University of Miami
College of Engineering
Structures and Materials Laboratory

Center for Integration of Composites into Infrastructure

CERTIFIED TEST REPORT

EVALUATION OF
DowAksa CarbonWrap^{TM}
FRP STRENGTHENING COMPOSITE SYSTEMS FOR CONCRETE ACCEPTANCE CRITERIA - AC125

Report Number: R-5.10_DOA_13-12-11.2

REVISION 2

September 15, 2016

REPORT PREPARED FOR:

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IAS ACCREDITED

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Superseded Report	R-5.10_DOA_13-12-11.1
Reason for Revision Effective Date	Addition of results 3000hrs aged interlaminar shear strength. September 15, 2016
Superseded Report	R-5.10_DOA_13-12-11
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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: September 15, 2016
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: September 15, 2016

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1. INTRODUCTION

1.1. PURPOSE

The purpose of this document is to a test plan to develop an ICC-ES Evaluation Report for file #13-12-11 for the applicant DowAksa CarbonWrap™ for Concrete Strengthening Using CarbonWrap™ Fiber-Reinforced Polymer Composite System that includes two carbon fabric materials (CFU-10T, CFU-20T) in combination with a polymer matrix (Carbon Bond 300 HT). This document presents the proposed qualifying test plan to evaluate the mechanical properties and environmental durability of the FRP strengthen systems to obtain an Evaluation Service Report (ESR). The test plan is designed 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, also technical representative of file #13-12-11. 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. CFU-10T

Uni-directional carbon fiber sheet with a minimum nominal fiber density of 340 gsm (10 oz/yd^2).

1.3.2. CFU-20T

Uni-directional carbon fiber sheet with a minimum nominal fiber density of 680 gsm (20 oz/yd^2).

1.3.3. Carbon Bond 300 HT

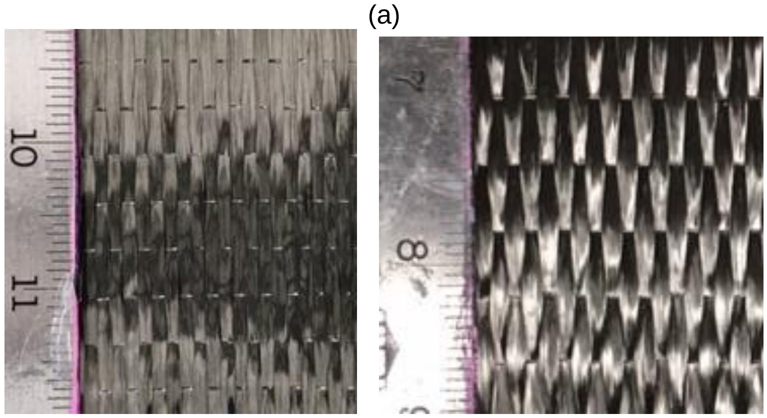
A two part 100% solids polymer matrix resin system used to saturate the fiber sheets composed of part A, 300 HT-A; and part B, 300 HT-B.

Refer to Table 1.1 and Figure 1.1 for the summary of the FRP systems under evaluation and 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
CFU-10T + Carbon Bond 300 HT	Uni-directional	C10T
CFU-20T + Carbon Bond 300 HT		C20T

(a)



(b) (c)

Figure 1.1 – Products under evaluation, (a) Carbon Bond 300 HT; (b) CFU-10T and (c) CFU-20T

1.4. CLIENT INFORMATION

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

DowAksa CarbonWrap™
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Global Director; Infrastructure Division
2820 E. Ft Lowell Rd. Tucson, AZ 85718, USA
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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 by a third party accredited entity

2.1.2. Sampling Data Report

A full detailed sampling report containing the sampling criteria, method, selection, and product information is described by the third party as indicated in document number **DA-1.1_10.06.15_TUS**.

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 Carbon Bond 300 HT was implemented following the manufacturer's specifications, where mixing of the approved resin was performed by trained personnel, as seen in Figure 4.1. The two part resin was mixed completely until a smooth, uniform streak-free consistency was reached.

4.1.1. *Mixing ratio*

Carbon Bond 300 HT part A and part B of the epoxy resin were mixed together in agreement with the mixing ratio suggested by the manufacturer's instructions by weight as follows:

- 100 part A to 32.4 part B

Figure 4.1 – Mixing of Carbon Bond 300 HT

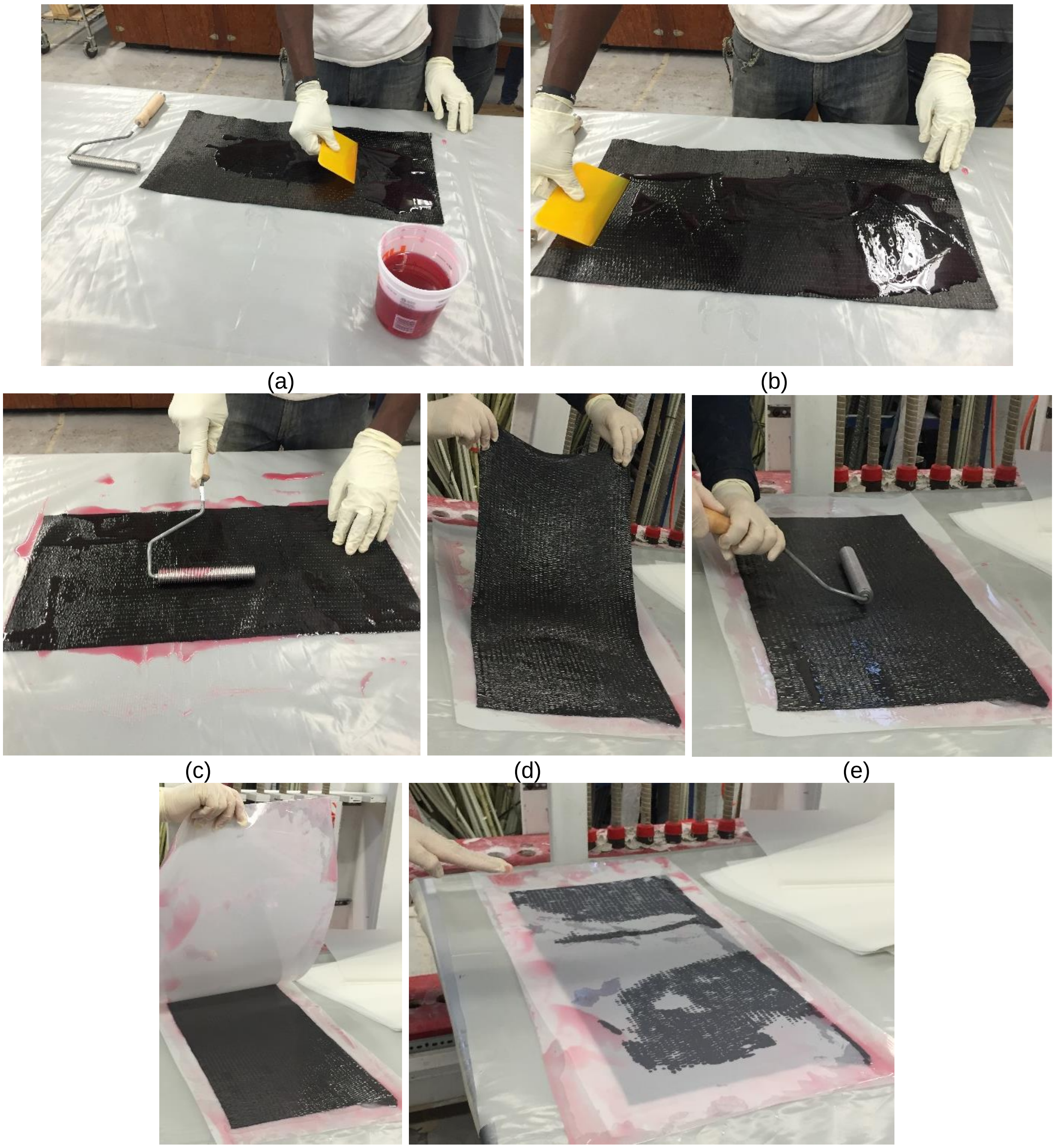
4.2. PRODUCT INSTALLATION

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*

Resin mix and fiber impregnation: 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. The saturate fiber sheet is them placed on an adhesion free film and rolled to ensure fibers are aligned. 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 4.2.

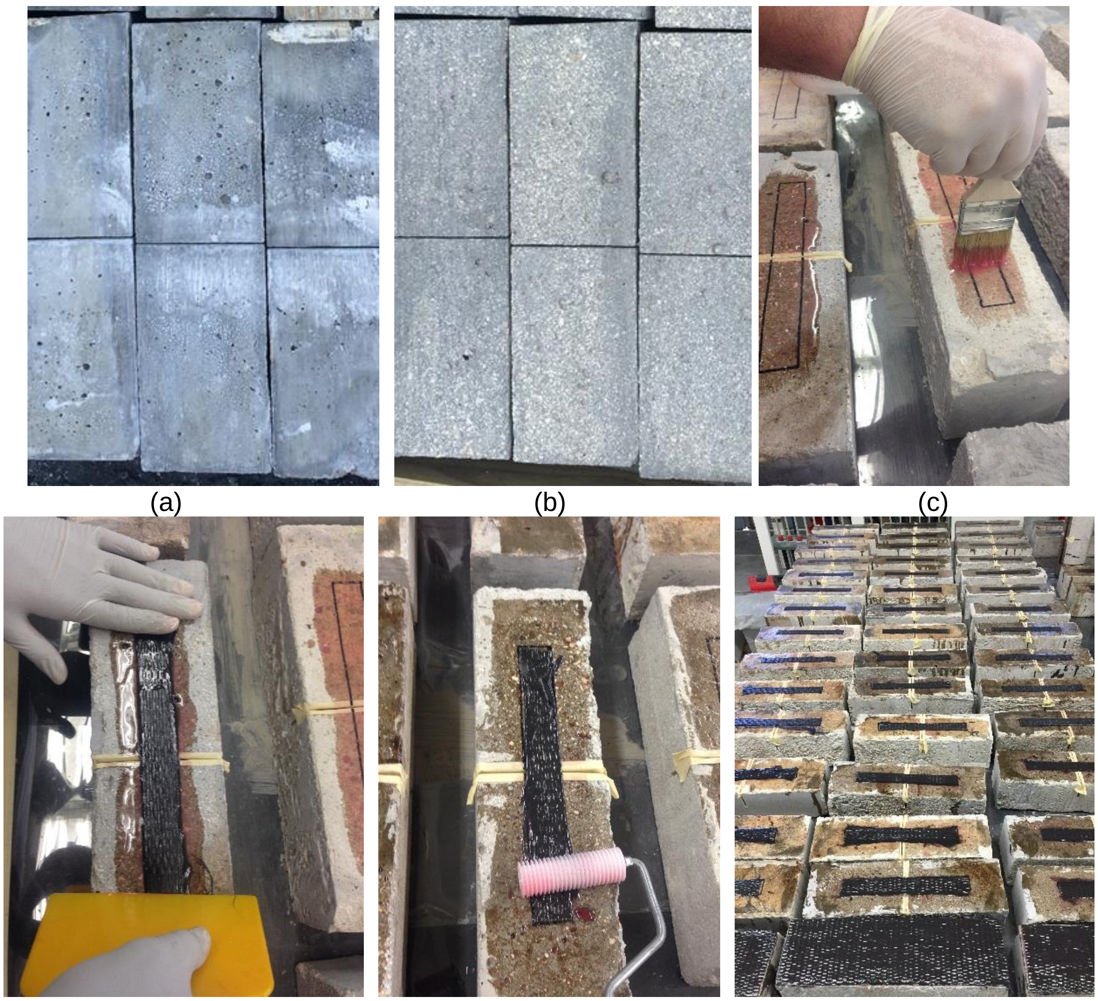


(a) (b) (c) (d) (e) (f) (g)

Figure 4.2 – Preparation of FRP panels by manual wet layup process

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. Full installation was performed by trained SML personnel. Before the installation of the FRP strengthening system, the concrete substrate surface was prepared to ensure that a minimum surface roughness of CPS 3 as defined by ICRI was achieved. The prepared concrete surface was primed using the Carbon Bond 300 HT 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 4.3



(a) (b) (c)
(d) (e) (f)

Figure 4.3 – 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.

All test specimens for structural tests have been uniquely labeled and identified for quality and traceability using the format:

CCC_PPPP_SSS_M_Y_XXX,

where CCC is the company name, PPPP is the product, SSS is the structural element and test type, M is the type and nominal strength of the substrate material, Y is the number of applied plies to the structural element, and XXX is the sample number. The detailed nomenclature is reported in Table 4.2.

Table 4.1 – Specimen identification for characterization tests

Parameter description	Detail		ID
Company name	DowAksa CarbonWrap™		DOA
Product	CFU-10T + Carbon Bond 300 HT		C10T
	CFU-20T + Carbon Bond 300 HT		C20T
	Carbon Bond 300 HT		CBHT
Mechanical property	Tensile Strength		TNS
	Glass Transition Temperature		TG
	Coef. of Thermal Expansion		CTE
	Creep Rupture		CRP
	Void content		VDC
	Interlaminar shear strength		ISS
	Bond Strength Tension	Concrete	BTC
	Bond Strength Shear	Concrete	BSC

Table 4.1 continuation - Specimen identification for characterization tests

Parameter description	Detail	ID

Exposure	None (control/benchmark tests)	CC
	Water Resistance	WR
	Saltwater Resistance	SW
	Alkaline Resistance	AR
	Dry Heat Resistance	DH
	Freezing and Thawing	FT
	Fuel Resistance	FR
	Exterior Exposure	EE
Exposure duration/ Test direction	1,000 hrs	01
	2,000 hrs	02
	3,000 hrs	03
	10,000 hrs	10
	Test direction relative to fiber sheet: 0º	00
	90º	90

Table 4.2 – Specimen identification for structural tests

Parameter description	**Detail**	**ID**
Company name	DowAksa CarbonWrap™	DOA
Product	CFU-10T + Carbon Bond 300 HT	C10T
	CFU-20T + Carbon Bond 300 HT	C20T
Structural element	Flexural Column	FLC
	Shear Column	SHC
	Axial Column	AXC
	Flexural Wall	FLW
	Shear Wall	SHW
	Fire Resistance Construction	FRC
Substrate material	Low strength concrete	L
	High strength concrete	H
	Concrete Masonry Unit (CMU)	U
FRP strengthening level	0 ply (control/benchmark)	0
	Number of plies on element	#

5. TENSILE PROPERTIES – 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 – 14, 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 benchmark (without any aging or environmental exposure). Average properties include experimental tensile chord modulus of elasticity, ultimate tensile stress and ultimate tensile strain (elongation).

5.1.4. Product/s Under Evaluation

CFU-10T fabric with Carbon Bond 300 HT resin (tested in the fiber direction: 0º). Note testing for CFU-20T has been provided.

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 and Andrea Correa.

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-DOA.

5.2. TEST MATRIX

5.2.1. Specimen Number

A total of 20 tests 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 testing coupon specimens (no aging).

Specimen ID	Fiber Lot #	Resin Batch #	Specimen Preparation (mm.dd.yy)	Tested (mm.dd.yy)
DOA_C10T_TNS_CC_001 to 010	Style# 1286/01/00	A: Batch# D553G3O081 and GMID# 97000852	02.01.16	03.15.16
DOA_C10T _TNS_CC_011 to 020		B: Batch# D553G29000 and GMID#97000847		03.21.16

5.3. SPECIMEN PREPARATION

5.3.1. *Specimen Size*

Nominal specimen dimensions are summarized in Table 5.2, including length and thickness. Computed average area is reported in Table 5.5 of this document.

Table 5.2 – Tensile specimen nominal dimensions

Specimen ID	Length		Thickness	
	mm	*in.*	*mm*	*in.*
DOA_C10T_TNS_EE	254.0	10.0	0.533	0.021

5.3.2. *Specimen Layout*

Specimens were obtained from manually fabricated FRP panels.

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, as prepared and referenced in Section 4.2.2. 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 with a maximum capacity of 100 kN (22 kip). 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 of 11.7 MPa (1700 psi). The test set up is shown is Figure 5.1. All data was gathered using a National Instruments data acquisition system at a rate of 100 Hz.

Figure 5.1 - Tensile test set-up

5.4.2. <u>Rate and Method of Loading</u>

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. <u>Results Summary</u>

All specimens behaved linear elastically until failure. Based on the experimental tests presented herein the average ultimate tensile strength (F^{tu}), the computed average ultimate 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 5.3.

Table 5.3 – Average result for tensile specimens per ASTM D3039

ID	P^{max} / W		F^{tu}		ε_u	E^{chord}	
	kN/mm	lbs/in.	*MPa*	*ksi*	*%*	*GPa*	*Msi*
DOA_C10T_TNS_CC	0.752	4290	1408	204.3	1.56	90.41	13.12

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 system.

(a) (b)

Figure 5.2 – Representative longitudinal splitting 'SGM' (a) and angled 'AGM' (b) failure modes.

5.5.3. Calculations

The results reported herein have been computed as per ASTM D3039 and summarized 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 5.4 - Definitions of calculations

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 5.5, based on nominal thickness.
F^{tu}	Ultimate tensile strength	$F^{tu} = P^{max}/A$
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
E^{chord}	Tensile chord modulus of elasticity, based on strain gauge measurement	Difference in applied tensile stress between the 1000 and 3000 με points (Δσ); divided by the difference between the two strain points, nominally 0.002 (Δε) as measured $E^{chord} = \Delta\sigma/\Delta\varepsilon$

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); 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 5.5 - Tabulated results for tensile test for CFU-10T, 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	%	
DOA_C10T_TNS_CC_001	25.91	1.020	13.82	0.021	18.67	4195	0.721	4113	1350	195.8	88.57	12.85	1.52	SGM
DOA_C10T_TNS_CC_002	28.12	1.107	15.00	0.023	20.60	4630	0.733	4182	1373	199.2	90.91	13.19	1.51	SGM
DOA_C10T_TNS_CC_003	28.04	1.104	14.96	0.023	20.50	4606	0.731	4172	1370	198.7	87.22	12.66	1.57	SMG
DOA_C10T_TNS_CC_004	27.00	1.063	14.40	0.022	20.16	4530	0.747	4262	1399	202.9	95.15	13.81	1.47	AGM
DOA_C10T_TNS_CC_005	27.53	1.084	14.69	0.023	20.51	4610	0.745	4253	1396	202.5	91.18	13.23	1.53	LGM
DOA_C10T_TNS_CC_006	27.61	1.087	14.73	0.023	20.18	4535	0.731	4172	1370	198.7	86.59	12.56	1.58	SGM
DOA_C10T_TNS_CC_007	25.48	1.003	13.59	0.021	18.66	4193	0.732	4180	1373	199.1	90.10	13.07	1.52	GSM
DOA_C10T_TNS_CC_008	28.14	1.108	15.01	0.023	20.21	4541	0.718	4098	1346	195.2	90.01	13.06	1.49	LGM
DOA_C10T_TNS_CC_009	27.23	1.072	14.52	0.023	20.81	4676	0.764	4362	1432	207.7	87.76	12.73	1.63	AGM
DOA_C10T_TNS_CC_010	26.54	1.045	14.16	0.022	18.75	4213	0.706	4032	1324	192.0	90.28	13.10	1.47	AGM
DOA_C10T_TNS_CC_011	26.72	1.052	14.25	0.022	20.47	4601	0.766	4374	1436	208.3	90.37	13.11	1.59	SGM
DOA_C10T_TNS_CC_012	26.24	1.033	14.00	0.022	20.98	4714	0.799	4563	1498	217.3	93.07	13.50	1.61	AGM
DOA_C10T_TNS_CC_013	24.77	0.975	13.21	0.020	21.08	4737	0.851	4858	1595	231.4	95.33	13.83	1.67	SGM
DOA_C10T_TNS_CC_014	26.77	1.054	14.28	0.022	20.00	4494	0.747	4264	1400	203.0	91.18	13.23	1.53	SGM
DOA_C10T_TNS_CC_015	25.70	1.012	13.71	0.021	20.39	4583	0.793	4529	1487	215.7	92.08	13.36	1.61	SGM
DOA_C10T_TNS_CC_016	27.84	1.096	14.85	0.023	20.39	4582	0.732	4181	1373	199.1	89.20	12.94	1.54	AGM
DOA_C10T_TNS_CC_017	26.82	1.056	14.31	0.022	19.00	4269	0.708	4043	1327	192.5	86.50	12.55	1.53	SGM
DOA_C10T_TNS_CC_018	25.70	1.012	13.71	0.021	19.93	4479	0.775	4426	1453	210.8	88.12	12.79	1.65	AGM
DOA_C10T_TNS_CC_019	27.84	1.096	14.85	0.023	20.39	4583	0.733	4182	1373	199.1	87.85	12.75	1.56	AGM
DOA_C10T_TNS_CC_020	25.63	1.009	13.67	0.021	20.41	4587	0.796	4546	1493	216.5	96.86	14.05	1.54	LGM
Average	**26.78**	**1.054**	**14.29**	**0.022**	**20.10**	**4518**	**0.752**	**4290**	**1408**	**204.3**	**90.41**	**13.12**	**1.56**	
S_{n-1}	1.01	0.040	0.54	0.001	0.74	167	0.037	208	68	9.9	2.93	0.43	0.06	
CV((%)	3.8	3.8	0.4	3.8	3.7	3.7	4.9	4.9	4.9	4.9	3.2	3.2	3.7	

6. COEFFICIENT OF THERMAL EXPANSION – 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 – 13, 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

CFU-10T and CFU-20T fabrics with Carbon Bond 300 HT resin, (tested in the fiber direction: 0º and perpendicular to the fiber direction: 90º).

6.1.5. Test Location

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

6.1.6. Laboratory Technician/s

BK

6.2. TEST MATRIX

6.2.1. Specimen Number

A total of 10 tests are reported per product under evaluation, refer to Table 6.1, where five 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 CTE specimens (no aging).

Specimen ID	Fiber Lot #	Resin Batch #	Specimen Preparation (mm.dd.yy)	Tested (mm.dd.yy)
DOA_C10T_CTE_CC_00_001 to 005	Style# 1286/01/00	A: Batch#D553G3O081 and GMID# 97000852 B: Batch#D553G29000 and GMID#97000847	05.06.16	06.23.16
DOA_C10T_CTE_CC_90_001 to 005				06.24.16
DOA_C20T_CTE_CC_00_001 to 005	Style# 1167/01/06			06.22.16
DOA_C20T_CTE_CC_90_001 to 005				06.23.16

6.3. SPECIMEN PREPARATION

6.3.1. Specimen Size

Nominal square specimen dimensions were 13 mm (0.51 in.) in length/width and 3 mm (0.12 in.) in thickness.

6.3.2. Preparation Procedure

The specimens were cut to the prescribed dimensions from a multi-ply panel as prepared and referenced in Section 4.2.2.

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 6.2.

Table 6.2 – Average results for CTE specimens

Specimen ID	α_m	
	µm/m/°C	µin./in./·°F
DOA_C10T_CTE_CC_00	3.9	2.2
DOA_C10T_CTE_CC_90	58.5	32.5
DOA_C20T_CTE_CC_00	2.1	1.2
DOA_C20T_CTE_CC_90	56.8	31.6

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 6.4.

