant QUAKEWRAP for the Concrete Strengthening Fiber-Reinforced Polymer Composite QuakeWrap® FRP systems comprised initially of three carbon fiber sheet materials (U20C, U41C, B20C) in combination with a two part epoxy matrix (300SR).

This document presents results evaluating the mechanical properties, environmental durability and structural validation tests of the QuakeWrap® strengthening systems to obtain an Evaluation Service Report (ESR). The results are provided according to the requirements of the ICC Evaluation Service (ICC-ES) Acceptance Criteria for Concrete and Reinforced and Unreinforced Masonry Strengthening Using Externally Bonded Fiber-Reinforced Polymer Composite Systems (AC 125).

1.2. STRUCTURES AND MATERIALS LABORATORY (SML)

All tests presented in this report, including material sampling and specimen preparation, were performed by and under the supervision of the University of Miami, College of Engineering, Structures and Materials Laboratory, herein referred to as SML. This testing laboratory has met the requirements of the International Accreditation Service (IAS) AC89 (Accreditation Criteria for Testing Laboratories), has demonstrated compliance with ANS/ISO/IEC Standard 17025:2005, “General requirements for the competence of testing and calibration laboratories, and has been accredited for the test methods listed in the approved scope of accreditation under Testing Laboratory # TL-478.

1.3. DESCRIPTION OF PRODUCTS UNDER EVALUATION

The components of the Fiber-Reinforced Polymer (FRP) composite systems considered for evaluation and tested as per AC125-15 are summarized as follows:

1.3.1. QuakeWrap™ VU20C Carbon Fabric (U20C)

Uni-directional carbon fiber sheet, herein referred to as U20C, with a minimum nominal fiber density of 678 gsm (20.0 oz/yd^2).

1.3.2. QuakeWrap ™ VU41C Carbon Fabric (U41C)

Uni-directional carbon fiber sheet, herein referred to as U41C, with a minimum nominal fiber density of 1390 gsm (41.0 oz/yd^2).

1.3.3. QuakeWrap™ TB20C Carbon Fabric (B20C)

Bi-directional balanced carbon fiber sheet, herein referred to as B20C, with a minimum total nominal fiber density of 678 gsm (20.0 oz/yd^2).

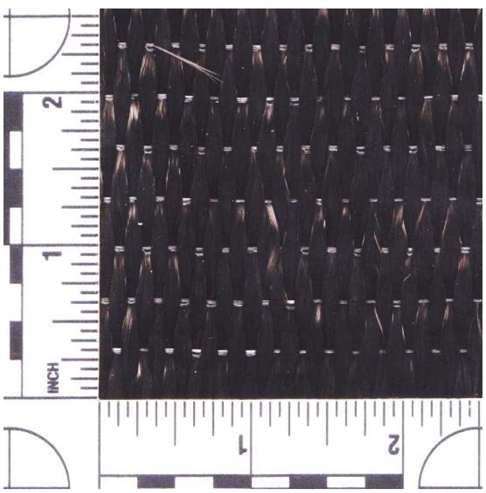
1.3.4. QuakeBond™ J300SR Saturating Resin (J300)

A two component polymer matrix used to saturate the aforementioned fiber sheets, with low viscosity and long pot life and fast curing time; composed of part A, J300SR-A; and part B, J300SR-B.

Refer to Table 1.1 and Figure 1.1 for the summary of the FRP systems under evaluation including the reference name of the systems within this report.

Table 1.1 - Summary of FRP systems under evaluation with the report reference ID

FRP composite systems under evaluation (fiber sheet + resin)	Fiber sheet type	Report Reference Name
QW U20C+J300SR	Carbon uni-directional	U20C
QW U41C+J300SR		U41C
QW B20C+J300SR	Carbon Bidirectional	B20C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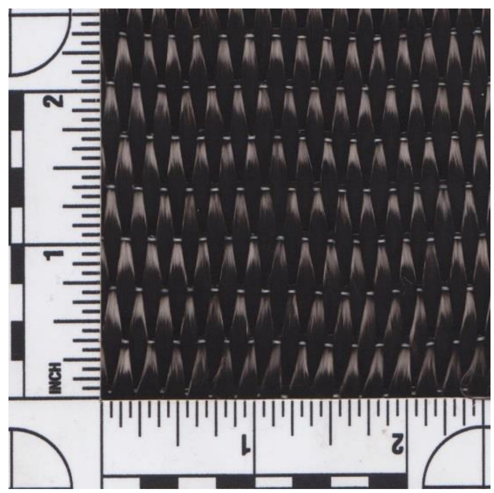
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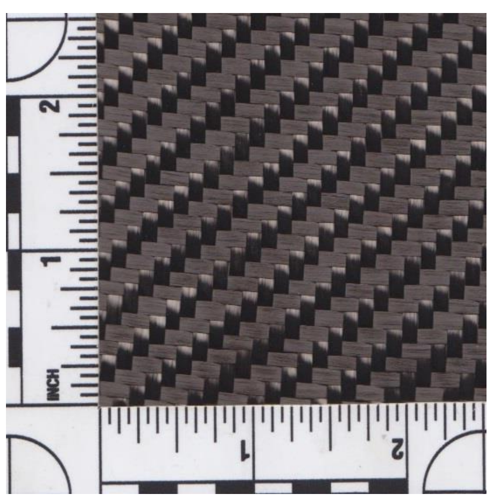

(c)

(d) (e)

Figure 1.1 – Products under evaluation, (a) U20C; (b) U41C;(c) B20C ;(d) 300SR-A and (e) 300SR-B.

1.4. CLIENT INFORMATION

The test report has been requested by the applicant to the ICC-EC:

Mo Ehsani, PhD, PE, SE
President, QuakeWrap Inc. and Professor Emeritus of Civil Eng., U. of AZ
2055 E. 17th Street, Tucson, AZ 85719
Office: (520) 791-7000 X 122;
email: Mo@QuakeWrap.com

2. TESTING OF REPRESENTATIVE PRODUCTS

2.1. PRODUCT SAMPLING

2.1.1. Sampling Guidelines

All the products tested and reported herein, were sampled in accordance with section 3.1 of AC85 and the SML standard operating procedures referred to in document SOP-5.7 at the manufacturing and warehouse site by SML personnel.

2.1.2. Product Sampling

Sampling of the FRP system components as referenced in Section 1.0 of this report was performed by Analyst Dr. Guillermo Claure, on August 21, 2017, at the manufacturing location of QUAKEWRAP, at 6840 S Tucson Blvd., Tucson, Arizona 85756, USA. Overall the products tested are truly representative of the standard manufactured products for which recognition is being sought

2.1.3. Sampling Data Report

A full detailed sampling data report containing the sampling criteria, method, selection, and product information is described in the attached documents number **R-5.7_08.21.17_QUA.**

2.2. ACKNOWLEDGED AND INSPECTION OF PRODUCTS

Upon arrival of the products for evaluation to the testing laboratory, the packages were acknowledged and identified to account for all the products and their batch numbers for quality assurance purposes. All products were then individually inspected to ensure validity for testing, free of damage, contamination or other criteria deviating from being representative of the standard manufactured products as initially sampled based on SML standard operating procedures.

3. TEST DATA

3.1. RAW DATA

All the test results presented herein are linked through unbroken chain to the raw data files recorded on the day of the test. Details regarding raw data can be found in the technical test record completed at the time of the tests. Raw data is available upon request.

3.2. ANALYZED DATA

Analyzed data are obtained directly from the recorded raw data during testing, from which the test results are presented. This report contains analyzed tabulated data results of each test assessment. Additionally, as part of the standard operating procedures and quality assurance of the SML, intermediate checks of the data analysis are performed at various stages of the data analysis process reducing the possible analysis errors. Fully analyzed data files are available upon request.

3.3. REPORT PRESENTATION OF TEST RESULTS

Test results are presented in the subsequent chapters of this report (indicated with X in Table 3.1), structured in the following chapter sub-sections:

Table 3.1 – Chapter sub-sections structure

Sub-chapter	Title	Description
X.1	TEST SUMMARY	Contains test standard references, objectives, product under evaluation, test location, test technician and reference to test additional information.
X.2	TEST MATRIX	Contains number of specimens reported, specimen ID nomenclature and test matrix table.
X.3	SPECIMEN PREPERATION	Contains specimen size, layout (if applicable), and relevant specimen preparation procedures and conditioning parameters as needed.
X.4	TEST SET-UP	Contains test set-up information as well as the rate and method of loading.
X.5	TEST RESULTS	Contains a brief test summary, modes of failure, calculations and/or graphs results (if applicable), and complete tabulated results for all test specimens.

4. PRODUCT PREPARATION AND INSTALLATION

4.1. PRODUCT PREPARATION

4.1.1. Mixing Method

Mechanical mixing of the saturating resin part A and B of QuakeBond J300SR was implemented following the manufacturer's specifications, where mixing of the approved resin was performed by trained personnel. The two part resin was mixed completely until a smooth, uniform streak-free consistency was reached.

4.1.2. Mixing ratio

QuakeBond J300SR part A and part B of the epoxy resin were mixed together in agreement with the mixing ratio suggested by the manufacturer's instructions, 2:1 by volume.

4.2. PRODUCT INSTALLATION

4.2.1. Installation Approval

The preparation and production of FRP panels for specimen testing of the products under evaluation was performed by trained personnel. The following section describes the process to produce the panel specimen for testing.

4.2.2. Panel Specimen Preparation without Substrate.

The designated saturating epoxy resin is mixed using mechanical means. The pre-cut fiber sheet is placed on a flat surface and resin poured over it, while using a flexible spatula so spread the resin over the fiber sheet. A ribbed roller is then used to saturate the fiber sheet by rolling in the fiber direction. The process is repeated on the other side of the fiber sheet. Then, the saturate fiber sheet is them placed on an adhesion free film and rolled to ensure fibers are aligned and air bubbles removed. Another non-stick sheet is used to sandwich the FRP panel ensuring a flat panel is produced. A plastic trowel is then used to remove excess resin and air bubbles. Panels were left to cure for a minimum of 24 hours before removing the non-stick sheets. Discreet coupons were then obtain from the panels for testing as seen in Figure 4.1.

4.2.3. FRP Installation Procedure with Substrate

The procedure to install the FRP strengthening systems under evaluation for tests considering a concrete substrate, followed the same impregnation process as described before. Before the installation of the FRP strengthening system, the concrete substrate surface was prepared to ensure that a minimum surface roughness of CPS 3 was achieved, as defined by ICRI. The prepared concrete surface was primed with a thin layer of the saturating resin QuakeBond J300SR with a brush. The saturated fiber sheet was then installed on the prepared and primed substrate by placing it in the desired location. The FRP sheet was then rolled in the fiber direction with a ribbed roller ensuring air bubbles and fiber alignment was achieved. Specimens and allowed to cure for 72 hours prior to initiation of any testing, as seen in Figure 4.2.

Figure 4.1 – Preparation of FRP panels by manual wet layup process

Figure 4.2 – FRP system installation on concrete substrate

4.3. QUALITY CONTROL

Quality control checks where performed throughout the processes of specimen preparation and installation on substrate. These checks included: proper surface preparation, ensuring fiber sheet alignment, removal of air pockets by use of ribbed roller, checking saturation of fiber sheet, removal of excess resin, monitoring environmental conditions and proper trained personnel.

4.4. PRODUCT HANDLING

All the products were handled based on the manufacturer's specifications and laboratory internal procedures, where handling and special storage considerations where provided as needed before products where used to fabricate specimens. All products have a unique batch number recorded during sampling, this number was tracked to individual test specimens as referenced in this report.

4.5. SPECIMEN ID NOMENCLATURE

All test specimens for mechanical and physical material tests have been uniquely labeled and identified for quality and traceability purposes using the following format:

CCC_PPPP_MMM_EE_DD_XXX

where, CCC refers to company name, PPPP refers to the products under evaluation, MMM refers to the mechanical property and test type, EE refers to the type of exposure, DD refers to the duration of the exposure and/or test direction, and XXX is the sample repetition number. The detailed nomenclature is reported in Table 4.1.

Table 4.1 – Specimen identification for characterization tests

Parameter description	Detail	ID
Company name	QuakeWrap Inc.	QUA
Product	QuakeWrap™ VU20C + QuakeBond™ J300SR	U20C
	QuakeWrap™ VU41C + QuakeBond™ J300SR	U41C
	QuakeWrap™ VU41C + QuakeBond™ J300SR	B20C
	QuakeBond™ J300SR	J300
Mechanical property / Test direction	Tensile Strength	TNS
	Coef. of Thermal Expansion	CTE
	Glass Transition Temperature	TG
	Creep Rupture	CRP
	Void content	VDC
	Interlaminar shear strength	ISS
	Bond Strength Tension, on concrete substrate	BTC
	Bond Strength Shear, on concrete substarte	BSC
	Test direction (if applicable):	
	0º (primary, parallel to roll direction)	00
	90º (secondary, perpendicular to roll direction)	90
Exposure	None (control/reference/benchmark tests)	CC
	Water Resistance	WR
	Saltwater Resistance	SW
	Alkaline Resistance	AR
	Dry Heat Resistance	DH
	Freezing and Thawing	FT
	Fuel Resistance	FR
	Alkaline Soil Resistance	SR
	Exterior Exposure	EE
Exposure duration	1,000 hrs	01
	2,000 hrs	02
	3,000 hrs	03
	10,000 hrs	10

5. TENSILE PROPERTIES (TNS) – ASTM D3039

5.1. TEST SUMMARY

5.1.1. AC125 Section/s

Section 5.8, Table 2 for Physical and Mechanical Properties of FRP Composite Materials.

5.1.2. Reference Standard/s

ASTM D3039/D3039M – 17, Standard test method for Tensile Properties of Polymer Matrix Composite Materials.

5.1.3. Test Objective

To determine the tensile properties in the fiber direction for the FRP systems under evaluation as a controlled reference (or benchmark) without any aging or environmental exposure. Average properties include experimental tensile chord modulus of elasticity, ultimate tensile stress and ultimate tensile strain (elongation), as well as guaranteed properties.

5.1.4. Product/s Under Evaluation

QuakeWrap™ VU20C with QuakeBond™ J300SR; QuakeWrap™ VU41C with QuakeBond™ J300SR; and QuakeWrap™ TB20C with QuakeBond™ J300SR (in the primary and secondary directions).

5.1.5. Test Location

Structures and Materials Laboratory, SML, Main Laboratory, University of Miami, 1251 Memorial Dr., MEB108 Coral Gables, FL, 33146

5.1.6. Laboratory Technician/s

Tais Hamilton, Ming Han Soh and Christian Marquina.

5.1.7. Technical Test Record

The date of each test; variations to the test method as applicable; calibration information for all measurements and test equipment; identification of the material tested; temperature and humidity of testing laboratory; and other applicable test data or details are provided in the Technical Test Record document number TDS-D3039-QUA.

5.2. TEST MATRIX

5.2.1. Specimen Number

A total of 20 tests per FRP system and test direction are reported, refer to Table 5.1.

5.2.2. Specimen ID Nomenclature

Specimens are identified throughout the report using the format described in Section 4.5 of this document.

5.2.3. Test Matrix Table

Table 5.1 – Test matrix for tensile tests (no aging)

Specimen ID	Fiber Lot #	Resin Batch #	Specimen Preparation (mm.dd.yy)	Tested (mm.dd.yy)
QUA_U20C_TNS-00_CC_001 to 020	CONFIRM	A: Lot# 072617-17583 B: Lot# 7156-1	01.11.18	02.01.18
QUA_U41C_TNS-00_CC_001 to 020	10012430		01.31.18	02.28.18
QUA_B20C_TNS-00_CC_001 to 020	10010188		01.31.18	03.08.18
QUA_B20C_TNS-90_CC_001 to 020			01.31.18	03.06.18

5.3. SPECIMEN PREPARATION

5.3.1. Specimen Size

Nominal specimen dimensions are summarized in Table 5.2, including length and thickness.

Table 5.2 – Tensile specimen nominal dimensions

Specimen ID	Length		Thickness	
	mm	*in.*	*mm*	*in.*
QUA_U20C_TNS_CC	254.0	10.0	0.99	0.039
QUA_U41C_TNS_CC	254.0	10.0	1.70	0.067
QUA_B20C_TNS_CC	254.0	10.0	0.48	0.019*

**Nominal thickness half the overall FRP thickness since a bi-directional system.*

5.3.2. Specimen Layout

Specimens were obtained from the fabricated FRP panels as prepared and referenced in Section 4.2.2.

5.3.3. Preparation Procedure

The specimens were cut to the prescribed dimensions using a high precision diamond blade saw from different randomly selected panels. Tabs were installed as indicated in ASTM D3039 by laboratory personnel after sanding the ends of the coupon specimens.

5.3.4. Conditioning Parameters

All specimens were conditioned under laboratory ambient conditions at room temperature 23 ± 1°C (73 ± 3°F) and 60 ± 5% relative humidity, for at least 24 hrs prior testing.

5.4. TEST SET-UP

5.4.1. Set-up

Uniaxial tensile load was applied to all specimens. Testing for the specimens was performed using a hydraulic type universal test frame. Tensile load was measured with the internal load cell of each frame in compliance with ASTM E4-10 (Standard Practice for Force Verification of Testing Machines), while the extension (elongation) of the specimen was measured using a Class B-2 clip on extensometer in accordance to ASTM E83-10a (Standard Practice for Verification and Classification of Extensometer Systems), with a 50 mm (2.0 in.) gauge length, placed at mid-length of the coupon specimen. The extensometer was removed half way during the test to avoid damage of the instrument. Specimens were gripped with hydraulic wedge type grips at a pressure summarized in Table 5.3. The test set up is shown is Figure 5.1. All data was gathered using a National Instruments data acquisition system.

Table 5.3 – Tensile specimen Grip pressure.

Specimen ID	**Grip pressure** ***psi***
QUA_U20C_TNS_CC	3000
QUA_U41C_TNS_CC	4000
QUA_B20C_TNS_CC	2500

Figure 5.1 - Tensile test set-up

5.4.2. Rate and Method of Loading

Load was applied in displacement control to effect a near constant strain rate in the gauge section until failure at a constant frame head displacement of 1.3 mm/min (0.05 in./min), producing failure within 1 to 10 minutes, as per ASTM D3039 requirements.

5.5. TEST RESULTS

5.5.1. Results Summary

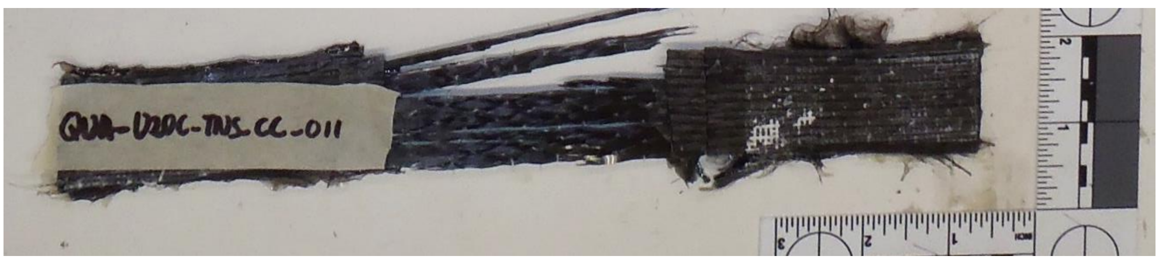
All specimens behaved linear elastically until failure. Based on the experimental tests presented herein the average ultimate and guaranteed tensile strength (F^{tu}), the computed average ultimate and guaranteed tensile strain (ε_u), and the average chord modulus of elasticity (E^{chord}) for the products under evaluation were found to be as summarized in Table 5.4.

Table 5.4 – Average result for tensile tests per ASTM D3039

	Ultimate Strength		***Guaranteed Strength***		***Ultimate Strain***	***Guaranteed Strain***	***Modulus of Elasticity***	
Specimen	f_{fu}		f^*_{fu}		ε_{fu}	ε^*_{fu}	E^{chord}	
ID	***MPa***	***MPa***	***MPa***	***ksi***	***%***	***%***	***GPa***	***Msi***
QUA_U20C_TNS-00_CC	1215.4	1215.4	1013.0	146.9	1.28	0.94	95.1	13.80
QUA_U41C_TNS-00_CC	1276.1	1276.1	1054.5	152.9	1.28	0.99	100.1	14.53
QUA_B20C_TNS-00_CC	1173.4	1173.4	1001.6	145.3	1.85	1.47	63.6	9.22
QUA_B20C_TNS-90_CC	1076.0	1076.0	891.8	129.3	2.02	1.57	53.5	7.76

5.5.2. Modes of Failure

Individual specimen failure modes are reported in the tabulated results section of this document, Figure 5.2 shows the representative failure mode for each FRP system.



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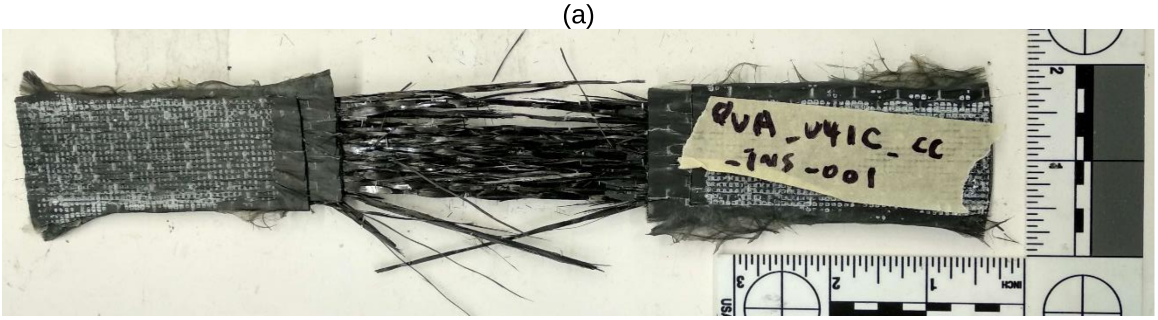

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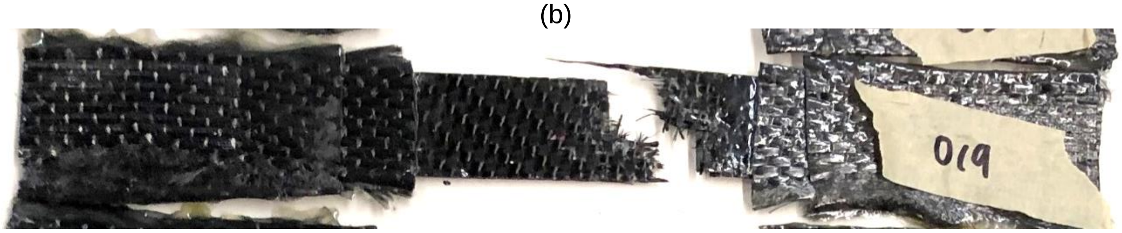

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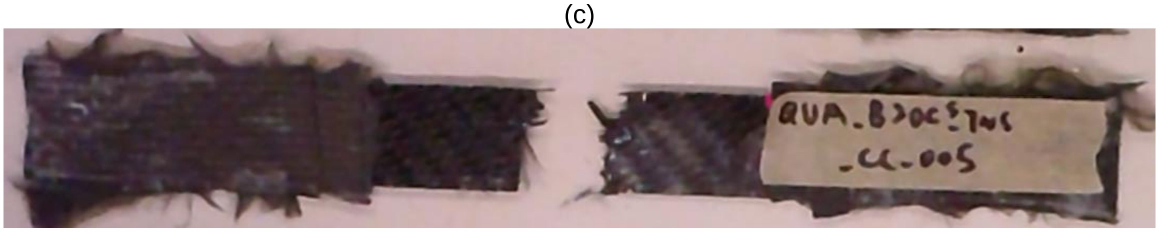


(d)

Figure 5.2 – Representative failure modes: (a) U20C and (b) U41C corresponding to ‘SGM’ longitudinal splitting at gauge; (c) B20C and (d) B20C primary and secondary directions ‘AGM’ angled at gauge

5.5.3. Calculations

The results reported herein have been computed per ASTM D3039, where the parameters are described and defined in Table 5.5. Note that the results have been calculated using the computed area based on average of three specimen width measurements and nominal thickness.

Table 5.5 - Definitions of parameters for tensile strength

Symbol	Parameter	Description
P^{max}	Maximum force at failure	Peak load recorded during test.
A	Average cross-section area	Cross-section area as reported in Table 5.2, based on nominal thickness.
f_{tu}	Ultimate tensile strength	P^{max} / A
ε_u	Computed ultimate strain, based on extensometer measurement	Strain based on the intersection of the computed chord modulus and ultimate tensile strength, equating to the ratio between the ultimate tensile strength and the tensile chord modulus
f^*_{tu}	Guaranteed tensile strength	f_{tu} minus three standard deviations (S_{n-1})
ε^*_u	Guaranteed strain,	ε_u minus three standard deviations (S_{n-1})
E^{chord}	Tensile chord modulus of elasticity, based on strain gauge measurement	Ration of the difference in applied tensile stress between that two points ($\Delta\sigma$); divided by the difference between the two strain points, nominally 0.002 ($\Delta\varepsilon$) as measured form the extensometer.

5.5.4. Tabulated Results

Table 5.5 contains the tabulated summary results for the products under evaluation. The table includes: average width based on three measurements (W); average nominal cross-sectional area based on three measurements of specimen width multiplied by a nominal thickness (A); experimental maximum tensile force (P^{max}); ultimate tensile strength (F^{tu}); chord modulus of elasticity (E^{chord}); computed ultimate tensile strain (ε_u); guaranteed values and failure mode as per ASTM D3039 FIGURE 4. Average, standard deviation (S_{n-1}), and coefficient of variance (CV) values are also reported, based on the complete set of specimens under evaluation for each product.