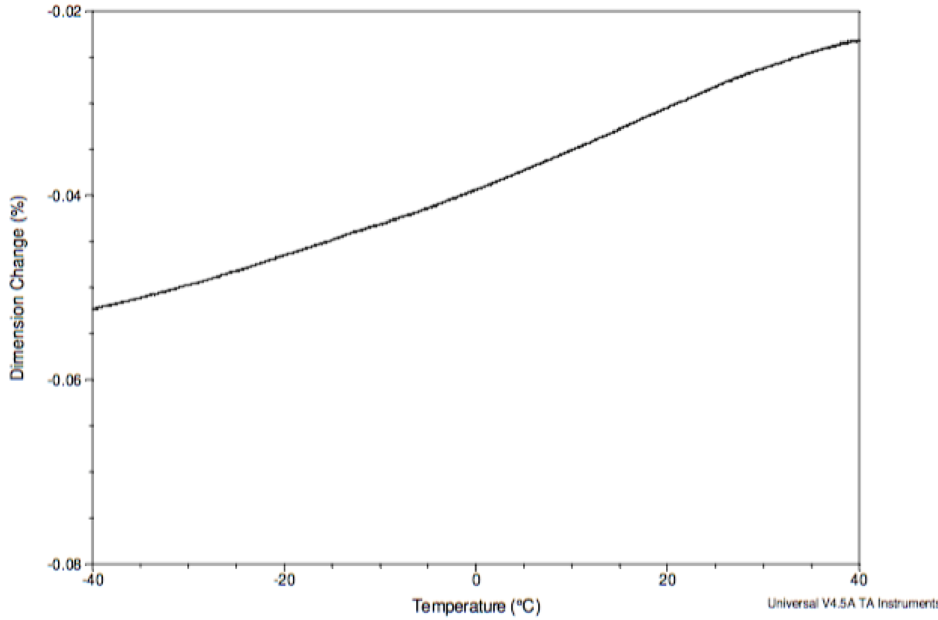


Figure 6.1 – Typical TMA graph for C10T specimens tested parallel to the fiber direction (00).

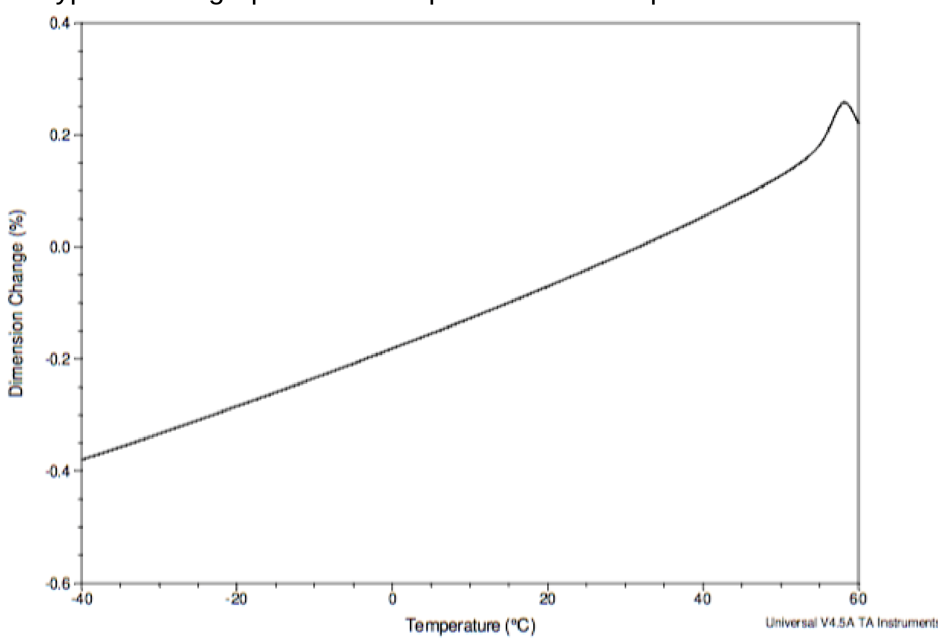


Figure 6.2– Typical TMA graph for C10T specimens tested perpendicular to the fiber direction (90).

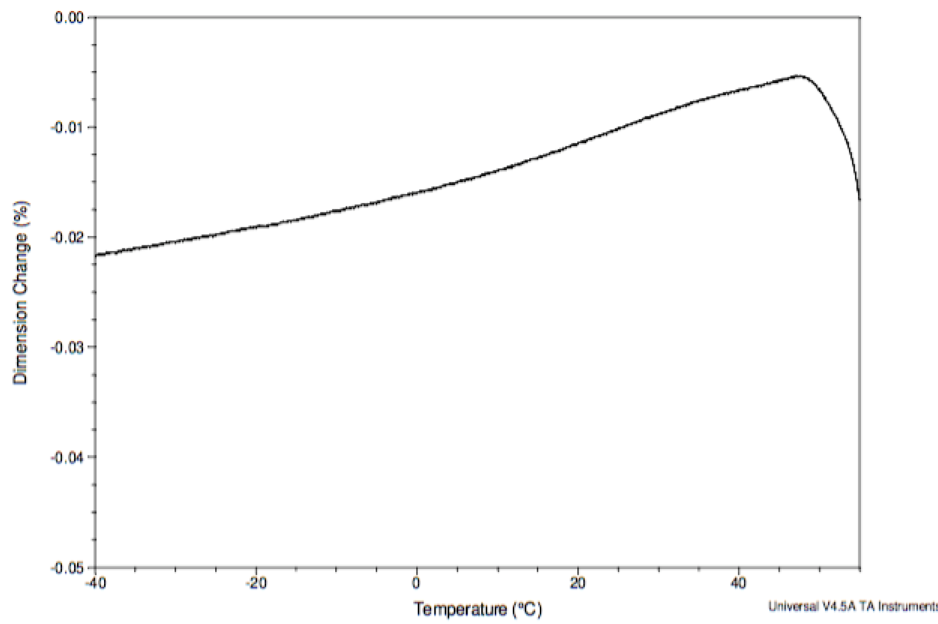


Figure 6.3 – Typical TMA graph for C20T specimens tested parallel to the fiber direction (00).

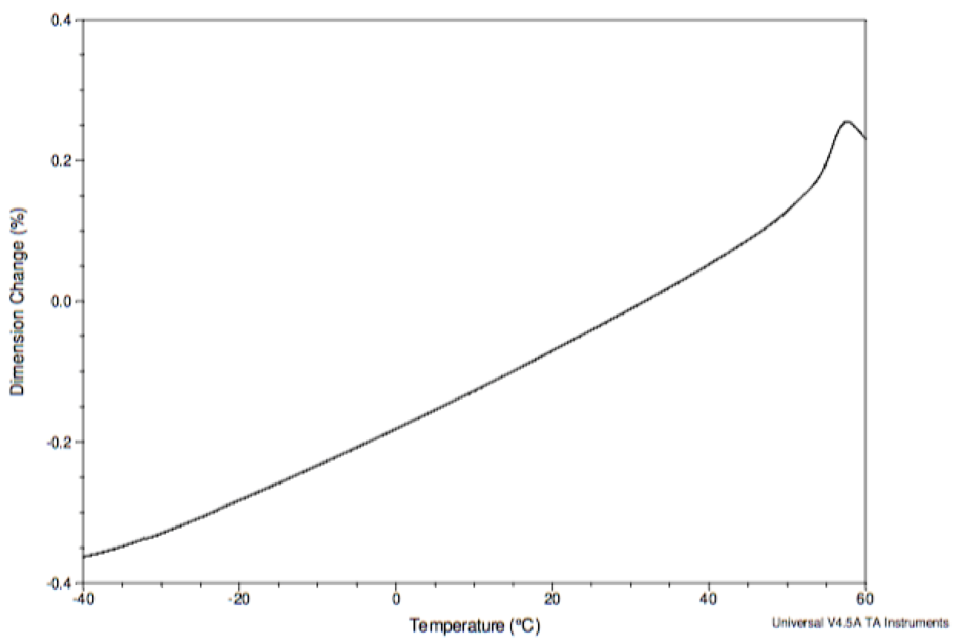


Figure 6.4– Typical TMA graph for C20T specimens tested perpendicular to the fiber direction (90).

6.5.4. Tabulated Results

Table 6.3 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 6.3 - Tabulated results for Coef. of Thermal Expansion for CFU-10T and CFU-20T, per ASTM E831

Specimen ID	*L*		T_s		T_e		α_m	
	mm	*in*	*°C*	*°F*	*°C*	*°F*	*µm/(m·°C)*	*µin/(in°F)*
DOA_C10T_CTE_CC_00_001	10.700	0.4213	-30	-22	30	86	3.9	2.2
DOA_C10T_CTE_CC_00_002	10.863	0.4277	-30	-22	30	86	3.4	1.9
DOA_C10T_CTE_CC_00_003	11.084	0.4364	-30	-22	30	86	5.1	2.8
DOA_C10T_CTE_CC_00_004	10.710	0.4217	-30	-22	30	86	3.1	1.7
DOA_C10T_CTE_CC_00_005	10.856	0.4274	-30	-22	30	86	3.9	2.2
Average	**10.843**	**0.4269**					**3.9**	**2.2**
S_{n-1}	0.156	0.0061					0.8	0.4
CV((%)	1.4	1.4					19.7	19.3
DOA_C10T_CTE_CC_90_001	8.048	0.3169	-30	-22	50	122	57.6	32.0
DOA_C10T_CTE_CC_90_002	9.702	0.3820	-30	-22	50	122	57.2	31.8
DOA_C10T_CTE_CC_90_003	9.188	0.3617	-30	-22	50	122	57.6	32.0
DOA_C10T_CTE_CC_90_004	8.727	0.3436	-30	-22	50	122	60.8	33.8
DOA_C10T_CTE_CC_90_005	8.420	0.3315	-30	-22	50	122	59.2	32.9
Average	**8.817**	**0.3471**					**58.5**	**32.5**
S_{n-1}	0.648	0.0255					1.5	0.8
CV((%)	7.3	7.3					2.6	2.6
DOA_C20T_CTE_CC_00_001	10.810	0.4256	-30	-22	45	113	2.0	1.1
DOA_C20T_CTE_CC_00_002	10.858	0.4275	-30	-22	45	113	2.0	1.1
DOA_C20T_CTE_CC_00_003	9.038	0.3558	-30	-22	45	113	1.1	0.6
DOA_C20T_CTE_CC_00_004	10.229	0.4027	-30	-22	45	113	4.2	2.3
DOA_C20T_CTE_CC_00_005	12.256	0.4825	-30	-22	45	113	1.4	0.8
Average	**10.638**	**0.4188**					**2.1**	**1.2**
S_{n-1}	1.164	0.0458					1.2	0.7
CV((%)	10.9	10.9					56.8	56.0
DOA_C20T_CTE_CC_90_001	12.080	0.4756	-30	-22	50	122	56.1	31.2
DOA_C20T_CTE_CC_90_002	12.854	0.5061	-30	-22	50	122	56.4	31.3
DOA_C20T_CTE_CC_90_003	12.386	0.4876	-30	-22	50	122	57.3	31.8
DOA_C20T_CTE_CC_90_004	12.006	0.4727	-30	-22	50	122	57.3	31.9
DOA_C20T_CTE_CC_90_005	13.209	0.5200	-30	-22	50	122	57.0	31,7
Average	**12.507**	**0.4924**					**56.8**	**31.6**
S_{n-1}	0.515	0.0203					0.5	0.4
CV((%)	4.1	4.1					1.0	1.1

7. CREEP RUPTURE – ASTM D2990

7.1. TEST SUMMARY

7.1.1. AC125 Section/s

Section 5.8 for Physical and Mechanical Properties of FRP Composite Materials, Table 1, and Table 2.

7.1.2. Reference Standard/s

ASTM D2990–09, Standard Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics.

7.1.3. Test Objective

Determine if the creep-rupture stresses of the FRP composite products under evaluation meet the AC125-Table 1 criteria more than 3,000 hours with a sustained load.

7.1.4. Product/s Under Evaluation

CFU-10T fabric with Carbon Bond 300 HT resin (tested in the fiber direction: 0º)

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

Keith Holmes and Francisco De Caso

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-D2990-DOA.

7.2. TEST MATRIX

7.2.1. Specimen Number

A total of five tests are reported. Refer to Table 7.1.

7.2.2. Specimen ID Nomenclature

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

7.2.3. *Test Matrix Table*

Table 7.1 – Test Matrix for Creep Rupture

Specimen ID	Fiber Lot #	Resin Batch #	Preparation (mm.dd.yy)	Specimen Start Test (mm.dd.yy)	Finish Test (mm.dd.yy)
DOA_C10T_CRP_CC_ 001 to 005	Style# 1286/01/00	A: Batch# D553G3O081 and GMID# 97000852 B: Batch# D553G29000 and GMID#97000847	02.17.16	02.24.16	06.28.16

7.3. SPECIMEN PREPARATION

7.3.1. *Specimen Size*

Nominal FRP specimen dimensions are summarized in Table 7.2, including FRP gauge length (C_M), width (b_f) and nominal thickness (d_f).

Table 7.2 – Creep Rupture Specimen Nominal Dimensions

Specimen ID	C_M		b_f		d_f	
	mm	*in.*	*mm*	*in.*	*mm*	*in.*
DOA_C10T_CRP_CC	100.00	3.94	6.35	0.25	0.533	0.021

7.3.2. *Specimen Layout*

The specimen layout is presented in Figure 7.1, while description and value of all parameters are reported in Table 7.3

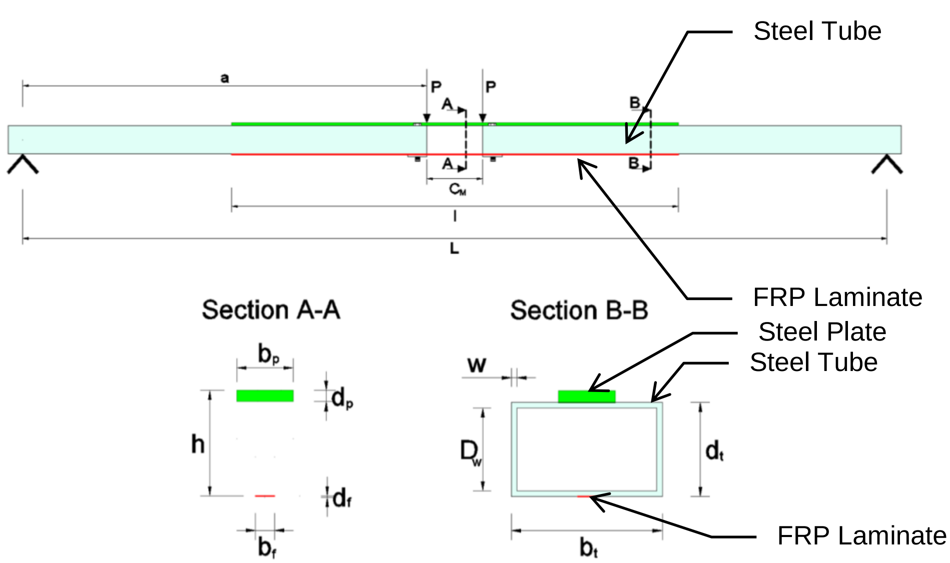


Figure 7.1 – Creep Rupture Specimen Layout

Table 7.3 – Summary of Parameters for Creep Rupture Test

Symbol	Parameter	Value	
		mm	*in*
d_p	Thickness of the steel plate	6.00	0.24
b_p	Width of the steel plate	30.00	1.18
d_t	Height of the steel tube	50.00	1.97
b_t	Width of the steel tube	80.00	3.15
w	Thickness of the steel tube	3.00	0.12
d_f	Thickness of the FRP	0.533	0.021
b_f	Average width of the FRP	19.38	0.763
a	Moment arm	724.00	28.50
l	Total length of FRP strip	800.00	31.50
h	Total height of the fixture	56.00	2.20
L	Span of creep fixture	1548.00	60.94
D_v	Inner height of the steel tube	44.00	1.73
C_M	FRP effective length (gauge)	100.00	3.94

7.3.3. *Preparation Procedure*

A FRP specimen strip was cut from a panel fabricated as described in Section 4.2.2. The creep rupture frame was composed of a top steel plate welded on the upper surface of the steel tubes to ensure rigid continuity between the elements. The FRP specimen was slid inside the tubes and centered in place. Inserts were used to hold the cured FRP laminate to center it in the steel tube while it was bonded to the inside of the steep tubes.

7.3.4. *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 to testing.

7.4. TEST SET-UP

7.4.1. *Set-up*

All specimens were tested in four point bending configuration (Figure 7.2). This ensures that no shear stress is present along the effective length of the FRP laminate (C_M in Table 7.3 and Figure 7.1). In addition, given the small nominal thickness of the FRP laminate, the stress on the FRP in the C_M portion were assumed constant and therefore treated as purely axial.

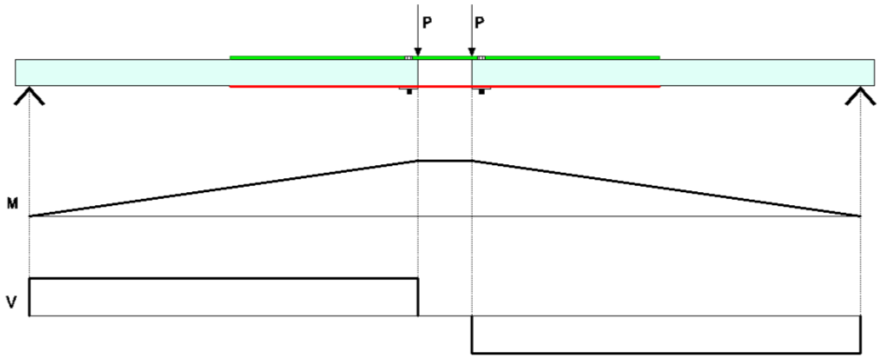
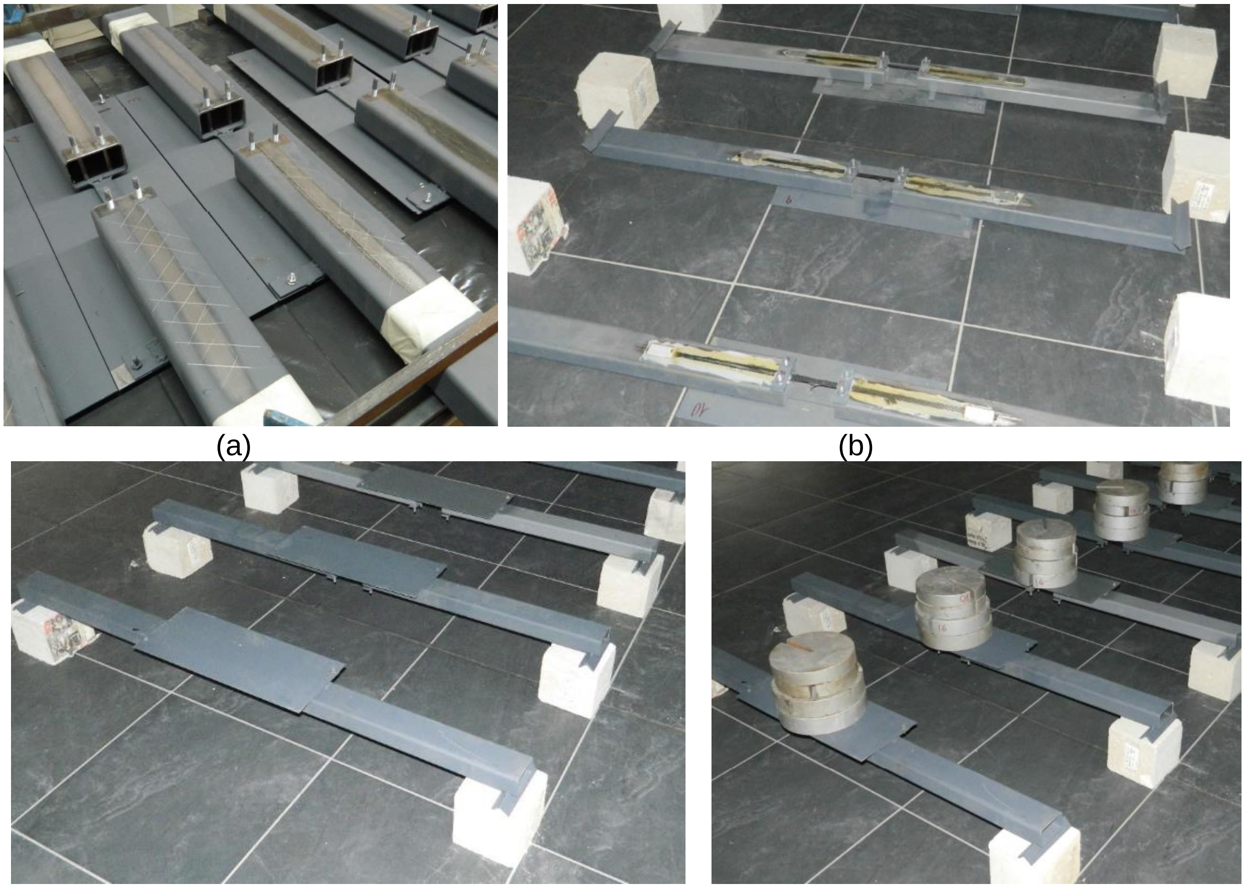


Figure 7.2 – Creep Rupture test scheme diagrams for applied moment and shear force



(a) (b)

(c) (d)

Figure 7.3 – Creep Rupture test set-up: underside of creep fixture preparation fo FRP installation (a); adhesion of FRP strip to underside of steel tube; test layout span and base plate for dead weight (c); and loading of creep fixture (d)

7.4.2. Rate and Method of Loading

Sustained tensile load of 601 lbf was manually applied by using dead weight for at least 3000 hrs. The applied load is such that the stress in the FRP is equal or greater than the requirements of AC125-Table 1 (equivalent to 0.55 of the average ultimate experimental tensile strength reported in Section 5). The actual level applied corresponded to 0.56 of the average ultimate experimental strength. Refer to Table 7.4.

Table 7.4 – Creep rupture load and applied stress level

Specimen ID	**Average experimental ultimate tensile stress**		**Sustained FRP Tensile Load, P**		**Corresponding Applied FRP Stress**	
	MPa	***ksi***	***kN***	***lbs***	***MPa***	***ksi***
DOA_C10T_CRP_CC	1408	204.3	2.67	600.6	789	114.4

7.5. TEST RESULTS

7.5.1. Results Summary

No creep rupture was reached by the CFU-10T FRP system under evaluation after more than 3000 hrs. of sustained load testing under a sustained stress equivalent to over 0.55 of the minimum requirement of the average ultimate experimental strength, hence the product meets the stress limits in FRP reinforced as per the requirements of AC125 Table 1.

7.5.2. Modes of Failure

No failure experienced.

7.5.3. Calculations

Equilibrium and compatibility equations were used to calculate the stress in the FRP as per section A-A, Figure 7.1. Note that compression stressed in the steel plate were also calculated in order to verify that no buckling would occur.

8. VOID CONTENT – ASTM D3171

8.1. TEST SUMMARY

8.1.1. AC125 Section

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

8.1.2. Reference Standard/s

ASTM D3171 -11, Standard Test Methods for Constituent Content of Composite Materials, Test Method I.

8.1.3. Test Objective

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

8.1.4. Product/s Under Evaluation

CFU-10T and CFU-20T fabrics with Carbon Bond 300 HT resin.

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

Tais Hamilton and Phil Lavonas

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-D3171(I)-DOA.

8.2. TEST MATRIX

8.2.1. Specimen Number

A total of five tests per product were under evaluation 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 void content

Specimen ID	Batch Fiber #	Batch Resin #	Specimen Preparation *mm.dd.yy*	Tested *mm.dd.yy*
DOA_C10T_VDC_CC_001 to 005	Style# 1286/01/00	A: Batch# D553G3O081 and GMID# 97000852	05.06.16	05.24.16
DOA_C20T_VDC_CC_001 to 005	Style# 1167/01/06	B: Batch# D553G29000 and GMID#97000847	07.28.16	08.12.16

8.3. SPECIMEN PREPARATION

8.3.1. Specimen Size

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

8.3.2. 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 4.2.2.

8.3.3. Specimen Conditioning

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

8.4. TEST SET-UP

8.4.1. 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, test method I as defined in Table 8.3.

8.5. TEST RESULTS

8.5.1. Results Summary

Based on the experimental tests presented herein the average matrix content (weight percent), ply thickness and void content based on ASTM D3171, test method I of the materials are summarized in Table 8.2, where the void volume was below the 6% requirement of AC125.

Table 8.2 – Average result for void content specimens

Specimen ID	Matrix Content V_m %	Reinforcement Content V_r %	Void Volume V_v %
DOA_C10T_VDC_CC	64.4	35.1	0.4
DOA_C20T_VDC_CC	64.3	35.3	0.4

8.5.2. Calculations

The results reported herein have been computed as per ASTM D3171 using the parameters defined in Table 8.3.

Table 8.3 - 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_c	Specimen density	Density
ρ_r	Reinforcement density	Density
ρ_m	Matrix density	Density
W_m	Matrix content (weight Percent)	$W_m = (M_i - M_f)/M_i \times 100$

8.5.3. Graphical Representation of Results

Not applicable.

8.5.4. Tabulated Results

Table 8.4 contains the tabulated summary results for the void content. Refer to the last two columns of each table where the matrix content (%) and thickness of the cured ply are reported. Average, standard deviation and coefficient of variance values are also reported.

Table 8.4 - Tabulated results for void content for CFU-10T, per ASTM D3171, Test Method I

Specimen ID	Area A		Initial Mass M_i		Final Mass M_f		Matrix Content, V_m	Reinforcement Content V_r	Void Volume* V_v
	mm²	*in²*	*mg*	*oz*	*mg*	*oz*	*%*	*%*	*%*
C10T_VOD_CC_001	536	0.83	496.0	0.0175	167.6	0.0059	65.7	33.8	0.5
C10T_VOD_CC_002	566	0.88	505.6	0.0178	177.5	0.0063	64.5	35.1	0.4
C10T_VOD_CC_003	553	0.86	489.2	0.0173	173.7	0.0061	64.1	35.5	0.4
C10T_VOD_CC_004	578	0.90	494.7	0.0175	181.1	0.0064	62.9	36.6	0.5
C10T_VOD_CC_005	606	0.94	547.8	0.0193	190.1	0.0067	64.9	34.7	0.4
Average	**568**	**0.88**	**506.7**	**0.0179**	**178.0**	**0.0063**	**64.4**	**35.1**	**0.4**
S_{n-1}	27	0.04	23.7	0.0008	8	0.0003	1.0	1.0	0.1
CV((%)	4.7	4.7	4.7	4.7	4.7	4.7	1.6	2.9	
C10T_VOD_CC_002	680	1.05	989.3	0.0349	352.2	0.0124	64.1	35.6	0.3
C10T_VOD_CC_003	604	0.94	1010.7	0.0357	361.8	0.0128	63.7	35.8	0.5
C10T_VOD_CC_003	610	0.95	1093.8	0.0386	397.0	0.0140	63.1	36.3	0.6
C10T_VOD_CC_004	627	0.97	982.9	0.0347	333.2	0.0118	65.8	33.9	0.3
C10T_VOD_CC_005	652	1.01	992.1	0.0350	344.3	0.0121	65.0	34.7	0.3
Average	**635**	**0.98**	**1013.8**	**0.0358**	**357.7**	**0.0126**	**64.3**	**35.3**	**0.4**
S_{n-1}	31	0.05	46	0.0016	24	0.0009	1.1	1.0	0.1
CV((%)	4.9	4.9	4.5	4.5	6.8	6.8	1.7	2.7	

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

9. GLASS TRANSITION TEMPERATURE – ASTM E1640

9.1. TEST SUMMARY

9.1.1. AC125 Section/s

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

9.1.2. Reference Standard/s

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

9.1.3. 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).

9.1.4. Product/s Under Evaluation

Carbon Bond 300 HT resin.

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

Andrea Correa, Phil Lavonas and Zahra Karim

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-E1640-DOA.

9.2. TEST MATRIX

9.2.1. Specimen Number

A total of 20 tests 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 T_g coupon specimens.

<table>
<tr><th>Specimen ID</th><th>Fiber Lot #</th><th>Resin Batch #</th><th>Specimen Preparation (mm.dd.yy)</th><th>Tested (mm.dd.yy)</th></tr>
<tr><td>DOA_CBHT_TG_CC_001 to 005</td><td>n/a</td><td rowspan="4">A: Batch# D553G3O081 and GMID# 97000852
B: Batch# D553G29000 and GMID#97000847</td><td rowspan="4">02.17.16</td><td>06.25.16</td></tr>
<tr><td>DOA_CBHT_TG_CC_006 to 010</td><td>n/a</td><td>06.22.16</td></tr>
<tr><td>DOA_CBHT_TG_CC_011 to 015</td><td>n/a</td><td>03.25.16</td></tr>
<tr><td>DOA_CBHT_TG_CC_016 to 020</td><td>n/a</td><td>03.29.16</td></tr>
</table>

9.3. SPECIMEN PREPARATION

9.3.1. Specimen Size

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.

9.3.2. Preparation Procedure

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

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

A Dynamic Mechanical Analyzer (DMA) was used with a flexural set up to apply a forced oscillation with constant amplitude at a fixed frequency. The tangent delta 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 9.1.

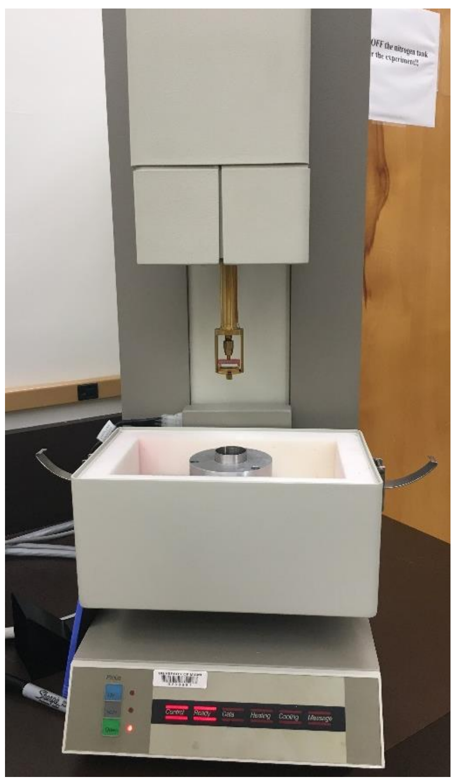


Figure 9.1 – T_g test set-up

9.4.2. 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.

9.5. TEST RESULTS

9.5.1. 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 9.2. The T_g meets the conditions of acceptance of AC125 being higher than 60°C (140°F).

Table 9.2 – Average result for glass transition temperature

Specimen ID	T_g	
	°C	**°F**
DOA_CBHT_TG_CC	69.3	156.7

9.5.2. Calculations

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

9.5.3. Graphical Representation of Results

Figure 9.2 show typical results for the determination of T_g.

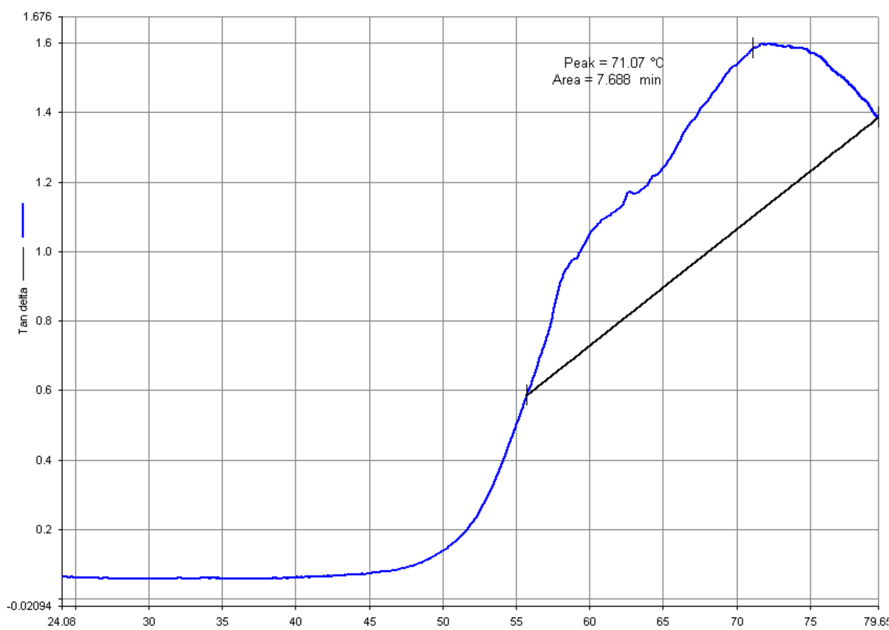


Figure 9.2 – Representative results for glass transition temperature test

9.5.4. Tabulated Results

Table 9.3 contains the tabulated summary results for the products under evaluation, including: glass transition temperature (T_g). 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 9.3 - Tabulated results for glass transition temperature for Carbon Bond 300 HT, per ASTM E1640

Specimen ID	***T_g****	
	°C	**°F**
DOA_CBHT_TG_CC_001	72.5	162.5
DOA_CBHT_TG_CC_002	75.1	167.2
DOA_CBHT_TG_CC_003	75.9	168.7
DOA_CBHT_TG_CC_004	72.4	162.2
DOA_CBHT_TG_CC_005	72.8	163.0
DOA_CBHT_TG_CC_006	70.0	158.0
DOA_CBHT_TG_CC_007	71.1	160.0
DOA_CBHT_TG_CC_008	74.8	166.6
DOA_CBHT_TG_CC_009	71.9	161.4
DOA_CBHT_TG_CC_010	72.8	163.0
DOA_CBHT_TG_CC_011	63.9	147.0
DOA_CBHT_TG_CC_012	68.4	155.1
DOA_CBHT_TG_CC_013	62.1	143.8
DOA_CBHT_TG_CC_014	67.0	152.6
DOA_CBHT_TG_CC_015	65.8	150.4
DOA_CBHT_TG_CC_016	66.7	152.1
DOA_CBHT_TG_CC_017	64.4	147.9
DOA_CBHT_TG_CC_018	64.8	148.6
DOA_CBHT_TG_CC_019	64.9	148.8
DOA_CBHT_TG_CC_020	68.6	155.5
Average	**69.3**	**156.7**
S_{n-1}	4.2	7.5
CV((%)	6.0	4.8

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

10. COMPOSITE INTERLAMINAR SHEAR STRENGTH – ASTM D2344

10.1. TEST SUMMARY

10.1.1. AC125 Section/s

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

10.1.2. Reference Standard/s

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

10.1.3. Test Objective

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

10.1.4. Product/s Under Evaluation

CFU-10T and CFU-20T fabric with Carbon Bond 300 HT resin.

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

Tais Hamilton, Andrea Correa and Philip Lavonas

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-D2344-DOA.

10.2. TEST MATRIX

10.2.1. Specimen Number

A total of 20 tests per product 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 interlaminar shear specimens (no aging).

Specimen ID	Fiber Lot #	Resin Batch #	Specimen Preparation (mm.dd.yy)	Tested (mm.dd.yy)
DOA_C10T_ISS_CC_001 to 020	Style# 1286/01/00	A: Batch# D553G3O081 and GMID# 97000852	05.06.16	05.26.16
DOA_C20T_ISS_CC_001 to 020	Style# 1167/01/06	B: Batch# D553G29000 and GMID#97000847		05.25.16

10.3. SPECIMEN PREPARATION

10.3.1. Specimen Size

Average rectangular prism specimen dimensions are summarized in Table 10.4 including width (w) and thickness (t), based on 3 measurements. Specimens were composed of five plies of the FRP system.

10.3.2. 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 4.2.2.

10.3.3. 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.

10.4. TEST SET-UP

10.4.1. Set-up

The specimen was loaded in three-point bending. Testing was performed using a screw driven Instron Universal Test Frame. The load was measured with a 2225 kN (500 kip) load cell in compliance with ASTM E4-10 (Standard Practice for Force Verification of Testing Machines). The test set-up is shown is Figure 10.1. Load and crosshead displacement were recorded throughout the test using Instron's Bluehill software and data acquisition system.

10.4.2. 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 10.1 – Interlaminar shear test set-up

10.5. TEST RESULTS

10.5.1. 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 Table 10.2.

Table 10.2 – Average interlaminar shear strength results (ASTM D2344)

Specimen ID	***F^{sbs}***	
	MPa	***ksi***
DOA_C10T_ISS_CC	45.26	6.56
DOA_C20T_ISS_CC	45.91	6.66

10.5.2. Modes of Failure

The primary mode of failure was by interlaminar shear of the test specimens, equivalent to FIG. 7.1 of ASTM D2344 and as seen in Figure 10.2.

Figure 10.2 – Representative failure mode showing interlaminar shear between plies

10.5.3. Calculations

The results reported herein have been computed per ASTM D2344 and summarized in the next section, where the parameters are defined in Table 10.3.

Table 10.3 - 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	$F^{sbs} = 0.75\, P_m/(b \times h)$

10.5.4. Tabulated Results

Table 10.4 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 10.4 - Tabulated results for interlaminar shear strength for CFU-10T, per ASTM D2344

Specimen ID	***b***		***h***		P_m		F^{sbs}	
	mm	***in.***	**mm**	***in.***	***kN***	***lbf***	***MPa***	***ksi***
DOA_C10T_ISS_CC_001	5.89	0.23	4.38	0.17	1.66	373.1	48.21	6.99
DOA_C10T_ISS_CC_002	6.24	0.25	4.86	0.19	1.82	409.3	45.02	6.53
DOA_C10T_ISS_CC_003	5.94	0.23	4.78	0.19	1.76	394.7	46.40	6.73
DOA_C10T_ISS_CC_004	6.44	0.25	4.62	0.18	1.80	405.5	45.45	6.59
DOA_C10T_ISS_CC_005	5.73	0.23	4.41	0.17	1.57	353.5	46.73	6.78
DOA_C10T_ISS_CC_006	6.29	0.25	4.69	0.18	1.73	388.1	43.95	6.37
DOA_C10T_ISS_CC_007	5.59	0.22	4.38	0.17	1.48	332.2	45.27	6.57
DOA_C10T_ISS_CC_008	6.52	0.26	4.15	0.16	1.63	366.1	45.14	6.55
DOA_C10T_ISS_CC_009	5.27	0.21	4.62	0.18	1.43	320.3	43.86	6.36
DOA_C10T_ISS_CC_010	6.67	0.26	4.83	0.19	1.89	423.7	43.93	6.37
DOA_C10T_ISS_CC_011	6.10	0.24	4.45	0.18	1.62	363.8	44.79	6.50
DOA_C10T_ISS_CC_012	6.57	0.26	4.19	0.17	1.63	366.0	44.37	6.43
DOA_C10T_ISS_CC_013	6.24	0.25	4.72	0.19	1.77	397.9	45.05	6.53
DOA_C10T_ISS_CC_014	5.82	0.23	4.46	0.18	1.56	350.1	45.05	6.53
DOA_C10T_ISS_CC_015	5.28	0.21	4.47	0.18	1.47	330.7	46.71	6.77
DOA_C10T_ISS_CC_016	5.31	0.21	3.92	0.15	1.23	276.0	44.20	6.41
DOA_C10T_ISS_CC_017	6.01	0.24	4.33	0.17	1.56	350.9	44.99	6.53
DOA_C10T_ISS_CC_018	5.18	0.20	4.41	0.17	1.42	318.5	46.53	6.75
DOA_C10T_ISS_CC_019	4.95	0.20	4.24	0.17	1.23	277.5	44.07	6.39
DOA_C10T_ISS_CC_020	5.12	0.20	4.60	0.18	1.43	320.9	45.49	6.60
Average	**5.86**	**0.23**	**4.48**	**0.18**	**1.58**	**355.9**	**45.26**	**6.56**
S_{n-1}	0.53	0.02	0.24	0.01	0.18	41.3	1.15	0.17
CV((%)	9.1	9.1	5.4	5.4	11.6	11.6	2.5	2.5

Table 10.4 Continued - Tabulated results for interlaminar shear strength for and CFU-20T, per ASTM D2344.

Specimen ID	*b*		*h*		P_m		F^{sbs}	
	mm	***in.***	**mm**	***in.***	***kN***	***lbf***	***MPa***	***ksi***
DOA_C20T_ISS_CC_001	10.71	0.42	6.69	0.26	4.24	952.8	44.36	6.43
DOA_C20T_ISS_CC_002	10.68	0.42	6.68	0.26	4.29	964.0	45.07	6.54
DOA_C20T_ISS_CC_003	11.60	0.46	6.01	0.24	4.25	954.2	45.70	6.63
DOA_C20T_ISS_CC_004	11.34	0.45	5.26	0.21	3.54	796.3	44.55	6.46
DOA_C20T_ISS_CC_005	10.45	0.41	6.17	0.24	4.07	915.4	47.34	6.87
DOA_C20T_ISS_CC_006	10.50	0.41	6.64	0.26	4.29	964.3	46.12	6.69
DOA_C20T_ISS_CC_007	10.91	0.43	6.15	0.24	4.24	953.6	47.44	6.88
DOA_C20T_ISS_CC_008	10.72	0.42	6.49	0.26	4.43	994.5	47.70	6.92
DOA_C20T_ISS_CC_009	10.50	0.41	6.44	0.25	4.18	939.7	46.36	6.72
DOA_C20T_ISS_CC_010	10.62	0.42	6.73	0.27	4.50	1012.2	47.25	6.85
DOA_C20T_ISS_CC_011	11.75	0.46	6.05	0.24	4.32	971.0	45.62	6.62
DOA_C20T_ISS_CC_012	10.69	0.42	5.94	0.23	3.94	885.5	46.48	6.74
DOA_C20T_ISS_CC_013	10.82	0.43	6.18	0.24	3.96	889.9	44.36	6.43
DOA_C20T_ISS_CC_014	10.87	0.43	6.24	0.25	4.23	951.2	46.81	6.79
DOA_C20T_ISS_CC_015	10.06	0.40	6.55	0.26	4.03	906.0	45.86	6.65
DOA_C20T_ISS_CC_016	10.16	0.40	6.72	0.26	4.23	951.1	46.49	6.74
DOA_C20T_ISS_CC_017	11.05	0.44	5.94	0.23	4.04	908.5	46.15	6.69
DOA_C20T_ISS_CC_018	10.69	0.42	6.13	0.24	3.92	881.5	44.83	6.50
DOA_C20T_ISS_CC_019	10.87	0.43	6.20	0.24	4.02	904.0	44.76	6.49
DOA_C20T_ISS_CC_020	10.97	0.43	5.47	0.22	3.60	809.9	44.99	6.52
Average	**10.80**	**0.43**	**6.23**	**0.25**	**4.12**	**925.3**	**45.91**	**6.66**
S_{n-1}	0.42	0.02	0.40	0.02	0.24	54.9	1.07	0.16
CV((%)	3.8	3.8	6.5	6.5	5.9	5.9	2.3	2.3

11. BOND STRENGTH: TENSION – ASTM D7234

11.1. TEST SUMMARY

11.1.1. AC125 Section/s

Section 5.17, for bond strength.

11.1.2. Reference Standard/s

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

11.1.3. Test Objective

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

11.1.4. Product/s Under Evaluation

CFU-10T and CFU-20T fabrics with Carbon Bond 300 HT resin.

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

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-D7234-DOA.

11.2. TEST MATRIX

11.2.1. Specimen Number

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

11.2.2. Specimen ID Nomenclature

Specimens are identified throughout 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 tension bond strength tests (no aging).

Specimen ID	Fiber Lot #	Resin Batch #	Specimen Preparation (mm.dd.yy)	Tested (mm.dd.yy)
DOA_C10T_BTC_CC_001 to 005	Style# 1286/01/00	A: Batch# D553G3O081 and GMID# 97000852	02.17.16	03.04.16
DOA_C20T_BTC_CC_001 to 005	Style# 1167/01/06	B: Batch# D553G29000 and GMID#97000847	05.06.16	05.18.16

11.3. SPECIMEN PREPARATION

11.3.1. 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.

11.3.2. Specimen Layout

The specimen layout is presented in Figure 11.1. 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 11.2. 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.

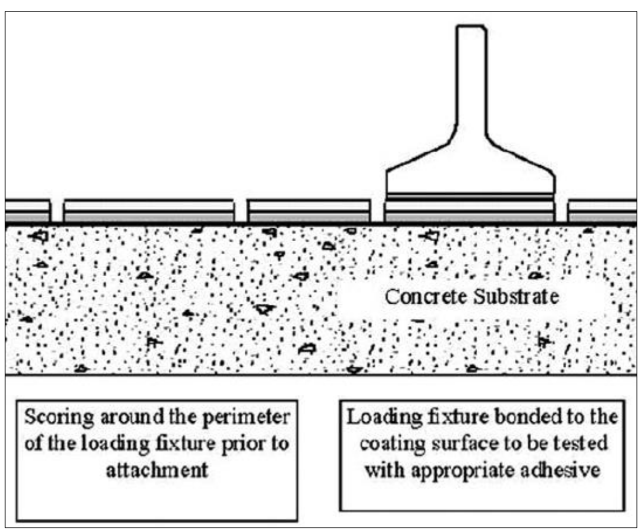


Figure 11.1 - Tension bond specimen layout (ASTM D7234)

Table 11.2 – Concrete compressive strength results (ASTM C39) for substrate used in testing

Specimen	Diameter		Area		P_{max}		f'$_c$		Failure
ID	mm	in	mm^2	in^2	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	

11.3.3. Preparation Procedure

The FRP layer was applied to the concrete surface as referenced in Section 0. 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. 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 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.

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 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 a pressure dial gauge. The test set-up is shown is Figure 11.2.

Figure 11.2 – Tension bond strength test set-up

11.4.2. 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).

11.5. TEST RESULTS

11.5.1. 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 11.3.

Table 11.3 – Average tensile strength for tension bond specimens

Specimen ID	**Average Bond Tensile Strength**	
	MPa	***psi***
DOA_C10T_BTC_CC	4.92	713
DOA_C20T_BTC_CC	4.66	675

11.5.2. Modes of Failure

The mode of failure was in the substrate (Type A) equivalent to FIG. 1 of ASTM D7234. Figure 12.3 shows a typical failure of the specimen.

Figure 11.3 - Typical failure of performed tension bond strength test.

11.5.3. Calculations

The results reported herein have been computed as per ASTM D7234. Definitions of the parameters used for calculation is provided in Table 11.4.

Table 11.4 - 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

11.5.4. Tabulated Results

Table 11.5 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 11.5 - Tabulated results for tensile bond tests for CFU-10T and CFU-20T, per ASTM D7234

Specimen ID	**Time**	**A**		**T_l**		**T_S***		**Failure Mode**
	sec	**mm²**	**in²**	**N**	**lbf**	**MPa**	**psi**	
DOA_C10T_BTC_CC_001	142	2026	3.14	10013	2250	4.94	717	A
DOA_C10T_BTC_CC_002	126	2026	3.14	9790	2200	4.83	701	A
DOA_C10T_BTC_CC_003	130	2026	3.14	10013	2250	4.94	717	A
DOA_C10T_BTC_CC_004	135	2026	3.14	10680	2400	5.27	764	A
DOA_C10T_BTC_CC_005	126	2026	3.14	9345	2100	4.61	669	A
Average	**132**	**2026**	**3.14**	**9968**	**2240**	**4.92**	**713**	
S_{n-1}	7	0	0.00	482	108	0.24	35	
CV((%)	5.2	0.0	0.0	4.8	4.8	4.8	4.8	
DOA_C20T_BTC_CC_001	137	2026	3.14	8678	1950	4.28	621	A
DOA_C20T_BTC_CC_002	129	2026	3.14	9568	2150	4.72	685	A
DOA_C20T_BTC_CC_003	144	2026	3.14	9790	2200	4.83	701	A
DOA_C20T_BTC_CC_004	150	2026	3.14	9345	2100	4.61	669	A
DOA_C20T_BTC_CC_005	137	2026	3.14	9790	2200	4.83	701	A
Average	**139**	**2026**	**3.14**	**9434**	**2120**	**4.66**	**675**	
S_{n-1}	8	0	0.00	461	104	0.23	33	
CV((%)	5.7	0.0	0.0	4.9	4.9	4.9	4.9	

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

12. BOND STRENGTH: SHEAR – LAB METHOD

12.1. TEST SUMMARY

12.1.1. AC125 Section/s

Section 5.17, for bond strength.

12.1.2. 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).