Table 5.6 - Tabulated results for tensile test for QuakeWrap™ VU20C with QuakeBond™ J300SR, per ASTM D3039

Specimen ID	W		A		P^{max}		P^{max} / W		F^{tu}		E^{chord}		ε_u	Mode of failure
	mm	in.	mm²	in²	kN	lbs	kN/mm	lbs/in.	MPa	ksi	GPa	Msi	%	
QUA_U20C_TNS-00_CC_001	23.99	0.944	23.76	0.037	27.35	6146	1.14	6509	1150.6	166.9	100.3	14.55	1.15	SGM
QUA_U20C_TNS-00_CC_002	21.59	0.850	21.39	0.033	25.74	5784	1.19	6805	1203.0	174.5	97.6	14.16	1.23	LGB
QUA_U20C_TNS-00_CC_003	18.65	0.734	18.47	0.029	20.71	4654	1.11	6338	1120.6	162.5	99.0	14.37	1.13	SGV
QUA_U20C_TNS-00_CC_004	21.27	0.837	21.07	0.033	25.39	5705	1.19	6814	1204.6	174.7	102.0	14.80	1.18	SGV
QUA_U20C_TNS-00_CC_005	25.27	0.995	25.04	0.039	29.79	6695	1.18	6729	1189.5	172.5	87.7	12.73	1.36	SGV
QUA_U20C_TNS-00_CC_006	25.25	0.994	25.01	0.039	31.22	7015	1.24	7057	1247.7	181.0	102.0	14.80	1.22	SGM
QUA_U20C_TNS-00_CC_007	25.15	0.990	24.91	0.039	31.80	7145	1.26	7217	1275.9	185.1	91.7	13.31	1.39	SGV
QUA_U20C_TNS-00_CC_008	24.56	0.967	24.33	0.038	28.04	6300	1.14	6515	1151.8	167.1	87.3	12.66	1.32	SGV
QUA_U20C_TNS-00_CC_009	25.10	0.988	24.86	0.039	31.87	7161	1.27	7248	1281.4	185.8	91.8	13.31	1.40	SGM
QUA_U20C_TNS-00_CC_010	25.20	0.992	24.96	0.039	33.74	7581	1.34	7642	1351.0	196.0	91.7	13.30	1.47	SGV
QUA_U20C_TNS-00_CC_011	25.58	1.007	25.34	0.039	33.95	7629	1.33	7576	1339.3	194.3	87.2	12.65	1.54	SGM
QUA_U20C_TNS-00_CC_012	21.55	0.848	21.34	0.033	27.16	6104	1.26	7196	1272.1	184.5	98.1	14.23	1.30	SGM
QUA_U20C_TNS-00_CC_013	18.84	0.742	18.66	0.029	22.46	5048	1.19	6806	1203.1	174.5	99.9	14.49	1.20	SGM
QUA_U20C_TNS-00_CC_014	24.87	0.979	24.63	0.038	29.69	6672	1.19	6815	1204.8	174.7	102.5	14.88	1.17	SGV
QUA_U20C_TNS-00_CC_015	21.57	0.849	21.37	0.033	26.97	6061	1.25	7138	1261.9	183.0	88.7	12.87	1.42	SGV
QUA_U20C_TNS-00_CC_016	25.22	0.993	24.99	0.039	30.87	6937	1.22	6986	1235.0	179.1	104.0	15.09	1.19	SGM
QUA_U20C_TNS-00_CC_017	18.94	0.746	18.76	0.029	21.63	4861	1.14	6520	1152.7	167.2	96.4	13.99	1.19	LGB
QUA_U20C_TNS-00_CC_018	13.83	0.545	13.70	0.021	15.35	3450	1.11	6336	1120.1	162.5	91.0	13.21	1.23	SGV
QUA_U20C_TNS-00_CC_019	25.17	0.991	24.93	0.039	28.32	6363	1.12	6421	1135.1	164.6	92.1	13.37	1.23	SGM
QUA_U20C_TNS-00_CC_020	17.96	0.707	17.79	0.028	21.50	4831	1.20	6831	1207.7	175.2	91.7	13.30	1.32	SGM
Average	**22.48**	**0.885**	**22.27**	**0.035**	**27.18**	**6107**	**1.20**	**6875**	**1215.4**	**176.3**	**95.1**	**13.80**	**1.28**	
S_{n-1}	3.35	0.132	3.32	0.005	4.86	1093	0.07	382	67.5	9.8	5.6	0.82	0.11	
CV%)	14.9	14.9	14.9	14.9	17.9	17.9	5.6	5.6	5.6	5.6	5.9	5.9	9.0	
Guaranteed Values							**1.00**	**5730**	**1013.0**	**146.9**			**0.94**	

Cont. Table 5.6 - Tabulated results for tensile test for QuakeWrap™ VU41C with QuakeBond™ J300SR, per ASTM D3039

Specimen	W		A		P^{max}		P^{max} / W		F^{tu}		E^{chord}		ε_u	Mode of failure
ID	mm	in.	mm²	in²	kN	lbs	kN/mm	lbs/in.	MPa	ksi	GPa	Msi	%	
QUA_U41C_TNS-00_CC_001	26.34	1.037	44.83	0.069	58.47	13140	2.22	12671	1304.0	189.1	107.5	15.60	1.21	SGV
QUA_U41C_TNS-00_CC_002	26.11	1.028	44.44	0.069	55.48	12468	2.12	12128	1248.1	181.0	106.0	15.39	1.18	SGV
QUA_U41C_TNS-00_CC_003	15.16	0.597	25.81	0.040	36.68	8242	2.42	13806	1420.7	206.1	103.6	15.03	1.37	SGV
QUA_U41C_TNS-00_CC_004	15.35	0.604	26.12	0.040	35.36	7945	2.30	13150	1353.2	196.3	91.3	13.25	1.48	SGM
QUA_U41C_TNS-00_CC_005	15.38	0.605	26.17	0.041	36.33	8165	2.36	13487	1387.9	201.3	95.7	13.88	1.45	SGM
QUA_U41C_TNS-00_CC_006	25.96	1.022	44.18	0.068	56.33	12658	2.17	12386	1274.6	184.9	94.1	13.66	1.35	SGM
QUA_U41C_TNS-00_CC_007	27.10	1.067	46.12	0.071	57.06	12821	2.11	12016	1236.6	179.3	106.4	15.44	1.16	SGM
QUA_U41C_TNS-00_CC_008	25.53	1.005	43.44	0.067	51.34	11538	2.01	11481	1181.4	171.4	89.5	12.99	1.32	SGM
QUA_U41C_TNS-00_CC_009	18.84	0.742	32.06	0.050	38.88	8736	2.06	11778	1212.0	175.8	98.4	14.28	1.23	SGM
QUA_U41C_TNS-00_CC_010	26.34	1.037	44.83	0.069	52.16	11722	1.98	11304	1163.2	168.7	103.9	15.07	1.12	SGM
QUA_U41C_TNS-00_CC_011	26.80	1.055	45.60	0.071	59.56	13384	2.22	12686	1305.5	189.3	101.0	14.65	1.29	SGM
QUA_U41C_TNS-00_CC_012	26.01	1.024	44.26	0.069	55.03	12366	2.12	12076	1242.7	180.2	100.2	14.55	1.24	SGM
QUA_U41C_TNS-00_CC_013	25.20	0.992	42.88	0.066	54.61	12273	2.17	12372	1273.2	184.7	105.3	15.28	1.21	SGV
QUA_U41C_TNS-00_CC_014	16.87	0.664	28.71	0.045	36.11	8115	2.14	12216	1257.1	182.3	100.4	14.57	1.25	SGV
QUA_U41C_TNS-00_CC_015	26.42	1.040	44.95	0.070	64.14	14413	2.43	13859	1426.2	206.8	107.5	15.60	1.33	SGM
QUA_U41C_TNS-00_CC_016	26.14	1.029	44.48	0.069	54.66	12284	2.09	11938	1228.5	178.2	88.5	12.85	1.39	SGV
QUA_U41C_TNS-00_CC_017	16.86	0.664	28.69	0.044	34.74	7806	2.06	11762	1210.4	175.6	98.7	14.32	1.23	SGM
QUA_U41C_TNS-00_CC_018	19.53	0.769	33.23	0.052	41.79	9392	2.14	12217	1257.2	182.3	98.8	14.33	1.27	SGM
QUA_U41C_TNS-00_CC_019	19.53	0.769	33.23	0.052	43.58	9794	2.23	12740	1311.1	190.2	100.8	14.63	1.30	SGV
QUA_U41C_TNS-00_CC_020	17.25	0.679	29.36	0.046	36.07	8106	2.09	11934	1228.1	178.1	104.9	15.22	1.17	SGV
Average	**22.13**	**0.871**	**37.67**	**0.058**	**47.92**	**10768**	**2.17**	**12400**	**1276.1**	**185.1**	**100.1**	**14.53**	**1.28**	
S_{n-1}	4.74	0.187	8.06	0.012	10.01	2248	0.13	718	73.8	10.7	5.8	0.85	0.10	
CV%)	21.4	21.4	21.4	21.4	20.9	20.9	5.8	5.8	5.8	5.8	5.8	5.8	7.6	
Guaranteed Values							**1.80**	**10247**	**1054.5**	**152.9**			**0.99**	

Cont. Table 5.6 - Tabulated results for tensile test for QuakeWrap™ TB20C with QuakeBond™ J300SR, primary direction, per ASTM D3039

Specimen	W		A		P^{max}		P^{max} / W		F^{tu}		E^{chord}		ε_u	Mode of
ID	mm	in.	mm²	in²	kN	lbs	kN/mm	lbs/in.	MPa	ksi	GPa	Msi	%	failure
QUA_B20C_TNS-00_CC_001	26.11	1.028	12.60	0.020	15.13	3401	0.58	3308	1200.5	174.1	61.9	8.99	1.94	AGM
QUA_B20C_TNS-00_CC_002	21.57	0.849	10.41	0.016	12.63	2838	0.59	3342	1212.8	175.9	59.0	8.56	2.05	LGV
QUA_B20C_TNS-00_CC_003	26.67	1.050	12.87	0.020	13.99	3144	0.52	2994	1086.6	157.6	60.7	8.80	1.79	AGB
QUA_B20C_TNS-00_CC_004	22.09	0.870	10.66	0.017	13.05	2933	0.59	3373	1224.0	177.5	68.8	9.99	1.78	AGM
QUA_B20C_TNS-00_CC_005	19.35	0.762	9.34	0.014	11.14	2504	0.58	3286	1192.5	173.0	69.7	10.12	1.71	AGM
QUA_B20C_TNS-00_CC_006	26.26	1.034	12.67	0.020	16.01	3597	0.61	3479	1262.4	183.1	61.9	8.98	2.04	AGM
QUA_B20C_TNS-00_CC_007	26.42	1.040	12.75	0.020	14.59	3278	0.55	3152	1143.8	165.9	66.6	9.67	1.72	LGT
QUA_B20C_TNS-00_CC_008	25.63	1.009	12.37	0.019	13.30	2988	0.52	2961	1074.6	155.9	58.2	8.44	1.85	AGT
QUA_B20C_TNS-00_CC_009	25.98	1.023	12.54	0.019	14.04	3154	0.54	3083	1118.8	162.3	63.0	9.14	1.78	AGM
QUA_B20C_TNS-00_CC_010	19.56	0.770	9.44	0.015	10.60	2382	0.54	3093	1122.2	162.8	62.6	9.08	1.79	AGM
QUA_B20C_TNS-00_CC_011	18.61	0.733	8.98	0.014	10.27	2307	0.55	3148	1142.5	165.7	69.2	10.04	1.65	AGM
QUA_B20C_TNS-00_CC_012	25.68	1.011	12.39	0.019	14.88	3343	0.58	3307	1199.9	174.0	69.0	10.01	1.74	AGB
QUA_B20C_TNS-00_CC_013	19.74	0.777	9.52	0.015	11.75	2640	0.60	3398	1233.0	178.8	62.0	9.00	1.99	AGT
QUA_B20C_TNS-00_CC_014	26.54	1.045	12.81	0.020	15.67	3522	0.59	3370	1223.0	177.4	60.7	8.81	2.01	LGM
QUA_B20C_TNS-00_CC_015	19.87	0.782	9.59	0.015	11.91	2677	0.60	3422	1241.8	180.1	62.6	9.08	1.98	LGB
QUA_B20C_TNS-00_CC_016	24.35	0.959	11.75	0.018	13.34	2997	0.55	3127	1134.6	164.6	59.4	8.62	1.91	AGM
QUA_B20C_TNS-00_CC_017	24.42	0.961	11.78	0.018	13.27	2983	0.54	3103	1125.9	163.3	61.5	8.93	1.83	AGM
QUA_B20C_TNS-00_CC_018	25.19	0.992	12.16	0.019	13.48	3030	0.54	3055	1108.6	160.8	67.0	9.73	1.65	AGM
QUA_B20C_TNS-00_CC_019	24.08	0.948	11.62	0.018	13.67	3072	0.57	3240	1175.8	170.5	61.5	8.93	1.91	AGM
QUA_B20C_TNS-00_CC_020	18.97	0.747	9.16	0.014	11.40	2562	0.60	3430	1244.6	180.5	65.9	9.56	1.89	LGM
Average	**23.36**	**0.919**	**11.27**	**0.017**	**13.21**	**2968**	**0.57**	**3234**	**1173.4**	**170.2**	**63.6**	**9.22**	**1.85**	
S_{n-1}	3.01	0.119	1.45	0.002	1.64	368	0.03	158	57.3	8.3	3.7	0.53	0.13	
CV%)	12.9	12.9	12.9	12.9	12.4	12.4	4.9	4.9	4.9	4.9	5.8	5.8	6.8	
Guaranteed Values							**0.48**	**2760**	**1001.6**	**145.3**			**1.47**	

Cont. Table 5.6 - Tabulated results for tensile test for QuakeWrap™ TB20C with QuakeBond™ J300SR, secondary direction, per ASTM D3039

Specimen	W		A		P^{max}		P^{max} / W		F^{tu}		E^{chord}		ε_u	Mode of failure
ID	mm	in.	mm²	in²	kN	lbs	kN/mm	lbs/in.	MPa	ksi	GPa	Msi	%	
QUA_B20C_TNS-90_CC_001	25.68	1.011	12.39	0.019	14.37	3230	0.56	3195	1159.4	168.2	58.2	8.45	1.99	LGB
QUA_B20C_TNS-90_CC_002	26.06	1.026	12.58	0.019	12.77	2870	0.49	2797	1015.1	147.2	57.3	8.32	1.77	LGB
QUA_B20C_TNS-90_CC_003	26.16	1.030	12.63	0.020	12.99	2919	0.50	2834	1028.4	149.2	55.3	8.02	1.86	AGB
QUA_B20C_TNS-90_CC_004	26.29	1.035	12.69	0.020	13.88	3120	0.53	3014	1093.9	158.7	56.7	8.23	1.93	AGT
QUA_B20C_TNS-90_CC_005	26.75	1.053	12.91	0.020	13.91	3126	0.52	2969	1077.3	156.2	56.6	8.21	1.90	AGM
QUA_B20C_TNS-90_CC_006	25.02	0.985	12.07	0.019	13.88	3118	0.55	3165	1148.7	166.6	52.0	7.55	2.21	LGM
QUA_B20C_TNS-90_CC_007	26.19	1.031	12.64	0.020	12.56	2822	0.48	2737	993.3	144.1	52.6	7.63	1.89	AGT
QUA_B20C_TNS-90_CC_008	23.27	0.916	11.23	0.017	11.53	2592	0.50	2829	1026.6	148.9	47.9	6.95	2.14	AGT
QUA_B20C_TNS-90_CC_009	26.47	1.042	12.77	0.020	13.09	2941	0.49	2822	1024.2	148.6	49.1	7.13	2.08	AGB
QUA_B20C_TNS-90_CC_010	25.63	1.009	12.37	0.019	12.90	2898	0.50	2872	1042.3	151.2	51.8	7.51	2.01	AGM
QUA_B20C_TNS-90_CC_011	26.37	1.038	12.72	0.020	13.24	2976	0.50	2867	1040.4	150.9	48.4	7.02	2.15	AGB
QUA_B20C_TNS-90_CC_012	25.98	1.023	12.54	0.019	12.61	2833	0.49	2769	1004.9	145.8	54.3	7.88	1.85	AGB
QUA_B20C_TNS-90_CC_013	23.36	0.920	11.27	0.017	11.82	2657	0.51	2889	1048.2	152.0	54.4	7.90	1.92	AGT
QUA_B20C_TNS-90_CC_014	25.83	1.017	12.47	0.019	12.83	2883	0.50	2835	1028.7	149.2	53.8	7.80	1.91	AGT
QUA_B20C_TNS-90_CC_015	26.80	1.055	12.93	0.020	14.55	3269	0.54	3099	1124.4	163.1	48.0	6.97	2.34	AGM
QUA_B20C_TNS-90_CC_016	27.13	1.068	13.09	0.020	14.59	3279	0.54	3070	1114.1	161.6	55.2	8.01	2.02	AGB
QUA_B20C_TNS-90_CC_017	25.96	1.022	12.53	0.019	14.81	3327	0.57	3255	1181.3	171.3	55.5	8.05	2.13	LGB
QUA_B20C_TNS-90_CC_018	25.45	1.002	12.28	0.019	14.61	3284	0.57	3277	1189.3	172.5	53.9	7.82	2.21	AGB
QUA_B20C_TNS-90_CC_019	25.76	1.014	12.43	0.019	14.00	3146	0.54	3103	1125.9	163.3	53.0	7.69	2.12	AGM
QUA_B20C_TNS-90_CC_020	24.28	0.956	11.72	0.018	12.36	2777	0.51	2905	1054.3	152.9	55.4	8.04	1.90	AGM
Average	**25.72**	**1.013**	**12.41**	**0.019**	**13.36**	**3003**	**0.52**	**2965**	**1076.0**	**156.1**	**53.5**	**7.76**	**2.02**	
S_{n-1}	1.04	0.041	0.50	0.001	0.97	218	0.03	169	61.4	8.9	3.1	0.45	0.15	
CV%)	4.0	4.0	4.0	4.0	7.3	7.3	5.7	5.7	5.7	5.7	5.8	5.8	7.4	
Guaranteed Values							**0.43**	**2458**	**891.8**	**129.3**			**1.57**	

6. COEFFICIENT OF THERMAL EXPANSION (CTE) – ASTM E831

6.1. TEST SUMMARY

6.1.1. AC125 Section/s

Section 5.8, Table 2 for Physical and Mechanical Properties of FRP Composite Materials.

6.1.2. Reference Standard/s

ASTM E831–14, Standard test method for linear thermal expansion of solid materials by thermomechanical analysis.

6.1.3. Test Objective

Determine, by means of thermomechanical analysis (TMA) technique, the average apparent coefficient of linear thermal expansion (CTE) of the materials under evaluation in the different orthogonal directions.

6.1.4. Product/s Under Evaluation

QuakeWrap™ VU20C with QuakeBond™ J300SR; QuakeWrap™ VU41C with QuakeBond™ J300SR; and QuakeWrap™ TB20C with QuakeBond™ J300SR, all FRP systems in both primary and secondary directions.

6.1.5. Test Location

Advanced Plastic & Material Testing, Inc., 42 Dutch Mill Road, Ithaca, NY 14850.

6.1.6. Laboratory Technician/s

Ashley Colvin and Francisco De Caso

6.2. TEST MATRIX

6.2.1. Specimen Number

A total of five tests per FRP system are reported, refer to Table 6.1, where tests were performed in each orthogonal direction relative to the fiber direction.

6.2.2. Specimen ID Nomenclature

Specimens are identified throughout the report using the format described in Section 4.5 of this document.

6.2.3. Test Matrix Table

Table 6.1– Test matrix for coefficient of thermal expansion tests (no aging)

Specimen ID	Fiber Lot #	Resin Batch #	Specimen Preparation (mm.dd.yy)	Tested (mm.dd.yy)
QUA_U20C_CTE_CC_00_001 to 005	CONFIRM	A: Lot# 072617-17583 B: Lot# 7156-1	01.11.18	03.01.18
QUA_U20C_CTE _CC_90_001 to 005				02.28.18
QUA_U41C_CTE _CC_00_001 to 005	10012430		01.31.18	03.08.18
QUA_U41C_CTE _CC_90_001 to 005				03.09.18
QUA_B20C_CTE _CC_00_001 to 005	10010188		02.05.18	03.05.18
QUA_B20C_CTE _CC_90_001 to 005				03.02.18

6.3. SPECIMEN PREPARATION

6.3.1. Specimen Size

Nominal square specimen dimensions were 10 mm (0.39 in.) in length/width and thickness as detail in Table 6.2.

Table 6.2 – Coefficient of thermal expansion specimen dimensions

Specimen ID	**Thickness**	
	mm	***in.***
QUA_U20C_CTE_CC	3.0	0.12
QUA_U41C_CTE_CC	8.0	0.31
QUA_B20C_CTE_CC	3.0	0.12

6.3.2. Preparation Procedure

The specimens were cut to the prescribed dimensions from a multi-ply panel as prepared and referenced in Section 4.2.

6.4. TEST SET-UP

6.4.1. Set-up

A TMA Q400em thermomechanical analyzer was used to perform the tests, on a 3 mm diameter expansion probe with a 0.05 N force.

6.4.2. Rate and Method of Loading

The heating rate was 5°C/min, in Nitrogen (UHP Grade). Purge flow rate was 50 cubic centimeters per minute.

6.5. TEST RESULTS

6.5.1. Results Summary

Based on the experimental tests presented herein the average apparent coefficient of linear thermal expansion (α_m) of the materials under evaluation without any aging or exposure conditioning are summarized in Table 6.3.

Table 6.3 – Average results for coefficient of thermal expansion tests, per ASTM E831

Specimen ID	α_m	
	µm/m/°C	**µin./in./·°F**
QUA_U20C_CTE-00_CC	1.7	0.9
QUA_U20C_CTE-90_CC	48.6	27.0
QUA_U41C_CTE-00_CC	2.4	1.4
QUA_U41C_CTE-90_CC	58.1	32.3
QUA_B20C_CTE-00_CC	9.6	5.3
QUA_B20C_CTE-90_CC	6.3	3.5

6.5.2. Calculations

The results reported herein have been computed as per ASTM E831.

6.5.3. Graphical Representation of Results

Refer to Figure 6.1 to and Figure 6.6.

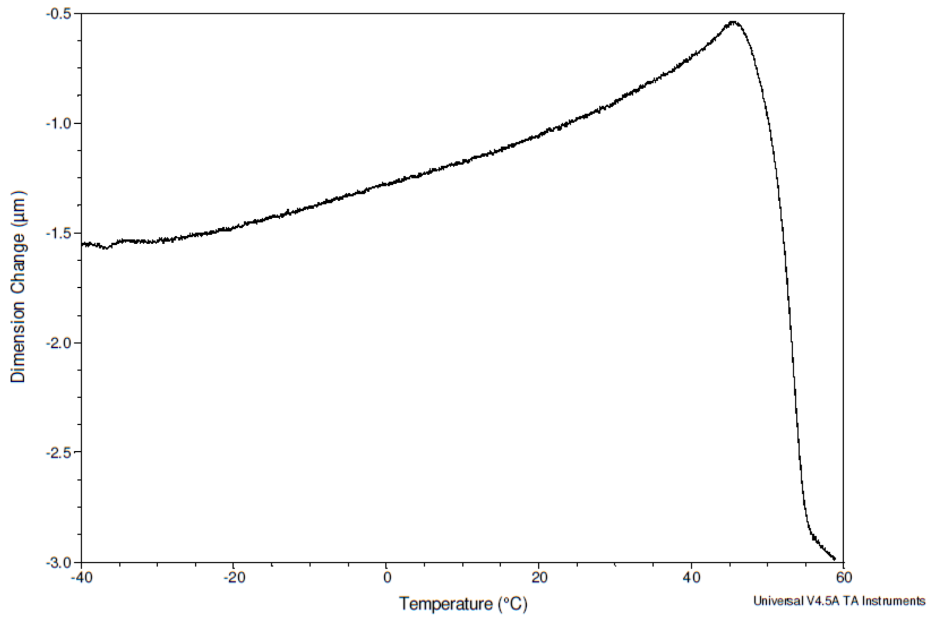


Figure 6.1 – Typical TMA graph for U20C specimens tested parallel to the fiber direction (00)

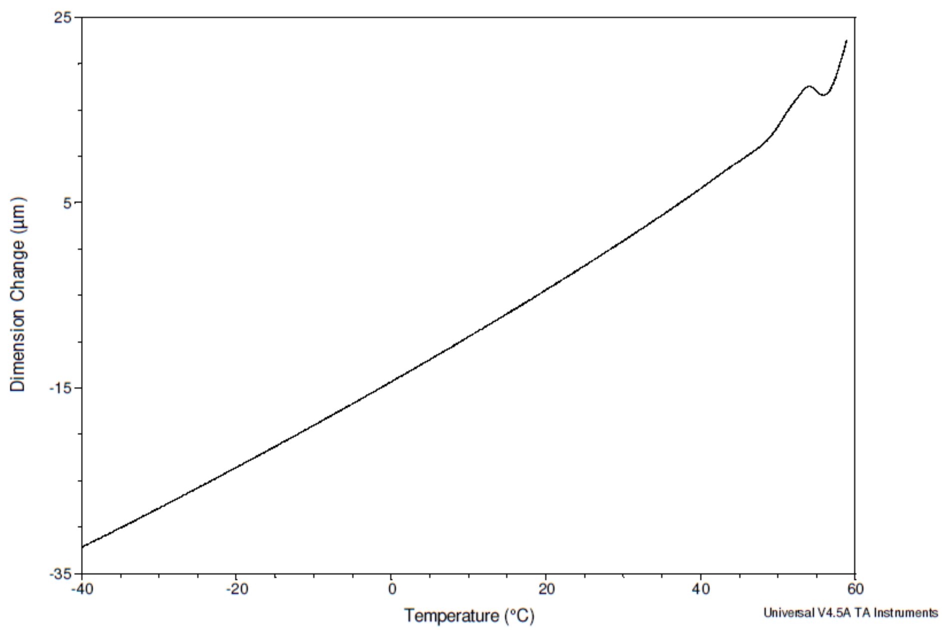


Figure 6.2– Typical TMA graph for U20C specimens tested perpendicular to the fiber direction (90)

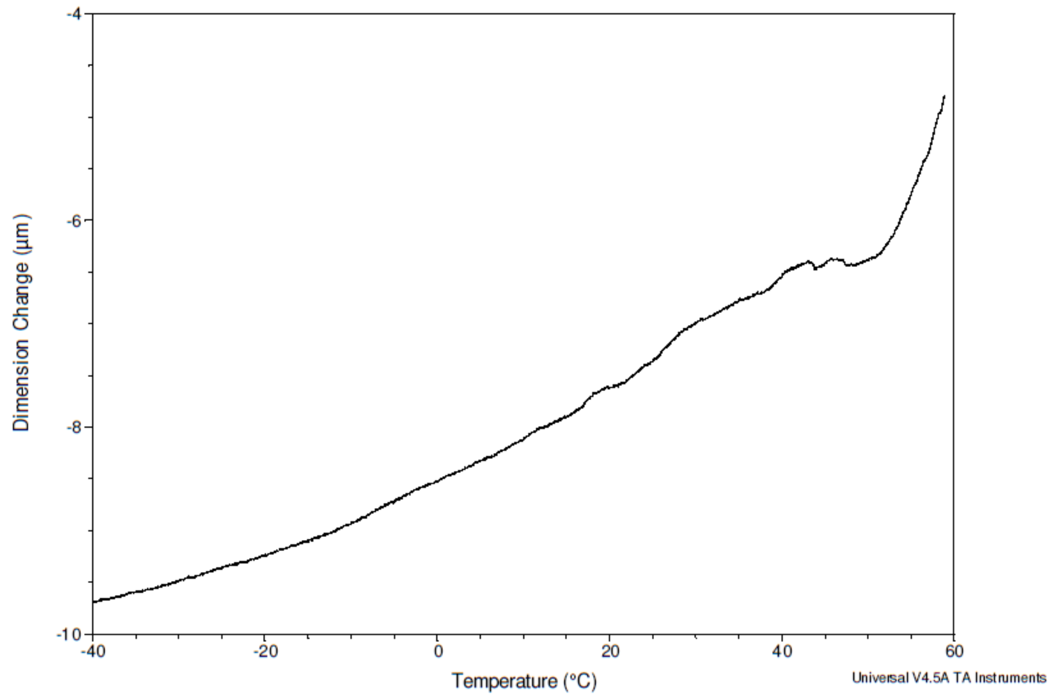


Figure 6.3 – Typical TMA graph for U41C specimens tested parallel to the fiber direction (00)