12.1.3. Test Objective

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

12.1.4. Product/s Under Evaluation

CFU-10T and CFU-20T fabrics with Carbon Bond 300 HT resin.

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

Tais Hamilton

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-BTC-DOA.

12.2. TEST MATRIX

12.2.1. Specimen Number

A total of five tests per product under evaluation are reported, refer to Table 12.1.

12.2.2. Specimen ID Nomenclature

Specimens are identified through 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 shear bond test specimens (no aging).

Specimen ID	Fiber Lot #	Resin Batch #	Specimen Preparation (mm.dd.yy)	Tested (mm.dd.yy)
DOA_C10T_BSC_CC_001 to 005	Style# 1286/01/00	A: Batch# D553G3O081 and GMID# 97000852 B: Batch# D553G29000 and GMID#97000847	02.17.16	03.01.16
DOA_C20T_BSC_CC_001 to 005	Style# 1167/01/06		05.06.16	05.16.16

12.3. SPECIMEN PREPARATION

12.3.1. Specimen Size

The FRP systems were applied on concrete beams 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).

12.3.2. Specimen Layout

Shear bond specimen layout is presented in Figure 12.1, the span of the notched 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 Section 11.3.2.

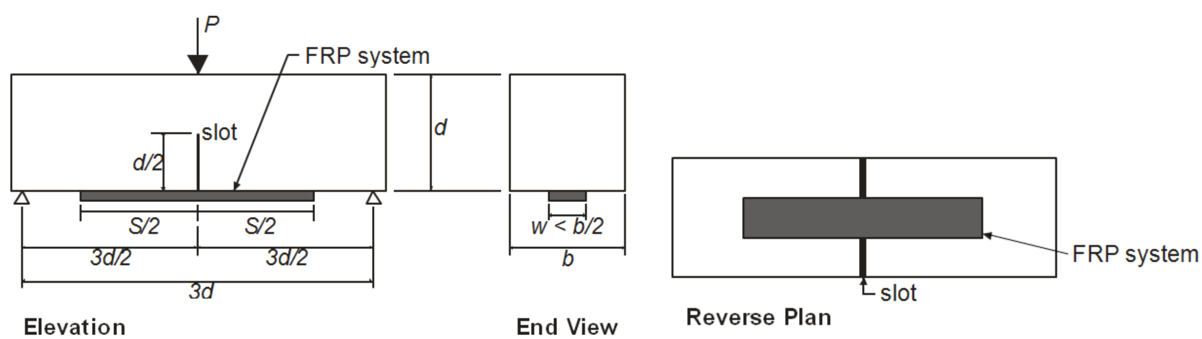


Figure 12.1 - Shear bond specimen layout

12.3.3. Preparation Procedure

The FRP one ply strip installed on the concrete beams had a nominal dimension of 228 mm (9.0 in.) length 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 strip was saturate and installed on the concrete surface as described in Section 0. The nominal thickness used in computing the shear bond strength was 0.533 mm (0.021 in.) and 0.914 mm (0.036 in.) for the C10T and C20T fiber sheets, respectively.

12.3.4. 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.

12.4. TEST SET-UP

12.4.1. 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 with a maximum capacity of 130 kN (30 kip). 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 12.2. Load and crosshead displacement were recorded throughout the test using Instron's Bluehill software and data acquisition system.

Figure 12.2 – Shear bond test set-up

12.4.2. 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).

12.5. TEST RESULTS

12.5.1. Results Summary

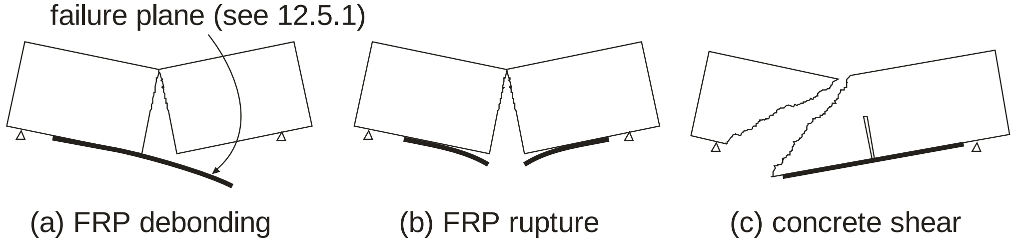
Based on the experimental tests presented herein the average shear bond strength was found to be above the minimum AC125 requirement of 1378 kPa (200 psi) as summarized in Table 12.2.

Table 12.2 – Average tensile strength for shear bond specimens

Specimen ID	**Average shear bond strength**	
	MPa	***psi***
DOA_C10T_BSC_CC	2.90	420
DOA_C20T_BSC_CC	3.02	438

12.5.2. Modes of Failure

Figure 12.3 shows possible failure modes of a shear bond test as per the ASTM under development as well as the primary mode of failure mode observed. The primary mode of failure was FRP debonding (delamination) by peeling off from the substrate (*failure type a*). Individual failure modes are reported in the tabulated results section of this document.



(a)

(b)

Figure 12.3 – Failure modes types for shear bond test (a), and representative shear bond failure mode (b)

12.5.3. 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 12.3 and Table 11.4, respectively.

Table 12.3 - Definitions of parameters

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 12.4 - 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

12.5.4. Tabulated Results

Table 12.5 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 12.5 - Tabulated results for shear bond test for CFU-10T and CFU-20T per Lab Method

Specimen ID	w		S		P		τ_d		Failure Mode	Pass/Fail*
	mm	*in*	*mm*	*in*	*kN*	*lbf*	*MPa*	*psi*		
DOA_C10T_BSC_CC_001	25.40	1.00	228.60	9.00	10.06	2260	2.67	387	FRP debonding	Pass
DOA_C10T_BSC_CC_002	25.40	1.00	228.60	9.00	10.81	2430	2.87	416	FRP debonding	Pass
DOA_C10T_BSC_CC_003	25.40	1.00	228.60	9.00	10.90	2450	2.90	420	FRP debonding	Pass
DOA_C10T_BSC_CC_004	25.40	1.00	228.60	9.00	11.79	2650	3.13	454	FRP debonding	Pass
DOA_C10T_BSC_CC_005	25.40	1.00	228.60	9.00	10.99	2470	2.92	423	FRP debonding	Pass
Average	**25.40**	**1.00**	**228.60**	**9.00**	**10.91**	**2452**	**2.90**	**420**		
S_{n-1}					0.62	139	0.16	24		
CV((%)					5.7	5.7	5.7	5.7		
DOA_C20T_BSC_CC_001	25.40	1.00	228.60	9.00	10.53	2367	2.80	406	FRP debonding	Pass
DOA_C20T_BSC_CC_002	25.40	1.00	228.60	9.00	12.05	2708	3.23	468	FRP debonding	Pass
DOA_C20T_BSC_CC_003	25.40	1.00	228.60	9.00	11.65	2617	3.12	452	FRP debonding	Pass
DOA_C20T_BSC_CC_004	25.40	1.00	228.60	9.00	10.85	2438	2.90	421	FRP debonding	Pass
DOA_C20T_BSC_CC_005	25.40	1.00	228.60	9.00	11.41	2563	3.05	443	FRP debonding	Pass
Average	**25.40**	**1.00**	**228.60**	**9.00**	**11.30**	**2539**	**3.02**	**438**		
S_{n-1}					0.61	137	0.17	25		
CV((%)					5.4	5.4	5.6	5.6		

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

13. FREEZING AND THAWING

13.1. TEST SUMMARY

13.1.1. AC125 Section/s

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

13.1.2. Reference Standard/s

ASTM D3039/D3039M-14, 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, and interlaminar shear strength after exposure to freeze thaw cycles as per AC125 Section 5.10.

13.1.4. Product/s Under Evaluation

CFU-10T fabric with Carbon Bond 300 HT resin.

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

Philip Lavonas and Christian Marquina

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-DOA-FT.

13.2. TEST MATRIX

13.2.1. Specimen Number

Five test repetitions for each test type (ASTM D3039, ASTM D2344, ASTM E1640 and Shear bond strength lab method) for the FRP system under evaluation were performed. A total of 5 repetitions 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 tensile tests post freezing and thawing conditioning.

Specimen ID	Fiber Lot #	Resin Batch #	Specimen Preparation (mm.dd.yy)	Tested (mm.dd.yy)
DOA_C10T_TNS_FT_001 to 005	Style# 1286/01/00	A: Batch# D553G3O081 and GMID# 97000852 B: Batch# D553G29000 and GMID#97000847	02.01.16	04.07.16
DOA_C10T_ISS_FT_001 to 005			05.06.16	06.15.16
DOA_CBHT_TG_FT_001 to 005			02.17.16	04.14.16
DOA_C10T_BSC_FT_001 to 005				04.11.16

13.3. SPECIMEN PREPARATION

13.3.1. *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.

13.3.2. *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.).

13.4. TEST SET-UP

13.4.1. *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.

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 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.

13.5.2. 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.

13.5.3. 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.

13.5.4. Tabulated Results

Table 13.2 through Table 13.5 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.

Table 13.2 - Tabulated results for tensile tests for CFU-10T (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
DOA_C10T_TNS_FT_001	13.56	0.021	18.60	4180	1371.0	198.85	91.25	13.24	1.50	SGM	97	101	96
DOA_C10T_TNS_FT_002	13.71	0.021	19.04	4279	1388.2	201.35	88.84	12.89	1.56	SGM	99	98	100
DOA_C10T_TNS_FT_003	13.67	0.021	19.66	4419	1437.9	208.55	96.28	13.97	1.49	SGM	102	106	96
DOA_C10T_TNS_FT_004	13.85	0.021	17.72	3982	1279.2	185.54	92.14	13.37	1.39	LGM	91	102	89
DOA_C10T_TNS_FT_005	13.48	0.021	20.06	4508	1487.5	215.75	90.21	13.09	1.65	SGM	106	100	106
Average	**13.65**	**0.021**	**19.02**	**4274**	**1392.8**	**202.01**	**91.74**	**13.31**	**1.52**		**99**	**101**	**98**
S_{n-1}	0.14	0.000	0.92	206	78.1	11.33	2.82	0.41	0.10				
CV((%)	1.0	1.0	4.8	4.8	5.6	5.6	3.1	3.1	6.3				

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

Table 13.3 - Tabulated results for interlaminar shear tests for CFU-10T (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}
DOA_C10T_ISS_FT_001	6.40	0.252	4.50	0.177	1.82	408	47.30	6.86	Interlaminar shear	105
DOA_C10T_ISS_FT_002	6.01	0.237	4.33	0.171	1.74	391	50.14	7.27	Interlaminar shear	111
DOA_C10T_ISS_FT_003	5.78	0.228	4.31	0.170	1.64	369	49.48	7.18	Interlaminar shear	110
DOA_C10T_ISS_FT_004	6.44	0.254	4.33	0.171	1.70	382	45.70	6.63	Interlaminar shear	101
DOA_C10T_ISS_FT_005	4.95	0.195	4.24	0.167	1.47	331	52.56	7.62	Interlaminar shear	116
Average	**5.92**	**0.233**	**4.34**	**0.171**	**1.67**	**376**	**49.04**	**7.11**		**109**
S_{n-1}	0.60	0.024	0.09	0.004	0.13	29	2.64	0.38		
CV((%)	10.2	10.2	2.2	2.2	7.7	7.7	5.4	5.4		

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

Table 13.4 - Tabulated results for glass transition temperature for Carbon Bond 300 HT (ASTM E1640) post freezing and thawing conditioning (AC125, Section 5.10.1)

Specimen ID	***T_g***		**Acceptance**
	°*C*	**°*F***	**Criteria***
DOA_CBHT_TG_FT_001	66.3	151.3	Pass
DOA_CBHT_TG_FT_002	66.5	151.7	Pass
DOA_CBHT_TG_FT_003	68.7	155.7	Pass
DOA_CBHT_TG_FT_004	67.1	152.8	Pass
DOA_CBHT_TG_FT_005	67.2	153.0	Pass
Average	**67.2**	**152.9**	
S_{n-1}	0.9	1.7	
CV((%)	1.4	1.1	

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

Table 13.5 - Tabulated results for shear bond strength for CFU-10T (Lab Method) tests post freezing and thawing conditioning (AC125, Section 5.10.1)

Specimen ID	***w***		***S***		***P***		***τ_d***		***Failure Mode***	***Pass/Fail****
	mm	***in***	**mm**	***in***	***kN***	***lbf***	***MPa***	***psi***		***τ_d***
DOA_C10T_BSC_FT_001	25.40	1.00	228.60	9.00	10.36	2328	2.75	399	FRP debonding	Pass
DOA_C10T_BSC_FT_002	25.40	1.00	228.60	9.00	10.50	2359	2.79	404	FRP debonding	Pass
DOA_C10T_BSC_FT_003	25.40	1.00	228.60	9.00	9.84	2211	2.61	379	FRP debonding	Pass
DOA_C10T_BSC_FT_004	25.40	1.00	228.60	9.00	10.00	2248	2.65	385	FRP debonding	Pass
DOA_C10T_BSC_FT_005	25.40	1.00	228.60	9.00	9.25	2079	2.45	356	FRP debonding	Pass
Average	**25.40**	**1.00**	**228.60**	**9.00**	**9.99**	**2245**	**2.65**	**385**		
S_{n-1}					0.49	110	0.13	19		
CV((%)					4.9	4.9	4.9	4.9		

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

14. AGING: WATER RESISTANCE – ASTM D2247

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 D3039/D3039M-14, 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 water resistant (warm and humid) environment.

14.1.4. Product/s Under Evaluation

CFU-10T fabric and Carbon Bond 300 HT resin

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

Zahra Karim, Tais Hamilton, Andrea Correa and Philip Lavonas

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-DOA-WR.

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 tensile tests exposed to water resistance aging.

Specimen ID	FRP Batch ID Fiber #	 Resin #	Aging Start mm.dd.yy	 Finish mm.dd.yy	Tested mm.dd.yy
DOA_C10T_TNS_WR_01_001 to 005	Style# 1286/01/00	A: Batch# D553G3O081 and GMID# 97000852 B: Batch#D553G29000 and 0GMID#97000847	02.08.16	03.20.16	03.29.16
DOA_C10T_TNS_WR_03_001 to 005				06.12.16	06.17.16
DOA_C10T_TNS_WR_10_001 to 005				03.20.17	PENDING*
DOA_C10T_ISS_WR_01_001 to 005			05.17.16	06.13.16	06.17.16
DOA_C10T_ISS_WR_03_001 to 005				09.05.16	09.12.16
DOA_C10T_ISS_WR_10_001 to 005				06.23.17	PENDING*
DOA_CBHT_TG_WR_01_001 to 005			02.22.16	03.20.16	03.30.16
DOA_CBHT_TG_WR_03_001 to 005				06.12.16	06.21.16
DOA_CBHT_TG_WR_10_001 to 005				03.30.17	PENDING
DOA_C10T_BSC_WR_01_001 to 005				03.20.16	04.01.16
DOA_C10T_BSC_WR_03_001 to 005				06.12.16	06.22.16
DOA_C10T_BSC_WR_10_001 to 005				03.30.17	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 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 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 heated 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 72 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; 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. Testing for 10,000hrs is on ongoing.

14.5.2. 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.

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 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 14.2 - Tabulated results for tensile tests for CFU-10T (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
DOA_C10T_TNS_WR_01_001	14.40	0.022	19.43	4367	1348.9	195.6	95.03	13.79	1.42	SGM	1000	96	105	91
DOA_C10T_TNS_WR_01_002	12.75	0.020	16.45	3696	1289.4	187.0	84.93	12.32	1.52	LGB		92	94	97
DOA_C10T_TNS_WR_01_003	13.20	0.020	17.83	4007	1350.7	195.9	92.78	13.46	1.46	SGM		96	103	93
DOA_C10T_TNS_WR_01_004	13.07	0.020	17.16	3857	1312.3	190.3	89.53	12.99	1.47	SGM		93	99	94
DOA_C10T_TNS_WR_01_005	12.94	0.020	16.85	3786	1301.7	188.8	86.75	12.59	1.50	LGT		92	96	96
Average	**13.27**	**0.021**	**17.54**	**3943**	**1320.6**	**191.5**	**89.80**	**13.03**	**1.47**			**94**	**99**	**94**
S_{n-1}	0.65	0.001	1.17	263	27.9	4.0	4.16	0.60	0.04					
CV((%)	4.9	4.9	6.7	6.7	2.1	2.1	4.6	4.6	2.6					
DOA_C10T_TNS_WR_03_001	13.74	0.021	17.67	3970	1285.4	186.4	87.73	12.73	1.46	SGM	3000	91	97	94
DOA_C10T_TNS_WR_03_002	13.81	0.021	18.33	4119	1327.1	192.5	91.61	13.29	1.45	SGM		94	101	93
DOA_C10T_TNS_WR_03_003	13.39	0.021	19.28	4334	1440.1	208.9	83.32	12.09	1.73	SGM		102	92	111
DOA_C10T_TNS_WR_03_004	14.10	0.022	19.13	4298	1355.5	196.6	83.41	12.10	1.62	MGM		96	92	104
DOA_C10T_TNS_WR_03_005	14.92	0.023	18.83	4231	1261.6	183.0	80.98	11.75	1.56	SGM		90	90	100
Average	**13.99**	**0.022**	**18.65**	**4190**	**1333.9**	**193.5**	**85.41**	**12.39**	**1.56**			**95**	**94**	**100**
S_{n-1}	0.58	0.001	0.66	148	69.6	10.1	4.24	0.61	0.12					
CV((%)	4.1	4.1	3.5	3.5	5.2	5.2	5.0	5.0	7.4					

**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 CFU-10T (ASTM D2344) post water resistance conditioning (ASTM D2247)

Specimen ID	*b*		*h*		P_m		F^{sbs}		Failure Mode	Exposure	% Retention*
	mm	***in***	**mm**	***in***	***kN***	***lbf***	***MPa***	***ksi***		***hrs.***	F^{sbs}
DOA_C10T_ISS_WR_01_001	9.99	0.39	4.90	0.19	2.91	655	44.58	6.47	Interlaminar Shear	1000	99
DOA_C10T_ISS_WR_01_002	10.29	0.41	5.00	0.20	3.20	720	46.68	6.77	Interlaminar Shear		103
DOA_C10T_ISS_WR_01_003	10.06	0.40	5.23	0.21	3.25	730	46.28	6.71	Interlaminar Shear		102
DOA_C10T_ISS_WR_01_004	9.78	0.39	4.99	0.20	3.12	701	47.92	6.95	Interlaminar Shear		106
DOA_C10T_ISS_WR_01_005	10.07	0.40	5.18	0.20	3.03	682	43.60	6.32	Interlaminar Shear		96
Average	**10.04**	**0.40**	**5.06**	**0.20**	**3.10**	**698**	**45.81**	**6.64**			**101**
S_{n-1}	0.18	0.01	0.14	0.01	0.13	30	1.72	0.25			
CV((%)	1.8	1.8	2.7	2.7	4.3	4.3	3.8	3.8			
DOA_C10T_ISS_WR_03_001	5.55	0.22	4.64	0.18	1.44	323	41.90	6.08	Interlaminar Shear	3000	93
DOA_C10T_ISS_WR_03_002	5.74	0.23	4.76	0.19	1.47	330	40.29	5.84	Interlaminar Shear		89
DOA_C10T_ISS_WR_03_003	5.60	0.22	4.50	0.18	1.42	318	42.16	6.11	Interlaminar Shear		93
DOA_C10T_ISS_WR_03_004	5.41	0.21	4.72	0.19	1.47	331	43.24	6.27	Interlaminar Shear		96
DOA_C10T_ISS_WR_03_005	5.18	0.20	4.80	0.19	1.33	299	40.05	5.81	Interlaminar Shear		88
Average	**5.50**	**0.22**	**4.68**	**0.18**	**1.43**	**320**	**41.53**	**6.02**			**92**
S_{n-1}	0.21	0.01	0.12	0.00	0.06	13	1.34	0.19			
CV((%)	3.9	3.9	2.6	2.6	4.1	4.1	3.2	3.2			

**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 Carbon Bond 300 HT (ASTM E1640) post water resistance conditioning (ASTM D2247)

Specimen ID	**T_g**		**Exposure**	**Acceptance**
	°C	**°F**	**Hrs.**	**Criteria***
DOA_CBHT_TG_WR_01_001	67.8	154.0		Pass
DOA_CBHT_TG_WR_01_002	66.2	151.2		Pass
DOA_CBHT_TG_WR_01_003	70.3	158.6	1000	Pass
DOA_CBHT_TG_WR_01_004	61.8	143.3		Pass
DOA_CBHT_TG_WR_01_005	70.3	158.6		Pass
Average	**67.3**	**153.1**		
S_{n-1}	3.5	6.4		
CV((%)	5.2	4.1		
DOA_CBHT_TG_WR_03_001	74.1	165.4		Pass
DOA_CBHT_TG_WR_03_002	78.5	173.3		Pass
DOA_CBHT_TG_WR_03_003	71.9	161.4	3000	Pass
DOA_CBHT_TG_WR_03_004	70.3	158.5		Pass
DOA_CBHT_TG_WR_03_005	73.8	164.8		Pass
Average	**73.7**	**164.7**		
S_{n-1}	3.1	5.5		
CV((%)	4.2	3.4		

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

Table 14.5 - Tabulated results for shear bond strength for CFU-10T (Lab Method) post water resistance conditioning (ASTM D2247)

Specimen ID	w		S		P		τ_d		Failure Mode	Exposure	Acceptance
	mm	in	mm	in	kN	lbf	MPa	psi		hrs.	criteria*
DOA_C10T_BSC_WR_01_001	25.40	1.00	228.60	9.00	10.56	2374	2.81	407	FRP debonding	1000	Pass
DOA_C10T_BSC_WR_01_002	25.40	1.00	228.60	9.00	10.95	2461	2.91	422	FRP debonding		Pass
DOA_C10T_BSC_WR_01_003	25.40	1.00	228.60	9.00	9.11	2047	2.42	351	FRP debonding		Pass
DOA_C10T_BSC_WR_01_004	25.40	1.00	228.60	9.00	9.43	2118	2.50	363	FRP debonding		Pass
DOA_C10T_BSC_WR_01_005	25.40	1.00	228.60	9.00	10.71	2407	2.85	413	FRP debonding		Pass
Average	**25.40**	**1.00**	**228.60**	**9.00**	**10.15**	**2281**	**2.70**	**391**			
S_{n-1}					0.83	186	0.22	32			
CV((%)					8.1	8.1	8.2	8.2			
DOA_C10T_BSC_WR_03_001	25.40	1.00	228.60	9.00	8.36	1879	2.22	322	FRP debonding	3000	Pass
DOA_C10T_BSC_WR_03_002	25.40	1.00	228.60	9.00	10.83	2433	2.88	417	FRP debonding		Pass
DOA_C10T_BSC_WR_03_003	25.40	1.00	228.60	9.00	8.55	1922	2.27	329	FRP debonding		Pass
DOA_C10T_BSC_WR_03_004	25.40	1.00	228.60	9.00	9.19	2066	2.44	354	FRP debonding		Pass
DOA_C10T_BSC_WR_03_005	25.40	1.00	228.60	9.00	9.68	2175	2.57	373	FRP debonding		Pass
Average	**25.40**	**1.00**	**228.60**	**9.00**	**9.32**	**2095**	**2.48**	**359**			
S_{n-1}					0.99	223	0.26	38			
CV((%)					10.6	10.6	10.7	10.7			

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

15. AGING: SALT WATER RESISTANCE – ASTM D1141

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

ASTM D3039/D3039M-14, 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 salt water environment.

15.1.4. Product/s Under Evaluation

CFU-10T fabric and Carbon Bond 300 HT resin.

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

Zahra Karim, Tais Hamilton, Andrea Correa and Philip Lavonas

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-DOA-SW.

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, 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 15.1.