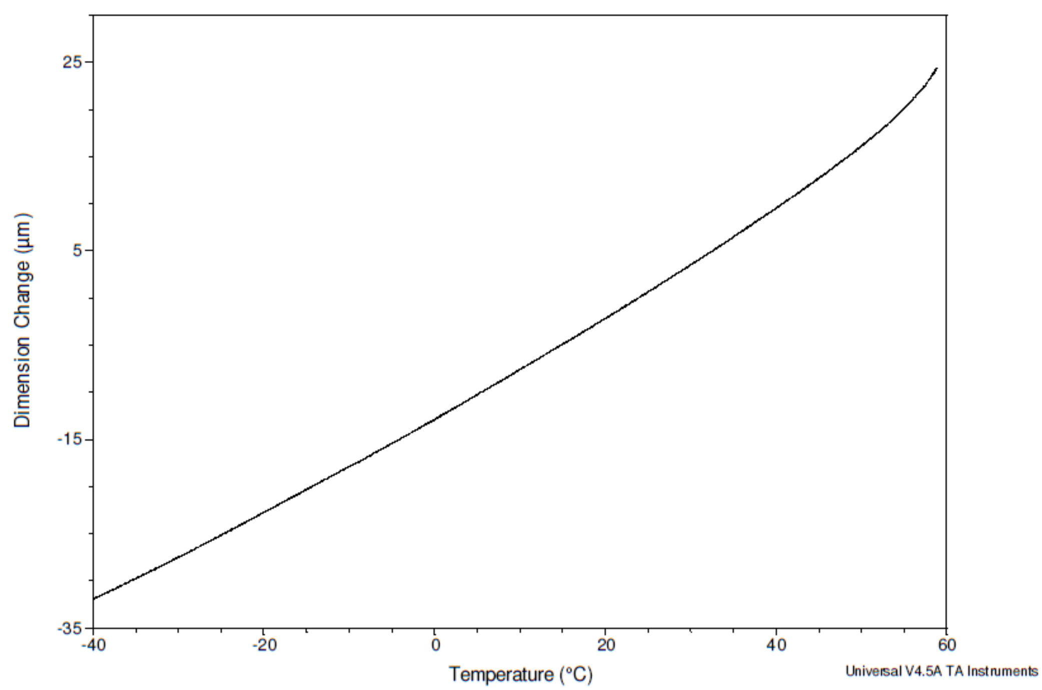


Figure 6.4– Typical TMA graph for U41C specimens tested perpendicular to the fiber direction (90)

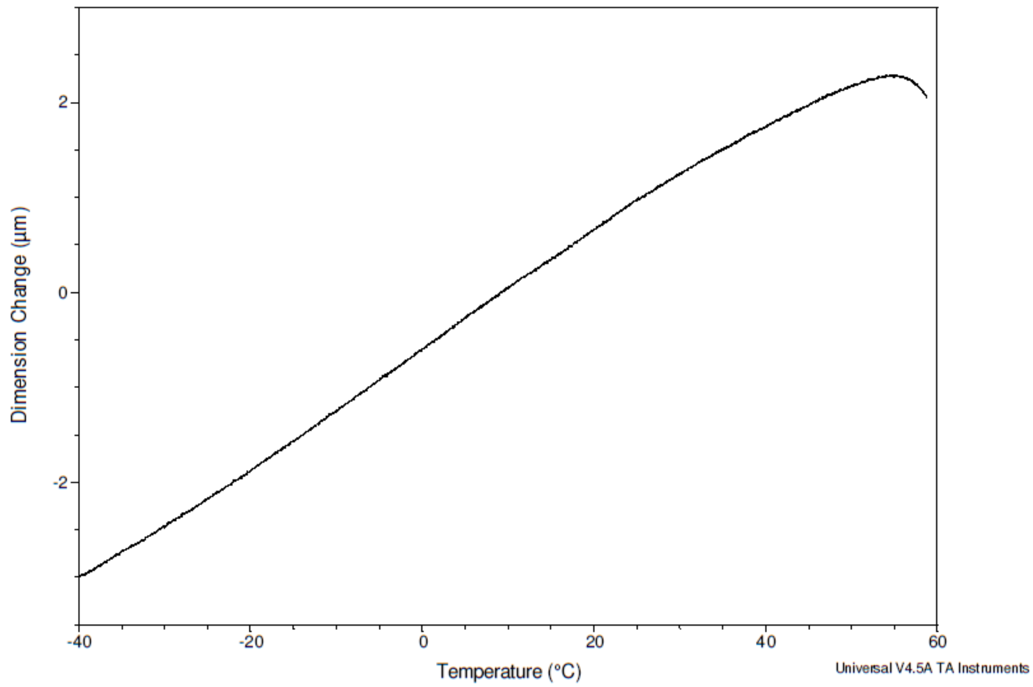


Figure 6.5– Typical TMA graph for B20C specimens tested parallel to the fiber direction (00)

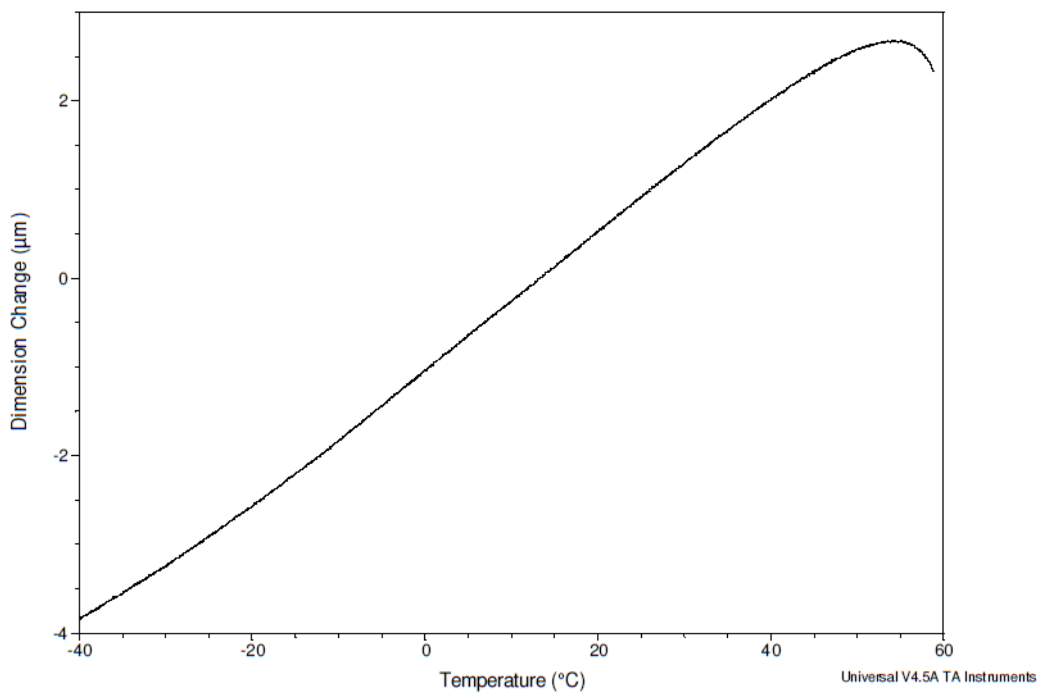


Figure 6.6– Typical TMA graph for B20C specimens tested perpendicular to the fiber direction (90)

6.5.4. Tabulated Results

Table 6.4 contains the tabulated summary results for the products under evaluation, including: the average length of the specimen (L), the analysis start point (T_s), the analysis end point (T_e) and the coefficient of thermal expansion (α_m). Average, standard deviation (S_{n-1}), and coefficient of variance (CV) values are also reported, based on the complete set of specimens under evaluation for each product.

Table 6.4 - Tabulated results for coefficient of thermal expansion for QuakeWrap™ VU20C and QuakeWrap™ VU41C with QuakeBond™ J300SR, per ASTM E831

Specimen ID		*L*		T_s		T_e		α_m	
		mm	*in*	*°C*	*°F*	*°C*	*°F*	*μm/(m·°C)*	*μin/(in°F)*
QUA_U20C_CTE-00_CC_001		8.097	0.3188	-30	-22	50	122	0.8	0.4
QUA_U20C_CTE-00_CC_002		9.248	0.3641	-30	-22	50	122	1.5	0.8
QUA_U20C_CTE-00_CC_003		8.970	0.3531	-30	-22	50	122	1.8	1.0
QUA_U20C_CTE-00_CC_004		9.836	0.3872	-30	-22	50	122	3.1	1.7
QUA_U20C_CTE-00_CC_005		9.117	0.3589	-30	-22	50	122	1.1	0.6
	Average	**9.054**	**0.3564**					**1.7**	**0.9**
	S_{n-1}	0.628	0.0247					0.9	0.5
	CV%)	6.9	6.9					53.6	53.6
QUA_U20C_CTE-90_CC_001		8.602	0.3387	-30	-22	50	122	46.8	26.0
QUA_U20C_CTE-90_CC_002		9.041	0.3559	-30	-22	50	122	47.6	26.4
QUA_U20C_CTE-90_CC_003		8.952	0.3524	-30	-22	50	122	49.5	27.5
QUA_U20C_CTE-90_CC_004		9.283	0.3655	-30	-22	50	122	49.2	27.3
QUA_U20C_CTE-90_CC_005		9.894	0.3895	-30	-22	50	122	49.8	27.7
	Average	**9.154**	**0.3604**					**48.6**	**27.0**
	S_{n-1}	0.480	0.0189					1.3	0.7
	CV%)	5.2	5.2					2.7	2.7
QUA_U41C_CTE-00_CC_001		9.417	0.3707	-30	-22	50	122	1.1	0.6
QUA_U41C_CTE-00_CC_002		8.725	0.3435	-30	-22	50	122	3.0	1.7
QUA_U41C_CTE-00_CC_003		9.347	0.3680	-30	-22	50	122	1.9	1.1
QUA_U41C_CTE-00_CC_004		9.268	0.3649	-30	-22	50	122	2.1	1.2
QUA_U41C_CTE-00_CC_005		9.020	0.3551	-30	-22	50	122	4.1	2.3
	Average	**9.155**	**0.3605**					**2.4**	**1.4**
	S_{n-1}	0.283	0.0112					1.1	0.6
	CV%)	3.1	3.1					47.1	47.1
QUA_U41C_CTE-90_CC_001		9.084	0.3576	-30	-22	50	122	59.1	32.8
QUA_U41C_CTE-90_CC_002		9.454	0.3722	-30	-22	50	122	56.7	31.5
QUA_U41C_CTE-90_CC_003		9.137	0.3597	-30	-22	50	122	59.5	33.1
QUA_U41C_CTE-90_CC_004		9.670	0.3807	-30	-22	50	122	59.4	33.0
QUA_U41C_CTE-90_CC_005		9.475	0.3730	-30	-22	50	122	55.8	31.0
	Average	**9.364**	**0.3687**					**58.1**	**32.3**
	S_{n-1}	0.247	0.0097					1.7	1.0
	CV%)	2.6	2.6					3.0	3.0

Cont. Table 6.4 - Tabulated results for coefficient of thermal expansion for QuakeWrap™ TB20C with QuakeBond™ J300SR, per ASTM E831

Specimen ID	*L*		T_s		T_e		α_m	
	mm	*in*	*°C*	*°F*	*°C*	*°F*	*μm/(m·°C)*	*μin/(in°F)*
QUA_B20C_CTE-00_CC_001	9.105	0.3585	-30	-22	50	122	7.3	4.1
QUA_B20C_CTE-00_CC_002	8.594	0.3383	-30	-22	50	122	8.6	4.8
QUA_B20C_CTE-00_CC_003	8.641	0.3402	-30	-22	50	122	10.3	5.7
QUA_B20C_CTE-00_CC_004	8.626	0.3396	-30	-22	50	122	14.5	8.1
QUA_B20C_CTE-00_CC_005	8.479	0.3338	-30	-22	50	122	7.1	3.9
Average	**8.689**	**0.3421**					**9.6**	**5.3**
S_{n-1}	0.241	0.0095					3.0	1.7
CV%)	2.8	2.8					31.8	31.8
QUA_B20C_CTE-90_CC_001	10.883	0.4285	-30	-22	50	122	6.3	3.5
QUA_B20C_CTE-90_CC_002	9.988	0.3932	-30	-22	50	122	6.5	3.6
QUA_B20C_CTE-90_CC_003	10.590	0.4169	-30	-22	50	122	6.0	3.3
QUA_B20C_CTE-90_CC_004	11.174	0.4399	-30	-22	50	122	6.8	3.8
QUA_B20C_CTE-90_CC_005	10.438	0.4109	-30	-22	50	122	5.9	3.3
Average	**10.615**	**0.4179**					**6.3**	**3.5**
S_{n-1}	0.450	0.0177					0.4	0.2
CV%)	4.2	4.2					5.8	5.8

7. VOID CONTENT (VDC) – ASTM D3171

7.1. TEST SUMMARY

7.1.1. AC125 Section

Section 5.8, Table 2 for physical and mechanical properties of FRP composite materials.

7.1.2. Reference Standard/s

ASTM D3171 -15, Standard Test Methods for Constituent Content of Composite Materials.

7.1.3. Test Objective

Calculate the reinforcement or matrix content by weight of the composite, cured ply thickness and void content.

7.1.4. Product/s Under Evaluation

QuakeWrap™ VU20C with QuakeBond™ J300SR; QuakeWrap™ VU41C with QuakeBond™ J300SR; and QuakeWrap™ TB20C with QuakeBond™ J300SR.

7.1.5. Test Location

Structures and Materials Laboratory, SML, Main Laboratory, University of Miami, 1251 Memorial Dr., MEB108 Coral Gables, FL, 33146

7.1.6. Laboratory Technician/s

Tais Hamilton, Phil Lavonas and Ming Han Soh.

7.1.7. Technical Test Record

The date of each test; variations to the test method as applicable; calibration information for all measurements and test equipment; identification of the material tested; temperature and humidity of testing laboratory; and other applicable test data or details are provided in the Technical Test Record document number TDS-D3171(I)-QUA.

7.2. TEST MATRIX

7.2.1. Specimen Number

A total of five tests per FRP system under evaluation are reported, refer to Table 7.1.

7.2.2. Specimen ID Nomenclature

Specimens are identified throughout the report using the format described in Section 4.5 of this document.

7.2.3. Test Matrix Table

Table 7.1 – Test matrix for void content

Specimen ID	Batch Fiber #	Batch Resin #	Specimen Preparation mm.dd.yy	Tested mm.dd.yy
QUA_U20C_VDC_CC_001 to 005	CONFIRM	A: Lot# 072617-17583 B: Lot# 7156-1	01.11.18	03.01.18
QUA_U41C_VDC_CC_001 to 005	10012430		01.31.18	02.25.18
QUA_B20C_VDC_CC_001 to 005	10010188		02.05.18	03.05.18

7.3. SPECIMEN PREPARATION

7.3.1. Specimen Size

Nominal specimen based on weight as reported in the results section.

7.3.2. Preparation Procedure

The specimens were cut to the prescribed dimensions using a high precision diamond blade saw from different panels randomly selected as prepared and referenced in Section 4.2.

7.3.3. Specimen Conditioning

All specimens were conditioned under laboratory ambient conditions at room temperature 23 ± 3°C (73 ± 6°F) and 50 ± 10% relative humidity.

7.4. TEST SET-UP

7.4.1. Set-up

Specimens were weighed to the nearest 0.0001 g (2.2×10^{-7} lbs). A micrometer was used to determine the thickness of the laminate. The thickness was measured in three different locations. The density of each specimen was determined in accordance with ASTM D3171.

7.5. TEST RESULTS

7.5.1. Results Summary

Based on the experimental tests presented herein the average matrix content (weight percent), ply thickness and void content based on ASTM D3171 of the materials are summarized in Table 7.2, where the void volume was below the 6.0% requirement of AC125.

Table 7.2 – Average results for void content, per ASTM D3171

Specimen ID	Reinforcement Content V_r %	Matrix Content V_m %	Void Volume V_v %
QUA_U20C_VDC_CC	42.9	55.6	1.5
QUA_U41C_VDC_CC	36.6	61.2	2.2
QUA_B20C_VDC_CC	44.7	52.7	2.6

7.5.2. Calculations

The results reported herein have been computed as per ASTM D3171 using the parameters defined in Table 7.3.

Table 7.3 - Definitions of calculations

Symbol	Parameter	Description
M_i	Initial mass of the specimen	Mass of the specimen
M_f	Final mass of specimen	Mass of the specimen
V_r	Reinforcement content	$V_r = (M_f / M_i) \times 100 \times \rho_c / \rho_r$
V_m	Matrix content	$V_m = (M_i - M_f)/M_i \times \rho_c / \rho_m \times 100$
V_v	Void volume	$V_v = 100 - (V_r + V_m)$
ρ_r	Reinforcement density	ρ_r=1.8 g/cm^3
ρ_m	Matrix density	ρ_m=1.13 g/cm^3
W_m	Matrix content (weight Percent)	$W_m = (M_i - M_f)/M_i \times 100$

7.5.3. Tabulated Results

Table 7.4 contains the tabulated summary results for the void content. Reinforcement and matrix weight, reinforcement, matrix and void percent are reported. Average, standard deviation and coefficient of variance values are also reported.

Table 7.4 - Tabulated results for void content for QuakeWrapTM VU20C, VU41C and TB20C with QuakeBondTM J300SR, per ASTM D3171

Specimen ID	Initial Mass M_i		Final Mass M_f		Reinforcement Content V_r	Matrix Content V_m	Void Volume* V_v
	mg	*oz*	*mg*	*oz*	*%*	*%*	*%*
QUA_U20C_VDC_CC_001	914.9	0.0323	497.0	0.0175	42.3	56.6	1.2
QUA_U20C_VDC_CC_002	820.4	0.0289	451.9	0.0159	42.8	55.6	1.5
QUA_U20C_VDC_CC_003	891.6	0.0315	498.5	0.0176	43.5	54.6	1.9
QUA_U20C_VDC_CC_004	848.0	0.0299	469.5	0.0166	43.1	55.3	1.6
QUA_U20C_VDC_CC_005	879.4	0.0310	483.2	0.0170	42.7	55.8	1.4
Average	**870.8**	**0.0307**	**480.0**	**0.0169**	**42.9**	**55.6**	**1.5**
S_{n-1}	37.12	0.0013	19.63	0.0007	0.45	0.72	0.27
CV%)	4.3	4.3	4.1	4.1	1.1	1.3	17.5
QUA_U41C_VDC_CC_001	1080.9	0.0381	522.9	0.0184	36.3	61.7	2.0
QUA_U41C_VDC_CC_002	1092.3	0.0385	530.3	0.0187	36.4	61.5	2.1
QUA_U41C_VDC_CC_003	1056.7	0.0373	506.1	0.0179	35.9	62.2	1.8
QUA_U41C_VDC_CC_004	1050.9	0.0371	510.4	0.0180	36.4	61.4	2.1
QUA_U41C_VDC_CC_005	1000.0	0.0353	503.3	0.0178	37.7	59.3	2.9
Average	**1056.2**	**0.0373**	**514.6**	**0.0182**	**36.6**	**61.2**	**2.2**
S_{n-1}	35.69	0.0013	11.54	0.0004	0.7	1.1	0.4
CV%)	3.4	3.4	2.2	2.2	1.9	1.8	18.7
QUA_B20C_VDC_CC_001	932.2	0.0329	53.3	0.0019	44.5	53.1	2.5
QUA_B20C_VDC_CC_002	1047.6	0.0370	59.3	0.0021	44.0	53.8	2.2
QUA_B20C_VDC_CC_003	1070.1	0.0377	62.0	0.0022	45.0	52.1	2.8
QUA_B20C_VDC_CC_004	942.8	0.0333	55.6	0.0020	45.9	50.8	3.3
QUA_B20C_VDC_CC_005	977.2	0.0345	55.5	0.0020	44.2	53.5	2.3
Average	**994.0**	**0.0**	**57.1**	**0.0**	**44.7**	**52.7**	**2.6**
S_{n-1}	62.00	0.00	3.45	0.00	0.8	1.2	0.5
CV%)	6.2	6.2	6.0	6.0	1.7	2.3	17.3

**Condition of acceptance is equivalent to Vv < 6%*

8. GLASS TRANSITION TEMPERATURE (TG) – ASTM E1640

8.1. TEST SUMMARY

8.1.1. AC125 Section/s

Section 5.8 for Physical and Mechanical Properties of FRP Composite Materials, and Table 2.

8.1.2. Reference Standard/s

ASTM E1640 – 13 (Re-approved 2018) Standard test method for assignment of the glass transition temperature by dynamic mechanical analysis.

8.1.3. Test Objective

Determine the glass transition temperature (T_g) of the saturating resin under evaluation based on dynamic mechanical analysis (DMA) without any aging or environmental exposure.

8.1.4. Product/s Under Evaluation

QuakeBond™ J300SR.

8.1.5. Test Location

Structures and Materials Laboratory, SML, Main Laboratory, University of Miami, 1251 Memorial Dr., MEB108 Coral Gables, FL, 33146

8.1.6. Laboratory Technician/s

Ming Han Soh

8.1.7. Technical Test Record

The date of each test; variations to the test method as applicable; calibration information for all measurements and test equipment; identification of the material tested; temperature and humidity of testing laboratory; and other applicable test data or details are provided in the Technical Test Record document number TDS-E1640-QUA.

8.2. TEST MATRIX

8.2.1. Specimen Number

A total of 20 tests for the FRP saturating resin system are reported, refer to Table 8.1.

8.2.2. Specimen ID Nomenclature

Specimens are identified throughout the report using the format described in Section 4.5 of this document.

8.2.3. Test Matrix Table

Table 8.1 – Test matrix for glass transition tests (no aging)

Specimen ID	Fiber Lot #	Resin Batch #	Specimen Preparation (mm.dd.yy)	Tested (mm.dd.yy)
QUA_J300_TG_CC_001 to 005	n/a	A: Lot# 072617-17583 B: Lot# 7156-1	01.11.18	01.30.18
QUA_J300_TG_CC_006 to 010				01.31.18
QUA_J300_TG_CC_011 to 015				02.08.18
QUA_J300_TG_CC_016 to 020				02.12.18

8.3. SPECIMEN PREPARATION

8.3.1. <u>Specimen Size</u>

Nominal specimen dimensions were 20 mm (0.8 in.) span length, 5 mm (0.2 in.) width, and 1 mm (0.04 in.) thickness, as per ASTM E1640.

8.3.2. <u>Preparation Procedure</u>

Panels of resin were batched on adhesion free silicon based molds at the desired thickness. The specimens were then cut to the prescribed dimensions using a high precision saw band.

8.3.3. <u>Conditioning Parameters</u>

All specimens were conditioned under laboratory ambient conditions at room temperature 23 ± 1°C (73 ± 3°F) and 60 ± 5% relative humidity, for at least 24 hrs. prior testing.

8.4. TEST SET-UP

8.4.1. <u>Set-up</u>

A Dynamic Mechanical Analyzer (DMA) was used with a three-point flexural set up to apply a forced oscillation with constant amplitude at a fixed frequency as indicated in the next section. The loss modulus is obtained based on the tangent change with the increasing temperature by the analysis of the flexural mechanical response and plotted in a graph to determine the T_g. The test set-up is shown is Figure 8.1.

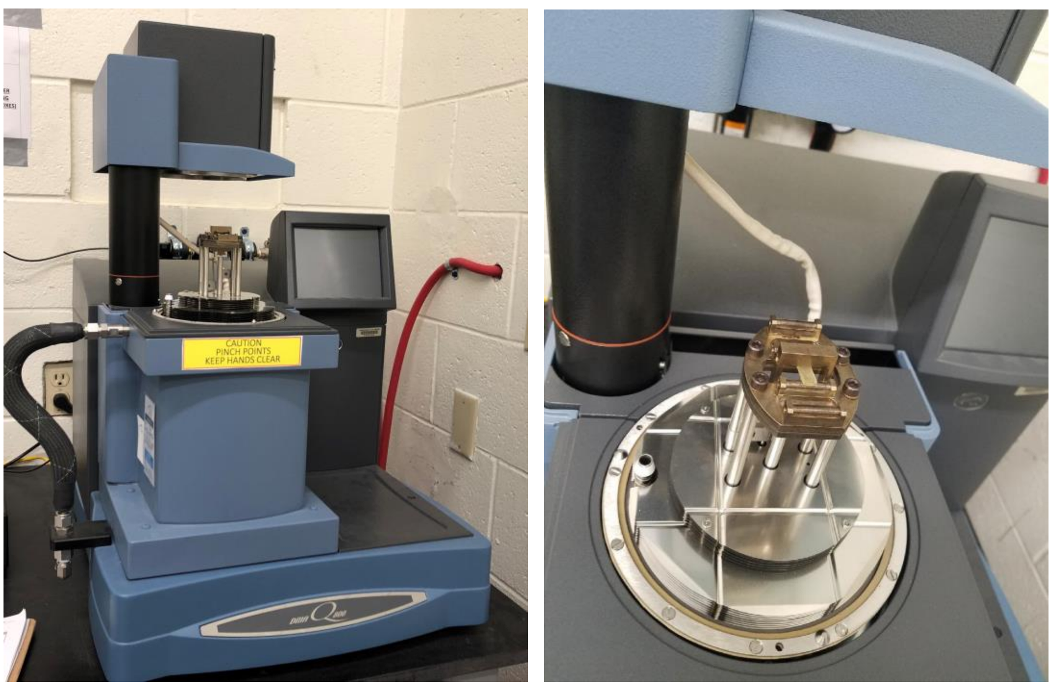


Figure 8.1 – Glass transition temperature test set-up

8.4.2. Rate and Method of Loading

A heating rate of 1°C/min (1°F/min) and a frequency of 1 Hz was applied, with sub-ambient of liquid nitrogen and elevated nitrogen.

8.5. TEST RESULTS

8.5.1. Results Summary

Based on the experimental tests presented herein the average glass transition temperature (T_g) of the materials under evaluation without any aging or exposure conditioning are summarized in Table 8.2. The T_g based on the loss modulus meets the conditions of acceptance of AC125 being higher than 60°C (140°F).

Table 8.2 – Average result for glass transition temperature

Specimen	***T_g***	
ID	***°C***	***°F***
QUA_J300SR _TG_CC	69.8	157.7

8.5.2. Calculations

The T_g is determined by the extrapolated onset to the sigmoidal change and resultant peak of the Loss modulus value recorded during the transition from the hard, brittle region to the soft, rubbery region of the material under evaluation.

8.5.3. Graphical Representation of Results

Figure 8.2 shows typical results for the determination of T_g.

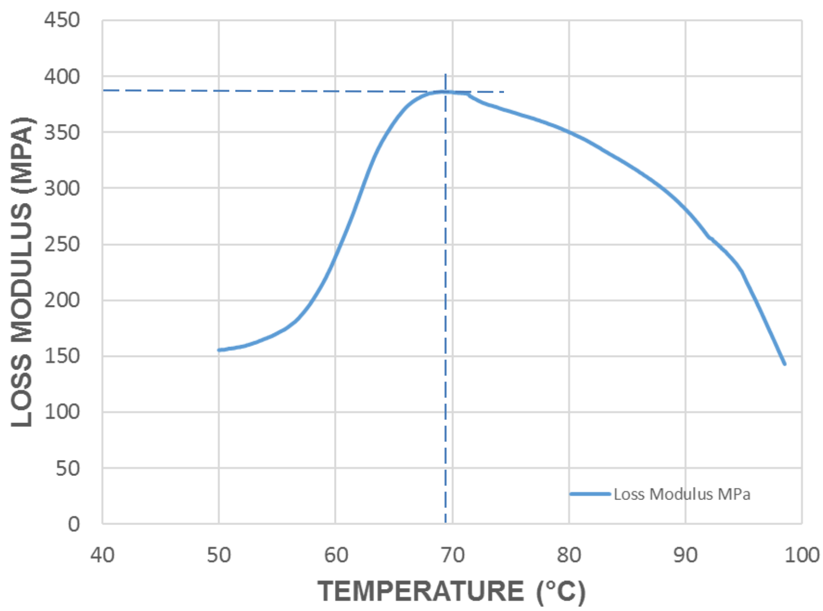


Figure 8.2 – Representative loss modulus versus temperature for J300 glass transition temperature

8.5.4. Tabulated Results

Table 8.3 contains the tabulated summary results for the products under evaluation, including: glass transition temperature (T_g) based on Loss Modulus. Average, standard deviation (S_{n-1}), and coefficient of variance (CV) values are also reported, based on the complete set of specimens under evaluation for each product.

Table 8.3 - Tabulated results for glass transition temperature for QuakeBond J300SR, per ASTM E1640

Specimen ID		***T_g****	
		°C	**°F**
QUA_J300_TG_CC_001		66.7	152.1
QUA_J300_TG_CC_002		64.8	148.6
QUA_J300_TG_CC_003		65.8	150.5
QUA_J300_TG_CC_004		72.2	162.0
QUA_J300_TG_CC_005		68.3	155.0
QUA_J300_TG_CC_006		69.2	156.6
QUA_J300_TG_CC_007		74.3	165.8
QUA_J300_TG_CC_008		68.8	155.8
QUA_J300_TG_CC_009		69.0	156.1
QUA_J300_TG_CC_010		71.6	160.8
QUA_J300_TG_CC_011		69.2	156.6
QUA_J300_TG_CC_012		71.7	161.0
QUA_J300_TG_CC_013		80.7	177.3
QUA_J300_TG_CC_014		69.8	157.7
QUA_J300_TG_CC_015		68.5	155.2
QUA_J300_TG_CC_016		66.4	151.5
QUA_J300_TG_CC_017		66.6	151.9
QUA_J300_TG_CC_018		73.1	163.5
QUA_J300_TG_CC_019		68.4	155.0
QUA_J300_TG_CC_020		71.2	160.2
	Average	**69.8**	**157.7**
	S_{n-1}	3.6	6.5
	CV%)	5.1	4.1

**Condition of acceptance is equivalent to T_g > 60°C (140°F)*

9. COMPOSITE INTERLAMINAR SHEAR STRENGTH (ISS) – ASTM D2344

9.1. TEST SUMMARY

9.1.1. AC125 Section/s

Section 5.8, Table 2 for Physical and Mechanical Properties of FRP Composite Materials.

9.1.2. Reference Standard/s

ASTM D2344/D2344M−13, Standard test method for short-beam strength of polymer matrix composite materials and their laminates.

9.1.3. Test Objective

Determine the short-beam interlaminar shear strength of the FRP systems under evaluation, without any aging or environmental exposure.

9.1.4. Product/s Under Evaluation

QuakeWrap™ VU20C with QuakeBond™ J300SR; QuakeWrap™ VU41C with QuakeBond™ J300SR; and QuakeWrap™ TB20C with QuakeBond™ J300SR (all in primary direction).

9.1.5. Test Location

Structures and Materials Laboratory, SML, Main Laboratory, University of Miami, 1251 Memorial Dr., MEB108 Coral Gables, FL, 33146

9.1.6. Laboratory Technician/s

Tais Hamilton and Ming Hang.

9.1.7. Technical Test Record

The date of each test; variations to the test method as applicable; calibration information for all measurements and test equipment; identification of the material tested; temperature and humidity of testing laboratory; and other applicable test data or details are provided in the Technical Test Record document number TDS-D2344-QUA.

9.2. TEST MATRIX

9.2.1. Specimen Number

A total of 20 tests per FRP system under evaluation are reported, refer to Table 9.1.

9.2.2. Specimen ID Nomenclature

Specimens are identified throughout the report using the format described in Section 4.5 of this document.

9.2.3. Test Matrix Table

Table 9.1– Test matrix for interlaminar shear specimens (no aging).

Specimen ID	Fiber Lot #	Resin Batch #	Specimen Preparation (mm.dd.yy)	Tested (mm.dd.yy)
QUA_U20C_ISS_CC_001 to 020	CONFIRM	A: Lot# 072617-17583 B: Lot# 7156-1	01.11.18	04.02.18
QUA_U41C_ISS_CC_001 to 020	10012430		01.31.18	04.09.18
QUA_B20C_ISS_CC_001 to 020	10010188		01.31.18	04.17.18

9.3. SPECIMEN PREPARATION

9.3.1. Specimen Size

Average rectangular prism specimen dimensions are summarized in the tabulated section of this chapter including width (w) and thickness (t), based on three measurements. Test specimens were composed of three plies (layers) applied in the same fiber direction.

9.3.2. Preparation Procedure

The specimens were cut to the prescribed dimensions using a high precision diamond blade saw from different panels randomly selected and prepared as referenced in Section 4.2.

9.3.3. Conditioning Parameters

All specimens were conditioned under laboratory ambient conditions at room temperature 23 ± 1°C (73 ± 3°F) and 60 ± 5% relative humidity, for at least 24 hrs prior testing.

9.4. TEST SET-UP

9.4.1. Set-up

The specimen was loaded in three-point bending, where the primary fiber direction was in the span orientation. Testing was performed using a screw driven Instron Universal Test Frame with a load cell in compliance with ASTM E4-10 (Standard Practice for Force Verification of Testing Machines). The test set-up is shown is Figure 9.1. Load and crosshead displacement were recorded throughout the test using Instron's Bluehill software and data acquisition system.

9.4.2. Rate and Method of Loading

Load was applied in displacement control at a constant frame head displacement of 1.27 mm/min (0.05 in./min) as per ASTM D2344 requirements.

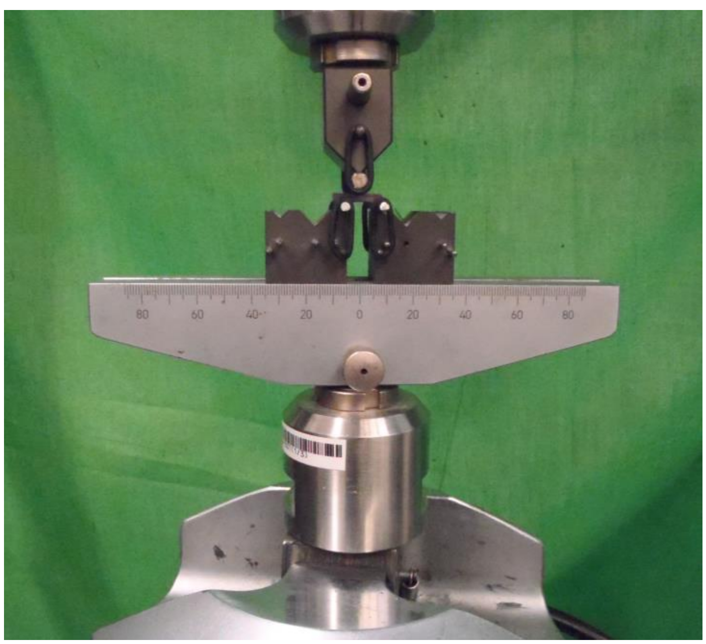


Figure 9.1 – Interlaminar shear test set-up

9.5. TEST RESULTS

9.5.1. Results Summary

Based on the experimental tests presented herein the average short-beam strength (F^{sbs}) of the materials under evaluation without any aging or exposure conditioning was found to be as summarized in Tale 9.2.

Table 9.2 – Average interlaminar shear strength results (ASTM D2344)

Specimen ID	***F^{sbs}***	
	MPa	***ksi***
QUA_U20C_ISS_CC	51.47	7.47
QUA_U41C_ISS_CC	25.71	3.73
QUA_B20C_ISS_CC	44.38	6.44

9.5.2. Modes of Failure

The primary mode of failure was by interlaminar shear of the test specimens, equivalent to failure ‘type 1’ per ASTM D2344 FIG. 7. Figure 10.2 shows a representative failure mode.

Figure 9.2 – Representative type 1 failure mode showing interlaminar shear between plies

9.5.3. Calculations

The results reported herein have been computed per ASTM D2344 and summarized in the next section, where the parameters are defined in Table 9.3.

Table 9.3 - Definitions of interlaminar shear strength calculations

Symbol	**Parameter**	**Description**
P_m	Maximum force	Peak load recorded during test.
b	Measured width	Average specimen width based on three measurements.
h	Measured thickness	Average specimen thickness based on three measurements.
F^{sbs}	Short-beam strength	Composite interlaminar shear strength

9.5.4. Tabulated Results

Table 9.4 contains the tabulated summary for the products under evaluation, including: average measured width (b) and thickness (h) of each specimen; maximum tensile force (P^{max}); ultimate strength (F^{sbs}) as per ASTM D2344. Average, standard deviation (s_{n-1}), and coefficient of variance (CV) values are also reported, based on the complete set of specimens under evaluation for each product.

Table 9.4 - Tabulated results for interlaminar shear strength for QuakeWrap™ VU20C with QuakeBond™ J300SR, per ASTM D2344

Specimen	***b***		***h***		***P$_m$***		***F^{sbs}***		***Failure***
ID	**mm**	***in.***	**mm**	***in.***	***kN***	***lbf***	***MPa***	***ksi***	***Mode***
QUA_U20C_ISS_CC_001	9.66	0.38	3.37	0.13	2.13	479.7	49.20	7.14	Interlaminar shear
QUA_U20C_ISS_CC_002	9.36	0.37	3.35	0.13	2.31	519.8	55.26	8.01	Interlaminar shear
QUA_U20C_ISS_CC_003	9.56	0.38	3.43	0.14	2.26	506.7	51.56	7.48	Interlaminar shear
QUA_U20C_ISS_CC_004	9.41	0.37	3.37	0.13	2.29	514.0	54.14	7.85	Interlaminar shear
QUA_U20C_ISS_CC_005	9.51	0.37	3.42	0.13	2.19	493.2	50.63	7.34	Interlaminar shear
QUA_U20C_ISS_CC_006	9.49	0.37	3.44	0.14	2.32	522.4	53.38	7.74	Interlaminar shear
QUA_U20C_ISS_CC_007	9.41	0.37	3.20	0.13	2.24	504.5	55.88	8.10	Interlaminar shear
QUA_U20C_ISS_CC_008	9.37	0.37	3.26	0.13	1.99	447.2	48.77	7.07	Interlaminar shear
QUA_U20C_ISS_CC_009	9.28	0.37	3.37	0.13	1.86	417.9	44.62	6.47	Interlaminar shear
QUA_U20C_ISS_CC_010	9.79	0.39	3.35	0.13	2.17	488.2	49.61	7.19	Interlaminar shear
QUA_U20C_ISS_CC_011	9.61	0.38	3.37	0.13	2.25	504.9	52.06	7.55	Interlaminar shear
QUA_U20C_ISS_CC_012	9.78	0.39	3.30	0.13	2.19	492.2	50.85	7.38	Interlaminar shear
QUA_U20C_ISS_CC_013	9.70	0.38	3.31	0.13	2.16	485.4	50.35	7.30	Interlaminar shear
QUA_U20C_ISS_CC_014	9.78	0.39	3.35	0.13	2.18	490.0	49.86	7.23	Interlaminar shear
QUA_U20C_ISS_CC_015	9.72	0.38	3.37	0.13	2.30	516.2	52.67	7.64	Interlaminar shear
QUA_U20C_ISS_CC_016	9.66	0.38	3.35	0.13	2.33	524.2	53.97	7.83	Interlaminar shear
QUA_U20C_ISS_CC_017	9.69	0.38	3.38	0.13	2.14	480.0	48.92	7.10	Interlaminar shear
QUA_U20C_ISS_CC_018	9.42	0.37	3.15	0.12	2.05	460.6	51.77	7.51	Interlaminar shear
QUA_U20C_ISS_CC_019	8.80	0.35	3.40	0.13	2.00	450.1	50.13	7.27	Interlaminar shear
QUA_U20C_ISS_CC_020	9.25	0.36	3.37	0.13	2.31	520.2	55.77	8.09	Interlaminar shear
Average	**9.51**	**0.37**	**3.35**	**0.13**	**2.18**	**490.9**	**51.47**	**7.47**	
S_{n-1}	0.24	0.01	0.07	0.00	0.13	28.8	2.78	0.40	
CV (%)	2.5	2.5	2.1	2.1	5.9	5.9	5.4	5.4	

Cont.Table 9.4 - Tabulated results for interlaminar shear strength for QuakeWrap™ VU41C with QuakeBond™ J300SR, per ASTM D2344

Specimen ID	*b*		*h*		P_m		F^{sbs}		*Failure*
	mm	***in.***	**mm**	***in.***	***kN***	***lbf***	***MPa***	***ksi***	***Mode***
QUA_U41C_ISS_CC_001	11.57	0.46	5.73	0.23	2.28	513.0	25.83	3.75	Interlaminar shear
QUA_U41C_ISS_CC_002	12.07	0.48	5.58	0.22	2.46	553.0	27.43	3.98	Interlaminar shear
QUA_U41C_ISS_CC_003	11.33	0.45	5.93	0.23	2.24	503.0	24.98	3.62	Interlaminar shear
QUA_U41C_ISS_CC_004	14.99	0.59	5.68	0.22	2.67	600.0	23.53	3.41	Interlaminar shear
QUA_U41C_ISS_CC_005	11.44	0.45	6.01	0.24	2.43	545.0	26.45	3.84	Interlaminar shear
QUA_U41C_ISS_CC_006	15.96	0.63	5.38	0.21	2.87	645.0	25.03	3.63	Interlaminar shear
QUA_U41C_ISS_CC_007	12.81	0.50	5.65	0.22	2.67	601.0	27.69	4.02	Interlaminar shear
QUA_U41C_ISS_CC_008	11.91	0.47	6.18	0.24	2.69	605.0	27.39	3.97	Interlaminar shear
QUA_U41C_ISS_CC_009	12.26	0.48	6.03	0.24	2.36	531.0	23.96	3.48	Interlaminar shear
QUA_U41C_ISS_CC_010	13.35	0.53	5.89	0.23	2.71	610.0	25.87	3.75	Interlaminar shear
QUA_U41C_ISS_CC_011	11.54	0.45	6.08	0.24	2.61	587.0	27.89	4.04	Interlaminar shear
QUA_U41C_ISS_CC_012	15.94	0.63	5.22	0.21	2.69	604.0	24.22	3.51	Interlaminar shear
QUA_U41C_ISS_CC_013	12.52	0.49	5.46	0.22	2.48	558.0	27.22	3.95	Interlaminar shear
QUA_U41C_ISS_CC_014	12.43	0.49	5.38	0.21	2.40	539.0	26.86	3.90	Interlaminar shear
QUA_U41C_ISS_CC_015	15.38	0.61	5.85	0.23	2.78	625.0	23.16	3.36	Interlaminar shear
QUA_U41C_ISS_CC_016	15.54	0.61	5.93	0.23	2.96	666.0	24.10	3.50	Interlaminar shear
QUA_U41C_ISS_CC_017	11.98	0.47	5.50	0.22	2.29	514.0	26.04	3.78	Interlaminar shear
QUA_U41C_ISS_CC_018	8.61	0.34	5.46	0.22	1.67	376.0	26.68	3.87	Interlaminar shear
QUA_U41C_ISS_CC_019	13.41	0.53	6.18	0.24	2.63	591.0	23.77	3.45	Interlaminar shear
QUA_U41C_ISS_CC_020	12.99	0.51	5.89	0.23	2.66	598.0	26.06	3.78	Interlaminar shear
Average	**12.90**	**0.51**	**5.75**	**0.23**	**2.53**	**568.2**	**25.71**	**3.73**	
S_{n-1}	1.87	0.07	0.29	0.01	0.28	63.7	1.52	0.22	
CV (%)	14.5	14.5	5.0	5.0	11.2	11.2	5.9	5.9	

Cont.Table 9.4 - Tabulated results for interlaminar shear strength for QuakeWrap™ TB20C with QuakeBond™ J300SR, per ASTM D2344

Specimen ID	***b***		***h***		***P_m***		***F^{sbs}***		***Failure***
	mm	***in.***	**mm**	***in.***	***kN***	***lbf***	***MPa***	***ksi***	***Mode***
QUA_B20C_ISS_CC_001	7.81	0.31	2.83	0.11	1.32	295.7	44.60	6.47	Interlaminar shear
QUA_B20C_ISS_CC_002	7.40	0.29	2.90	0.11	1.34	302.0	46.99	6.82	Interlaminar shear
QUA_B20C_ISS_CC_003	7.90	0.31	2.97	0.12	1.47	329.3	46.80	6.79	Interlaminar shear
QUA_B20C_ISS_CC_004	7.16	0.28	2.86	0.11	1.26	284.1	46.31	6.72	Interlaminar shear
QUA_B20C_ISS_CC_005	7.16	0.28	3.44	0.14	1.35	303.2	41.03	5.95	Interlaminar shear
QUA_B20C_ISS_CC_006	7.54	0.30	3.06	0.12	1.47	330.7	47.78	6.93	Interlaminar shear
QUA_B20C_ISS_CC_007	5.97	0.24	3.52	0.14	1.32	295.9	47.01	6.82	Interlaminar shear
QUA_B20C_ISS_CC_008	8.80	0.35	2.92	0.12	1.59	358.3	46.50	6.74	Interlaminar shear
QUA_B20C_ISS_CC_009	7.23	0.28	2.95	0.12	1.29	290.6	45.50	6.60	Interlaminar shear
QUA_B20C_ISS_CC_010	7.02	0.28	3.02	0.12	1.29	290.8	45.70	6.63	Interlaminar shear
QUA_B20C_ISS_CC_011	8.57	0.34	2.95	0.12	1.34	300.8	39.73	5.76	Interlaminar shear
QUA_B20C_ISS_CC_012	7.23	0.28	2.88	0.11	1.26	282.2	45.19	6.55	Interlaminar shear
QUA_B20C_ISS_CC_013	7.07	0.28	2.90	0.11	1.21	271.6	44.24	6.42	Interlaminar shear
QUA_B20C_ISS_CC_014	7.63	0.30	2.92	0.12	1.37	307.6	46.03	6.68	Interlaminar shear
QUA_B20C_ISS_CC_015	8.48	0.33	2.91	0.11	1.38	309.1	41.80	6.06	Interlaminar shear
QUA_B20C_ISS_CC_016	6.26	0.25	2.87	0.11	1.02	229.7	42.64	6.18	Interlaminar shear
QUA_B20C_ISS_CC_017	8.33	0.33	3.04	0.12	1.50	336.2	44.35	6.43	Interlaminar shear
QUA_B20C_ISS_CC_018	8.15	0.32	2.88	0.11	1.34	300.6	42.66	6.19	Interlaminar shear
QUA_B20C_ISS_CC_019	7.30	0.29	2.81	0.11	1.22	273.1	44.45	6.45	Interlaminar shear
QUA_B20C_ISS_CC_020	7.91	0.31	3.21	0.13	1.30	292.0	38.32	5.56	Interlaminar shear
Average	**7.55**	**0.30**	**2.99**	**0.12**	**1.33**	**299.2**	**44.38**	**6.44**	
S_{n-1}	0.73	0.03	0.19	0.01	0.12	27.1	2.60	0.38	
CV (%)	9.6	9.6	6.4	6.4	9.1	9.1	5.8	5.8	

10. BOND STRENGTH: TENSION (BTC) – ASTM D7234

10.1. TEST SUMMARY

10.1.1. AC125 Section/s

Section 5.17, for bond strength.

10.1.2. Reference Standard/s

ASTM D7234 – 12, Standard Test Method for Pull-Off Adhesion Strength of Coatings on Concrete Using Portable Pull-Off Adhesion Testers.

10.1.3. Test Objective

Determine the tensile bond strength on concrete substrate of the FRP systems under evaluation without any aging or exposure conditioning.

10.1.4. Product/s Under Evaluation

QuakeWrap™ VU20C with QuakeBond™ J300SR; QuakeWrap™ VU41C with QuakeBond™ J300SR; and QuakeWrap™ TB20C with QuakeBond™ J300SR.

10.1.5. Test Location

Structures and Materials Laboratory, SML, Main Laboratory, University of Miami, 1251 Memorial Dr., MEB108 Coral Gables, FL, 33146

10.1.6. Laboratory Technician/s

Ming Han and Christian Marquina

10.1.7. Technical Test Record

The date of each test; variations to the test method as applicable; calibration information for all measurements and test equipment; identification of the material tested; temperature and humidity of testing laboratory; and other applicable test data or details are provided in the Technical Test Record document number TDS-D7234-QUA.

10.2. TEST MATRIX

10.2.1. Specimen Number

A total of five tests per FRP system under evaluation are reported, refer to Table 10.1.

10.2.2. Specimen ID Nomenclature

Specimens are identified throughout the report using the format described in Section 4.5 of this document.

10.2.3. Test Matrix Table

Table 10.1– Test matrix for tensile bond strength tests (no aging)

Specimen ID	Fiber Lot #	Resin Batch #	Specimen Preparation (mm.dd.yy)	Tested (mm.dd.yy)
QUA_U20C_BTC_CC_001 to 005	CONFIMR	A: Lot# 072617-17583 B: Lot# 7156-1	10.10.17	12.14.17
QUA_U41C_BTC_CC_001 to 005	100112430		10.10.17	12.14.17
QUA_B20C_BTC_CC_001 to 005	10010188		02.05.18	04.13.18

10.3. SPECIMEN PREPARATION

10.3.1. Specimen Size

The FRP systems were applied on solid plain concrete blocks with nominal dimensions of 355 mm (14.0 in.) length, 100 mm (4.0 in.) width, and 100 mm (4.0 in.) thickness. The concrete surface was strengthened with one ply of each FRP system under evaluation.

10.3.2. Specimen Layout

The specimen layout is presented in Figure 10.1. The concrete substrate 28 day compressive strength as determined by ASTM C39/C39M-14 (Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens), was equivalent to 57.86 MPa (8392 psi) based on three compressive cylinder tests as reported in Table 10.2. All concrete specimens were cast simultaneously in one single batch on January 19, 2016 following ASTM C192/C192M-13a, Practice for Making and Curing Concrete Test Specimens in the Laboratory.

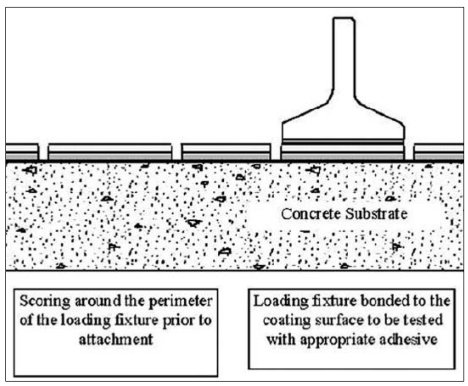


Figure 10.1 - Tensile bond specimen layout, per ASTM D7234

Table 10.2 – Concrete compressive strength results (ASTM C39) for substrate used in testing

Specimen	Diameter		Area		P_{max}		f'_c		Failure
ID	mm	in	mm²	in²	kN	lbf	MPa	psi	Mode
C1	102.11	4.02	8188.6	12.69	463.9	104280	56.65	8216	Type 4
C2	102.10	4.02	8187.3	12.69	474.0	106560	57.90	8397	Type 4
C3	101.96	4.01	8165.5	12.66	482.1	108370	59.04	8562	Type 2
Average	102.06	4.02	8180.5	12.68	473.3	106403	57.86	8392	
S_{n-1}	0.08	0.00	12.9	0.02	9.1	2049	1.19	173	
CV (%)	0.1	0.1	0.2	0.2	1.9	1.9	2.1	2.1	

10.3.3. Preparation Procedure

The FRP layer was applied to the concrete surface as referenced in Section 4.2. After the curing process a circular cut perpendicular to the surface using a diamond coring drill to score the surface of the FRP layer as indicated in ASTM D7234 FIG 2, going into the substrate 13 mm (0.5 in.). The test specimen was left intact, attached to the substrate. Any standing water was removed; the surface was cleaned from any debris from the drilling operation and was allowed to dry. A steel disk was then attached to the top FRP surface using high strength adhesive epoxy. The disk was centered with the test specimen and the axis of the disk was placed parallel to the axis of the test specimen. The epoxy adhesive was cured following the manufacturer's instructions prior testing.

10.3.4. Conditioning Parameters

All specimens were conditioned under laboratory ambient conditions at room temperature 23 ± 1°C (73 ± 3°F) and 60 ± 5% relative humidity, for at least 24 hrs prior testing.

10.4. TEST SET-UP

10.4.1. Set-up

The tensile load device was connected to the steel disk using a coupling device. The tensile load was then applied to the test specimen so that the force was parallel to, and coincident with, the axis of the specimen. The load was measured with load cell in compliance with ASTM E4-10 (Standard Practice for Force Verification of Testing Machines). The test set-up is shown is Figure 10.2.

Figure 10.2 – Tension bond strength test set-up

10.4.2. Rate and Method of Loading

The tensile load was applied manually at a constant rate so that the tensile stress increased at a rate of 35 ± 15 kPa/s (5 ± 2 psi/s).