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 tensile 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***
DOA_C10T_TNS_SW_01_001 to 005	Style# 1286/01/00	A: Batch# D553G3O081 and GMID# 97000852 B: Batch#D553G29000 and 0GMID#97000847	02.08.16	03.20.16	03.28.16
DOA_C10T_TNS_SW_03_001 to 005				06.12.16	06.20.16
DOA_C10T_TNS_SW_10_001 to 005				03.20.17	PENDING*
DOA_C10T_ISS_SW_01_001 to 005			05.17.16	06.13.16	06.17.16
DOA_C10T_ISS_SW_03_001 to 005				09.05.16	09.12.16
DOA_C10T_ISS_SW_10_001 to 005				06.23.17	PENDING*
DOA_CBHT_TG_SW_01_001 to 005			02.22.16	03.20.16	03.28.16
DOA_CBHT_TG_SW_03_001 to 005				06.12.16	06.16.16
DOA_CBHT_TG_SW_10_001 to 005				03.30.17	PENDING
DOA_C10T_BSC_SW_01_001 to 005				03.20.16	04.01.16
DOA_C10T_BSC_SW_03_001 to 005				06.12.16	06.22.16
DOA_C10T_BSC_SW_10_001 to 005				03.30.17	PENDING

*Visual inspection only, no test required.

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 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.

15.4. TEST SET-UP

15.4.1. 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 72 hours). 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. For the 10,000 hrs. exposure, only visual inspection of the conditioned specimens is required. Testing for 10,000hrs is on ongoing.

15.5.2. 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.

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 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 15.2 - Tabulated results for tensile tests for CFU-10T, (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
DOA_C10T_TNS_SW_01_001	13.07	0.020	17.40	3909	1330.1	192.9	89.59	13.00	1.48	SGM		94	99	95
DOA_C10T_TNS_SW_01_002	13.63	0.021	18.52	4162	1358.2	197.0	88.01	12.77	1.54	SGM		96	97	99
DOA_C10T_TNS_SW_01_003	13.21	0.020	18.80	4224	1422.4	206.3	81.25	11.79	1.75	SGM	1000	101	90	112
DOA_C10T_TNS_SW_01_004	13.56	0.021	17.14	3852	1263.5	183.2	83.18	12.07	1.52	SGM		90	92	98
DOA_C10T_TNS_SW_01_005	13.64	0.021	18.94	4257	1387.9	201.3	89.18	12.94	1.56	SGM		99	99	100
Average	**13.42**	**0.021**	**18.16**	**4081**	**1352.4**	**196.2**	**86.24**	**12.51**	**1.57**			**96**	**95**	**101**
S_{n-1}	0.26	0.000	0.83	187	60.4	8.8	3.78	0.55	0.10					
CV((%)	2.0	2.0	4.6	4.6	4.5	4.5	4.4	4.4	6.6					
DOA_C10T_TNS_SW_03_001	13.48	0.021	17.64	3963	1307.7	189.7	95.12	13.80	1.37	SGM		93	105	88
DOA_C10T_TNS_SW_03_002	13.95	0.022	18.08	4062	1294.9	187.8	82.56	11.98	1.57	SGM		92	91	101
DOA_C10T_TNS_SW_03_003	14.58	0.023	17.71	3981	1214.6	176.2	88.09	12.78	1.38	SGM	3000	86	97	89
DOA_C10T_TNS_SW_03_004	13.98	0.022	19.82	4454	1417.1	205.5	86.49	12.55	1.64	MGV		101	96	105
DOA_C10T_TNS_SW_03_005	14.43	0.022	17.54	3942	1215.2	176.3	76.43	11.09	1.59	SGM		86	85	102
Average	**14.08**	**0.022**	**18.16**	**4080**	**1289.9**	**187.1**	**85.74**	**12.44**	**1.51**			**92**	**95**	**97**
S_{n-1}	0.43	0.001	0.95	214	83.3	12.1	6.91	1.00	0.12					
CV((%)	3.1	3.1	5.2	5.2	6.5	6.5	8.1	8.1	8.2					

**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 CFU-10T, (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}
DOA_C10T_ISS_SW_01_001	11.19	0.44	4.98	0.20	3.45	775	46.42	6.73	Interlaminar Shear	1000	103
DOA_C10T_ISS_SW_01_002	11.34	0.45	4.91	0.19	3.53	792	47.42	6.88	Interlaminar Shear		105
DOA_C10T_ISS_SW_01_003	10.11	0.40	4.86	0.19	3.00	675	45.79	6.64	Interlaminar Shear		103
DOA_C10T_ISS_SW_01_004	10.25	0.40	4.78	0.19	2.92	655	44.68	6.48	Interlaminar Shear		101
DOA_C10T_ISS_SW_01_005	10.11	0.40	4.65	0.18	2.81	632	44.88	6.51	Interlaminar Shear		101
Average	**10.60**	**0.42**	**4.84**	**0.19**	**3.14**	**706**	**45.84**	**6.65**			**102**
S_{n-1}	0.61	0.02	0.13	0.01	0.32	73	1.13	0.16			
CV((%)	5.8	5.8	2.7	2.7	10.3	10.3	2.5	2.5			
DOA_C10T_ISS_SW_03_001	6.05	0.24	4.93	0.19	1.67	376	42.12	6.11	Interlaminar Shear	3000	93
DOA_C10T_ISS_SW_03_002	5.68	0.22	5.02	0.20	1.57	352	41.26	5.98	Interlaminar Shear		91
DOA_C10T_ISS_SW_03_003	5.69	0.22	4.89	0.19	1.59	358	42.90	6.22	Interlaminar Shear		95
DOA_C10T_ISS_SW_03_004	5.92	0.23	5.00	0.20	1.65	372	41.87	6.07	Interlaminar Shear		93
DOA_C10T_ISS_SW_03_005	5.89	0.23	5.03	0.20	1.75	393	44.23	6.41	Interlaminar Shear		98
Average	**5.36**	**0.21**	**4.98**	**0.20**	**1.48**	**333**	**41.66**	**6.04**			**92**
S_{n-1}	5.76	0.23	4.97	0.20	1.62	364	42.34	6.14			
CV((%)	0.24	0.01	0.05	0.00	0.09	21	1.07	0.16			

**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 Carbon Bond 300 HT (ASTM E1640) post salt water resistance conditioning (ASTM D1141)

Specimen ID	T_g		**Acceptance Criteria***
	°C	**°F**	
DOA_CBHT_TG_SW_01_001	60.3	140.6	Pass
DOA_CBHT_TG_SW_01_002	61.2	142.2	Pass
DOA_CBHT_TG_SW_01_003	65.7	150.3	Pass
DOA_CBHT_TG_SW_01_004	59.9	139.8	Pass
DOA_CBHT_TG_SW_01_005	64.5	148.1	Pass
Average	**62.3**	**144.2**	
S_{n-1}	2.6	4.7	
CV((%)	4.2	3.3	
DOA_CBHT_TG_SW_03_001	60.9	141.6	Pass
DOA_CBHT_TG_SW_03_002	67.1	152.8	Pass
DOA_CBHT_TG_SW_03_003	65.5	149.9	Pass
DOA_CBHT_TG_SW_03_004	62.8	145.0	Pass
DOA_CBHT_TG_SW_03_005	61.7	143.1	Pass
Average	**63.6**	**146.5**	
S_{n-1}	2.6	4.7	
CV((%)	4.1	3.2	

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

Table 15.5 - Tabulated results for shear bond strength tests for CFU-10T, (Lab Method) post salt water resistance conditioning (ASTM D1141)

Specimen ID	w		S		P		τ_d		Failure Mode	Exposure	Pass/Fail
	mm	in	mm	in	kN	lbf		psi		hrs.	
DOA_C10T_BSC_SW_01_001	25.40	1.00	228.60	9.00	9.11	2047	2.42	351	FRP debonding	1000	Pass
DOA_C10T_BSC_SW_01_002	25.40	1.00	228.60	9.00	8.62	1937	2.29	332	FRP debonding		Pass
DOA_C10T_BSC_SW_01_003	25.40	1.00	228.60	9.00	9.97	2240	2.65	384	FRP debonding		Pass
DOA_C10T_BSC_SW_01_004	25.40	1.00	228.60	9.00	8.41	1891	2.23	324	FRP debonding		Pass
DOA_C10T_BSC_SW_01_005	25.40	1.00	228.60	9.00	9.18	2064	2.44	354	FRP debonding		Pass
Average	**25.40**	**1.00**	**228.60**	**9.00**	**9.06**	**2036**	**2.41**	**349**			
S_{n-1}					0.60	135	0.16	23			
CV((%)					6.7	6.7	6.7	6.7			
DOA_C10T_BSC_SW_03_001	25.40	1.00	228.60	9.00	8.10	1821	2.15	312	FRP debonding	3000	Pass
DOA_C10T_BSC_SW_03_002	25.40	1.00	228.60	9.00	6.39	1436	1.70	246	FRP debonding		Pass
DOA_C10T_BSC_SW_03_003	25.40	1.00	228.60	9.00	8.00	1798	2.12	308	FRP debonding		Pass
DOA_C10T_BSC_SW_03_004	25.40	1.00	228.60	9.00	8.71	1958	2.32	336	FRP debonding		Pass
DOA_C10T_BSC_SW_03_005	25.40	1.00	228.60	9.00	8.29	1864	2.20	319	FRP debonding		Pass
Average	**25.40**	**1.00**	**228.60**	**9.00**	**7.90**	**1775**	**2.10**	**304**			
S_{n-1}					0.89	199	0.24	34			
CV((%)					11.2	11.2	11.3	11.3			

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

16. AGING: ALKALI RESISTANCE– ASTM C581

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 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-14, 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, interlaminar shear strength, after ageing exposure to an alkaline water environment.

16.1.4. Product/s Under Evaluation

CFU-10T fabric and Carbon Bond 300 HT resin.

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

Zahra Karim, Tais Hamilton, Andrea Correa and Philip Lavonas

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-DOA-AR.

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 hours) and physical/mechanical test designation (ASTM D3039, ASTM D2344, ASTM E1640 and shear bond strength lab method) were performed. A total of 10 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 tensile tests post alkali resistance conditioning

Specimen ID	FRP Batch ID		Aging		Tested
	Fiber #	*Resin* #	*Start* mm.dd.yy	*Finish* mm.dd.yy	mm.dd.yy
DOA_C10T_TNS_AR_01_001 to 005	Style# 1286/01/00	A: Batch# D553G3O081 and GMID# 97000852 B: Batch#D553G29000 and 0GMID#97000847	02.08.16	03.20.16	03.28.16
DOA_C10T_TNS_AR_03_001 to 005				06.12.16	06.20.16
DOA_C10T_ISS_AR_01_001 to 005			05.17.16	06.13.16	06.17.16
DOA_C10T_ISS_AR_03_001 to 005				09.05.16	09.12.16
DOA_CBHT_TG_AR_01_001 to 005			02.22.16	03.20.16	04.05.16
DOA_CBHT_TG_AR_03_001 to 005				06.12.16	06.20.16
DOA_C10T_BSC_AR_01_001 to 005				03.20.16	04.01.16
DOA_C10T_BSC_AR_03_001 to 005				06.12.16	06.22.16

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 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.

16.4. TEST SET-UP

16.4.1. 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 72 hours). 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, and of 1.38 MPa (200 psi) for shear bond strength. Detailed test results are reported in Section 16.5.4.

16.5.2. 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.

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 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 16.2 - Tabulated results for tensile tests for CFU-10T (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
DOA_C10T_TNS_AR_01_001	13.90	0.022	19.02	4274	1367.7	198.4	81.46	11.82	1.68	SGM	1000	97	90	108
DOA_C10T_TNS_AR_01_002	13.93	0.022	19.70	4427	1413.9	205.1	91.25	13.24	1.55	LGT		100	101	99
DOA_C10T_TNS_AR_01_003	13.81	0.021	17.51	3935	1267.9	183.9	86.70	12.58	1.46	SGM		90	96	94
DOA_C10T_TNS_AR_01_004	13.71	0.021	18.27	4105	1331.7	193.1	86.84	12.60	1.53	LGB		95	96	98
DOA_C10T_TNS_AR_01_005	13.85	0.021	19.41	4362	1401.2	203.2	90.08	13.07	1.55	LGB		99	100	100
Average	**13.84**	**0.021**	**18.78**	**4221**	**1356.5**	**196.7**	**87.26**	**12.66**	**1.56**			**96**	**97**	**100**
S_{n-1}	0.09	0.000	0.89	200	58.9	8.5	3.81	0.55	0.08					
CV((%)	0.6	0.6	4.7	4.7	4.3	4.3	4.4	4.4	5.0					
DOA_C10T_TNS_AR_03_001	14.51	0.022	17.42	3914	1199.8	174.0	87.37	12.68	1.37	SGM	3000	85	97	88
DOA_C10T_TNS_AR_03_002	14.16	0.022	19.71	4429	1391.6	201.8	80.15	11.63	1.74	SGM		99	89	111
DOA_C10T_TNS_AR_03_003	14.67	0.023	17.59	3952	1198.1	173.8	79.32	11.51	1.51	SGM		85	88	97
DOA_C10T_TNS_AR_03_004	13.66	0.021	18.12	4071	1326.1	192.3	83.94	12.18	1.58	SGM		94	93	101
DOA_C10T_TNS_AR_03_005	13.98	0.022	17.10	3842	1222.2	177.3	90.08	13.07	1.36	SGM		87	100	87
Average	**14.20**	**0.022**	**17.99**	**4042**	**1267.6**	**183.8**	**84.17**	**12.21**	**1.51**			**90**	**93**	**97**
S_{n-1}	0.41	0.001	1.03	232	87.0	12.6	4.60	0.67	0.16					
CV((%)	2.9	2.9	5.7	5.7	6.9	6.9	5.5	5.5	10.4					

**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 CFU-10T (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}***
DOA_C10T_ISS_AR_01_001	10.53	0.41	5.19	0.20	3.42	769	46.93	6.81	Interlaminar Shear	1000	104
DOA_C10T_ISS_AR_01_002	11.29	0.44	5.00	0.20	3.45	776	45.83	6.65	Interlaminar Shear		101
DOA_C10T_ISS_AR_01_003	12.03	0.47	5.19	0.20	3.79	852	45.48	6.60	Interlaminar Shear		100
DOA_C10T_ISS_AR_01_004	10.33	0.41	5.16	0.20	3.32	745	46.69	6.77	Interlaminar Shear		105
DOA_C10T_ISS_AR_01_005	10.49	0.41	4.41	0.17	2.76	620	44.74	6.49	Interlaminar Shear		101
Average	**10.93**	**0.43**	**4.99**	**0.20**	**3.35**	**752**	**45.93**	**6.66**			**102**
S_{n-1}	0.72	0.03	0.34	0.01	0.37	84	0.90	0.13			
CV((%)	6.6	6.6	6.7	6.7	11.2	11.2	2.0	2.0			
DOA_C10T_ISS_AR_03_001	5.33	0.21	4.74	0.19	1.41	317	41.81	6.06	Interlaminar Shear	3000	92
DOA_C10T_ISS_AR_03_002	5.42	0.21	4.79	0.19	1.48	333	42.79	6.21	Interlaminar Shear		95
DOA_C10T_ISS_AR_03_003	5.32	0.21	4.91	0.19	1.44	323	41.16	5.97	Interlaminar Shear		91
DOA_C10T_ISS_AR_03_004	5.33	0.21	4.71	0.19	1.37	309	40.97	5.94	Interlaminar Shear		91
DOA_C10T_ISS_AR_03_005	5.44	0.21	4.86	0.19	1.45	326	41.12	5.96	Interlaminar Shear		91
Average	**5.37**	**0.21**	**4.80**	**0.19**	**1.43**	**321**	**41.57**	**6.03**			**92**
S_{n-1}	0.05	0.00	0.09	0.00	0.04	9	0.75	0.11			
CV((%)	1.0	1.0	1.8	1.8	2.9	2.9	1.8	1.8			

**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 Carbon Bond 300 HT (ASTM E1640) post alkali resistance conditioning (ASTM C581)

Specimen ID	T_g		Acceptance
	°C	**°F**	**Criteria***
DOA_CBHT_TG_AR_01_001	65.8	150.4	Pass
DOA_CBHT_TG_AR_01_002	63.9	147.0	Pass
DOA_CBHT_TG_AR_01_003	60.3	140.5	Pass
DOA_CBHT_TG_AR_01_004	61.6	142.9	Pass
DOA_CBHT_TG_AR_01_005	65.3	149.5	Pass
Average	**63.4**	**146.1**	
S_{n-1}	2.4	4.3	
CV((%)	3.7	2.9	
DOA_CBHT_TG_AR_03_001	61.8	143.2	Pass
DOA_CBHT_TG_AR_03_002	60.0	140.0	Pass
DOA_CBHT_TG_AR_03_003	65.4	149.7	Pass
DOA_CBHT_TG_AR_03_004	61.7	143.1	Pass
DOA_CBHT_TG_AR_03_005	60.2	140.4	Pass
Average	**61.8**	**143.3**	
S_{n-1}	2.2	3.9	
CV((%)	3.5	2.7	

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

Table 16.5 - Tabulated results for shear bond strength tests for CFU-10T (Lab Method) post alkali resistance conditioning (ASTM C581)

Specimen ID	w		S		P		τ_d		Failure Mode	Exposure	Pass/Fail*
	mm	in	mm	in	kN	lbf		psi		hrs.	
DOA_C10T_BSC_AR_01_001	25.40	1.00	228.60	9.00	9.01	2024	2.39	347	FRP debonding	1000	Pass
DOA_C10T_BSC_AR_01_002	25.40	1.00	228.60	9.00	8.93	2006	2.37	344	FRP debonding		Pass
DOA_C10T_BSC_AR_01_003	25.40	1.00	228.60	9.00	9.95	2235	2.64	383	FRP debonding		Pass
DOA_C10T_BSC_AR_01_004	25.40	1.00	228.60	9.00	9.38	2108	2.49	361	FRP debonding		Pass
DOA_C10T_BSC_AR_01_005	25.40	1.00	228.60	9.00	10.49	2358	2.79	404	FRP debonding		Pass
Average	**25.40**	**1.00**	**228.60**	**9.00**	**9.55**	**2146**	**2.54**	**368**			
S_{n-1}					0.66	149	0.18	25			
CV((%)					6.9	6.9	6.9	6.9			
DOA_C10T_BSC_AR_03_001	25.40	1.00	228.60	9.00	5.81	1306	1.54	224	FRP debonding	3000	Pass
DOA_C10T_BSC_AR_03_002	25.40	1.00	228.60	9.00	7.89	1773	2.10	304	FRP debonding		Pass
DOA_C10T_BSC_AR_03_003	25.40	1.00	228.60	9.00	9.36	2103	2.48	360	FRP debonding		Pass
DOA_C10T_BSC_AR_03_004	25.40	1.00	228.60	9.00	9.41	2114	2.50	362	FRP debonding		Pass
DOA_C10T_BSC_AR_03_005	25.40	1.00	228.60	9.00	8.81	1980	2.34	339	FRP debonding		Pass
Average	**25.40**	**1.00**	**228.60**	**9.00**	**8.26**	**1855**	**2.19**	**318**			
S_{n-1}					1.50	336	0.40	57			
CV((%)					18.1	18.1	18.1	18.1			

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

17. AGING: DRY HEAT RESISTANCE– ASTM D3045

17.1. TEST SUMMARY

17.1.1. 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.

17.1.2. Reference Standard/s

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

ASTM D3039/D3039M-14, 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

17.1.3. 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.

17.1.4. Product/s Under Evaluation

CFU-10T fabric and Carbon Bond 300 HT resin.

17.1.5. Test Location

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

17.1.6. Laboratory Technician/s

Zahra Karim, Tais Hamilton, Andrea Correa and Philip Lavonas

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-DOA-DH.

17.2. TEST MATRIX

17.2.1. 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 10 tests per test type are reported, refer to Table 17.1.

17.2.2. Specimen ID Nomenclature

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

17.2.3. Test Matrix Table

Table 17.1 – Test matrix for tensile tests post dry heat resistance conditioning

Specimen ID	FRP Batch ID		Aging		Tested
	Fiber	***Resin***	***Start***	***Finish***	
	#	**#**	***mm.dd.yy***	***mm.dd.yy***	***mm.dd.yy***
DOA_C10T_TNS_DH_01_001 to 005	Style# 1286/01/00	A: Batch# D553G3O081 and GMID# 97000852 B: Batch#D553G29000 and 0GMID#97000847	02.08.16	03.20.16	03.29.16
DOA_C10T_TNS_DH_03_001 to 005				06.12.16	06.20.16
DOA_C10T_ISS_DH_01_001 to 005			05.17.16	06.13.16	06.17.16
DOA_C10T_ISS_DH_03_001 to 005				09.05.16	09.12.16
DOA_CBHT_TG_DH_01_001 to 005			02.22.16	03.20.16	03.31.16
DOA_CBHT_TG_DH_03_001 to 005				06.12.16	06.17.16
DOA_C10T_BSC_DH_01_001 to 005				03.20.16	04.01.16
DOA_C10T_BSC_DH_03_001 to 005				06.12.16	06.22.16

17.3. SPECIMEN PREPARATION

17.3.1. 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.

17.3.2. 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.

17.4. TEST SET-UP

17.4.1. 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 72 hours). 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.

17.4.2. 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.

17.5. TEST RESULTS

17.5.1. 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 Section 17.5.4.

17.5.2. 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.

17.5.3. 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.