10.5. TEST RESULTS

10.5.1. Results Summary

Based on the experimental tests presented herein the average tensile strength was found to be above the minimum AC125 requirement of 1378 kPa (200 psi) as summarized in Table 10.3.

Table 10.3 – Average tensile strength for tension bond specimens

Specimen ID	**Average Bond Tensile Strength**	
	MPa	***psi***
QUA_U20C_BTC_CC	3.16	458
QUA_U41C_BTC_CC	2.73	396
QUA_B20C_BTC_CC	3.45	501

10.5.2. Modes of Failure

The mode of failure was in the cohesive located in the concrete substrate equivalent to Type A per ASTM D7234 FIG. 1. Figure 10.3 shows a typical failure of the specimen.

Figure 10.3 - Typical failure of performed tension bond strength test.

10.5.3. Calculations

The results reported herein have been computed as per ASTM D7234. Definitions of the parameters used for calculation is provided in Table 10.4.

Table 10.4 - Definitions of calculations

Symbol	**Parameter**	**Description**
A	Area of test specimen	Area of circular cut
T_l	Tensile load	Tensile load applied with the load device
T_S	Tensile Strength	Tensile strength when the failure occurs in the substrate

10.5.4. Tabulated Results

Table 10.5 contains the tabulated summary for the products under evaluation, including: area of the test specimen (A), tensile load (T_l), tensile strength (T_S), and failure mode as per ASTM D7234. Average, standard deviation (S_{n-1}), and coefficient of variance (CV) values are also reported, based on the complete set of specimens under evaluation for each product.

Table 10.5 - Tabulated results for tensile bond tests for QuakeWrap™ VU20C, VU41C and TB20C with QuakeBond™ J300SR, per ASTM D7234

Specimen ID	Area, A		Tensile Force, T_l		Bond Strength, T_S*		Failure Mode
	mm²	in²	N	lbf	MPa	psi	
QUA-U20C-BTC-CC-001	2026	3.14	6723	1511	3.32	481	A
QUA-U20C-BTC-CC-002	2026	3.14	5955	1338	2.94	426	A
QUA-U20C-BTC-CC-003	2026	3.14	6937	1559	3.42	496	A
QUA-U20C-BTC-CC-004	2026	3.14	6027	1354	2.97	431	A
QUA-U20C-BTC-CC-005	2026	3.14	6336	1424	3.13	453	A
Average			**6396**	**1437**	**3.16**	**458**	
S_{n-1}			429	96	0.21	31	
CV (%)			6.7	6.7	6.7	6.7	
QUA-U41C-BTC-CC-001	2026	3.14	6038	1357	2.98	432	A
QUA-U41C-BTC-CC-002	2026	3.14	5937	1334	2.93	425	A
QUA-U41C-BTC-CC-003	2026	3.14	4976	1118	2.46	356	A
QUA-U41C-BTC-CC-004	2026	3.14	5513	1239	2.72	395	A
QUA-U41C-BTC-CC-005	2026	3.14	5181	1164	2.56	371	A
Average			**5529**	**1242**	**2.73**	**396**	
S_{n-1}			462	104	0.23	33	
CV (%)			8.4	8.4	8.4	8.4	
QUA-B20C-BTC-CC-001	2026	3.14	6678	1501	3.30	478	A
QUA-B20C-BTC-CC-002	2026	3.14	7293	1639	3.60	522	A
QUA-B20C-BTC-CC-003	2026	3.14	8170	1836	4.03	585	A
QUA-B20C-BTC-CC-004	2026	3.14	7023	1578	3.47	503	A
QUA-B20C-BTC-CC-005	2026	3.14	5833	1311	2.88	417	A
Average			**6999**	**1573**	**3.45**	**501**	
S_{n-1}			855	192	0.42	61	
CV (%)			12.2	12.2	12.2	12.2	

**Condition of acceptance is equivalent to* $\tau_s > 200$*psi*

11. BOND STRENGTH: SHEAR (BSC) – LAB METHOD

11.1. TEST SUMMARY

11.1.1. AC125 Section/s

Section 5.17, for bond strength.

11.1.2. Reference Standard/s

An internal laboratory developed standard test procedure was used for the shear bond strength test derived from a test method currently under evaluation by ACI and an ASTM (Standard Test Method for Evaluation of Performance for FRP Bonded to Concrete Substrate using Beam Test).

11.1.3. Test Objective

Determine the shear bond strength on concrete substrate of the FRP systems under evaluation without any aging or exposure conditioning.

11.1.4. Product/s Under Evaluation

QuakeWrap™ VU20C with QuakeBond™ J300SR; QuakeWrap™ VU41C with QuakeBond™ J300SR; and QuakeWrap™ TB20C with QuakeBond™ J300SR.

11.1.5. Test Location

Structures and Materials Laboratory, SML, Main Laboratory, University of Miami, 1251 Memorial Dr., MEB108 Coral Gables, FL, 33146

11.1.6. Laboratory Technician/s

Ming Han and Christian Marquina

11.1.7. Technical Test Record

The date of each test; variations to the test method as applicable; calibration information for all measurements and test equipment; identification of the material tested; temperature and humidity of testing laboratory; and other applicable test data or details are provided in the Technical Test Record document number TDS-BSC-QUA.

11.2. TEST MATRIX

11.2.1. Specimen Number

A total of five tests per FRP system under evaluation are reported, refer to Table 11.1.

11.2.2. Specimen ID Nomenclature

Specimens are identified through the report using the format described in Section 4.5 of this document.

11.2.3. Test Matrix Table

Table 11.1– Test matrix for shear bond tests (no aging)

Specimen ID	Fiber Lot #	Resin Batch #	Specimen Preparation (mm.dd.yy)	Tested (mm.dd.yy)
QUA_U20C_BSC_CC_001 to 005	CONFIRM	A: Lot# 072617-17583 B: Lot# 7156-1	10.10.17	12.07.17
QUA_U41C_BSC_CC_001 to 005	10012430		10.10.17	12.07.17
QUA_B20C_BSC_CC_001 to 005	10010188		02.05.18	04.09.18

11.3. SPECIMEN PREPARATION

11.3.1. Specimen Size

The FRP systems were applied on concrete bond-shear beam of nominal dimension equivalent to 350 mm (14.0 in.) length, with a square cross-section of 100 mm (4.0 in.). The concrete beams were notched with a slot at the center using a high precision diamond blade saw. The notch depth was equal to half the height of the block or 50 mm (2.0 in).

11.3.2. Specimen Layout

Shear bond specimen layout is presented in Figure 11.1 the span of the beam was equivalent to 304.8 mm (12.0 in.). All concrete specimens were cast simultaneously in one single batch on January 19, 2016, where the 28 day compressive strength of the concrete was equivalent to 57.86 MPa (8392 psi), as detailed in Table 10.2.

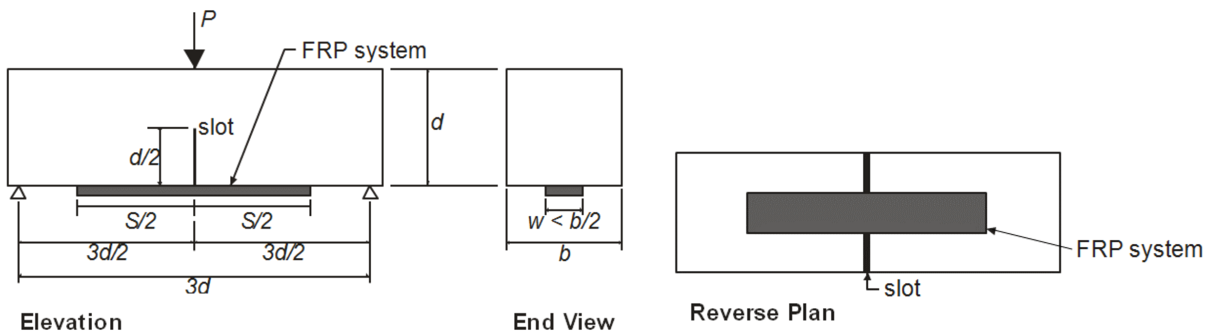


Figure 11.1 - Shear bond specimen layout

11.3.3. Preparation Procedure

One ply of each FRP system was installed on the concrete beams with an overall nominal dimension of 216 mm (9.0 in.) length (including the notchy and deboned) segment by 25 mm (1.0 in.) wide placed at the center of the flexural (lower side) of the concrete beam, bridging the notch. The FRP ply was saturate and installed on the concrete surface as described in Section 4.2. The nominal thickness used in computing the shear bond strength was equal to the tensile tests as reported in Table 5.2.

11.3.4. Conditioning Parameters

All specimens were conditioned under laboratory ambient conditions at room temperature 23 ± 1°C (73 ± 3°F) and 60 ± 5% relative humidity, for at least 24 hrs. prior testing.

11.4. TEST SET-UP

11.4.1. Set-up

The specimen was loaded in three point bending as per the lab method. Testing was performed using a screw driven Instron Universal Test Frame, where the load was measured with the internal load cell of the frame in compliance with ASTM E4. The test set-up is shown in Figure 11.2. Load and crosshead displacement were recorded throughout the test using Instron's Bluehill software and data acquisition system.

Figure 11.2 – Shear bond test set-up

11.4.2. Rate and Method of Loading

Load was applied in displacement control at a constant frame head displacement of 0.5 mm/min (0.02 in./min).

11.5. TEST RESULTS

11.5.1. Results Summary

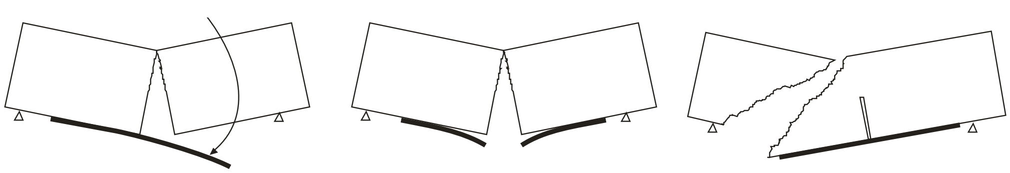
Based on the experimental tests presented herein the average shear bond strength was found to be above the minimum AC125 requirement of 1378 kPa (200 psi) as summarized in Table 11.2.

Table 11.2 – Average tensile strength for shear bond specimens

Specimen ID	**Average shear bond strength**	
	MPa	***psi***
QUA_U20C_BSC_CC	3.85	558
QUA_U41C_BSC_CC	3.68	533
QUA_B20C_BSC_CC	2.65	385

11.5.2. Modes of Failure

Figure 12.3 shows possible failure modes of a shear bond test. The primary mode is also provided in Figure 12.3, representing the FRP debonding (delamination) from the substrate (failure type a).



(a) FRP debonding (b) FRP rupture (c) concrete shear

(a)

(b)

Figure 11.3 – (a) Possible failure mode types for shear bond test; and (b) representative shear bond failure mode (side and plan views)

11.5.3. Calculations

The results reported herein have been computed as per shear bond lab method. Definitions of the parameters and equations used to compute the shear bond strength are provided in Table 11.3 and Table 11.4, respectively. Note this methodology is currently being considered for an ASTM.

Table 11.3 - Definitions of parameters for shear bond strength

Symbol	**Parameter**	**Description**
w	bonded width of FRP	shear bonded width of FRP
S	bonded length of FRP	shear bonded length of FRP
P	maximum applied force	maximum applied force indicated by testing machine
τ_d	bond strength of FRP	bond strength of FRP composite material to concrete
F_d	force in FRP	force in FRP required to detach FRP from concrete substrate,
K*	FRP tensile stiffness	FRP tensile stiffness per unit width
E_c	modulus of elasticity	modulus of elasticity of concrete
b	Width	width of concrete test beam
d	Depth	overall depth of concrete test beam

Table 11.4 - Equations used to compute the shear bond strength of FRP

Equations		Description
$F_d = \left(\frac{P}{2}\right)\left(\frac{1.5}{1-\alpha/3}\right)$	(1)	Force in FRP for pull-out
$\alpha = -\beta + \sqrt{\beta^2 + 2\beta} \leq 0.5$	(2)	Ratio of neutral axis depth
$\beta = \frac{K^* w}{E_c bd}$	(3)	Ratio of axial stiffness
$T_d = \frac{F_d}{(w \times S)/2}$	(4)	Shear bond strength of FRP

11.5.4. Tabulated Results

Table 11.5 contains the tabulated summary results for the products under evaluation, including: bonded width of FRP (w); bonded length (S); maximum applied force (P); bonded strength of FRP (T_d), and failure mode as per Shear Bond Lab Method. Average, standard deviation (S_{n-1}), and coefficient of variance (CV) values are also reported, based on the complete set of specimens under evaluation for each product.

Table 11.5 - Tabulated results for shear bond test for per U20C, U41C and B20C Lab Method

Specimen ID	w		S		P		τ_d		Failure Mode	Pass/Fail*
	mm	*in*	*mm*	*in*	*kN*	*lbf*	*MPa*	*psi*		
QUA_U20C_BSC_CC_001	25.40	1.00	219.08	8.63	11.43	2569	3.20	465	A	Pass
QUA_U20C_BSC_CC_002	25.40	1.00	219.08	8.63	16.00	3594	4.48	650	A	Pass
QUA_U20C_BSC_CC_003	25.40	1.00	219.08	8.63	12.15	2731	3.41	494	A	Pass
QUA_U20C_BSC_CC_004	25.40	1.00	219.08	8.63	14.77	3320	4.14	601	A	Pass
QUA_U20C_BSC_CC_005	25.40	1.00	219.08	8.63	14.06	3159	3.94	572	A	Pass
Average					**13.68**	**3074**	**3.83**	**556**		
S_{n-1}					1.88	422	0.53	76		
CV (%)					13.7	13.7	13.7	13.7		
QUA_U41C_BSC_CC_001	28.96	1.14	219.20	8.63	15.97	3589	3.99	578	A	Pass
QUA_U41C_BSC_CC_002	32.51	1.28	219.08	8.63	13.65	3068	3.05	442	A	Pass
QUA_U41C_BSC_CC_003	27.69	1.09	219.08	8.63	13.29	2986	3.47	503	A	Pass
QUA_U41C_BSC_CC_004	33.27	1.31	219.08	8.63	19.09	4290	4.17	604	A	Pass
QUA_U41C_BSC_CC_005	33.02	1.30	219.08	8.63	16.91	3801	3.72	539	A	Pass
Average					**15.78**	**3547**	**3.68**	**533**		
S_{n-1}					2.40	539	0.44	64		
CV (%)					15.2	15.2	12.0	12.0		
QUA_B20C_BSC_CC_001	25.40	1.00	219.08	8.63	10.56	2374	2.91	422	A	Pass
QUA_B20C_BSC_CC_002	25.40	1.00	219.08	8.63	10.20	2293	2.81	408	A	Pass
QUA_B20C_BSC_CC_003	25.40	1.00	219.08	8.63	12.18	2738	3.36	487	A	Pass
QUA_B20C_BSC_CC_004	25.40	1.00	219.08	8.63	8.92	2005	2.46	357	A	Pass
QUA_B20C_BSC_CC_005	25.40	1.00	219.08	8.63	9.78	2199	2.70	391	A	Pass
Average					**10.33**	**2322**	**2.85**	**413**		
S_{n-1}					1.20	270	0.33	48		
CV (%)					11.6	11.6	11.6	11.6		

**Condition of acceptance is equivalent to τ_d > 200psi*

12. FREEZING AND THAWING

12.1. TEST SUMMARY

12.1.1. AC125 Section/s

Section 5.10, Table 2 for physical and mechanical properties of FRP composite materials.

12.1.2. Reference Standard/s

ASTM D3039/D3039M-17, Standard test method for Tensile Properties of Polymer Matrix Composite Materials.

ASTM D2344/D2344M-13, Standard test method for short-beam strength of polymer matrix composite materials and their laminates.

ASTM E1640-13, Standard test method for assignment of the glass transition temperature by dynamic mechanical analysis.

Shear Bond Lab method

12.1.3. Test Objective

Determine the average experimental percentage retention of tensile strength, tensile modulus, elongation, glass transition temperature, and interlaminar shear strength after exposure to freeze thaw cycles as per AC125 Section 5.10.

12.1.4. Product/s Under Evaluation

QuakeWrap™ TB20C with QuakeBond™ J300SR (in the primary direction) and QuakeBond™ J300SR.

12.1.5. Test Location

Structures and Materials Laboratory, SML, Main Laboratory, University of Miami, 1251 Memorial Dr., MEB108 Coral Gables, FL, 33146

12.1.6. Laboratory Technician/s

Ming Han and Christian Marquina.

12.1.7. Technical Test Record

The date of each test; variations to the test method as applicable; calibration information for all measurements and test equipment; identification of the material tested; temperature and humidity of testing laboratory; and other applicable test data or details are provided in the Technical Test Record document number TDS-QUA-TNS-FT, TDS-QUA-ISS-FT, TDS-QUA-TG-FT and TDS-QUA-BSC-FT.

12.2. TEST MATRIX

12.2.1. Specimen Number

Five test repetitions for each test type (ASTM D3039, ASTM D2344, ASTM E1640 and Shear bond strength lab method) and FRP system under evaluation were performed and reported, refer to Table 12.1.

12.2.2. Specimen ID Nomenclature

Specimens are identified throughout the report using the format described in Section 4.5 of this document.

12.2.3. Test Matrix Table

Table 12.1 – Test matrix for tests post freezing and thawing conditioning

Specimen ID	Fiber Lot #	Resin Batch #	Specimen Preparation (mm.dd.yy)	Tested (mm.dd.yy)
QUA_B20C_TNS_FT_001 to 005	10010188	Provided A: Lot# 072617-17583 B: Lot# 7156-1	01.31.18	04.06.18
QUA_B20C_ISS_FT_001 to 005			01.31.18	04.04.18
QUA_J300SR_TG_FT_001 to 005			01.11.18	04.10.18

12.3. SPECIMEN PREPARATION

12.3.1. Specimen Size and Preparation Procedure

Nominal specimen geometry and preparation procedure varied for each test type, as previously referenced in Chapter 5 for tensile tests; Chapter 10 for interlaminar shear strength; Chapter 9 for glass transition temperature; and Chapter 12 for shear bond strength. Individual specimen geometry parameters are reported the results section of this Chapter.

12.3.2. Conditioning Parameters

All specimens were exposed to 20 cycles, where each cycle consisted of a minimum of 4 hours in a freeze-thaw chamber at -18°C (0°F) followed by a minimum of 12 hours in a humidity chamber at 38°C (100°F) with 100% relative humidity. Prior to the 20 cycles the samples were conditioned in 100% relative humidity chamber at 38°C (100°F) for a period of three weeks (504 hrs.).

12.4. TEST SET-UP

12.4.1. Set-up

Upon completion of conditioning, specimens were removed from conditioning chamber, wiped to dry the surface, and visually inspected prior testing. Refer to applicable test set-ups in Chapter 5 for tensile tests; Chapter 10 for interlaminar shear strength; Chapter 9 for glass transition temperature; and Chapter 12 for shear bond strength.

12.4.2. Rate and Method of Loading

Refer to applicable rates and method of loading in Chapter 5 for tensile tests; Chapter 10 for interlaminar shear strength; Chapter 9 for glass transition temperature; and Chapter 12 for shear bond strength.

12.5. TEST RESULTS

12.5.1. Results Summary

No specimens showed surface changes (such as erosion, cracking, crazing and chalking) after a visual inspection with a high resolution USB microscope with a varying magnification from x20 to x50, meeting the conditions of acceptance of AC125, as well as 90 percent retention of the tensile properties, and of 1.38 MPa (200 psi) for shear bond strength. Detailed test results are reported in the tabulated results of this Chapter.

12.5.2. Modes of Failure

Modes of failure for the different physical and mechanical tests after freezing and thawing cycles conditioning are reported in the tabulated results of this Chapter.

12.5.3. Calculations

Refer to applicable calculations and analysis of data in Chapter 5 for tensile tests; Chapter 10 for interlaminar shear strength; Chapter 9 for glass transition temperature; and Chapter 12for shear bond strength.

12.5.4. Tabulated Results

Table 12.2 through Table 12.5 contain the tabulated summary results after freezing and thawing cycles conditioning for the tensile, interlaminar shear strength, glass transition temperature and shear bond strength tests, respectively. Average, standard deviation (S_{n-1}), and coefficient of variance (CV) values are also reported, based on the complete set of specimens under evaluation for each product.

T *CV%)*able 12.2 - Tabulated results for tensile tests for B20C (ASTM D3039) post freezing and thawing conditioning (AC125, Section 5.10.1)

Specimen ID	A		P^{max}		F^{tu}		E^{chord}		ε_u	FM	% Retention*		
	mm²	in²	kN	lbs	MPa	ksi	GPa	Msi	%		F^{tu}	E^{chord}	ε_u
QUA_B20C_TNS_FT_001	9.95	0.015	11.11	2496	1115.5	161.8	61.3	8.90	1.82	LGB	98	95	96
QUA_B20C_TNS_FT_002	10.76	0.017	11.95	2686	1110.8	161.1	56.9	8.26	1.95	AGT	105	95	90
QUA_B20C_TNS_FT_003	11.26	0.017	12.44	2796	1104.2	160.1	58.8	8.53	1.88	AGB	101	94	92
QUA_B20C_TNS_FT_004	11.61	0.018	12.90	2898	1110.7	161.1	61.9	8.98	1.79	LGT	97	95	97
QUA_B20C_TNS_FT_005	10.99	0.017	12.26	2756	1115.7	161.8	58.0	8.42	1.92	AGT	104	95	91
Average	**10.91**	**0.017**	**12.13**	**2726**	**1111.4**	**161.2**	**59.4**	**8.62**	**1.87**		**101**	**95**	**93**
S_{n-1}	0.62	0.001	0.67	150	4.7	0.7	2.1	0.31	0.07				
CV (%)	5.7	5.7	5.5	5.5	0.4	0.4	3.6	3.6	3.6				

**Condition of acceptance is equivalent to 90% retention.*

Table 12.3 - Tabulated results for interlaminar shear tests for B20C (ASTM D2344) post freezing and thawing conditioning (AC125, Section 5.10.1)

Specimen ID	*b*		*h*		P_m		F^{sbs}		Failure Mode	% Retention*
	mm	*in*	*mm*	*in*	*kN*	*lbf*	*MPa*	*ksi*		F^{sbs}
QUA_B20C_ISS_FT_001	7.28	0.29	2.57	0.10	1.01	228.0	40.74	5.91	Interlaminar Shear	92
QUA_B20C_ISS_FT_002	6.79	0.27	2.48	0.10	0.92	207.0	41.04	5.95	Interlaminar Shear	92
QUA_B20C_ISS_FT_003	7.11	0.28	2.58	0.10	0.95	214.0	38.94	5.65	Interlaminar Shear	88
QUA_B20C_ISS_FT_004	6.77	0.27	2.45	0.10	1.05	236.0	47.45	6.88	Interlaminar Shear	107
QUA_B20C_ISS_FT_005	6.01	0.24	2.59	0.10	0.89	201.0	43.09	6.25	Interlaminar Shear	97
Average	**6.79**	**0.27**	**2.53**	**0.10**	**0.97**	**217.2**	**42.25**	**6.13**		**95**
S_{n-1}	0.49	0.02	0.06	0.00	0.06	14.5	3.26	0.47		
CV (%)	7.2	7.2	2.5	2.5	6.7	6.7	7.7	7.7		

**Condition of acceptance is equivalent to 90% retention.*

Table 12.4 - Tabulated results for glass transition temperature for J300 (ASTM E1640) post freezing and thawing conditioning (AC125, Section 5.10.1)

Specimen ID	T_g		Acceptance
	°C	**°F**	**Criteria***
QUA_J300_TG_FT_001	78.3	173.0	Pass
QUA_J300_TG_FT_002	71.1	160.0	Pass
QUA_J300_TG_FT_003	73.4	164.1	Pass
QUA_J300_TG_FT_004	76.0	168.9	Pass
QUA_J300_TG_FT_005	75.7	168.2	Pass
Average	**74.9**	**166.8**	
S_{n-1}	2.7	4.9	
CV (%)	3.7	3.0	

**Condition of acceptance is equivalent to T_g > 60°C (140°F)*

Table 12.5 - Tabulated results for shear bond strength for B20C (Lab Method) tests post freezing and thawing conditioning (AC125, Section 5.10.1)

Specimen ID	*w*		*S*		*P*		τ_d		*Failure Mode*	% Retention*
	mm	***in***	**mm**	***in***	***kN***	***lbf***	***MPa***	***psi***		τ_d
QUA_B20C_BSC_FT_001	25.40	1.00	219.08	8.63	9.68	2176	2.67	387	A	94
QUA_B20C_BSC_FT_002	25.40	1.00	219.08	8.63	9.33	2097	2.57	373	A	90
QUA_B20C_BSC_FT_003	25.40	1.00	219.08	8.63	9.46	2125	2.61	378	A	92
QUA_B20C_BSC_FT_004	25.40	1.00	219.08	8.63	10.13	2276	2.79	405	A	98
QUA_B20C_BSC_FT_005	25.40	1.00	219.08	8.63	9.82	2207	2.71	393	A	95
Average					**9.68**	**2176**	**2.67**	**387**		**94**
S_{n-1}					0.31	70	0.09	12.5		
CV (%)					3.2	3.2	3.2	3.2		

**Condition of acceptance is equivalent to τ_d > 200psi and 90% bond strength retention*

13. AGING: WATER RESISTANCE – ASTM D2247

13.1. TEST SUMMARY

13.1.1. AC125 Section/s

Section 5.11, Table 3 for Aging and environmental durability tests.

Section 5.8, Table 2 for physical and mechanical properties of FRP composite materials.

13.1.2. Reference Standard/s

ASSTM D2247 – 15, Standard practice for Testing Water Resistance of Coatings in 100 % Relative Humidity

ASTM D3039/D3039M-17, Standard test method for Tensile Properties of Polymer Matrix Composite Materials.

ASTM D2344/D2344M-13, Standard test method for short-beam strength of polymer matrix composite materials and their laminates.

ASTM E1640-13, Standard test method for assignment of the glass transition temperature by dynamic mechanical analysis.

Shear Bond Lab method

13.1.3. Test Objective

Determine the average experimental percentage retention of tensile strength, tensile modulus, elongation, glass transition temperature, interlaminar shear strength, after ageing exposure to water resistant (warm and humid) environment.

13.1.4. Product/s Under Evaluation

QuakeWrap™ TB20C with QuakeBond™ J300SR (in the primary direction) and QuakeBond™ J300SR.

13.1.5. Test Location

Structures and Materials Laboratory, SML, Main Laboratory, University of Miami, 1251 Memorial Dr., MEB108 Coral Gables, FL, 33146

13.1.6. Laboratory Technician/s

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13.1.7. Technical Test Record

The date of each test; variations to the test method as applicable; calibration information for all measurements and test equipment; identification of the material tested; temperature and humidity of testing laboratory; and other applicable test data or details are provided in the Technical Test Record document number TDS-QUA-TNS-WR, TDS-QUA-ISS-WR, TDS-QUA-TG-WR and TDS-QUA-BSC-WR.

13.2. TEST MATRIX

13.2.1. Specimen Number

Specimens were made from different FRP panels, where five test repetitions for each environment cycle duration (1000, 3000, and 10000 hours) and physical/mechanical test designation (ASTM

D3039, ASTM D2344, ASTM E1640 and shear bond strength lab method) were performed. A total of 15 tests per test type are reported, refer to Table 13.1.

13.2.2. Specimen ID Nomenclature

Specimens are identified throughout the report using the format described in Section 4.5 of this document.

13.2.3. Test Matrix Table

Table 13.1 – Test matrix for tests exposed to water resistance aging

Specimen ID	FRP Batch ID		Aging		Tested
	Fiber	*Resin*	*Start*	*Finish*	
	#	*#*	*mm.dd.yy*	*mm.dd.yy*	*mm.dd.yy*
QUA_B20C_TNS_WR-01-001 TO 005	10010188	A: Lot# 072617-17583 B: Lot# 7156-1	02.12.18	03.27.18	04.05.18
QUA_B20C_TNS_WR-03-001 TO 005				06.19.18	07.06.18
QUA_B20C_TNS_WR-10-001 TO 005				04.04.19*	Pending
QUA_B20C_ISS_WR-01-001 TO 005				03.27.18	04.11.18
QUA_B20C_ISS_WR-03-001 TO 005				06.19.18	07.16.18
QUA_B20C_ISS_WR-10-001 TO 005				04.04.19*	Pending
QUA_B20C_BSC_WR-01-001 TO 005				03.27.18	04.24.18
QUA_B20C_BSC_WR-03-001 TO 005				06.19.18	06.29.18
QUA_B20C_BSC_WR-10-001 TO 005				04.04.19*	Pending
QUA_J300_TG_WR-01-001 TO 005	n/a			03.27.18	04.02.18
QUA_J300_TG_WR-03-001 TO 005				06.19.18	07.02.18
QUA_J300_TG_WR-10-001 TO 005				04.04.19*	Pending

**Visual inspection only, no test required*

13.3. SPECIMEN PREPARATION

13.3.1. Specimen Size and Preparation Procedure

Nominal specimen geometry, layout and preparation procedure varied for each test type, as previously referenced in Chapter 5 for tensile tests; Chapter 10 for interlaminar shear strength; Chapter 9 for glass transition temperature; and Chapter 12 for shear bond strength. Individual specimen geometry parameters are reported the results section of this Chapter.

13.3.2. Conditioning Parameters

All specimens were conditioned and aged in an environmental test chamber under a water resistance environment at a temperature of 38 ± 2°C (100 ± 4°F) and 100% relative humidity, for three different duration periods of 1000, 3000, and 10000 hours prior testing. The temperature of the chamber was monitored continuously. FRP panels where placed at an approximate angle of 15° from the vertical, while the shear bond strength concrete beams specimens were positioned vertically, following requirements of as per ASTM D2247. All specimens were arranged so that condensation from one specimen did not drip on other specimens and so that condensation appeared evenly on the specimens at all times. The environmental chamber and specimens were visually checked approximately every 200 hours for quality purposes.

13.4. TEST SET-UP

13.4.1. Set-up

Upon completion of aging exposure, specimens were removed from the environmental test chamber and wiped to dry the surface. A visual inspection was conducted immediately after the removal of the specimens from the chamber. Prior physical and mechanical testing, a recovery period long enough so that the specimens reached moisture equilibrium with laboratory testing conditions was established (minimum 3 to 7 days). Following the recovery period, specimens were tested. Refer to applicable test set-ups in Chapter 5 for tensile tests; Chapter 10 for interlaminar shear strength; Chapter 9 for glass transition temperature; and Chapter 12 for shear bond strength.

13.4.2. Rate and Method of Loading

Refer to applicable rates and method of loading in Chapter 5 for tensile tests; Chapter 10 for interlaminar shear strength; Chapter 9 for glass transition temperature; and Chapter 12 for shear bond strength.

13.5. TEST RESULTS

13.5.1. Results Summary

No specimens showed surface changes (such as erosion, cracking, crazing and chalking) after a visual inspection with a high resolution USB microscope with a varying magnification from x20 to x50, meeting the conditions of acceptance of AC125, as well as 90% or 85% percent retention for the 1000 and 3000 hrs. exposure, respectively, corresponding to the tensile and interlaminar shear strength properties, and of 1.38 MPa (200 psi) for shear bond strength.

For the 10,000 hrs. exposure, only visual inspection of the conditioned specimens is required per AC125. Specimens are under exposure at this time.

13.5.2. Modes of Failure

Modes of failure for the different physical and mechanical tests after water resistance conditioning are reported in tabulated results of this Chapter.

13.5.3. Calculations

Refer to applicable calculations and analysis of data in Chapter 5 for tensile tests; 10 for interlaminar shear strength; Chapter 9 for glass transition temperature; and Chapter 12 for shear bond strength.

13.5.4. Tabulated Results

Table 13.2 through Table 13.5 contain the tabulated summary results after water resistance conditioning for the tensile, interlaminar shear strength, glass transition temperature and shear bond strength tests, respectively. Refer to the last column of each table where it states the strength retention of the physical mechanical property under evaluation. Average, standard deviation (S_{n-1}), and coefficient of variance (CV) values are also reported, based on the complete set of specimens under evaluation for each product.

Table 13.2 - Tabulated results for tensile tests for B20C (ASTM D3039) post water resistance conditioning (ASTM D2247)

Specimen ID	A		P^{max}		F^{tu}		E^{chord}		ε_u	Failure Mode	Exposure	% Retention*		
	mm²	in²	kN	lbs	MPa	ksi	GPa	Msi	%		hrs.	F^{tu}	E^{chord}	ε_u
QUA_B20C_TNS_WR_01_001	11.18	0.017	11.95	2686	1068.2	154.9	64.5	9.36	1.65	LGM		89	91	102
QUA_B20C_TNS_WR_01_002	11.46	0.018	13.99	3143	1219.7	176.9	66.9	9.71	1.82	LGT		98	104	105
QUA_B20C_TNS_WR_01_003	11.41	0.018	13.15	2954	1151.9	167.1	64.1	9.29	1.80	LGB	1000	97	98	101
QUA_B20C_TNS_WR_01_004	11.10	0.017	13.01	2924	1171.3	169.9	60.4	8.77	1.94	AGT		105	100	95
QUA_B20C_TNS_WR_01_005	11.37	0.018	12.60	2832	1107.5	160.6	63.5	9.22	1.74	AGB		94	94	100
Average	**11.31**	**0.018**	**12.94**	**2908**	**1143.7**	**165.9**	**63.9**	**9.27**	**1.79**			**97**	**97**	**101**
S_{n-1}	0.15	0.000	0.75	168	58.3	8.5	2.3	0.34	0.10					
CV (%)	1.4	1.4	5.8	5.8	5.1	5.1	3.7	3.7	5.8					
QUA_B20C_TNS_WR_03_001	11.61	0.018	12.43	2793	1070.3	155.2	59.3	8.60	1.80	LGB		98	91	93
QUA_B20C_TNS_WR_03_002	11.47	0.018	11.09	2492	966.1	140.1	58.4	8.47	1.65	LGT		89	82	92
QUA_B20C_TNS_WR_03_003	11.23	0.017	11.97	2690	1065.7	154.6	58.1	8.43	1.83	LGB	3000	99	91	91
QUA_B20C_TNS_WR_03_004	11.60	0.018	12.42	2792	1071.0	155.3	59.5	8.64	1.80	LGM		97	91	94
QUA_B20C_TNS_WR_03_005	11.50	0.018	11.68	2625	1015.5	147.3	54.2	7.87	1.87	LGT		101	87	85
Average	**11.48**	**0.018**	**11.92**	**2678**	**1037.7**	**150.5**	**57.9**	**8.40**	**1.79**			**97**	**88**	**91**
S_{n-1}	0.15	0.000	0.56	126	46.3	6.7	2.1	0.31	0.08					
CV (%)	1.3	1.3	4.7	4.7	4.5	4.5	3.7	3.7	4.6					

**Condition of acceptance is equivalent to 90% and 85% retention for 1000 and 3000hrs exposure, respectively.*

Table 13.3 - Tabulated results for interlaminar shear tests for B20C (ASTM D2344) post water resistance conditioning (ASTM D2247)

Specimen ID	***b***		***h***		P_m		F^{sbs}		**Failure**	**Exposure**	**% Retention***
	mm	***in***	**mm**	***in***	***kN***	***lbf***	***MPa***	***ksi***	**Mode**	***hrs.***	F^{sbs}
QUA_B20C_ISS_WR_01_001	6.95	0.27	3.38	0.13	1.49	335.0	47.62	6.91	1		107
QUA_B20C_ISS_WR_01_002	7.79	0.31	3.44	0.14	1.48	332.0	41.34	6.00	1		93
QUA_B20C_ISS_WR_01_003	7.25	0.29	3.49	0.14	1.38	309.0	40.70	5.90	1	1000	92
QUA_B20C_ISS_WR_01_004	8.06	0.32	3.34	0.13	1.44	324.0	40.13	5.82	1		90
QUA_B20C_ISS_WR_01_005	7.19	0.28	3.52	0.14	1.40	314.0	41.43	6.01	1		93
Average	**7.45**	**0.29**	**3.43**	**0.14**	**1.44**	**322.8**	**42.24**	**6.13**			**95**
S_{n-1}	0.46	0.02	0.07	0.00	0.05	11.2	3.05	0.44			
CV (%)	6.2	6.2	2.2	2.2	3.5	3.5	7.2	7.2			
QUA_B20C_ISS_WR_03_001	6.02	0.24	2.79	0.11	0.92	207.0	41.06	5.96	1		93
QUA_B20C_ISS_WR_03_002	7.29	0.29	2.88	0.11	1.15	259.0	41.12	5.96	1		93
QUA_B20C_ISS_WR_03_003	6.83	0.27	2.86	0.11	1.00	224.0	38.28	5.55	1	3000	86
QUA_B20C_ISS_WR_03_004	6.20	0.24	2.79	0.11	0.97	218.0	42.00	6.09	1		95
QUA_B20C_ISS_WR_03_005	6.50	0.26	2.91	0.11	0.99	222.0	39.16	5.68	1		88
Average	**6.57**	**0.26**	**2.85**	**0.11**	**1.01**	**226.0**	**40.32**	**5.85**	**6.57**		**91**
S_{n-1}	0.51	0.02	0.05	0.00	0.09	19.6	1.54	0.22	0.51		
CV (%)	7.7	7.7	1.8	1.8	8.7	8.7	3.8	3.8	7.7		

**Condition of acceptance is equivalent to 90% and 85% retention for 1000 and 3000hrs exposure, respectively.*

Table 13.4 - Tabulated results for glass transition temperature for J300 (ASTM E1640) post water resistance conditioning (ASTM D2247)

Specimen ID		T_g °C	T_g °F	Exposure Hrs.	Acceptance Criteria*
QUA_J300_TG_WR_01_001		63.2	145.8		Pass
QUA_J300_TG_WR_01_002		81.6	178.9		Pass
QUA_J300_TG_WR_01_003		78.7	173.6	1000	Pass
QUA_J300_TG_WR_01_004		67.6	153.7		Pass
QUA_J300_TG_WR_01_005		83.1	181.5		Pass
	Average	**74.8**	**166.7**		
	S_{n-1}	8.9	16.0		
	CV (%)	11.9	9.6		
QUA_J300_TG_WR_03_001		81.6	178.8		Pass
QUA_J300_TG_WR_03_002		79.2	174.6		Pass
QUA_J300_TG_WR_03_003		82.5	180.4	3000	Pass
QUA_J300_TG_WR_03_004		80.0	176.1		Pass
QUA_J300_TG_WR_03_005		79.9	175.8		Pass
	Average	**80.6**	**177.1**		
	S_{n-1}	1.3	2.4		
	CV (%)	1.7	1.4		

**Condition of acceptance is equivalent to T_g > 60°C (140°F)*

Table 13.5 - Tabulated results for shear bond strength for B20C (Lab Method), post water resistance conditioning (ASTM D2247)

Specimen ID	w		S		P		τ_d		Failure Mode	Exposure	% Retention*
	mm	in	mm	in	kN	lbf	MPa	psi		hrs.	τ_d
QUA_B20C_BSC_WR_01_001	25.40	1.00	219.20	8.63	12.66	2845	3.49	506	A	1000	122
QUA_B20C_BSC_WR_01_002	25.40	1.00	219.08	8.63	15.24	3424	4.20	609	A		147
QUA_B20C_BSC_WR_01_003	25.40	1.00	219.08	8.63	11.09	2492	3.06	443	A		107
QUA_B20C_BSC_WR_01_004	25.40	1.00	219.08	8.63	14.85	3336	4.09	594	A		144
QUA_B20C_BSC_WR_01_005	25.40	1.00	219.08	8.63	12.44	2796	3.43	497	A		120
Average					**13.25**	**2978**	**3.65**	**530**			**128**
S_{n-1}					1.74	392	0.48	70			
CV (%)					13.2	13.2	13.2	13.2			
QUA_B20C_BSC_WR_03_001	25.40	1.00	219.20	8.63	12.43	2793	3.42	497	A	3000	120
QUA_B20C_BSC_WR_03_002	25.40	1.00	219.08	8.63	14.14	3177	3.90	565	A		137
QUA_B20C_BSC_WR_03_003	25.40	1.00	219.08	8.63	11.82	2655	3.26	473	A		114
QUA_B20C_BSC_WR_03_004	25.40	1.00	219.08	8.63	14.02	3151	3.87	561	A		136
QUA_B20C_BSC_WR_03_005	25.40	1.00	219.08	8.63	12.94	2907	3.57	517	A		125
Average					**13.07**	**2937**	**3.60**	**522**			**126**
S_{n-1}					1.01	226	0.28	40			
CV (%)					7.7	7.7	7.7	7.7			

**Condition of acceptance is equivalent to* τ_d *> 200 psi 90% bond strength retention*

14. AGING: SALT WATER RESISTANCE – ASTM D1141

14.1. TEST SUMMARY

14.1.1. AC125 Section/s

Section 5.11, Table 3 for Aging and environmental durability tests.

Section 5.8, Table 2 for physical and mechanical properties of FRP composite materials.

14.1.2. Reference Standard/s

ASTM D1141 – 98, Standard practice for the preparation of Substitute Ocean Water

ASTM D3039/D3039M-17, Standard test method for Tensile Properties of Polymer Matrix Composite Materials.

ASTM D2344/D2344M-13, Standard test method for short-beam strength of polymer matrix composite materials and their laminates.

ASTM E1640-13, Standard test method for assignment of the glass transition temperature by dynamic mechanical analysis.

Shear Bond Lab method

14.1.3. Test Objective

Determine the average experimental percentage retention of tensile strength, tensile modulus, elongation, glass transition temperature, interlaminar shear strength, after ageing exposure to salt water environment.

14.1.4. Product/s Under Evaluation

QuakeWrap™ TB20C with QuakeBond™ J300SR (in the primary direction) and QuakeBond™ J300SR.

14.1.5. Test Location

Structures and Materials Laboratory, SML, Main Laboratory, University of Miami, 1251 Memorial Dr., MEB108 Coral Gables, FL, 33146

14.1.6. Laboratory Technician/s

Ming Han, Tais Hamilton and Christian Marquina.

14.1.7. Technical Test Record

The date of each test; variations to the test method as applicable; calibration information for all measurements and test equipment; identification of the material tested; temperature and humidity of testing laboratory; and other applicable test data or details are provided in the Technical Test Record document number TDS-QUA-TNS-SW, TDS-QUA-ISS-SW, TDS-QUA-TG-SW and TDS-QUA-BSC-SW.

14.2. TEST MATRIX

14.2.1. Specimen Number

Specimens were made from different FRP panels, where five test repetitions for each environment cycle duration (1000, 3000, and 10000 hours) and physical/mechanical test designation (ASTM D3039, ASTM D2344, ASTM E1640 and shear bond strength lab method) were performed. A total of 15 tests per test type are reported, refer to Table 14.1.

14.2.2. Specimen ID Nomenclature

Specimens are identified throughout the report using the format described in Section 4.5 of this document.

14.2.3. Test Matrix Table

Table 14.1 – Test matrix for tests post salt water resistance aging

Specimen ID	FRP Batch ID		Aging		Tested
	Fiber	*Resin*	*Start*	*Finish*	
	#	#	*mm.dd.yy*	*mm.dd.yy*	*mm.dd.yy*
QUA_B20C_TNS_SW-01-001 TO 005	10010188	A: Lot# 072617-17583 B: Lot# 7156-1	02.12.18	03.27.18	04.05.18
QUA_B20C_TNS_SW-03-001 TO 005				06.19.18	07.03.18
QUA_B20C_TNS_SW-10-001 TO 005				04.04.19*	Pending
QUA_B20C_ISS_SW-01-001 TO 005				03.27.18	04.11.18
QUA_B20C_ISS_SW-03-001 TO 005				06.19.18	07.16.18
QUA_B20C_ISS_SW-10-001 TO 005				04.04.19*	Pending
QUA_B20C_BSC_SW-01-001 TO 005				03.27.18	04.24.18
QUA_B20C_BSC_SW-03-001 TO 005				06.19.18	06.29.18
QUA_B20C_BSC_SW-10-001 TO 005				04.04.19*	Pending
QUA_J300_TG_SW-01-001 TO 005	n/a			03.27.18	04.06.18
QUA_J300_TG_SW-03-001 TO 005				06.19.18	06.29.18
QUA_J300_TG_SW-10-001 TO 005				04.04.19*	Pending

**Visual inspection only, no test required*

14.3. SPECIMEN PREPARATION

14.3.1. Specimen Size and Preparation Procedure

Nominal specimen geometry, layout and preparation procedure varied for each test type, as previously referenced in Chapter 5 for tensile tests; Chapter 10 for interlaminar shear strength; Chapter 9 for glass transition temperature; and Chapter 12 for shear bond strength. Individual specimen geometry parameters are reported the results section of this Chapter..

14.3.2. Conditioning Parameters

All specimens were conditioned to be aged in a submerged salt water tank chamber at a temperature of 23 ± 2°C (73 ± 2°F), for three different duration periods of 1000, 3000, and 10000 hours prior testing. The temperature of the chamber was monitored continuously. Salt water was prepared using inorganic salts in proportions and concentrations representative of ocean water, as per ASTM D1141. A circulation pump was active to ensure the solution maintained original composition, and replacement was added as necessary. The chamber and random specimens were visually checked approximately every 200 hours for quality purposes.

14.4. TEST SET-UP

14.4.1. Set-up

Upon completion of aging exposure, specimens were removed from the environmental test chamber and wiped to dry the surface. A visual inspection was conducted immediately after the removal of the specimens from the chamber. Prior to physical and mechanical testing, a recovery period long enough so that the specimens reached moisture equilibrium with laboratory testing conditions was established (minimum 3 to 7 days). Following the recovery period, specimens were tested. Refer to applicable test set-ups in in Chapter 5 for tensile tests; Chapter 10 for interlaminar shear strength; Chapter 9 for glass transition temperature; and Chapter 12 for shear bond strength.

14.4.2. Rate and Method of Loading

Refer to applicable rates and method of loading in Chapter 5 for tensile tests; Chapter 10 for interlaminar shear strength; Chapter 9 for glass transition temperature; and Chapter 12 for shear bond strength.

14.5. TEST RESULTS

14.5.1. Results Summary

No specimens showed surface changes (such as erosion, cracking, crazing and chalking) after a visual inspection with a high resolution USB microscope with a varying magnification from x20 to x50, meeting the conditions of acceptance of AC125, as well as 90% or 85% percent retention for the 1000 and 3000 hrs. exposure, respectively, corresponding to the tensile and interlaminar shear strength properties and of 1.38 MPa (200 psi) for shear bond strength.

For the 10,000 hrs. exposure, only visual inspection of the conditioned specimens is required per AC125. Specimens are under exposure at this time.

14.5.2. Modes of Failure

Modes of failure for the different physical and mechanical tests after salt water resistance conditioning are reported in the tabulated results of this Chapter.

14.5.3. Calculations

Refer to applicable calculations and analysis of data in Chapter 5 for tensile tests; Chapter 10 for interlaminar shear strength; Chapter 9 for glass transition temperature; and Chapter 12 for shear bond strength.

14.5.4. Tabulated Results

Table 14.2 through Table 14.5 contain the tabulated summary results after salt water resistance conditioning for the tensile, interlaminar shear strength, glass transition temperature and shear bond strength tests, respectively. Refer to the last column of each table where it states the percentage retention of the physical mechanical property under evaluation. Average, standard deviation (S_{n-1}), and coefficient of variance (CV) values are also reported, based on the complete set of specimens under evaluation for each product.

Table 14.2 - Tabulated results for tensile tests for B20C (ASTM D3039) post salt water resistance conditioning (ASTM D1141)

Specimen ID	A		P^{max}		F^{tu}		E^{chord}		ε_u	Failure Mode	Exposure	% Retention*		
	mm²	in²	kN	lbs	MPa	ksi	GPa	Msi	%		hrs.	F^{tu}	E^{chord}	ε_u
QUA_B20C_TNS_SW_01_001	12.88	0.020	15.46	3475	1200.5	174.1	62.6	9.08	1.92	AGT		104	102	98
QUA_B20C_TNS_SW_01_002	12.02	0.019	12.82	2880	1065.5	154.5	57.0	8.27	1.87	AGB		101	91	90
QUA_B20C_TNS_SW_01_003	12.03	0.019	14.26	3205	1185.5	171.9	66.5	9.65	1.78	LGT	1000	96	101	105
QUA_B20C_TNS_SW_01_004	11.98	0.019	13.23	2972	1103.8	160.1	60.4	8.77	1.83	AGB		99	94	95
QUA_B20C_TNS_SW_01_005	11.95	0.019	13.88	3120	1161.8	168.5	57.1	8.28	2.03	AGT		110	99	90
Average	**12.17**	**0.019**	**13.93**	**3130**	**1143.4**	**165.8**	**60.7**	**8.81**	**1.89**			**102**	**97**	**96**
S_{n-1}	0.40	0.001	1.02	230	57.0	8.3	4.0	0.58	0.10					
CV (%)	3.3	3.3	7.4	7.4	5.0	5.0	6.6	6.6	5.1					
QUA_B20C_TNS_SW_03_001	12.33	0.019	13.81	3103	1119.3	162.3	61.2	8.88	1.83	LGM		99	95	96
QUA_B20C_TNS_SW_03_002	11.95	0.019	13.46	3025	1125.9	163.3	60.0	8.71	1.87	LGB		101	96	94
QUA_B20C_TNS_SW_03_003	9.40	0.015	10.69	2403	1136.6	164.9	58.8	8.53	1.93	AGT	3000	104	97	92
QUA_B20C_TNS_SW_03_004	11.87	0.018	12.27	2758	1033.9	150.0	59.7	8.66	1.73	AGT		94	88	94
QUA_B20C_TNS_SW_03_005	9.47	0.015	11.58	2602	1221.8	177.2	61.5	8.93	1.98	AGB		107	104	97
Average	**11.01**	**0.017**	**12.36**	**2778**	**1127.5**	**163.5**	**60.2**	**8.74**	**1.87**			**101**	**96**	**95**
S_{n-1}	1.44	0.002	1.29	291	66.7	9.7	1.1	0.16	0.10					
CV (%)	13.1	13.1	10.5	10.5	5.9	5.9	1.9	1.9	5.2					

**Condition of acceptance is equivalent to 90% and 85% retention for 1000 and 3000hrs exposure, respectively.*

Table 14.3 - Tabulated results for interlaminar shear tests for B20C, (ASTM D2344) post salt water resistance conditioning (ASTM D1141)

Specimen ID	*b*		*h*		P_m		F^{sbs}		Failure Mode	Exposure	% Retention*
	mm	*in*	mm	*in*	*kN*	*lbf*	*MPa*	*ksi*		*hrs.*	F^{sbs}
QUA_B20C_ISS_SW_01_001	7.20	0.28	2.45	0.10	0.98	221.0	41.77	6.06	1		94
QUA_B20C_ISS_SW_01_002	8.53	0.34	2.91	0.11	1.37	308.0	41.40	6.00	1		93
QUA_B20C_ISS_SW_01_003	6.45	0.25	2.98	0.12	1.18	266.0	46.09	6.68	1	1000	104
QUA_B20C_ISS_SW_01_004	8.42	0.33	2.84	0.11	1.34	302.0	42.06	6.10	1		95
QUA_B20C_ISS_SW_01_005	7.53	0.30	2.95	0.12	1.29	291.0	43.75	6.35	1		99
Average	**7.63**	**0.30**	**2.83**	**0.11**	**1.24**	**277.6**	**43.01**	**6.24**			**97**
S_{n-1}	0.87	0.03	0.22	0.01	0.16	35.5	1.94	0.28			
CV (%)	11.4	11.4	7.7	7.7	12.8	12.8	4.5	4.5			
QUA_B20C_ISS_SW_03_001	7.35	0.29	3.06	0.12	1.56	351.0	52.03	7.55	1		117
QUA_B20C_ISS_SW_03_002	6.36	0.25	3.01	0.12	1.14	255.8	44.56	6.46	1		100
QUA_B20C_ISS_SW_03_003	7.01	0.28	3.23	0.13	1.82	408.0	60.19	8.73	1	3000	136
QUA_B20C_ISS_SW_03_004	6.53	0.26	3.10	0.12	1.90	427.0	70.42	10.21	1		159
QUA_B20C_ISS_SW_03_005	6.39	0.25	3.02	0.12	1.40	315.0	54.43	7.89	1		123
Average	**6.73**	**0.26**	**3.08**	**0.12**	**1.56**	**351.4**	**56.33**	**8.17**			**127**
S_{n-1}	0.44	0.02	0.09	0.00	0.31	69.6	9.67	1.40			
CV (%)	6.5	6.5	2.8	2.8	19.8	19.8	17.2	17.2			

**Condition of acceptance is equivalent to 90% and 85% retention for 1000 and 3000hrs exposure, respectively.*

Table 14.4 - Tabulated results for glass transition temperature for J300SR (ASTM E1640) post salt water resistance conditioning (ASTM D1141)

Specimen ID		T_g		Acceptance
		°C	**°F**	**Criteria***
QUA_J300_TG_SW_01_001		68.5	155.4	Pass
QUA_J300_TG_SW_01_002		70.5	158.9	Pass
QUA_J300_TG_SW_01_003		71.7	161.0	Pass
QUA_J300_TG_SW_01_004		68.6	155.4	Pass
QUA_J300_TG_SW_01_005		70.5	158.9	Pass
	Average	**69.9**	**157.9**	
	S_{n-1}	1.4	2.4	
	CV (%)	1.9	1.6	
QUA_J300_TG_SW_03_001		69.9	157.9	Pass
QUA_J300_TG_SW_03_002		70.6	159.1	Pass
QUA_J300_TG_SW_03_003		72.5	162.5	Pass
QUA_J300_TG_SW_03_004		69.9	157.8	Pass
QUA_J300_TG_SW_03_005		69.9	157.9	Pass
	Average	**70.6**	**159.0**	
	S_{n-1}	1.1	2.0	
	CV (%)	1.6	1.3	

**Condition of acceptance is equivalent to T_g > 60°C (140°F)*

Table 14.5 - Tabulated results for shear bond strength tests for B20C, (Lab Method), post salt water resistance conditioning (ASTM D1141)

Specimen ID	w		S		P		τ_d		Failure	Exposure	% Retention*
	mm	in	mm	in	kN	lbf		psi	Mode	hrs.	τ_d
QUA_B20C_BSC_SW_01_001	25.40	1.00	219.20	8.63	12.22	2746	3.37	488	A	1000	118
QUA_B20C_BSC_SW_01_002	25.40	1.00	219.08	8.63	15.44	3471	4.26	618	A		149
QUA_B20C_BSC_SW_01_003	25.40	1.00	219.08	8.63	11.38	2558	3.14	455	A		110
QUA_B20C_BSC_SW_01_004	25.40	1.00	219.08	8.63	12.63	2839	3.48	505	A		122
QUA_B20C_BSC_SW_01_005	25.40	1.00	219.08	8.63	12.02	2702	3.32	481	A		116
Average					**12.74**	**2863**	**3.51**	**509**			**123**
S_{n-1}					1.58	354	0.44	63			
CV (%)					12.4	12.4	12.4	12.4			
QUA_B20C_BSC_SW_03_001	25.40	1.00	219.20	8.63	13.99	3143	3.85	559	A	3000	135
QUA_B20C_BSC_SW_03_002	25.40	1.00	219.08	8.63	15.05	3381	4.15	602	A		146
QUA_B20C_BSC_SW_03_003	25.40	1.00	219.08	8.63	13.98	3141	3.85	559	A		135
QUA_B20C_BSC_SW_03_004	25.40	1.00	219.08	8.63	12.07	2712	3.33	483	A		117
QUA_B20C_BSC_SW_03_005	25.40	1.00	219.08	8.63	12.06	2709	3.32	482	A		117
Average					**13.43**	**3017**	**3.70**	**537**			**130**
S_{n-1}					1.32	296	0.36	53			
CV (%)					9.8	9.8	9.8	9.8			

**Condition of acceptance is equivalent to τ_d > 200psi and 90% bond strength retention*

15. AGING: ALKALI RESISTANCE – ASTM C581

15.1. TEST SUMMARY

15.1.1. AC125 Section/s

Section 5.11, Table 3 for Aging and environmental durability tests.