17.5.4. Tabulated Results

Table 17.2 through Table 17.5 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 17.2 - Tabulated results for tensile tests for CFU-10T (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
DOA_C10T_TNS_DH_01_001	13.10	0.020	20.15	4528	1537.4	223.0	85.53	12.41	1.80	SGM	1000	109	95	115
DOA_C10T_TNS_DH_01_002	13.43	0.021	19.43	4367	1446.8	209.8	94.00	13.64	1.54	SGM		103	104	99
DOA_C10T_TNS_DH_01_003	13.58	0.021	20.51	4608	1509.9	219.0	82.63	11.99	1.83	LGT		107	91	117
DOA_C10T_TNS_DH_01_004	13.21	0.020	18.72	4206	1416.3	205.4	88.35	12.82	1.60	SGB		101	98	103
DOA_C10T_TNS_DH_01_005	13.30	0.021	18.66	4194	1402.2	203.4	89.59	13.00	1.56	LGT		100	99	100
Average	**13.32**	**0.021**	**19.49**	**4381**	**1462.5**	**212.1**	**88.02**	**12.77**	**1.67**			**104**	**97**	**107**
S_{n-1}	0.18	0.000	0.83	186	58.9	8.5	4.29	0.62	0.14					
CV((%)	1.4	1.4	4.3	4.3	4.0	4.0	4.9	4.9	8.1					
DOA_C10T_TNS_DH_03_001	14.00	0.022	20.60	4628	1471.0	213.4	90.53	13.14	1.62	SGM	3000	104	100	104
DOA_C10T_TNS_DH_03_002	14.65	0.023	19.44	4369	1327.0	192.5	91.59	13.29	1.45	SGM		94	101	93
DOA_C10T_TNS_DH_03_003	13.62	0.021	20.52	4612	1506.6	218.5	88.49	12.84	1.70	LGM		107	98	109
DOA_C10T_TNS_DH_03_004	13.78	0.021	19.75	4438	1432.8	207.8	85.25	12.37	1.68	SGM		102	94	108
DOA_C10T_TNS_DH_03_005	14.59	0.023	18.74	4212	1284.0	186.2	88.99	12.91	1.44	SGM		91	98	93
Average	**14.13**	**0.022**	**19.81**	**4452**	**1404.3**	**203.7**	**88.97**	**12.91**	**1.58**			**100**	**98**	**101**
S_{n-1}	0.47	0.001	0.77	174	95.1	13.8	2.42	0.35	0.13					
CV((%)	3.3	3.3	3.9	3.9	6.8	6.8	2.7	2.7	8.0					

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

Table 17.3 - Tabulated results for interlaminar shear tests for CFU-10T (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}***
DOA_C10T_ISS_DH_01_001	10.60	0.42	4.98	0.20	3.68	828	52.32	7.59	Interlaminar Shear	1000	116
DOA_C10T_ISS_DH_01_002	9.94	0.39	4.95	0.20	3.44	773	52.39	7.60	Interlaminar Shear		116
DOA_C10T_ISS_DH_01_003	10.36	0.41	4.88	0.19	3.65	819	54.07	7.84	Interlaminar Shear		119
DOA_C10T_ISS_DH_01_004	9.78	0.39	4.99	0.20	3.43	770	52.62	7.63	Interlaminar Shear		116
DOA_C10T_ISS_DH_01_005	9.73	0.38	4.90	0.19	3.30	742	51.92	7.53	Interlaminar Shear		115
Average	**10.08**	**0.40**	**4.94**	**0.19**	**3.50**	**786**	**52.66**	**7.64**			**116**
S_{n-1}	0.38	0.02	0.05	0.00	0.16	36	0.83	0.12			
CV((%)	3.8	3.8	1.0	1.0	4.6	4.6	1.6	1.6			
DOA_C10T_ISS_DH_03_001	5.23	0.21	4.56	0.18	1.52	341	47.73	6.92	Interlaminar Shear	3000	105
DOA_C10T_ISS_DH_03_002	5.35	0.21	4.52	0.18	1.58	354	48.88	7.09	Interlaminar Shear		108
DOA_C10T_ISS_DH_03_003	5.30	0.21	4.56	0.18	1.55	347	47.99	6.96	Interlaminar Shear		106
DOA_C10T_ISS_DH_03_004	5.45	0.21	4.61	0.18	1.65	372	49.34	7.16	Interlaminar Shear		109
DOA_C10T_ISS_DH_03_005	5.19	0.20	4.51	0.18	1.53	343	48.92	7.10	Interlaminar Shear		108
Average	**5.30**	**0.21**	**4.55**	**0.18**	**1.56**	**352**	**48.57**	**7.04**			**107**
S_{n-1}	0.10	0.00	0.04	0.00	0.05	12	0.68	0.10			
CV((%)	1.9	1.9	0.9	1.1	3.5	3.5	1.4	1.4			

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

Table 17.4 - Tabulated results for glass transition temperature for Carbon Bond 300 HT (ASTM E1640) post dry heat conditioning (ASTM D3045)

Specimen ID	T_g		Acceptance
	°C	**°F**	**Criteria***
DOA_CBHT_TG_DH_01_001	81.5	178.7	Pass
DOA_CBHT_TG_DH_01_002	80.6	177.1	Pass
DOA_CBHT_TG_DH_01_003	79.5	175.1	Pass
DOA_CBHT_TG_DH_01_004	85.4	185.7	Pass
DOA_CBHT_TG_DH_01_005	82.7	180.9	Pass
Average	**81.9**	**179.5**	
S_{n-1}	2.3	4.1	
CV((%)	2.8	2.3	
DOA_CBHT_TG_DH_03_001	79.4	174.9	Pass
DOA_CBHT_TG_DH_03_002	83.4	182.1	Pass
DOA_CBHT_TG_DH_03_003	77.2	171.0	Pass
DOA_CBHT_TG_DH_03_004	86.5	187.7	Pass
DOA_CBHT_TG_DH_03_005	84.8	184.6	Pass
Average	**82.3**	**180.1**	
S_{n-1}	3.9	6.9	
CV((%)	4.7	3.9	

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

Table 17.5 - Tabulated results for shear bond strength tests for CFU-10T (Lab Method) post dry heat conditioning (ASTM D3045)

Specimen ID	w		S		P		τ_d		Failure Mode	Exposure	Pass/Fail*
	mm	in	mm	in	kN	lbf	MPa	psi		hrs.	
DOA_C10T_BSC_DH_01_001	25.40	1.00	228.60	9.00	9.94	2234	2.64	383	FRP debonding	1000	Pass
DOA_C10T_BSC_DH_01_002	25.40	1.00	228.60	9.00	9.39	2109	2.49	361	FRP debonding		Pass
DOA_C10T_BSC_DH_01_003	25.40	1.00	228.60	9.00	9.08	2041	2.41	350	FRP debonding		Pass
DOA_C10T_BSC_DH_01_004	25.40	1.00	228.60	9.00	8.62	1936	2.29	332	FRP debonding		Pass
DOA_C10T_BSC_DH_01_005	25.40	1.00	228.60	9.00	9.38	2107	2.49	361	FRP debonding		Pass
Average	**25.40**	**1.00**	**228.60**	**9.00**	**9.28**	**2085**	**2.46**	**357**			
S_{n-1}					0.48	109	0.13	19			
CV((%)					5.2	5.2	5.2	5.2			
DOA_C10T_BSC_DH_03_001	25.40	1.00	228.60	9.00	8.28	1861	2.20	319	FRP debonding	3000	Pass
DOA_C10T_BSC_DH_03_002	25.40	1.00	228.60	9.00	9.47	2129	2.52	365	FRP debonding		Pass
DOA_C10T_BSC_DH_03_003	25.40	1.00	228.60	9.00	9.07	2039	2.39	346	FRP debonding		Pass
DOA_C10T_BSC_DH_03_004	25.40	1.00	228.60	9.00	9.65	2169	2.56	372	FRP debonding		Pass
DOA_C10T_BSC_DH_03_005	25.40	1.00	228.60	9.00	9.32	2094	2.48	359	FRP debonding		Pass
Average	**25.40**	**1.00**	**228.60**	**9.00**	**9.16**	**2058**	**2.43**	**352**			
S_{n-1}					0.54	120	0.14	21			
CV((%)					5.8	5.8	5.9	5.9			

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

18. EXTERIOR EXPOSURE – ASTM D2565

18.1. TEST SUMMARY

18.1.1. AC125 Section/s

Section 5.9 for Exterior Exposure

18.1.2. Reference StandARd/s

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

ASTM D3039/D3039M – 14, StandARd test method for Tensile Properties of Polymer Matrix Composite Materials.

18.1.3. 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.

18.1.4. Product/s Under Evaluation

CFU-10T fabric with Carbon Bond 300 HT resin.

18.1.5. Test Location

Exposure under the supervision of SML technicians at: Florida Department of Transportation - State Materials Office, 5007 NE 39th Avenue, Gainesville, FL 32609
Tensile testing at: University of Miami, College of Engineering, Structures and Materials Laboratory, 1251 Memorial Dr., Coral Gables, FL, 33146

18.1.6. Laboratory Technician/s

Andrea Correa and Francisco De Caso

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-DOA-EE.

18.2. TEST MATRIX

18.2.1. Specimen Number

A total of 6 tests (one benchmark and 5 conditioned) are reported, refer to Table 18.1.

18.2.2. Specimen ID Nomenclature

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

18.2.3. Test Matrix Table

Table 18.1– Test matrix for external exposure specimens

Specimen ID	Fiber Lot #	Resin Batch #	Specimen Preparation (mm.dd.yy)	Exposure Start - End (mm.dd.yy)	Tested (mm.dd.yy)
DOA_C10T_TNS_EE_00_001	Style# 1286/01/00	A: Batch# D553G3O081 and GMID# 97000852 B: Batch# D553G29000 and GMID#97000847	02.01.16	N/A	07.01.16
DOA_C10T_TNS_EE_02_001 to 005				03.29.16 – 06.20.16	

18.3. SPECIMEN PREPARATION

18.3.1. Specimen Size

Nominal specimen dimensions are reported in Table 18.2, including length and nominal thickness. Average values, determined based on three measurements of the width for each specimen prior testing were recorded to compute the area as reported in the results Chapter.

Table 18.2 – External exposure specimen nominal dimensions

Specimen ID	Length		Thickness	
	mm	*in.*	*mm*	*in.*
DOA_C10T_TNS_EE_02	254.0	10.0	0.533	0.021

18.3.2. 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 4.2.1.

18.3.3. Conditioning Parameters

One specimen was conditioned under laboratory ambient conditions at room temperature 23 ± 1°C (73 ± 3°F) and 60 ± 5% relative humidity, for at least 24 hrs prior testing. The remaining 5 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 as seen in Figure 18.1 . The black-body temperature is 145°F (63°C).

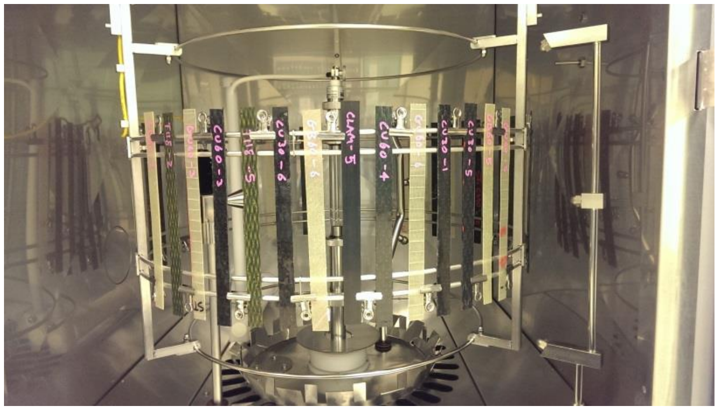


Figure 18.1 - Weatherometer chamber set-up with tensile specimens

18.4. TEST SET-UP

18.4.1. Set-up

Specimens were tested in pure tension as described in Section 5.4.1.

18.4.2. Rate and Method of Loading

Rate and method of loading are described in Section 5.4.2

18.5. TEST RESULTS

18.5.1. 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 the 2000 hrs. of exterior exposure.

18.5.2. Modes of Failure

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

18.5.3. Calculations

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

18.5.4. Tabulated Results

Table 13.3 contains the tabulated summary tensile test results after exterior exposure, and Table 13.5 the results for the control specimen. Refer to the last column of the 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.

Table13.3 - Tabulated results for tensile tests for CFU-10T (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.***	***F^tu^***	***E^chord^***	***ε~u~***
DOA_C10T_TNS_EE_02_001	10.13	0.016	14.20	3191	1400.6	203.14	87.04	12.63	1.61	LGM		99	96	103
DOA_C10T_TNS_EE_02_002	10.31	0.016	13.06	2934	1265.8	183.59	84.15	12.21	1.50	AGM		90	93	97
DOA_C10T_TNS_EE_02_003	10.23	0.016	13.75	3089	1343.3	194.83	84.01	12.19	1.60	SGM	2000	95	93	103
DOA_C10T_TNS_EE_02_004	9.90	0.015	13.42	3016	1354.6	196.47	89.94	13.05	1.51	LGM		96	99	97
DOA_C10T_TNS_EE_02_005	10.08	0.016	12.94	2907	1282.8	186.06	82.77	12.01	1.55	AGM		91	92	99
Average	**10.13**	**0.016**	**13.47**	**3027**	**1329.4**	**192.82**	**85.58**	**12.42**	**1.55**			**94**	**95**	**100**
S_{n-1}	0.15	0.000	0.52	116	55.0	7.98	2.90	0.42	0.05					
CV((%)	1.5	1.5	3.8	3.8	4.1	4.1	3.4	3.4	3.2					

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

Table 13.4 – Exterior Exposure control test specimen

Specimen ID	***A***		***P^max^***		***F^tu^***		***E^chord^***		***ε~u~***	**Failure Mode**
	mm²	***in²***	***kN***	***lbs***	***MPa***	***ksi***	***GPa***	***Msi***	***%***	
DOA_C10T_TNS_EE_00_001	10.12	0.016	15.03	3378	1484.7	215.34	91.32	13.25	1.63	SGM

19. FUEL RESISTANCE – ASTM C581

19.1. TEST SUMMARY

19.1.1. AC125 Section/s

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

19.1.2. 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-14, 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.

19.1.3. 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.

19.1.4. Product/s Under Evaluation

CFU-10T fabric and Carbon Bond 300 HT resin.

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

Zahra Karim, Tais Hamilton and Philip Lavonas

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-DOA-FR.

19.2. TEST MATRIX

19.2.1. Specimen Number

Specimens were made from different FRP panels, where five test repetitions for physical/mechanical test designation (ASTM D3039, ASTM D2344 and ASTM E1640) were performed. A total of 5 per test type are reported, refer to Table 19.1.

19.2.2. Specimen ID Nomenclature

Specimens are identified throughout 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 fuel resistance conditioning

Specimen ID	Fiber Lot #	Resin Batch #	Specimen Preparation (mm.dd.yy)	Tested (mm.dd.yy)
DOA_C10T_TNS_FR_001 to 005	Style# 1286/01/00	A: Batch# D553G3O081 and GMID# 97000852 B: Batch# D553G29000 and GMID#97000847	02.01.16	03.03.16
DOA_C10T_ISS_FR_001 to 005			05.06.16	02.29.16
DOA_CBHT_TG_FR_001 to 005			02.17.16	03.09.16

19.3. SPECIMEN PREPARATION

19.3.1. 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.

19.3.2. 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.

19.4. TEST SET-UP

19.4.1. 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.

19.4.2. 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.

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. 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 Section 19.5.4 for detailed results.

19.5.2. Modes of Failure

Modes of failure for the different physical and mechanical tests after fuel resistance conditioning cycles 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; Chapter 10 for interlaminar shear strength; and Chapter 9 for glass transition temperature.

19.5.4. Tabulated Results

Table 19.2 through Table 19.4, 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 19.2 - Tabulated results for tensile tests for CFU-10T (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
DOA_C10T_TNS_FR_001	13.70	0.021	18.60	4180	1357.5	196.88	82.49	11.97	1.64	LGM		96	91	106
DOA_C10T_TNS_FR_002	13.67	0.021	17.69	3976	1293.8	187.64	86.63	12.57	1.49	AGM		92	96	96
DOA_C10T_TNS_FR_003	13.44	0.021	18.23	4096	1355.7	196.62	89.94	13.05	1.51	LGM	4	96	99	97
DOA_C10T_TNS_FR_004	13.51	0.021	17.84	4008	1319.9	191.43	86.01	12.48	1.53	SGM		94	95	99
DOA_C10T_TNS_FR_005	13.83	0.021	18.26	4103	1319.4	191.36	83.32	12.09	1.58	SGM		94	92	102
Average	**13.63**	**0.021**	**18.12**	**4073**	**1329.2**	**192.79**	**85.68**	**12.43**	**1.55**			**94**	**95**	**100**
S_{n-1}	0.16	0.000	0.36	81	27.1	3.93	2.95	0.43	0.06					
CV((%)	1.2	1.2	2.0	2.0	2.0	2.0	3.4	3.4	4.0					

**No conditions of acceptance specified in AC125*

Table 19.3 - Tabulated results for interlaminar shear tests CFU-10T (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}
DOA_C10T_ISS_FR_001	6.17	0.243	4.39	0.173	1.62	365	44.90	6.51	Interlaminar shear		99
DOA_C10T_ISS_FR_002	6.02	0.237	4.55	0.179	1.51	339	41.32	5.99	Interlaminar shear		92
DOA_C10T_ISS_FR_003	6.81	0.268	4.37	0.172	1.61	362	40.61	5.89	Interlaminar shear	4	90
DOA_C10T_ISS_FR_004	5.72	0.225	4.34	0.171	1.37	307	41.26	5.98	Interlaminar shear		91
DOA_C10T_ISS_FR_005	6.63	0.261	4.29	0.169	1.62	365	42.79	6.21	Interlaminar shear		95
Average	**6.27**	**0.247**	**4.39**	**0.173**	**1.55**	**348**	**42.18**	**6.12**			**93**
S_{n-1}	0.45	0.018	0.10	0.004	0.11	25	1.72	0.25			
CV((%)	7.1	7.1	2.2	2.2	7.2	7.2	4.1	4.1			

**No conditions of acceptance specified in AC125*

Table 19.4 -Tabulated results for glass transition temperature for Carbon Bond 300 HT (ASTM D2344) post fuel resistance conditioning (ASTM C581)

Specimen ID	**T_g**		**Exposure**	**Acceptance**
	°C	**°F**	**Hrs.**	**Criteria***
DOA_CBHT_TG_FR_001	63.9	147.0		Pass
DOA_CBHT_TG_FR_002	60.8	141.4		Pass
DOA_CBHT_TG_FR_003	59.8	139.6	4	Pass
DOA_CBHT_TG_FR_004	65.3	149.5		Pass
DOA_CBHT_TG_FR_005	64.2	147.6		Pass
Average	**62.8**	**145.0**		
S_{n-1}	2.4	4.3		
CV(%)	3.8	2.9		

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

20. ALKALINE SOIL RESISTANCE – ASTM D3083

20.1. TEST SUMMARY

20.1.1. AC125 Section/s

Section 5.12, Alkaline Soil Resistance.

20.1.2. 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 – 14, Standard test method for Tensile Properties of Polymer Matrix Composite Materials.

20.1.3. Test Objective

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

20.1.4. Product/s Under Evaluation

CFU-10T fabric and Carbon Bond 300 HT resin.

20.1.5. Test Location

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

20.1.6. Laboratory Technician/s

Francisco De Caso

20.1.7. 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-DOA-SR.

20.2. TEST MATRIX

20.2.1. Specimen Number

Specimens were made from different FRP panels, where five test repetitions were tested.

20.2.2. Specimen ID Nomenclature

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

20.2.3. Test Matrix Table

Table 20.1– Test matrix for tensile tests post fuel resistance conditioning

Specimen ID	FRP Batch ID		Aging		Tested
	Fiber	*Resin*	*Start*	*Finish*	
	#	#	mm.dd.yy	mm.dd.yy	mm.dd.yy
DOA_C10T_TNS_ SR_01_001 to 005	Style# 1286/01/00	A: Batch# D553G3O081 and GMID# 97000852 B: Batch# D553G29000 and GMID#97000847	05.17.16	06.13.16	08.17.16

20.3. SPECIMEN PREPARATION

20.3.1. Specimen Size and Preparation Procedure

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

20.3.2. Conditioning Parameters

All specimens were conditioned to be aged by vertically burial to a depth of approximately 127 mm (5 in.) in a soil chamber containing a soil rich in cellulose-destroying micro-organisms (prepared with garden compost) for a period of 1000 hrs. where each specimen was surrounded by soil not touch each other. 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 with the use of untreated cotton duck for quality purposes.

20.4. TEST SET-UP

20.4.1. Set-up

Upon completion of soil burial 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 72 hours). Following the recovery period, specimens were tested. Refer to applicable test set-ups in in Chapter 5 for tensile tests

20.4.2. Rate and Method of Loading

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

20.5. TEST RESULTS

20.5.1. 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 1000 hrs. of exposure

20.5.2. Modes of Failure

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

20.5.3. Calculations

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

20.5.4. Tabulated Results

Table 20.2 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 20.2 - Tabulated results for tensile tests for CFU-10T (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	in²	kN	lbs	MPa	ksi	GPa	Msi	%		hrs.	F^{tu}	E^{chord}	ε_u
DOA_C10T_TNS_SR_01_001	24.59	0.968	13.11	0.020	19.12	4297	1457.4	211.38	93.11	13.51		103	103	100
DOA_C10T_TNS_SR_01_002	25.37	0.999	13.53	0.021	17.31	3891	1278.8	185.47	87.11	12.64		91	96	94
DOA_C10T_TNS_SR_01_003	25.53	1.005	13.62	0.021	19.17	4308	1407.4	204.12	85.94	12.47	1000	100	95	105
DOA_C10T_TNS_SR_01_004	25.32	0.997	13.51	0.021	18.81	4228	1392.3	201.94	92.63	13.44		99	102	96
DOA_C10T_TNS_SR_01_005	25.76	1.014	13.74	0.021	19.60	4405	1426.3	206.87	85.87	12.46		101	95	107
Average	25.31	0.997	13.50	0.021	18.80	4226	1392.4	201.96	88.93	12.90		99	98	101
S_{n-1}	0.44	0.017	0.23	0.000	0.88	198	68.0	9.87	3.63	0.53				
CV((%)	1.7	1.7	1.7	1.7	4.7	4.7	4.9	4.9	4.1	4.1				

**Condition of acceptance is equivalent to 90%*

21. 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 was issued directly to the client.

Refer to attached documents:

Test Report number: **RJ4497-2**, with test results equivalent to a flame spread index of 0, and smoke development index of 10. Refer to report for full test results.

Test Report number: **RJ3831-1-Rev. 1**, with test results equivalent to a flame spread index of 0, and smoke development index of 15. Refer to report for full test results.

22. COLUMN: FLEXURAL TEST

22.1. TEST SUMMARY

22.1.1. AC125 Section/s

Section 5.2.1 for Columns: Flexural Tests

22.1.2. Reference Standard/s

An internal laboratory developed standard test procedure is used for the flexural tests, available upon request. The procedure was developed from good laboratory practices and university research test programs of reinforced concrete (RC) structural elements testing, including columns.

22.1.3. Test Objective

Evaluate the flexural strengthening characteristics of the FRP composite materials under evaluation when applied to RC columns elements with different concrete strengths and FRP strengthening levels, subjected to flexure (bending).

22.1.4. Product/s Under Evaluation

CFU-10T fabric with Carbon Bond 300 HT resin

22.1.5. Test Location

University of Miami, College of Engineering, Structures and Materials Off-Site Testing Location (OTL) Laboratory located at North Carolina State University at the Construction Facilities Laboratory (CFL).

22.1.6. Laboratory Technician/s

Francisco De Caso and Greg Lucier

22.1.7. Technical Test Record

PENDING

23. COLUMN: SHEAR TEST

23.1. TEST SUMMARY

23.1.1. <u>AC125 Section/s</u>

Section 5.2.2 for Columns: Shear Tests

23.1.2. <u>Reference Standard/s</u>

An internal laboratory developed standard test procedure is used for the column shear tests, available upon request. The procedure was developed from good laboratory practices and university research test programs of reinforced concrete (RC) structural elements testing, including columns.

23.1.3. <u>Test Objective</u>

Evaluate the shear strengthening characteristics of the FRP composite system under evaluation when applied to RC columns elements with different concrete strengths and FRP strengthening levels, subjected to shear.

23.1.4. <u>Product/s Under Evaluation</u>

CFU-10T fabric with Carbon Bond 300 HT resin

23.1.5. <u>Test Location</u>

University of Miami, College of Engineering, Structures and Materials Off-Site Testing Location (OTL) Laboratory located at North Carolina State University at the Construction Facilities Laboratory (CFL).

23.1.6. <u>Laboratory Technician/s</u>

Francisco De Caso and Greg Lucier

23.1.7. <u>Technical Test Record</u>

PENDING

24. COLUMN: AXIAL TEST

24.1. TEST SUMMARY

24.1.1. AC125 Section/s

Section 5.2.3 for Columns: Pure axial Tests

24.1.2. Reference Standard/s

An internal laboratory developed standard test procedure is used for the column axial tests, available upon request. The procedure was developed from good laboratory practices and university research test programs of reinforced concrete (RC) structural elements testing, including columns.

24.1.3. Test Objective

Evaluate the axial strengthening characteristics of the FRP composite system under evaluation when applied to RC columns elements with different concrete strengths and FRP strengthening levels, subjected to axial force.

24.1.4. Product/s Under Evaluation

CFU-10T fabric with Carbon Bond 300 HT resin

24.1.5. Test Location

University of Miami, College of Engineering, Structures and Materials Off-Site Testing Location (OTL) Laboratory located at North Carolina State University at the Construction Facilities Laboratory (CFL).

24.1.6. Laboratory Technician/s

Francisco De Caso and Greg Lucier

24.1.7. Technical Test Record

PENDING

25. WALL: FLEXURAL TEST

25.1. TEST SUMMARY

25.1.1. AC125 Section/s

Section 5.2.2 for Shear Tests

25.1.2. Reference Standard/s

An internal laboratory developed standard test procedure is used for the flexural tests, available upon request. The procedure was developed from good laboratory practices and university research test programs of masonry walls structural elements testing, including columns.

25.1.3. Test Objective

Evaluate the structural performance of the FRP composite system under evaluation when applied to masonry walls subjected to out-of-plane load.

25.1.4. Product/s Under Evaluation

CFU-10T fabric with Carbon Bond 300 HT resin

25.1.5. Test Location

University of Miami, College of Engineering, Structures and Materials Off-Site Testing Location (OTL) Laboratory located at North Carolina State University at the Construction Facilities Laboratory (CFL).