Section 5.8, Table 2 for physical and mechanical properties of FRP composite materials.

15.1.2. Reference Standard/s

ASTM C581 -03 (Reapproved 2008), Standard practice for determining chemical resistance of thermosetting resins used in glass-fiber-reinforced structures intended for liquid service

ASTM D3039/D3039M-17, Standard test method for Tensile Properties of Polymer Matrix Composite Materials.

ASTM D2344/D2344M-13, Standard test method for short-beam strength of polymer matrix composite materials and their laminates.

ASTM E1640-13, Standard test method for assignment of the glass transition temperature by dynamic mechanical analysis.

Shear Bond Lab method

15.1.3. Test Objective

Determine the average experimental percentage retention of tensile strength, tensile modulus, elongation, glass transition temperature, interlaminar shear strength, after ageing exposure to an alkaline water environment.

15.1.4. Product/s Under Evaluation

QuakeWrap™ TB20C with QuakeBond™ J300SR (in the primary direction) and QuakeBond™ J300SR.

15.1.5. Test Location

Structures and Materials Laboratory, SML, Main Laboratory, University of Miami, 1251 Memorial Dr., MEB108 Coral Gables, FL, 33146

15.1.6. Laboratory Technician/s

Ming Han, Tais Hamilton and Christian Marquina.

15.1.7. Technical Test Record

The date of each test; variations to the test method as applicable; calibration information for all measurements and test equipment; identification of the material tested; temperature and humidity of testing laboratory; and other applicable test data or details are provided in the Technical Test Record document number TDS-QUA-TNS-AR, TDS-QUA-ISS-AR, TDS-QUA-TG-AR and TDS-QUA-BSC-AR.

15.2. TEST MATRIX

15.2.1. Specimen Number

Specimens were made from different FRP panels, where five test repetitions for each environment cycle duration (1000, and 3000 hours) and physical/mechanical test designation (ASTM D3039, ASTM D2344, ASTM E1640 and shear bond strength lab method) were performed. A total of ten tests per test type are reported, refer to Table15.1.

15.2.2. Specimen ID Nomenclature

Specimens are identified throughout the report using the format described in Section 4.5 of this document.

15.2.3. Test Matrix Table

Table 15.1 – Test matrix for tests post alkali resistance conditioning

Specimen ID	FRP Batch ID Fiber #	FRP Batch ID Resin #	Aging Start mm.dd.yy	Aging Finish mm.dd.yy	Tested mm.dd.yy
QUA_B20C_TNS_AR-01-001 TO 005	10010188	A: Lot# 072617-17583 B: Lot# 7156-1	02.12.18	03.27.18	04.05.18
QUA_B20C_TNS_AR-03-001 TO 005				06.19.18	07.09.18
QUA_B20C_ISS_AR-01-001 TO 005				03.27.18	04.11.18
QUA_B20C_ISS_AR-03-001 TO 005				06.19.18	07.16.18
QUA_B20C_BSC_AR-01-001 TO 005				03.27.18	04.06.18
QUA_B20C_BSC_AR-03-001 TO 005				06.19.18	06.29.18
QUA_J300_TG_AR-01-001 TO 005	n/a			03.27.18	04.10.18
QUA_J300_TG_AR-03-001 TO 005				06.19.18	07.09.18

15.3. SPECIMEN PREPARATION

15.3.1. Specimen Size and Preparation Procedure

Nominal specimen geometry, layout and preparation procedure varied for each test type, as previously referenced in Chapter 5 for tensile tests; Chapter 10 for interlaminar shear strength; Chapter 9 for glass transition temperature; and Chapter 12 for shear bond strength. Individual specimen geometry parameters are reported the results section of this Chapter.

15.3.2. Conditioning Parameters

All specimens were conditioned by submersion in an alkali solution Ca(CO_3) environmental chamber at a constant temperature of 23 ± 2°C (73 ± 2°F) for two different duration periods of 1000 and 3000 hours prior testing. The test solution was replaced with fresh solution as often as necessary to maintain original composition and concentration equivalent to 9.5 pH. The specimens and chamber were visually checked approximately every 200 hours for quality purposes.

15.4. TEST SET-UP

15.4.1. Set-up

Upon termination of aging exposure, specimens were removed from the environmental test chamber and wiped to dry the surface. A visual inspection was conducted immediately after the removal of the specimens from the chamber. Prior to physical and mechanical testing, a recovery period long enough so that the specimens reached moisture equilibrium with laboratory testing conditions was established (minimum 3 to 7 days). Following the recovery period, specimens were tested. Refer to applicable test set-ups in in Chapter 5 for tensile tests; Chapter 10 for interlaminar shear strength; Chapter 9 for glass transition temperature; and Chapter 12 for shear bond strength.

15.4.2. Rate and Method of Loading

Refer to applicable rates and method of loading in Chapter 5 for tensile tests; Chapter 10 for interlaminar shear strength; Chapter 9 for glass transition temperature; and Chapter 12 for shear bond strength.

15.5. TEST RESULTS

15.5.1. Results Summary

No specimens showed surface changes (such as erosion, cracking, crazing and chalking) after a visual inspection with a high resolution USB microscope with a varying magnification from x20 to x50, meeting the conditions of acceptance of AC125, as well as 90% or 85% percent retention for the 1000 and 3000 hrs. exposure, respectively, corresponding to the tensile and interlaminar shear strength properties, and of 1.38 MPa (200 psi) for shear bond strength. Detailed test results are reported in tabulated section of this chapter.

15.5.2. Modes of Failure

Modes of failure for the different physical and mechanical tests after alkali resistance conditioning are reported in the tabulated results of this Chapter.

15.5.3. Calculations

Refer to applicable calculations and analysis of data in Chapter 5 for tensile tests; Chapter 10 for interlaminar shear strength; Chapter 9 for glass transition temperature; and Chapter 12 for shear bond strength.

15.5.4. Tabulated Results

Table 15.2 through Table 15.5 contain the tabulated summary results after alkali resistance conditioning for the tensile, interlaminar shear strength, glass transition temperature and shear bond strength tests, respectively. Refer to the last column of each table where it states the percentage retention of the physical mechanical property under evaluation. Average, standard deviation (S_{n-1}), and coefficient of variance (CV) values are also reported, based on the complete set of specimens under evaluation for each product.

Table 15.2 - Tabulated results for tensile tests for B20C (ASTM D3039) post alkali resistance conditioning (ASTM C581)

Specimen ID	A		P^{max}		F^{tu}		E^{chord}		ε_u	Failure Mode	Exposure	% Retention*		
	mm²	*in²*	*kN*	*lbs*	*MPa*	*ksi*	*GPa*	*Msi*	*%*		*hrs.*	F^{tu}	E^{chord}	ε_u
QUA_B20C_TNS_AR_01_001	9.94	0.015	10.68	2399	1073.9	155.8	59.0	8.57	1.82	AGB		98	92	93
QUA_B20C_TNS_AR_01_002	12.57	0.019	13.43	3017	1067.4	154.8	61.2	8.88	1.74	AGT		94	91	96
QUA_B20C_TNS_AR_01_003	12.00	0.019	13.06	2934	1087.5	157.7	64.6	9.38	1.68	AGB	1000	91	93	102
QUA_B20C_TNS_AR_01_004	12.44	0.019	13.19	2963	1059.3	153.6	61.1	8.87	1.73	AGT		94	90	96
QUA_B20C_TNS_AR_01_005	6.66	0.010	7.46	1677	1119.9	162.4	57.3	8.32	1.95	AGT		106	95	90
Average	**10.72**	**0.017**	**11.56**	**2598**	**1081.6**	**156.9**	**60.7**	**8.80**	**1.79**			**97**	**92**	**95**
S_{n-1}	2.51	0.004	2.55	572	23.8	3.4	2.7	0.40	0.11					
CV (%)	23.4	23.4	22.0	22.0	2.2	2.2	4.5	4.5	5.9					
QUA_B20C_TNS_AR_03_001	11.71	0.018	11.99	2695	1024.0	148.5	61.3	8.89	1.67	AGB		90	87	96
QUA_B20C_TNS_AR_03_002	12.04	0.019	13.29	2986	1103.4	160.0	66.3	9.62	1.66	LGM		90	94	104
QUA_B20C_TNS_AR_03_003	11.85	0.018	13.59	3054	1146.1	166.2	66.7	9.68	1.72	LGB	3000	93	98	105
QUA_B20C_TNS_AR_03_004	11.80	0.018	11.62	2612	984.3	142.8	60.4	8.76	1.63	LGB		88	84	95
QUA_B20C_TNS_AR_03_005	9.54	0.015	9.91	2226	1037.7	150.5	58.9	8.55	1.76	LGT		95	88	93
Average	**11.39**	**0.018**	**12.08**	**2715**	**1059.1**	**153.6**	**62.7**	**9.10**	**1.69**			**91**	**90**	**99**
S_{n-1}	1.04	0.002	1.47	331	64.8	9.4	3.6	0.52	0.05					
CV (%)	9.1	9.1	12.2	12.2	6.1	6.1	5.7	5.7	3.0					

**Condition of acceptance is equivalent to 90% and 85% retention for 1000 and 3000hrs exposure, respectively.*

Table 15.3 - Tabulated results for interlaminar shear tests for B20C (ASTM D2344) post alkali resistance conditioning (ASTM C581)

Specimen ID	*b*		*h*		P_m		F^{sbs}		Failure Mode	Exposure	% Retention*
	mm	*in*	mm	*in*	*kN*	*lbf*	*MPa*	*ksi*		*hrs.*	F^{sbs}
QUA_B20C_ISS_AR_01_001	7.06	0.28	2.78	0.11	1.43	321.0	54.53	7.91	1	1000	123
QUA_B20C_ISS_AR_01_002	7.45	0.29	2.29	0.09	1.41	317.0	62.06	9.00	1		140
QUA_B20C_ISS_AR_01_003	8.65	0.34	2.74	0.11	1.60	359.0	50.48	7.32	1		114
QUA_B20C_ISS_AR_01_004	8.43	0.33	2.55	0.10	1.49	334.0	51.76	7.51	1		117
QUA_B20C_ISS_AR_01_005	8.08	0.32	2.71	0.11	1.46	329.0	50.23	7.29	1		113
Average	**7.93**	**0.31**	**2.61**	**0.10**	**1.48**	**332.0**	**53.81**	**7.80**			**121**
S_{n-1}	0.67	0.03	0.20	0.01	0.07	16.5	4.91	0.71			
CV (%)	8.4	8.4	7.8	7.8	5.0	5.0	9.1	9.1			
QUA_B20C_ISS_AR_03_001	7.44	0.29	3.06	0.12	1.38	311.0	45.55	6.61	1	3000	103
QUA_B20C_ISS_AR_03_002	6.73	0.27	2.98	0.12	1.08	243.0	40.36	5.85	1		91
QUA_B20C_ISS_AR_03_003	7.71	0.30	3.09	0.12	1.21	271.0	38.00	5.51	1		86
QUA_B20C_ISS_AR_03_004	7.05	0.28	2.96	0.12	1.10	248.0	39.67	5.75	1		89
QUA_B20C_ISS_AR_03_005	6.74	0.27	2.98	0.12	1.13	255.0	42.27	6.13	1		95
Average	**7.13**	**0.28**	**3.01**	**0.12**	**1.18**	**265.6**	**41.17**	**5.97**			**93**
S_{n-1}	0.43	0.02	0.06	0.00	0.12	27.5	2.89	0.42			
CV (%)	6.1	6.1	1.8	1.8	10.4	10.4	7.0	7.0			

**Condition of acceptance is equivalent to 90% and 85% retention for 1000 and 3000hrs exposure, respectively.*

Table 15.4 - Tabulated results for glass transition temperature for J300SR (ASTM E1640) post alkali resistance conditioning (ASTM C581)

Specimen ID		**T_g**		**Acceptance Criteria***
		°C	**°F**	
QUA_J300_TG_AR_01_001		66.3	151.3	Pass
QUA_J300_TG_AR_01_002		68.3	155.0	Pass
QUA_J300_TG_AR_01_003		67.9	154.3	Pass
QUA_J300_TG_AR_01_004		67.0	152.7	Pass
QUA_J300_TG_AR_01_005		64.8	148.6	Pass
	Average	**66.9**	**152.4**	
	S_{n-1}	1.4	2.5	
	CV (%)	2.1	1.7	
QUA_J300_TG_AR_03_001		66.1	150.9	Pass
QUA_J300_TG_AR_03_002		69.0	156.2	Pass
QUA_J300_TG_AR_03_003		66.2	151.2	Pass
QUA_J300_TG_AR_03_004		68.2	154.7	Pass
QUA_J300_TG_AR_03_005		66.9	152.4	Pass
	Average	**67.3**	**153.1**	
	S_{n-1}	1.3	2.3	
	CV (%)	1.9	1.5	

**Condition of acceptance is equivalent to T_g > 60°C (140°F)*

Table 15.5 - Tabulated results for shear bond strength tests for U41C (Lab Method) post alkali resistance conditioning (ASTM C581)

Specimen ID	w		S		P		τ_d		Failure Mode	Exposure	% Retention*
	mm	in	mm	in	kN	lbf		psi		hrs.	τ_d
QUA_B20C_BSC_AR_01_001	25.40	1.00	219.20	8.63	12.33	2772	3.40	493	A		119
QUA_B20C_BSC_AR_01_002	25.40	1.00	219.08	8.63	11.32	2545	3.12	453	A		110
QUA_B20C_BSC_AR_01_003	25.40	1.00	219.08	8.63	13.32	2994	3.67	533	A	1000	129
QUA_B20C_BSC_AR_01_004	25.40	1.00	219.08	8.63	13.38	3007	3.69	535	A		130
QUA_B20C_BSC_AR_01_005	25.40	1.00	219.08	8.63	10.91	2452	3.01	436	A		106
Average					**12.25**	**2754**	**3.38**	**490**			**119**
S_{n-1}					1.13	253	0.31	45			
CV (%)					9.2	9.2	9.2	9.2			
QUA_B20C_BSC_AR_03_001	25.40	1.00	219.20	8.63	10.74	2413	2.96	429	A		104
QUA_B20C_BSC_AR_03_002	25.40	1.00	219.08	8.63	11.26	2530	3.10	450	A		109
QUA_B20C_BSC_AR_03_003	25.40	1.00	219.08	8.63	11.64	2616	3.21	465	A	3000	113
QUA_B20C_BSC_AR_03_004	25.40	1.00	219.08	8.63	13.89	3120	3.83	555	A		134
QUA_B20C_BSC_AR_03_005	25.40	1.00	219.08	8.63	12.86	2890	3.55	514	A		124
Average					**12.08**	**2714**	**3.33**	**483**			**117**
S_{n-1}					1.28	287	0.35	51			
CV (%)					10.6	10.6	10.6	10.6			

**Condition of acceptance is equivalent to τ_d > 200psi and 90% bond strength retention*

16. AGING: DRY HEAT RESISTANCE– ASTM D3045

16.1. TEST SUMMARY

16.1.1. AC125 Section/s

Section 5.11, Table 3 for Aging and environmental durability tests.

Section 5.8, Table 2 for physical and mechanical properties of FRP composite materials.

16.1.2. Reference Standard/s

ASTM D3045 -92 (Reapproved 2010), Standard practice for heat aging of plastics without load

ASTM D3039/D3039M-17, Standard test method for Tensile Properties of Polymer Matrix Composite Materials.

ASTM D2344/D2344M-13, Standard test method for short-beam strength of polymer matrix composite materials and their laminates.

ASTM E1640-13, Standard test method for assignment of the glass transition temperature by dynamic mechanical analysis.

Shear Bond Lab method

16.1.3. Test Objective

Determine the average experimental percentage retention of tensile strength, tensile modulus, elongation, glass transition temperature, and interlaminar shear strength, after ageing exposure to a dry heat environment.

16.1.4. Product/s Under Evaluation

QuakeWrap™ TB20C with QuakeBond™ J300SR (in the primary direction) and QuakeBond™ J300SR.

16.1.5. Test Location

Structures and Materials Laboratory, SML, Main Laboratory, University of Miami, 1251 Memorial Dr., MEB108 Coral Gables, FL, 33146

16.1.6. Laboratory Technician/s

Ming Han, Tais Hamilton and Christian Marquina.

16.1.7. Technical Test Record

The date of each test; variations to the test method as applicable; calibration information for all measurements and test equipment; identification of the material tested; temperature and humidity of testing laboratory; and other applicable test data or details are provided in the Technical Test Record document number TDS-QUA-TNS-DH, TDS-QUA-ISS-DH, TDS-QUA-TG-DH and TDS-QUA-BSC-DH.

16.2. TEST MATRIX

16.2.1. Specimen Number

Specimens were made from different FRP panels, where five test repetitions for each environment cycle duration (1000, and 3000) and physical/mechanical test designation (ASTM D3039, ASTM D2344, ASTM E1640 and shear bond strength lab method) were performed. A total of ten tests per test type are reported, refer to Table 16.1.

16.2.2. Specimen ID Nomenclature

Specimens are identified throughout the report using the format described in Section 4.5 of this document.

16.2.3. Test Matrix Table

Table 16.1 – Test matrix for tests post dry heat resistance conditioning

Specimen ID	FRP Batch ID		Aging		Tested
	Fiber	***Resin***	***StDHt***	***Finish***	
	#	***#***	***mm.dd.yy***	***mm.dd.yy***	***mm.dd.yy***
QUA_B20C_TNS_DH-01-001 TO 005	10010188	A: Lot# 072617-17583 B: Lot# 7156-1	02.12.18	04.03.18	04.05.18
QUA_B20C_TNS_DH-03-001 TO 005				06.27.18	07.11.18
QUA_B20C_ISS_DH-01-001 TO 005				04.03.18	04.11.18
QUA_B20C_ISS_DH-03-001 TO 005				06.27.18	07.11.18
QUA_B20C_BSC_DH-01-001 TO 005				04.03.18	04.24.18
QUA_B20C_BSC_DH-03-001 TO 005				06.27.18	06.29.18
QUA_J300_TG_DH-01-001 TO 005	n/a			04.03.18	04.13.18
QUA_J300_TG_DH-03-001 TO 005				06.27.18	07.03.18

16.3. SPECIMEN PREPARATION

16.3.1. Specimen Size and Preparation Procedure

Nominal specimen geometry, layout and preparation procedure varied for each test type, as previously referenced in Chapter 5 for tensile tests; Chapter 10 for interlaminar shear strength; Chapter 9 for glass transition temperature; and Chapter 12 for shear bond strength. Individual specimen geometry parameters are reported the results section of this Chapter.

16.3.2. Conditioning Parameters

All specimens were aged in an environmental chamber at a constant temperature of 60 ± 2°C (140 ± 5°F) for two different duration periods of 1000 and 3000 hours prior testing. The specimens and chamber were visually checked approximately every 200 hours for quality purposes.

16.4. TEST SET-UP

16.4.1. Set-up

Upon finalization of aging exposure, specimens were removed from the environmental test chamber and set to rest in laboratory conditions. A visual inspection was conducted immediately after the removal of the specimens from the chamber. Prior to physical and mechanical testing, a recovery period long enough so that the specimens reached temperature equilibrium with laboratory testing conditions was established (minimum 3 to 7 days). Following the recovery period, specimens were tested. Refer to applicable test set-ups in in Chapter 5 for tensile tests; Chapter 10 for interlaminar shear strength; Chapter 9 for glass transition temperature; and Chapter 12 for shear bond strength.

16.4.2. Rate and Method of Loading

Refer to applicable rates and method of loading in Chapter 5 for tensile tests; Chapter 10 for interlaminar shear strength; Chapter 9 for glass transition temperature; and Chapter 12 for shear bond strength.

16.5. TEST RESULTS

16.5.1. Results Summary

No specimens showed surface changes (such as erosion, cracking, crazing and chalking) after a visual inspection with a high resolution USB microscope with a varying magnification from x20 to x50, meeting the conditions of acceptance of AC125, as well as 90% or 85% percent retention for the 1000 and 3000 hrs. exposure, respectively, corresponding to the tensile and interlaminar shear strength properties, minimum glass transition temperature of 60°C (140°F), and of 1.38 MPa (200 psi) for shear bond strength. Detailed test results are reported in the tabulated section of this Chapter.

16.5.2. Modes of Failure

Modes of failure for the different physical and mechanical tests after dry heat conditioning are reported in the tabulated results of this Chapter.

16.5.3. Calculations

Refer to applicable calculations and analysis of data in Chapter 5 for tensile tests; Chapter 10 for interlaminar shear strength; Chapter 9 for glass transition temperature; and Chapter 12 for shear bond strength.

16.5.4. Tabulated Results

Table 16.2 through Table 16.5 contain the tabulated summary results after dry heat conditioning for the tensile, interlaminar shear strength, glass transition temperature and shear bond strength tests, respectively. Refer to the last column of each table where it states the percentage retention of the physical mechanical property under evaluation. Average, standard deviation (S_{n-1}), and coefficient of variance (CV) values are also reported, based on the complete set of specimens under evaluation for each product.