25.1.6. Laboratory Technician/s

Francisco De Caso and Greg Lucier

25.1.7. Technical Test Record

PENDING

26. WALL: SHEAR TEST

26.1. TEST SUMMARY

26.1.1. AC125 Section/s

Section 5.2.2 for Shear Tests

26.1.2. Reference Standard/s

An internal laboratory developed standard test procedure is used for the shear tests, available upon request. The procedure was developed from good laboratory practices and university research test programs of masonry walls structural elements testing, including columns.

26.1.3. Test Objective

Evaluate the structural performance of the FRP composite system under evaluation when applied to masonry walls subjected to in-plane shear.

26.1.4. Product/s Under Evaluation

CFU-10T fabric with Carbon Bond 300 HT resin

26.1.5. Test Location

University of Miami, College of Engineering, Structures and Materials Off-Site Testing Location (OTL) Laboratory located at North Carolina State University at the Construction Facilities Laboratory (CFL).

26.1.6. Laboratory Technician/s

Francisco De Caso and Greg Lucier

26.1.7. Technical Test Record

PENDING

♦ END OF TEST REPORT ♦

Identification Number of the test report: DowAksa-BFT-01 Report Date: 04.19.16

Test Report on DowAksa CFRP system

General:

This report is prepared in order to provide the necessary information and data to obtain approval of DowAksa Carbon Fiber Reinforcement Polymer (CFRP) System used as an externally bonded reinforcement for flexural strengthening of concrete beams. The report contains experimental verification of design equations and assumptions outlined in the International Code Council Acceptance Criteria (ICC-ES-AC125) for the engineering analysis of the concrete and masonry structural members strengthened, using DowAksa CarbonWrap^{TM} fiber reinforced composite system.

The report complies with ICC-ES-AC85.

Laboratory Information:

The CEEM Structure Laboratory at the University of Arizona (TL-619) is an accredited laboratory complying with ISO/IES Standard 17025 by the international Accreditation Service (IAS). The scope of the loboratory's accreditation includes the specific type of testing covered in this report.

Laboratory accreditation certification is attached to the end of this report (Appendix I). Address and phone number of the lab is indicated on footer.

Standard Test Method: According to ICC-ES-AC125 criteria

Description of tested product:

- DowAksa CFU20T Carbon Fabric, Medium Weight Uniderectional Fabric,
- CarbonBond^{TM} 300-HT Saturant Resin System.

DowAksa CFU20T Carbon Fabric is attached to the soffit of the beam in order to increase the flexural capacity of the concrete member. This Fabric is attached to the concrete using DowAksa epoxy system called CarbonBond^{TM} 300-HT Saturant Resin System. Properties of these materials are attached to this report (Appendix II).
General installation instruction provided by DowAksa is also attached in Appendix III.

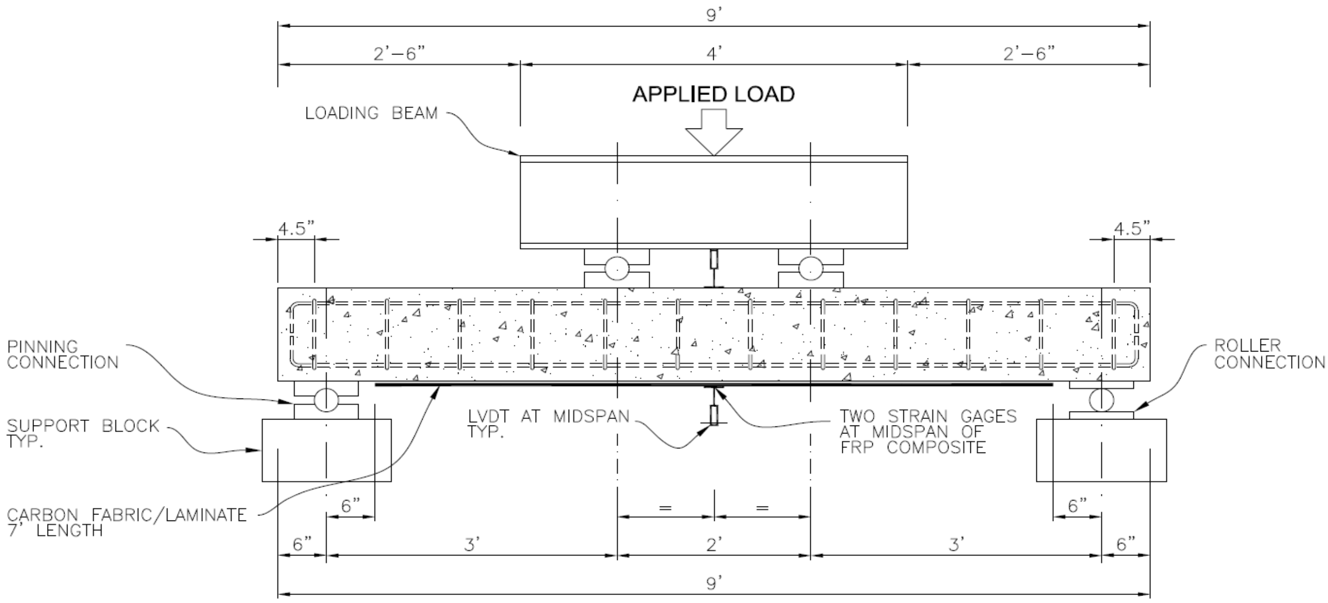
Test Description:

Concrete Beam Flexural Test, Group 1 of proposed plan

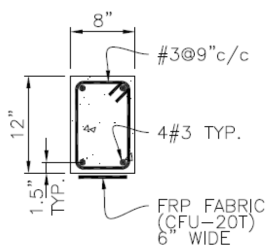
Test setup and Procedure:

The experimental justification consisted of casting 4 concrete beams with specification indicated in Figure.1.
Two samples with different compressive srengths were tested as control samples without any FRP strengthening and the remaining two were strengthened using DowAksa CFRP system.

Figure. 1:



BEAM ELEVATION
1:1"



BEAM SECTION
1:1"

Specimens were loaded continuously and without shock. Load was applied at a rate that constantly increases the maximum stress on the tension face at 150 psi/min. (According to ASTM C78, this rate should be between 0.9 and 1.2 MPa/min [125 and 175 psi/min] until rupture occurs.)

The loading rate is calculated using the following equation:

$$r = \frac{Sbd^2}{L} \qquad \text{(ASTM C78-10)}$$

where:

r = loading rate, N/min [lb/min],

S = rate of increase in maximum stress on the tension face, MPa/min [psi/min],

b = average width of the specimen as oriented for testing, mm [in.],

d = average depth of the specimen as oriented for testing, mm [in.], and

L = span length, mm [in.].

So, Considering S=150 psi/min, the load rating used in this test is 1.8 kip/min.

Notation:

f_y : Specified yield strength of nonprestressed steel reinforcement

ε_s : Strain level in nonprestressed steel reinforcement

ε_y : Strain corresponding to yield strength of nonprestressed steel reinforcement

E_s : Modulus of Elasticity of steel

f_c' : Specified compressive strength of concrete

E_c : Modulus of elasticity of concrete

α_1 : Multiplier on f_c' to determine intensity of an equivalent rectangular stress distribution for concrete

β_1 : Ratio of depth of equivalent rectangular stress block to depth of the neutral axis

b : width of compression face of member

c : Distance from extreme compression fiber to the neutral axis

ε_{cu} : Ultimate axial strain of unconfined concrete

ε_c' : Maximum strain of unconfined concrete corresponding to f_c'

ε_s' : Strain level in nonprestressed steel reinforcement on top of the section

A_s : Area of nonprestressed steel reinforcement

$A_{s'}$: Area of nonprestressed steel reinforcement on top of the section

f_s' : Stress level of steel reinforcement on top of the section

b_f : Width of fabric

t_f : Thickness of fabric

A_f : Area of fabric

E_f : Modulus of elasticity of fabric

ε_{fd} : Debonding strain of externally bonded FRP reinforcement

ε_{fe} : Effective strainlevel in FRP reinforcement attained at failure

ε_{fu} : Design rupture strain of FRP reinforcement

Ψ_f : FRP Strength reduction factor

Sample Information:

Sample ID#: ICC 1a.1

Date of Testing: 03.17.2016

Temperature at the time of testing: 72°F

Average Width of Beam (3 measurements): 7.95 inch

Average Depth of Beam (3 measurements): 12.05 inch

Clear Span Length: 96.4 inch

Concrete Compressive Strength:

Test Specimen	Proposal information
Average Compressive Strength of five sample (f_c'): 3485 psi	3000±500

Steel rebar grade: 60

f_y= 60,000 ksi, f_u= 90,000 ksi

For the control sample, since the amount of steel rebars was small, i.e., Underreinforced, the strain in the steel (ε_s) was significantly larger than ε_y, therefore, the steel stress exceeded the yeild point and reached to its ultimate rupture point. So in calculating the ultimate load, the ultimate steel stress, f_u, was used.

Analysis:

$\varepsilon_y = \frac{f_y}{E_s}$ = 60,000/29,000,000=0.00207

$f_c' = 3485$ psi → β_1=0.85 → a=β_1.c

From Strain Diagram: $\frac{\varepsilon_{cu}}{c} = \frac{\varepsilon_s'}{c-d'}$

From Equilibrium Equation:

$\sum Compression\ forces = \sum Tension\ forces$

0.85*f_c'*b*a+f_s'*$A_{s'}$ = f_y*A_s

Finding c → c = 1.192 inch

a = 0.85*1.192= 1.0132 inch

$\frac{\varepsilon_{cu}}{c} = \frac{\varepsilon_s'}{c-d'}$ → $\varepsilon_s' = 0.003 * \frac{1.5-1.192}{1.192} = 0.000775 < \varepsilon_y$ O.K.

f_s'= 22.48 ksi Tension

$\sum C$ = 24.11 kips
$\sum T$= 24.09 kips } c = 1.285 acceptable

Calculate Moment Capacity of section:

M = f_s'*$A_{s'}$*(1.5- a/2)+ f_y*A_s*(10.5-a/2) = 202.8 kip.in = 16.9 kip.ft

Mesured results:

$M_{measured}$ = 20.85 kip.ft

Failure Mode:

Mode of failure was confirmed.

Steel rebars reaches to ε_y before concrete crushed.

Photographs:

Sample ID#

Test Setup

Failure of beam

Sample Information:

Sample ID#: ICC 1a.2

Temperature at the time of testing: 72°F

Date of Testing: 03.24.2016

Average Width of Beam: 8.0 inch

Average Depth of Beam: 12.0 inch

Clear Span Length: 96.4 inch

Concrete Compressive Strength:

Test Specimen	Proposal information
Average Compressive Strength of five sample (f_c'): 3500 psi	3000±500

Steel rebar grade: 60

f_y= 60,000 ksi, f_u= 90,000 ksi

CFRP properties:

Type: DowAksa Unidirectional 20 ounce Fabric Saturated with DowAksa CarbonBond 300HT epoxy system

Thickness = 0.0354 inch

Modulus of Elasticity = 16220 ksi

Width of fabric = 6 inch

ε_{fu}= 1.3%

Design Criteria and minimum acceptable level:

$\varepsilon_y = \frac{f_y}{E_s}$ = 60,000/29,000,000=0.00207

$f_c' = 3500$ psi → β_1=0.85 → a=β_1.c

Assume:

- Concrete reaches ε_{cu} before FRP reaches ε_{fd}.
- Steel yields before concrete crushes.

From Equilibrium Equation:

$$\sum Compression\ forces = \sum Tension\ forces$$

$0.85 * f_c' * b * a + f_s' * A_{s'} = f_y * A_s + (b_f . t_f). \varepsilon_{fe}. E_f$ Where $\varepsilon_{fe} = 0.003 \frac{d_f - c}{c}$

Solving for c → c = 2.451 inch

a = 0.85*2.451= 2.083 inch

From Strain Diagram: $\frac{\varepsilon_{cu}}{c} = \frac{\varepsilon_s'}{c-d'} \rightarrow \varepsilon_s' = 0.003 * \frac{1.5-2.451}{2.451} = 0.0012 < \varepsilon_y$ O.K.

$$\varepsilon_{fd} = 0.083\sqrt{\frac{f_c'}{n.E_f.t_f}} = 0.083\sqrt{\frac{3.5}{1*16220*0.0354}} = 0.00648 < 0.9\ \varepsilon_{fu} = 0.0117$$

From Strain diagram:

ε_{fe}=0.003$\frac{d_f - c}{c}$ = 0.003*$\frac{12-2.451}{2.451}$ = 0.0117 $> \varepsilon_{fd}$=0.00648 N.G.

Since $\varepsilon_{fe} > \varepsilon_{fd}$, CFRP strain governs the equations and controls the failure:

So,

$\varepsilon_{fe} = \varepsilon_{fd}$ = 0.00648

From Strain Diagram: : $\frac{\varepsilon_{fe}}{\varepsilon_c} = \frac{12-c}{c} \rightarrow \varepsilon_c$ = 0.00648 $\frac{c}{12-c}$

$\frac{\varepsilon_{fe}}{12-c} = \frac{\varepsilon_s'}{c-1.5} \rightarrow \varepsilon_s'$ = 0.00648 $\frac{c-1.5}{12-c}$

$E_c\ (ksi)$ = 57$\sqrt{f_c'\ (psi)}$ = 57$\sqrt{3500}$ =3372 ksi

Concrete Stress Block → $\varepsilon_c' = \frac{1.7 f_c'}{E_c}$ = 0.001764

$$\beta_1 = \frac{4\varepsilon_c' - \varepsilon_c}{6\varepsilon_c' - 2\varepsilon_c}$$

$$\alpha_1 = \frac{3\varepsilon_c'\varepsilon_c - {\varepsilon_c}^2}{3\beta_1 {\varepsilon_c'}^2}$$

From Equilibrium Equation:

$\alpha_1 . f_c' . \beta_1 . c . b + (E_s . \varepsilon_s') . A_s = f_y . A_s + A_f . (E_f . \varepsilon_{fe})$

Solving for c:

c = 2.075 inch;

ε_c = 0.00648 $\frac{c}{12-c}$= 0.00648*$\frac{2.075}{12-2.075}$ = 0.00135

Calculate Moment Capacity of section:

M = f_y*A_s*(d - $\beta_1.c$ /2) + $\Psi_f.A_f.f_{fe}.(d-\beta_1.c$ /2) - $f_{s'}$*$A_{s'}$

M = 28.31 kip.ft

Measured Results:

Moment capacity:

$M_{measured}$ = 31.39 kip.ft compared to $M_{Analysis}$ = 28.31 kip.ft O.K.

CFRP Strain at specimen failure:

ε_f= 0.00642 compared to ε_{fe} = 0.00648 in Analysis. O.K.

Concrete Strain at specimen failure:

ε_c= 0.00114 compared to ε_c = 0.00135 in Analysis. O.K.

Failure Mode:

Mode of failure was confirmed.

FRP controlled the failure.

Photographs:

Sample ID#

Test setup

Failure of Beam

Sample Information:

Sample ID#: ICC 1b.1

Temperature at the time of testing: 71°F

Date of Testing: 03.28.2016

Average Width of Beam: 8.00 inch

Average Depth of Beam: 12.00 inch

Clear Span Length: 96.4 inch

Concrete Compressive Strength:

Test Specimen	Proposal information
Average Compressive Strength of five sample (f_c'): 5520 psi	6000±500

Steel rebar grade: 60

f_y= 60,000 ksi, f_u= 90,000 ksi

For the control sample, since the amount of steel rebars was small, the measured strain in steel, ε_s, was significantly larger than ε_y, the steel stress exceeded the yield value and reached to its ultimate.

Analysis:

$\varepsilon_y = \frac{f_y}{E_s}$ = 60,000/29,000,000=0.00207

$f_c' = 5520$ psi → β_1=1.05 – 0.05 $\frac{f_c'}{1000}$ = 0.774 → a=β_1.c

From Strain Diagram: $\frac{\varepsilon_{cu}}{c} = \frac{\varepsilon_s'}{c-d'}$

From Equilibrium Equation:

$\sum Compression\ forces = \sum Tension\ forces$

0.85*f_c'*b*a+f_s'*$A_{s'}$ = f_y*A_s

Solving for c → c = 0.995 inch

a = 0.774*1.0= 0.774 inch

$$\frac{\varepsilon_{cu}}{c} = \frac{\varepsilon_s'}{c-d'} \rightarrow \varepsilon_s' = 0.003 * \frac{1.5-0.995}{0.995} = 0.0015 < \varepsilon_y \quad \text{O.K.}$$

f_s'= 44.156 ksi Tension

$\sum C$ = 28.9 kips
$\sum T$= 28.5 kips
} C= 0.995 acceptable

Calculate Moment Capacity of section:

M = f_s'*$A_{s'}$*(1.5- a/2)+ f_y*A_s*(10.5-a/2) = 211.1 kip.in = 17.6 kip.ft

$M_{measured}$ = 20 kip.ft

<u>Failure Mode:</u>

Mode of failure was confirmed.

Steel rebars reaches ε_y before concrete crushes

Photographs:

Test setup

Sample ID#

Failure of beam

Sample Information:

Sample ID#: ICC 1b.2

Temperature at the time of testing: 72°F

Date of Testing: 03.30.2016

Average Width of Beam: 8.0 inch

Average Depth of Beam: 12.0 inch

Clear Span Length: 96.4 inch

Concrete Compressive Strength:

Test Specimen	Proposal information
Average Compressive Strength of five sample (f_c'): 5500 psi	6000±500

Steel rebar grade: 60

f_y= 60,000 ksi, f_u= 90,000 ksi

CFRP properties:

Type: DowAksa Unidirectional 20 ounce Fabric Saturated with DowAksa CarbonBond 300HT epoxy

Thickness = 0.0354 inch

Modulus of Elasticity = 16220 ksi

Width of fabric = 6 inch

ε_{fe}= 1.3%

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Fax: 520-621-2550

Design Criteria and minimum acceptable level:

$\varepsilon_y = \frac{f_y}{E_s}$ = 60,000/29,000,000=0.00207

$f_c' = 5500$ psi → β_1=1.05 – 0.05 $\frac{f_c'}{1000}$ → β_1= 0.775 → a=β_1.c

Assume:

- Concrete reaches ε_{cu} before FRP reaches ε_{fd}.
- Steel yields before concrete crushes.

From Equilibrium Equation:

$\sum Compression\ forces = \sum Tension\ forces$

0.85*f_c'*b*a+f_s'*$A_{s'}$ = f_y*A_s+ $(b_f.t_f).\ \varepsilon_{fe}.E_f$ Where ε_{fe}= 0.003$\frac{d_f-c}{c}$

Solving for c → c = 2.0314 inch

a = 0.775*2.0314= 1.5743 inch

From Strain Diagram: $\frac{\varepsilon_{cu}}{c} = \frac{\varepsilon_s'}{c-d'}$ → $\varepsilon_s' = 0.003 * \frac{1.5-2.0314}{2.0314} = 0.00078 < \varepsilon_y$ O.K.

ε_{fd} = 0.083$\sqrt{\frac{f_c'}{n.E_f.t_f}}$ = 0.083$\sqrt{\frac{5.5}{1*16220*0.0354}}$ = 0.00812 < 0.9 ε_{fu}= 0.0117

From Strain diagram: ε_{fe}=0.003$\frac{d_f-c}{c}$ = 0.003*$\frac{12-2.0314}{2.0314}$ = 0.01472 > ε_{fd}=0.00812 N.G.

Since $\varepsilon_{fe} > \varepsilon_{fd}$, CFRP strain governs the equations and controls the failure:

So,

$\varepsilon_{fe} = \varepsilon_{fd} = 0.00812$

From Strain Diagram: : $\frac{\varepsilon_{fe}}{\varepsilon_c} = \frac{12-c}{c} \rightarrow \varepsilon_c = 0.00812\,\frac{c}{12-c}$

$$\frac{\varepsilon_{fe}}{12-c} = \frac{\varepsilon_s'}{c-1.5} \rightarrow \varepsilon_s' = 0.00812\,\frac{c-1.5}{12-c}$$

$$E_c\ (ksi) = 57\sqrt{f_c'\ (psi)} = 57\sqrt{5500} = 4227\ \text{ksi}$$

Concrete Stress Block $\rightarrow \varepsilon_c' = \frac{1.7 f_c'}{E_c} = 0.002212$

$$\beta_1 = \frac{4\varepsilon_c' - \varepsilon_c}{6\varepsilon_c' - 2\varepsilon_c}$$

$$\alpha_1 = \frac{3\varepsilon_c'\varepsilon_c - {\varepsilon_c}^2}{3\beta_1 {\varepsilon_c'}^2}$$

From Equilibrium Equation:

$$\alpha_1 . f_c' . \beta_1 . c . b + (E_s . \varepsilon_s') . A_s = f_y . A_s + A_f . (E_f . \varepsilon_{fe})$$

Solving for c:

c = 1.788 inch

Calculate Moment Capacity of section:

M = f_y*A_s*(d - $\beta_1 . c$ /2) + $\Psi_f . A_f . f_{fe} . (d - \beta_1 . c$ /2) - $f_{s'}$*$A_{s'}$

M = 33.25 kip.ft

$M_{measured}$ = 34.1 kip.ft

Measured results:

Moment capacity:

$M_{measured}$ = 34.1 kip.ft compared to $M_{Analysis}$ = 33.25 kip.ft O.K.

CFRP Strain at specimen failure:

ε_f= 0.00792 compared to ε_{fe} = 0.00812 in Analysis. O.K.

Concrete Strain at specimen failure:

ε_c= 0.00111 compared to ε_c = 0.0014 in Analysis. O.K.

Failure Mode:

Mode of Failure was confirmed.

Failure: FRP controlled the failure.

Debonding of FRP/Cover delamination.

Photographs:

Sample ID#

Test setup

Beam Failure

Conclusion:

Testing data indicated in this report verified the design equations and assumptions outlined in the International Code Council Acceptance Criteria (ICC-ES-AC125) for the engineering analysis of the concrete beams flexurally strengthened, using DowAksa CarbonWrap^{TM} fiber reinforced composite system.

Appendix 1

INTERNATIONAL ACCREDITATION SERVICE®

CERTIFICATE OF ACCREDITATION

This is to attest that

CEEM STRUCTURE LABORATORY AT THE UNIVERSITY OF ARIZONA

1209 E. 2ND STREET, ROOM NO. 118
TUCSON, ARIZONA 85721-0072

Testing Laboratory TL-619

has met the requirements of the IAS Accreditation Criteria for Testing Laboratories (AC89), has demonstrated compliance with ISO/IEC Standard 17025:2005, *General requirements for the competence of testing and calibration laboratories*, and has been accredited, commencing January 11, 2016, for the test methods listed in the approved scope of accreditation.