Table 16.2 - Tabulated results for tensile tests for B20C (ASTM D3039) post dry heat conditioning (ASTM D3045)

Specimen ID	***A***		***P^max^***		***F^tu^***		***E^chord^***		***ε~u~***	**Failure Mode**	**Exposure**	**% Retention***		
	mm²	***in²***	***kN***	***lbs***	***MPa***	***ksi***	***GPa***	***Msi***	***με***		***hrs.***	***F^tu^***	***E^chord^***	***ε~u~***
QUA_B20C_TNS_DH_01_001	10.57	0.016	12.23	2749	1157.2	167.8	68.4	9.93	1.69	AGT		91	99	108
QUA_B20C_TNS_DH_01_002	11.16	0.017	13.56	3047	1214.6	176.2	58.8	8.53	2.07	AGT		112	104	92
QUA_B20C_TNS_DH_01_003	10.53	0.016	11.17	2511	1060.7	153.8	61.5	8.92	1.72	AGT	1000	93	90	97
QUA_B20C_TNS_DH_01_004	9.16	0.014	10.47	2353	1142.5	165.7	63.2	9.17	1.81	AGT		98	97	99
QUA_B20C_TNS_DH_01_005	10.80	0.017	12.48	2805	1154.8	167.5	60.6	8.79	1.91	AGB		103	98	95
Average	**10.44**	**0.016**	**11.98**	**2693**	**1145.9**	**166.2**	**62.5**	**9.07**	**1.84**			**99**	**98**	**98**
S_{n-1}	0.76	0.001	1.20	269	55.2	8.0	3.7	0.53	0.15					
CV (%)	7.3	7.3	10.0	10.0	4.8	4.8	5.9	5.9	8.3					
QUA_B20C_TNS_DH_03_001	9.80	0.015	9.77	2195	996.7	144.6	64.7	9.39	1.54	LGM		83	85	102
QUA_B20C_TNS_DH_03_002	9.70	0.015	10.08	2265	1038.8	150.7	62.9	9.13	1.65	LGB		89	89	99
QUA_B20C_TNS_DH_03_003	9.71	0.015	9.85	2214	1014.4	147.1	59.5	8.63	1.70	LGT	3000	92	86	94
QUA_B20C_TNS_DH_03_004	9.60	0.015	11.05	2484	1150.9	166.9	60.9	8.83	1.89	LGT		102	98	96
QUA_B20C_TNS_DH_03_005	9.46	0.015	11.69	2626	1234.4	179.0	66.9	9.71	1.84	LGB		100	105	105
Average	**9.65**	**0.015**	**10.49**	**2357**	**1087.0**	**157.7**	**63.0**	**9.14**	**1.73**			**93**	**93**	**99**
S_{n-1}	0.13	0.000	0.84	190	101.9	14.8	3.0	0.43	0.14					
CV (%)	1.3	1.3	8.0	8.0	9.4	9.4	4.7	4.7	8.3					

**Condition of acceptance is equivalent to 90% and 85% retention for 1000 and 3000hrs exposure, respectively.*

Table 16.3 - Tabulated results for interlaminar shear tests for B20C (ASTM D2344) post dry heat conditioning (ASTM D3045)

Specimen ID	*b*		*h*		P_m		F^{sbs}		Failure Mode	Exposure	% Retention*
	mm	***in***	**mm**	***in***	***kN***	***lbf***	***MPa***	***ksi***		***hrs.***	F^{sbs}
QUA_B20C_ISS_DH_01_001	7.76	0.31	3.54	0.14	1.52	341.0	41.38	6.00	1	1000	93
QUA_B20C_ISS_DH_01_002	7.00	0.28	3.64	0.14	1.50	337.0	44.08	6.39	1		99
QUA_B20C_ISS_DH_01_003	7.77	0.31	3.71	0.15	1.56	350.0	40.51	5.88	1		91
QUA_B20C_ISS_DH_01_004	6.07	0.24	3.28	0.13	1.24	279.0	46.79	6.79	1		105
QUA_B20C_ISS_DH_01_005	7.99	0.31	3.68	0.15	1.61	362.0	41.05	5.95	1		92
Average	**7.32**	**0.29**	**3.57**	**0.14**	**1.49**	**333.8**	**42.76**	**6.20**			**96**
S_{n-1}	0.79	0.03	0.18	0.01	0.14	32.1	2.64	0.38			
CV (%)	10.8	10.8	4.9	4.9	9.6	9.6	6.2	6.2			
QUA_B20C_ISS_DH_03_001	7.58	0.30	3.64	0.14	1.49	335.0	40.44	5.87	1	3000	91
QUA_B20C_ISS_DH_03_002	8.76	0.35	3.58	0.14	1.71	384.0	40.82	5.92	1		92
QUA_B20C_ISS_DH_03_003	8.62	0.34	3.77	0.15	1.69	379.5	38.92	5.65	1		88
QUA_B20C_ISS_DH_03_004	8.74	0.34	3.61	0.14	1.72	387.0	40.97	5.94	1		92
QUA_B20C_ISS_DH_03_005	7.72	0.30	3.77	0.15	1.77	397.0	45.47	6.60	1		102
Average	**8.29**	**0.33**	**3.68**	**0.14**	**1.68**	**376.5**	**41.33**	**5.99**			**93**
S_{n-1}	0.58	0.02	0.09	0.00	0.11	24.1	2.46	0.36			
CV (%)	7.0	7.0	2.5	2.5	6.4	6.4	5.9	5.9			

**Condition of acceptance is equivalent to 90% and 85% retention for 1000 and 3000hrs exposure, respectively.*

Table 16.4 - Tabulated results for glass transition temperature for J300 (ASTM E1640) post dry heat conditioning (ASTM D3045)

Specimen ID		***T_g*** °C	***T_g*** °F	**Acceptance Criteria***
QUA_J300_TG_DH_01_001		69.8	157.6	Pass
QUA_J300_TG_DH_01_002		65.4	149.6	Pass
QUA_J300_TG_DH_01_003		70.3	158.6	Pass
QUA_J300_TG_DH_01_004		62.0	143.6	Pass
QUA_J300_TG_DH_01_005		84.8	184.7	Pass
	Average	**70.5**	**158.8**	
	S_{n-1}	8.7	15.7	
	CV (%)	12.4	9.9	
QUA_J300_TG_DH_03_001		86.9	188.4	Pass
QUA_J300_TG_DH_03_002		86.3	187.3	Pass
QUA_J300_TG_DH_03_003		88.4	191.1	Pass
QUA_J300_TG_DH_03_004		84.7	184.5	Pass
QUA_J300_TG_DH_03_005		87.2	189.0	Pass
	Average	**86.7**	**188.0**	
	S_{n-1}	1.4	2.4	
	CV (%)	1.6	1.3	

**Condition of acceptance is equivalent to T_g > 60°C (140°F)*

Table 16.5 - Tabulated results for shear bond strength tests for B20C (Lab Method) post dry heat conditioning (ASTM D3045)

Specimen ID	w		S		P		τ_d		Failure	Exposure	% Retention*
	mm	in	mm	in	kN	lbf	τ_d	psi	Mode	hrs.	τ_d
QUA_B20C_BSC_DH_01_001	25.40	1.00	218.92	8.62	11.89	2673	3.28	476	A	1000	129
QUA_B20C_BSC_DH_01_002	25.40	1.00	218.92	8.62	13.03	2929	3.60	522	A		114
QUA_B20C_BSC_DH_01_003	25.40	1.00	221.62	8.73	12.81	2878	3.49	506	A		127
QUA_B20C_BSC_DH_01_004	25.40	1.00	220.35	8.68	11.24	2526	3.08	447	A		122
QUA_B20C_BSC_DH_01_005	25.40	1.00	216.47	8.52	12.62	2836	3.52	511	A		141
Average					**12.32**	**2768**	**3.39**	**492**			**127**
S_{n-1}					0.74	166	0.21	30			
CV (%)					6.0	6.0	6.2	6.2			
QUA_B20C_BSC_DH_03_001	25.40	1.00	219.20	8.63	13.36	3002	3.68	534	A	3000	115
QUA_B20C_BSC_DH_03_002	25.40	1.00	219.08	8.63	11.79	2650	3.25	471	A		126
QUA_B20C_BSC_DH_03_003	25.40	1.00	219.08	8.63	13.10	2945	3.61	524	A		123
QUA_B20C_BSC_DH_03_004	25.40	1.00	219.08	8.63	12.60	2832	3.47	504	A		108
QUA_B20C_BSC_DH_03_005	25.40	1.00	219.08	8.63	14.58	3277	4.02	583	A		124
Average					**13.09**	**2941**	**3.61**	**523**			**119**
S_{n-1}					1.03	231	0.28	41			
CV (%)					7.9	7.9	7.9	7.9			

**Condition of acceptance is equivalent to τ_d > 200 psi and 90% bond strength retention*

17. EXTERIOR EXPOSURE – ASTM D2565

17.1. TEST SUMMARY

17.1.1. AC125 Section/s

Section 5.9 for Exterior Exposure

17.1.2. Reference Standard/s

D2565 − 99 Standard Practice for Xenon-arc Exposure of Plastics Intended for Outdoor Applications

ASTM D3039/D3039M – 17, Standard test method for Tensile Properties of Polymer Matrix Composite Materials.

17.1.3. Test Objective

Determine the ability of the materials under evaluation to resist deterioration of its electrical, mechanical, and optical properties caused by exposure to light, heat, and water.

17.1.4. Product/s Under Evaluation

QuakeWrap™ TB20C with QuakeBond™ J300SR (in the primary direction).

17.1.5. Test Location

Florida Department of Transportation - State Materials Office, 5007 NE 39th Avenue, Gainesville, FL 32609 and University of Miami, College of Engineering, Structures and Materials Laboratory, 1251 Memorial Dr., Coral Gables, FL, 33146

17.1.6. Laboratory Technician/s

Francisco De Caso

17.1.7. Technical Test Record

The date of each test; variations to the test method as applicable; calibration information for all measurements and test equipment; identification of the material tested; temperature and humidity of testing laboratory; and other applicable test data or details are provided in the Technical Test Record document number TDS-QUA-TNS-EE.

17.2. TEST MATRIX

17.2.1. Specimen Number

A total of six tests (one benchmark and five conditioned) are reported, refer to Table 17.1.

17.2.2. Specimen ID Nomenclature

Specimens are identified through the report using the format described in the following in Section of this chapter.

17.2.3. Test Matrix Table

Table 17.1– Test matrix for exterior exposure specimens

Specimen ID	**FRP Batch ID**		**Aging**		**Tested**
	Fiber #	***Resin #***	***Start mm.dd.yy***	***Finish mm.dd.yy***	***mm.dd.yy***
QUA_B20C_TNS_EE_02_001 TO 005	10010188	A: Lot# 072617-17583 B: Lot# 7156-1	02.12.18	03.27.18	04.05.18
QUA_B20C_TNS_EE_00_001				06.19.18	07.09.18

17.3. SPECIMEN PREPARATION

17.3.1. Specimen Size

Nominal specimen dimensions are equivalent to tensile tests as reported in Table 5.2.

17.3.2. Preparation Procedure

The specimens were cut to the prescribed dimensions in the primary fiber direction using a high precision diamond blade saw from different panels randomly selected as prepared and referenced in Section 4.2.1.

17.3.3. Conditioning Parameters

One specimen was conditioned under laboratory ambient conditions at room temperature 23 ± 1°C (73 ± 3°F) and 60 ± 5% relative humidity, during the exposure of the other specimens. The remaining five specimens were exposed to cycles consisting of 102 minutes light and 18 minutes light and water spray in the weatherometer chamber for a minimum duration of 2,000 hours, where the black-body temperature was set to 145°F (63°C).

17.4. TEST SET-UP

17.4.1. Set-up

Specimens were tested in pure tension as described in Chapter 5.

17.4.2. Rate and Method of Loading

Rate and method of loading are described in Chapter 5.

17.5. TEST RESULTS

17.5.1. Results Summary

No specimens showed surface changes affecting performance (such as erosion, cracking, crazing and chalking) after a visual inspection with a high resolution USB microscope with a varying magnification from x20 to x50, meeting the conditions of acceptance of AC125, as well as the 90% retention after a minimum of 2000 hrs. of exterior exposure.

17.5.2. Modes of Failure

Individual failure modes are reported in the tabulated results of this Chapter.

17.5.3. Calculations

Refer to applicable calculations and analysis of data in Chapter 5.

17.5.4. Tabulated Results

Table 17.2 contains the tabulated summary tensile test results after exterior exposure, and Table 17.3 the results for the control specimen as a reference for exterior exposure tests per AC125 requirements. Refer to the last column of the table where it states the strength retention of the physical mechanical property under evaluation. Note the results reported in Chapter 5.0 are used as reference values. Average, standard deviation (S_{n-1}), and coefficient of variance (CV) values are also reported, based on the complete set of specimens under evaluation for each product.

Table17.2 - Tabulated results for tensile tests for B20C (ASTM D3039) post exterior finish conditioning (ASTM D2565)

Specimen ID	*A*		*P^max^*		*F^tu^*		*E^chord^*		*ε~u~*	Failure Mode	Exposure	% Retention*		
	mm²	***in²***	***kN***	***lbs***	***MPa***	***ksi***	***GPa***	***Msi***	***%***		***hrs.***	***ε~u~***	***F^tu^***	***E^chord^***
QUA_B20C_TNS_EE_02_001	9.21	0.014	9.86	2215	1070.3	155.2	70.8	10.27	1.51	AGM		82	91	111
QUA_B20C_TNS_EE_02_002	9.11	0.014	11.53	2591	1265.4	183.5	68.9	10.00	1.84	AGM		99	108	108
QUA_B20C_TNS_EE_02_003	9.25	0.014	10.99	2470	1187.2	172.2	64.9	9.41	1.83	LGT	2000	99	101	102
QUA_B20C_TNS_EE_02_004	9.18	0.014	10.24	2301	1114.8	161.7	66.6	9.66	1.67	AGB		90	95	105
QUA_B20C_TNS_EE_02_005	9.07	0.014	11.50	2585	1267.6	183.9	65.5	9.51	1.93	LGB		105	108	103
Average	**9.16**	**0.014**	**10.82**	**2432**	**1181.1**	**171.3**	**67.3**	**9.77**	**1.76**			**95**	**101**	**106**
S_{n-1}	0.07	0.000	0.75	169	88.5	12.8	2.5	0.36	0.17					
CV (%)	0.8	0.8	7.0	7.0	7.5	7.5	3.7	3.7	9.4					

**Condition of acceptance is equivalent to 90% based on Chapter 5 values*

Table 17.3 – Exterior Exposure control/reference test specimen

Specimen ID	*A*		*P^max^*		*F^tu^*		*E^chord^*		*ε~u~*	Failure Mode
	mm²	***in²***	***kN***	***lbs***	***MPa***	***ksi***	***GPa***	***Msi***	***%***	
QUA_B20C_TNS_EE_00_001	9.12	0.014	11.35	2551	1244.2	180.5	68.4	9.92	1.82	AGT

18. FUEL RESISTANCE – ASTM C581

18.1. TEST SUMMARY

18.1.1. AC125 Section/s

Section 5.15, Table 2 for physical and mechanical properties of FRP composite materials.

18.1.2. Reference Standard/s

ASTM C581, Standard practice for determining chemical resistance of thermosetting Resins used in Glass-Fiber-Reinforced structures intended for liquid service

ASTM D3039/D3039M-17, Standard test method for Tensile Properties of Polymer Matrix Composite Materials.

ASTM D2344/D2344M-13, Standard test method for short-beam strength of polymer matrix composite materials and their laminates.

ASTM E1640-13, Standard test method for assignment of the glass transition temperature by dynamic mechanical analysis.

18.1.3. Test Objective

Determine the average experimental percentage retention of tensile strength, tensile modulus, elongation, glass transition temperature, and interlaminar shear strength, after exposure to diesel fuel reagent.

18.1.4. Product/s Under Evaluation

QuakeWrap™ TB20C with QuakeBond™ J300SR (in the primary direction) and QuakeBond™ J300SR.

18.1.5. Test Location

Structures and Materials Laboratory, SML, Main Laboratory, University of Miami, 1251 Memorial Dr., MEB108 Coral Gables, FL, 33146

18.1.6. Laboratory Technician/s

Ming Han, Tais Hamilton and Christian Marquina.

18.1.7. Technical Test Record

The date of each test; variations to the test method as applicable; calibration information for all measurements and test equipment; identification of the material tested; temperature and humidity of testing laboratory; and other applicable test data or details are provided in the Technical Test Record document number TDS-QUA-TNS-FR, TDS-QUA-ISS-FR, TDS-QUA-TG-FR.

18.2. TEST MATRIX

18.2.1. Specimen Number

Specimens were made from different FRP panels, where five test repetitions per physical/mechanical test designation (ASTM D3039, ASTM D2344 and ASTM E1640) were performed. A total of five test per test type are reported, refer to Table 18.1.

18.2.2. Specimen ID Nomenclature

Specimens are identified throughout the report using the format described in Section 4.5 of this document.

18.2.3. Test Matrix Table

Table 18.1– Test matrix for tests post fuel resistance conditioning

Specimen ID	Fiber Lot #	Resin Batch #	Specimen Preparation (mm.dd.yy)	Tested (mm.dd.yy)
QUA_B20C_TNS_FR_001 to 005	10010188	A: Lot# 072617-17583 B: Lot# 7156-1	01.31.18	05.04.18
QUA_B20C_ISS_FR_001 to 005				04.30.18
QUA_J300_TG_FR_001 to 005				05.03.18

18.3. SPECIMEN PREPARATION

18.3.1. Specimen Size and Preparation Procedure

Nominal specimen geometry, layout and preparation procedure for varied each test type, as previously referenced in Chapter 5 for tensile tests; Chapter 10 for interlaminar shear strength; and Chapter 9 for glass transition temperature. Individual specimen geometry parameters are reported the results section of this Chapter.

18.3.2. Conditioning Parameters

FRP panels were exposed to diesel fuel reagent by submerging them in an environmental chamber for minimum four hours according to ASTM C581, at laboratory conditions.

18.4. TEST SET-UP

18.4.1. Set-up

Upon completion of diesel exposure, specimens were removed from the chamber and wiped to dry the surface. A visual inspection was conducted immediately after the removal of the specimens from the chamber. Prior physical and mechanical testing, a recovery period long enough so that the specimens reached equilibrium with laboratory testing conditions was established, (generally 24 hours). Following the recovery period, specimens were tested. Refer to applicable test set-ups in Chapter 5 for tensile tests; Chapter 10 for interlaminar shear strength; and Chapter 9 for glass transition temperature.

18.4.2. Rate and Method of Loading

Refer to applicable rates and method of loading in Chapter 5 for tensile tests; Chapter 10 for interlaminar shear strength; and Chapter 9 for glass transition temperature.

18.5. TEST RESULTS

18.5.1. Results Summary

No specimens showed surface changes (such as erosion, cracking, crazing and chalking) after a visual inspection with a high resolution USB microscope with a varying magnification from x20 to x50. No specific conditions of acceptance are stated this test under AC125, nonetheless, a similar analytical approach has been followed to the other aging environments, where the percentage of retention has been reported, refer to the tabulated section of this chapter for detailed results.

18.5.2. Modes of Failure

Modes of failure for the different physical and mechanical tests after fuel resistance conditioning are reported in the tabulated results of this Chapter.

18.5.3. Calculations

Refer to applicable calculations and analysis of data in Chapter 5 for tensile tests; Chapter 10 for interlaminar shear strength; and Chapter 9for glass transition temperature.

18.5.4. Tabulated Results

Table 18.2 through Table 18.4, contain the tabulated summary results after fuel resistance exposure for the tensile, interlaminar shear strength and glass transition temperature tests respectively. Average, standard deviation (S_{n-1}), and coefficient of variance (CV) values are also reported, based on the complete set of specimens under evaluation for each product.

Table 18.2 - Tabulated results for tensile tests for B20C (ASTM D3039) post fuel resistance conditioning (ASTM C581)

Specimen ID	A		P^{max}		F^{tu}		E^{chord}		ε_u	Failure	Exposure	% Retention*		
	mm²	in²	kN	lbs	MPa	ksi	GPa	Msi	με	Mode	hrs.	F^{tu}	E^{chord}	ε_u
QUA_B20C_TNS_FR_001	12.45	0.019	13.74	3087	1102.6	159.9	60.1	8.72	1.83	LGM, LAT		99	94	95
QUA_B20C_TNS_FR_002	11.68	0.018	13.13	2950	1123.2	162.9	71.0	10.30	1.58	LAT		85	96	112
QUA_B20C_TNS_FR_003	13.09	0.020	14.81	3329	1131.1	164.1	60.8	8.82	1.86	LGB	4	101	96	96
QUA_B20C_TNS_FR_004	12.82	0.020	14.14	3178	1102.5	159.9	69.5	10.08	1.59	LAT, LAB		86	94	109
QUA_B20C_TNS_FR_005	11.56	0.018	12.57	2825	1086.9	157.6	63.1	9.15	1.72	LAB		93	93	99
Average	**12.32**	**0.019**	**13.68**	**3074**	**1109.3**	**160.9**	**64.9**	**9.41**	**1.72**			**93**	**95**	**102**
S_{n-1}	0.68	0.001	0.87	196	17.8	2.6	5.0	0.73	0.13					
CV (%)	5.5	5.5	6.4	6.4	1.6	1.6	7.8	7.8	7.7					

**No conditions of acceptance specified in AC125*

Table 18.3 - Tabulated results for interlaminar shear tests B20C (ASTM D2344) post fuel resistance conditioning (ASTM C581)

Specimen ID	b		h		P_m		F^{sbs}		Failure Mode	Exposure	% Retention
	mm	in	mm	in	kN	lbf	MPa	ksi		hrs.	F^{sbs}
QUA_B20C_ISS_FR_001	8.93	0.35	3.48	0.14	1.66	373.0	40.05	5.81	1		90
QUA_B20C_ISS_FR_002	9.93	0.39	3.52	0.14	1.96	441.0	42.11	6.11	1		95
QUA_B20C_ISS_FR_003	9.45	0.37	3.51	0.14	1.96	441.0	44.42	6.44	1	4	100
QUA_B20C_ISS_FR_004	7.89	0.31	2.90	0.11	1.28	287.0	41.93	6.08	1		94
QUA_B20C_ISS_FR_005	9.18	0.36	3.24	0.13	1.82	408.0	45.77	6.64	1		103
Average	**9.08**	**0.36**	**3.33**	**0.13**	**1.74**	**390.0**	**42.86**	**6.22**			**97**
S_{n-1}	0.76	0.03	0.27	0.01	0.29	64.1	2.25	0.33			
CV (%)	8.4	8.4	8.0	8.0	16.4	16.4	5.2	5.2			

**No conditions of acceptance specified in AC125*

Table 18.4 -Tabulated results for glass transition temperature for J300 (ASTM D2344) post fuel resistance conditioning (ASTM C581)

Specimen ID	**T_g °C**	**T_g °F**	**Exposure Hrs.**	**Acceptance Criteria***
QUA_J300_TG_FR_001	69.0	156.2		Pass
QUA_J300_TG_FR_002	67.6	153.6		Pass
QUA_J300_TG_FR_003	68.0	154.3	4	Pass
QUA_J300_TG_FR_004	67.8	154.0		Pass
QUA_J300_TG_FR_005	70.4	158.8		Pass
Average	**68.5**	**155.4**		
S_{n-1}	1.2	2.1		
CV%)	1.7	1.4		

**Condition of acceptance is equivalent to T_g > 60°C (140°F)*

19. ALKALINE SOIL RESISTANCE

19.1. TEST SUMMARY

19.1.1. AC125 Section/s

Section 5.12, Alkaline Soil Resistance.

19.1.2. Reference Standard/s

ASTM D3083-89, Specification for Flexible Poly (Vinyl Chloride) Plastic Sheeting for Pond, Canal, and Reservoir Lining (Withdrawn 1998)

ASTM D3039/D3039M – 17, Standard test method for Tensile Properties of Polymer Matrix Composite Materials.

19.1.3. Test Objective

Determine the average experimental percentage retention of tensile strength, tensile modulus, elongation post exposure to alkaline soil.

19.1.4. Product/s Under Evaluation

QuakeWrap™ TB20C with QuakeBond™ J300SR.

19.1.5. Test Location

Structures and Materials Laboratory, SML, Main Laboratory, University of Miami, 1251 Memorial Dr., MEB108 Coral Gables, FL, 33146

19.1.6. Laboratory Technician/s

Ming Han and Francisco De Caso

19.1.7. Technical Test Record

The date of each test; variations to the test method as applicable; calibration information for all measurements and test equipment; identification of the material tested; temperature and humidity of testing laboratory; and other applicable test data or details are provided in the Technical Test Record document number TDS-QUA-TNS-SR.

19.2. TEST MATRIX

19.2.1. Specimen Number

Specimens came from the same exposed FRP panel, where five test repetitions were tested, refer to Table 19.1.

19.2.2. Specimen ID Nomenclature

Specimens are identified through the report using the format described in Section 4.5 of this document.

19.2.3. Test Matrix Table

Table 19.1– Test matrix for tensile tests post alkaline soil resiatnce conditioning

Specimen ID	**FRP Batch ID**		**Aging**		**Tested**
	Fiber #	***Resin #***	***Start mm.dd.yy***	***Finish mm.dd.yy***	***mm.dd.yy***
QUA_B20C_TNS_SR_01_001 TO 005	10010188	A: Lot# 072617-17583 B: Lot# 7156-1	05.28.18	07.09.18	07.20.18

19.3. SPECIMEN PREPARATION

19.3.1. Specimen Size and Preparation Procedure

Nominal specimen geometry, layout and preparation procedure are previously referenced in Chapter 5 for tensile tests.

19.3.2. Conditioning Parameters

All specimens were conditioned and aged vertically by buring them a depth of approximately 127 mm (5.0 in.) in a soil chamber containing soil rich in cellulose-destroying micro-organisms (prepared with garden compost) for a minimum period of 1000 hrs. where each the panel was surrounded by soil. The conditions of the soil chamber were a pH of 7.0, moisture between 25 and 30%, and a temperature 35 ± 2°C (95 ± 6°F). The soil chamber was checked approximately every 200 hours to ensure proper conditions and microbiological activity (via use of untreated cotton duck) for quality purposes.

19.4. TEST SET-UP

19.4.1. Set-up

Upon completion of exposure, specimens were removed from the environmental test chamber and wiped to dry the surface. A visual inspection was conducted immediately after the removal of the specimens from the chamber. Prior to physical and mechanical testing, a recovery period long enough so that the specimens reached moisture equilibrium with laboratory testing conditions was established (minimum 3 days). Following the recovery period, specimens were tested. Refer to applicable test set-ups in in Chapter 5 for tensile tests

19.4.2. Rate and Method of Loading

Refer to applicable rate and method of loading in Chapter 5.

19.5. TEST RESULTS

19.5.1. Results Summary

No specimens showed surface changes (such as erosion, cracking, crazing and chalking) after a visual inspection with a high resolution USB microscope with a varying magnification from x20 to x50, meeting the conditions of acceptance of AC125, as well as 90% retention post minimum 1000 hrs. of exposure.

19.5.2. Modes of Failure

Modes of failure are reported in the tabulated results of this Chapter.

19.5.3. Calculations

Refer to applicable calculations and analysis of data in Chapter 5 for tensile tests.

19.5.4. Tabulated Results

Table 19.2 contains the tabulated summary results after alkaline soil resistance conditioning for the tensile strength test. Refer to the last column of each table where it states the percentage retention of the physical mechanical property under evaluation. Average, standard deviation (S_{n-1}), and coefficient of variance (CV) values are also reported, based on the complete set of specimens under evaluation for each product.

Table 19.2 - Tabulated results for tensile tests for B20C (ASTM D3039) post alkaline soil resistance conditioning (ASTM D3083)

Specimen ID	A		P^{max}		F^{tu}		E^{chord}		ε_u	Failure Mode	Exposure	% Retention*		
	mm²	in.²	kN	lbs	MPa	ksi	GPa	Msi	%		hrs.	F^{tu}	E^{chord}	ε_u
QUA_B20C_TNS_SR_01_001	10.68	0.017	11.53	2591	0.52	2975	64.9	9.41	1.66	LGB	1000	90	92	102
QUA_B20C_TNS_SR_01_002	9.94	0.015	11.13	2502	0.54	3085	59.8	8.67	1.87	AGT		101	95	94
QUA_B20C_TNS_SR_01_003	9.72	0.015	10.57	2376	0.52	2996	60.8	8.82	1.79	AGT		97	93	96
QUA_B20C_TNS_SR_01_004	9.77	0.015	10.19	2289	0.50	2872	65.5	9.51	1.59	LGM		86	89	103
QUA_B20C_TNS_SR_01_005	9.82	0.015	11.59	2605	0.57	3252	60.0	8.71	1.97	AGB		106	101	94
Average	**9.99**	**0.015**	**11.00**	**2473**	**0.53**	**3036**	**62.2**	**9.02**	**1.78**			**96**	**94**	**98**
S_{n-1}	0.40	0.001	0.61	137	0.02	143	2.8	0.40	0.15					
CV (%)	4.0	4.0	5.6	5.6	4.7	4.7	4.5	4.5	8.6					

**Condition of acceptance is equivalent to 90%*

20. INTERIOR FINISH – ASTM E84

The interior finish test (Section 5.14 of AC125) was performed by an independent laboratory *QAI Laboratories, Certification Testing Inspection,* which is an ISO 17025 accredited laboratory by the International Accreditation Service (IAS). The test report contains full details of the interior finish test, and is provided as an attachment to this report. Results are summarized herein:

Test Report number: **RJ0000-0**, with test results equivalent to a flame spread index of X, and smoke development index of X.

♦ END OF TEST REPORT ♦