(see laboratory's scope of accreditation for fields of testing and accredited test methods)

This accreditation certificate supersedes any IAS accreditation bearing an earlier effective date. The certificate becomes invalid upon suspension, cancellation or revocation of accreditation.
See http://iasonline.org/More/search.html for current accreditation information, or contact IAS at 562-364-8201.

ilac-MRA

IAS ACCREDITED

C.P. Ramani, P.E., C.B.O
President

INTERNATIONAL ACCREDITATION SERVICE®

SCOPE OF ACCREDITATION

IAS Accreditation Number	TL-619
Accredited Entity	Ceem Structure Laboratory at the University of Arizona
Address	1209 E. 2nd Street, Room No. 118 Tucson, Arizona 85721-0072
Contact Name	Dr. Ehsan Mahmoudabadi
Telephone	(520) 621-0745
Effective Date of Scope	January 11, 2015

FIELDS OF TESTING	ACCREDITED TEST METHODS
Construction Materials Testing	ASTM C 39
	ASTM C 78
	ASTM C 293
	ASTM C 617
	ASTM C 1609
	Test methods referenced in Section 5.0 of ICC ES AC125 (Sections 5.1 to 5.8)
	Test methods referenced in Section 9 of ICC ES AC178
	Test methods referenced in Sections 3.0, 4.2.3, 4.3.4, 4.3, 4.7 and 5.0 of ICC ES AC434
Composites	ASTM D 3039
	ASTM D 7205
	ASTM D 7565
	ACI 440.3R (Except Part B.6)
Physical Testing of Structural Assemblies	ASTM D 2344
	ASTM D 3165
	ASTM D 3528
	ASTM D 4541
	Test methods referenced in Section 5.0 of ICC ES AC125 (Sections 5.1 to 5.8)
	Test methods referenced in Section 9 of ICC ES AC178
	Test methods referenced in Sections 3.0, 4.2.3, 4.2.4, 4.3, 4.7 and 5.0 of ICC ES AC434

CEEM STRUCTURE LABORATORY - TL619
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ACCREDITED

Appendix 2

DowAksa

Product Technical Information

DowAksa CFU20T Carbon Fabric

Medium Weight Unidirectional Fabric

Description

DowAksa CFU20T is a medium weight, high tensile strength unidirectional carbon fabric. It easily wets out with CarbonBond™ 300-HT Saturant Resin System and can be installed using the "wet lay-up" technique. This fabric has excellent mechanical properties as listed below. This system is a NSF/ANSI Standard 61 listed product for drinking water systems (see water system requirements below).

Applications

CFU20T Carbon Fabric is designed to fabricate on-site composite reinforcements to a variety of structures and substrates:

- Flexural and shear reinforcement of beams
- In-plane and out-of-plane reinforcement of concrete and masonry walls
- Column wrapping and reinforcement of slab
- Structural steel applications

CFU20T Carbon Fiber (Composite Laminate Properties)

Property[1]	Average Value	Design Value	Method
Tensile Strength (Ksi)	216.5	179.06	ASTM D3039
Elongation at Break (%)	1.5	1.3	
Tensile Modulus (Msi)	16.2	14.8	
Thickness (in)	0.035		
Longitudinal Coefficient of Linear Thermal Expansion (10^{-6} F^{-1})	0.5		ASTM E831
Trasnverse Coefficient of Linear Thermal Expansion (10^{-6} F^{-1})	29.7		
Water Adsorption (%)			ASTM D570
24 Hours	0.29%		
168 Hours	0.70%		
Hardness, Shore D	85		ASTM D2240
Glass Transition (^{o}F)	210		ASTM E1640
HDT (^{o}F)	572		ISO 75-1

1) Typical values and should not be construed as specifications.

Page 1 of 2 CFU20T Carbon Fabric

CFU20T Carbon Fiber (Dry Fiber Properties)

Property[1]	Value	Method
Avg. Tensile Strength (Ksi)	710	
Elongation at Break (%)	2.0	ISO 10618
Avg. Tensile Modulus (Msi)	34.8	
Density (lbs/in^3)	0.065	ISO 10119
Weight (oz/yd^2)	20	

(1) Typical values and should not be construed as specifications.

NSF/ANSI Standard 61 Requirments

This system is certified NSF/ANSI Standard 61 compliant only for use in drinking water systems with:

CarbonBond™ 300 Saturant Resin (Slow Cure System)

Minimum Diameter Pipe Size (Static Flow): 48 in

Minimum Tank Size: 10,000,000 gallons

Minimum Cure Times: 72 hours

Please contact DowAksa USA LLC for other requirments.

How Supplied (net weight)

CFU20T 24 in. wide, at 1 roll 50LY, 300 sq. ft.

DOWAKSA

Contact information:
North America: 520-292-3109
Toll Free: 866-380-1269
Emergency: 800-535-5053
http://www.dowaksausa.com

Technical Data Sheet

DOWAKSA CarbonWrap™

CarbonBond™ 300-HT Saturant Resin System
CarbonBond™ 300A-HT Saturant Resin - Part A
CarbonBond™ 300B-HT Hardener - Part B

Description

The CarbonBond™300-HT Saturant Resin System consists of an epoxy resin and an amine hardener formulated for saturating fiber reinforced composites. The CarbonBond™300-HT Saturant Resin System provides an excellent balance of viscosity, pot life and cure development. The low viscosity of the CarbonBond™300-HT Saturant Resin System results in excellent flow properties and fiber wetting while enhancing the toughness of the cured system without sacrificing the thermal resistance of the cured product.

Applications

CarbonBond™ 300-HT Saturant Resin System is designed for use with the CarbonBond™ 100 Primer, CarbonBond™ 200P Adhesive Putty and Carbon Fiber Fabrics to fabricate on-site composite reinforcements to a variety of structures and substrates.

CarbonBond™ 300-HT Saturant Resin System is recommended for the manufacture of fiber reinforced structural composites for diverse applications including Construction, Marine and Infrastructure Repair.

Mixing and Handling

Accurate proportioning and thorough mixing are essential to achieve full performance properties. Manually mix resin, hardener and catalyst components together for approximately 5 minutes while making sure to scrape the sides, bottom and corners of the mixing container. When automated meter mixing equipment is used, it should be tested for accuracy on a regular basis.

	Part A	Part B	Mix
	Parts	Parts	A:B
By Weight	100	32.4	3.1:1
By Volume	100	36.3	2.75:1

Hardener and the mixed system (epoxy resin and hardener) are hygroscopic and any absorbed moisture will moderately shorten the pot life of the system. This can be minimized by keeping containers of the hardener and the mixed system covered while transferring, dispensing and impregnating. For large applications, it is a good practice to mix and use several small batches rather than one large batch.

The epoxy resin and amine hardener used in this system will readily react with each other at ambient temperatures. This reaction is exothermic and, depending on the mass, can result in a significant temperature rise or fire. The utmost care must be taken to avoid inadvertent mixing of the system components. Refer to the Safety and Handling section for additional information.

Application and Curing Conditions

The recommended application conditions are between 20°C and 25°C with a maximum relative humidity (RH) of 70%. It is recommended that the minimum application temperature should be at least 3°C above the dew point temperature.

Higher temperatures will shorten the pot life and lower temperatures will increase the viscosity, significantly affecting the fiber wetting characteristics at the system.

Generally, with cure temperatures between 20°C and 30°C, mechanical property development will peak after about 2 weeks. To accelerate the mechanical property development and heat resistance of the resin system, an elevated temperature post cure is required. A post cure schedule can be started after the material has cured at ambient temperatures for a minimum of 24 hours. In order to obtain a full cure, the product must be kept at 110°C for at least 2 hours. Post cure schedules can be tailored for each application. If the post cure temperature is limited to 90°C for instance, the time should be increased to approximately 6 hours. Accordingly, times, temperatures, and ramp rates should be adjusted such that the entire composite article receives sufficient heat history to attain full properties.

Under cool / humid / damp conditions – the cured material may produce an oily film or exudate on the surface. See also the Dow technical bulletin entitled, Amine Blushing and Blooming of Epoxy Systems, Form No. 296-01656. This surface contaminant may affect the bonding of subsequent layers or materials. Should this occur, one must prepare the surface for secondary bonding by abrading the surface with coarse abrasive paper or similar treatments.

Safety and Handling

DowAksa USA, LLC provides its customers with a product specific Safety Data Sheet (SDS) to cover potential health effects, safe handling, storage, use and disposal information. DowAksa strongly encourages its customers to review the SDS on its products and other materials prior to their use.

Packaging, Storage and Shelf Life

CarbonBond™ 300A-HT Saturant Resin Part A is packaged in 20 kg pails or 200 kg tight-head drums. The epoxy resin should retain its chemical properties for at least 24 months when stored in a dry place in its original closed packaging between 25°C and 35°C. For further storage information on liquid epoxy resins consult the Dow technical bulletin, Product Coding, Shelf-life and Storage Stability, Form No. 296-01657.

As with many liquid epoxy resins, CarbonBond™ 300A-HT Saturant Resin Part A may crystallize during storage. The potential for crystallization can be minimized by storing the resin in a controlled temperature environment between 25°C and 35°C. Crystallized resin can be reconstituted by heating

CarbonBond™ 300-HT Saturant Resin System

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Technical Data Sheet

to 60°C. For further details see the Dow technical bulletin, Crystallization of Liquid Epoxy Resins, Form No. 296-01652.

CarbonBond™ 300B-HT Hardener Resin Part B is supplied in 18 Kg pails or 180 kg tight-head drums. This hardener should retain its chemical properties for at least 24 months when stored in its original closed packaging, in a cool, dry environment, away from direct sunlight and at a temperature not over 35°C. If possible, provide nitrogen padding in the headspace of opened containers and bulk storage facilities.

CarbonBond™ 300HT-B Saturant Hardener is hygroscopic and will absorb moisture and carbon dioxide from the atmosphere if not stored properly. Be sure to close containers immediately after use. The absorption of moisture and/or carbon dioxide will affect the chemical behavior of the material and the performance properties of the final product. In addition, the reaction of amine hardeners with moisture and See also the Dow technical bulletin entitled, *Amine Blushing and Blooming of Epoxy Systems, Form No. 296-01656./or* carbon dioxide will form a white precipitate; usually around the opening of the container. This precipitate is NOT soluble in the epoxy resin or the hardeners. To minimize the formation of this white precipitate, care should be taken to wipe away excess liquid material from around the opening of the container before closing it. To avoid contaminating the contents of the container with precipitate that may have formed, remove the precipitate BEFORE the container is opened.

Typical Properties of the System

Property(1)	Part A Epoxy Resin	Part B Hardener	Part A & B Combined	Method
Color	Clear	Clear Red	Clear Red	
Density @ 25°C (g/cc)	1.143	1.020	1.107	ASTM D4052
Brookfiled Viscosity @ 23°C LVT Spdl#3-30 rpm (mPa.s)	700	350	650	ASTM D2196
Gel Time 100 gm @ 23°C (min)			40-55	
Shelf Life (Months)(2)	24	24		

(1) Typical values and should not be construed as specifications.
(2) See Packaging, Storage and Shelf Life section for details.

Mechanical Properties of Cured System

Property(1)	After 14 days @ 23°C	After 4hrs @100°C	Method
Tensile Strength (Ksi)	10.15	10.88	ASTM D638
Elongation at Break (%)	2.3	8.1	
Tensile Modulus (Ksi)	536.64	435.12	
Flexural Strength (Ksi)	13.35	17.55	ASTM D790
Strain at Break (%)	2.8	>6	
Flexural Modulus (Ksi)	507.64	449.62	
Compression Strength (Ksi)	29.8		ASTM D695
Comprsive Modulus (Ksi)	508		
Glass Transition Temperature – DMA (°F)	210	230	ASTM E1640
Shore D Hardness	85.7		ASTM D2240

(1) Typical values and should not be construed as specifications.

Food Contact Applications

This epoxy resin system is not intended for food or portable water contact applications.

Clean Up

Flush with water. Dispose of in accordance with local and federal regulations. Uncured material can be removed with approved solvents. Cured material can only be removed mechanically.

CarbonBond™ 300-HT Saturant Resin System

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Appendix 3

DOWAKSA

Field Application and Installation Guidelines

Dow Aksa CarbonWrap® Systems for Concrete and Masonry Structures

Description

The DowAksa CarbonWrap® System for Concrete and Masonry Structures system provides a balance of properties most suitable for saturating carbon fiber fabrics predominantly applied to concrete structures as supplemental reinforcement or for the remediation of damaged structures. The low viscosity and thixotropic nature allow for fast and thorough wetting of the carbon fiber fabrics without drainage or sagging on vertical and overhead surfaces. The pot life and cure speed are balanced to allow for multiple applications or layers in a single day. Depending on temperature conditions, the system develops >95% of full properties in as little as 7 days. The system is designed with a colored hardener that makes it easy to identify and assess the thoroughness of the mixing process.

General

The integrity and quality of the DowAksa CarbonWrap® systems critically depend on a careful initial planning and evaluation of the project. All construction specifications, materials storage and handling, as well as installation steps, must be carefully reviewed by all those involved in the project and adhered to. The following sections describe various steps necessary for successful completion of the project.

Initial Planning

Because DowAksa CarbonWrap® materials can be affected by temperature and moisture during installation and curing, it is recommended that a careful plan for executing different stages of the project be put in place at the start of the project to assure a timely and efficient execution. Several important points to consider include, but are not limited to the following:

- Schedule: Plan installation dates and times
- Equipment: Provide all tools and equipment necessary for the particular project
- Materials: Provide sufficient lead time and order all materials from DowAksa to be ready at the site before the start of the work
- Workforce: Determine size, skill level and timeframe for the workforce
- On-Site Assistance: Work with DowAksa to determine if an on-site representative of DowAksa is required

Typical Tools and Equipment

The following are samples of tools required for installation:

- Heat gun, rags, measuring cups (1L)
- Scissors (4)
- Power generator
- Acetone (4 gallons)
- Silica-based dry sand
- Impregnating machine for automatically saturating the fabric
- Sand- or water-blasting equipment
- Grinder and wire wheel or wire brush
- Pressurized air and dust-removing tools
- Mixing and measuring containers (5 gallons and 2 gallons)
- Weight measuring scale
- Coveralls, chemical-resistant gloves and goggles
- Ventilation equipment
- Roller brush to apply resin, short-handled and long-handled
- Spiked wheel rollers to remove air pockets
- Industrial shears to cut the carbon fabric
- Jiffy or other rotary mixers and mixing paddles
- Rubber trowel or spatula to spread the putty
- Dropcloth and plastic sheets

Consult OSHA for appropriate safety equipment and measures for application of chemicals, resins and epoxies.

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Storage and Safe Handling

DowAksa CarbonWrap® epoxy and resin compounds must be stored in their unopened containers in temperatures between 10 °C and 38 °C (50 °F and 100 °F). Optimal storage temperature is between 18 °C and 29 °C (65 °F and 85 °F).

As with all chemicals, DowAksa CarbonWrap® epoxy and resin materials have a limited shelf life. In order to preserve their properties and reactivity, these materials should be stored in their unopened containers for periods of two years or less. Materials that have exceeded their shelf life and materials that have been stored improperly, as specified by DowAksa CarbonWrap®, must be disposed of in accordance with the disposal instructions given in the Clean Up and Disposal Section.

DowAksa CarbonWrap® fabrics and laminates have indefinite shelf life. Therefore, they can be stored indefinitely. All materials including the fabrics must be kept away from dust, moisture, chemicals, direct sunlight, physical damage and fire.

All DowAksa CarbonWrap® materials must be handled with care to avoid any physical damage and to avoid potential safety hazards. Those who are involved with handling and application of the epoxy compounds must be thoroughly informed of the safety hazards and potential dangers of the particular chemical they are handling. This includes access to and familiarity with the Safety Data Sheets (SDS). The SDS must be consistently placed in a familiar location and at all times be accessible to the work crew.

The contractor is responsible for providing SDS to all personnel and informing them of the potential safety hazards and other important characteristics of epoxies and resins. Furthermore, the contractor is responsible for making sure that all stages of the project are executed in accordance with federal, state and local environmental laws and regulations in addition to the OSHA requirements and laws to protect the safety of all workers.

When working with epoxy and resin compounds the work area must be very well ventilated. Safety goggles or glasses are necessary when working with epoxies. Coveralls and chemical-resistant gloves must be worn by all personnel in the work area. The gloves must have been tested for resistance to resins, epoxies and solvents.

Personal cleanliness is very important when working with chemical compounds. Involuntary habits such as eyeglass adjustment, face scratching and touching other objects, tools or equipment must be avoided. Eating, drinking or smoking must be avoided until the individual has washed up. Avoid unnecessary and prolonged handling of fabrics. Do not fold the fabrics as this may cause misalignment, pulling and/or breakage of the fibers.

Clean Up and Disposal

Any material that has exceeded its shelf life, is damaged or has not been stored according to the specified instructions, or is in excess or not used when opened must be disposed of in accordance with the SDS and all other federal, state and local laws.

The contractor must be thoroughly be familiar with the environmental laws and regulations governing the disposal of chemicals. He/she is responsible for the complete cleanup of the project site, including removal of excess and unused materials (waste), empty containers and other aesthetically unpleasing materials.

Surface Preparation

The effectiveness, integrity and performance of the DowAksa CarbonWrap® System critically depend on the preparation and soundness of the substrate. Therefore, preparing a clean and sound substrate is the most important part of the entire application process.

Removal of Damaged and Unsound Concrete: Environmental effects and corrosion of the reinforcing bars can cause damage to concrete or masonry. Any such concrete or masonry area that is determined by the engineer of record or other properly trained personnel to be damaged and unsound must be removed and repaired before DowAksa CarbonWrap® can be applied. Defects in concrete substrate can compromise the strength of the DowAksa CarbonWrap® System. Covering of carbonated or chloride-contaminated concrete with DowAksa CarbonWrap® without addressing the source of contamination will be detrimental to the effectiveness of the repair system. Special design consideration needs to be implemented by the engineer of record to address the possibilities of carbonation, alkali silica reactions or reactive aggregates. Careful attention must be paid when removing defective concrete to not damage the surrounding areas. The removal of defective concrete must be in accordance with the guidelines of ACI 546R-96 and ICRI No. 03730. Proper equipment such as chippers and electric jackhammers must be used to remove defective concrete at sufficient depth of at least 1/2 inch beyond the repair area to expose sound aggregates. If concrete removal exposes any pre-stressing or reinforcing steel that is corroded or de-bonded as a result of the removal of defective concrete, additional concrete shall be removed to a depth of 3/4 inch, or at least 1/4 inch larger than the largest aggregate size in the repair material, and repaired again before the application of DowAksa CarbonWrap®. Substrate must be cleaned and repaired before the application of DowAksa CarbonWrap®.

Repair of Defective Reinforcement: The corroded reinforcement must be cleaned and repaired in accordance with ICRI No. 03730, and to the satisfaction of the engineer of record. DowAksa CarbonWrap® should not be applied to concrete having unrepaired corroded reinforcement. The corroded reinforcement shall be cleaned to expose the white metal (SSPC SPS-5). Defective steel that is deemed unrepairable by the engineer of record and/or other properly trained persons shall be removed and new steel be spliced in according to the construction documents before the surface is rebuilt.

Repair of Concrete Surface: The DowAksa CarbonWrap® System must be bonded only to clean and sound substrate as verified by the engineer of record or a properly trained person. The concrete surface must be built up to its original conditions and all voids greater than 1/2 inch in diameter be filled with repair materials that conform to ICRI No. 03733. The repair materials must have compressive strength greater than that of the original concrete, but not less than 4,500 psi and 5,000 psi at 7 days and 28 days, respectively. Furthermore, the bond strength of the repair materials shall be a minimum of 200 psi according to ASTM D4541 pull-off test. The repair materials shall be cured for a minimum of 7 days before installing the FRP system, unless it's curing and strength are verified by tests.

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Surface Preparation: All sharp fins, protrusions, surface irregularities and unevenness shall be ground to a smooth surface with less than 1/32 inch in deviation. Surface preparation shall promote continuous intimate contact between the DowAksa CarbonWrap® material and concrete by providing a clean and smooth flat or convex surface. Disk grinders or similar equipment may be used to remove paint, stains and other surface substances that may affect the bond. All surface voids greater than1/2 inch in diameter and 1/8 in depth must be filed before bonding DowAksa CarbonWrap®. Cracks in the concrete surface must be injected with epoxy as well. Any surface protrusions caused by crack injection must be removed before bonding DowAksa CarbonWrap®. Crack injection will prevent water from getting behind the DowAksa CarbonWrap® material. The surface must be completely cleaned of any dust, grease, oil, curing compounds, wax, stains, paint, surface lubricants, foreign particles, weathered layers or any other bond inhibiting materials. If water blast is used to clean the surface, the surface shall be allowed to dry completely before installing DowAksa CarbonWrap®.

Chamfering Corners: All corners and sharp edges shall be rounded or chamfered to a minimum radius of 3/4 inch or greater. Ridges and form lines larger than1/4 inch shall be ground down or filed with epoxy before installation of DowAksa CarbonWrap®.

Installation of the DowAksa CarbonWrap® System

This section discusses the mixing of the resin systems and the saturation and placement of the fabric or laminate.

Temperature and Moisture: The temperature and moisture recommendations provided in the DowAksa literature and on the product labels must be adhered to during the installation and curing of the DowAksa CarbonWrap® System. Do not apply any of the resin or epoxy compounds on damp or moist surfaces. At no time should the resin or epoxy compounds be applied on frozen surfaces. The application temperature must be between 10 ºC and 38 ºC (50 ºF and 100 ºF). A minimum temperature of 24 ºC (75 ºF) must be maintained for at least one week to allow full cure of the system. Higher temperatures promote faster cure (less than one week); colder temperatures extend the full cure time beyond one week. Auxiliary heat sources may be used to elevate temperature and cure the system faster. Concrete dryness is essential when using elevated temperature cure to prevent moisture vapor transmission. At temperatures of above 38 ºC (100 ºF), the system will cure in less than 24 hours. It is recommended that the minimum application temperature should be at least 3 ºC (37 ºF) above the dew point temperature.

Mixing of Epoxy Components: All resin and epoxy compounds manufactured by DowAksa CarbonWrap® are two-part systems, containing a Part A (resin) and a Part B (hardener). The mix ratios of Part A and Part B for different DowAksa CarbonWrap® epoxies are specified on the container label and the product data sheets. In all cases, it is crucial that the two parts are thoroughly mixed for proper development of the adhesives properties. All epoxy systems must be mixed at the specified temperature range using a Jiffy blade, or other power rotary tools and blades, for a minimum of 3 minutes, until a uniform color and consistency is achieved. No organic solvents or thinners should be used to thin the epoxies. Do not mix more resin than can be used during the pot life of the specific resin system. Any mixed resin that begins to generate heat or display increased viscosity should not be used and should be disposed of properly, according to the instructions (see the Clean-Up and Disposal section. Epoxy components are exothermic (heat up) when mixed and, if left alone, can catch on fire. Mix only small quantities in containers with a large surface area to volume ratio to allow heat dissipation and to prevent potential fire hazards. As an example, do not mix more than three gallons total of Parts A and B in a 5 gallon pail and use immediately following the mixing. The longer they are epoxy components are left in the pail, the more heat they generate, resulting in hardening and wasting of the epoxy.

Application of the Primer: If CarbonBond™ 200P Adhesive Putty Resin (putty used as a filler for spalled concrete areas) is specified, the concrete surface must first be primed with CarbonBond™ 300 Saturating Resin prior to the application of the putty. CarbonBond™ 300 Saturating Resin must be applied at ambient and surface temperatures between 10 ºC and 38 ºC (50 ºF and 100 ºF). The putty should be applied as soon as the primer becomes tacky. If the primer is cured, the surface must be slightly scuffed and cleaned before the putty is applied. The cleaned and prepared surfaces must be protected against recontamination until the DowAksa CarbonWrap® System is applied.

Alignment of Fibers: The fabrics and laminates provide the necessary strength in the primary direction of their fibers. Therefore, it is paramount that the plies and fibers in the fabric be oriented in the directions that are shown on the construction documents and drawings. Any deviation in the alignment of more than 5 degrees (1 inch/foot) is not acceptable and must be corrected. The installed fibers must be free of kinks, folds, waviness and misalignments.

Anchoring of Fabrics or Laminates: Anchoring of the fabrics or laminates shall follow the specific directions provided on the construction documents and drawings. Care should be taken to not damage the fabric or the laminate when installing clamps, fasteners or other mechanical anchoring systems.

Lap Joints: The fibers must be fully continuous or lapped in their primary direction to be effective. Whenever there is an interruption in the primary direction of the fibers, a lap joint must be designed and fibers need to be overlapped. This must be done as part of the design and be shown on the construction documents and drawings; in no case should such overlap be less than 6 inches. For greater structural reliability, the lap joints on multiple layers should be staggered. No lap joint is necessary for unidirectional fabrics or laminates in a direction perpendicular to the direction of the primary fibers, unless specified on the construction drawings.

Multiple Fabrics Plies: When multiple plies are installed, the sequence and stacking shall follow the special instructions in the construction documents. Each ply shall be installed before the onset of complete gelation of the previous layer. Multiple plies can also be applied on different days and after the previously applied ply is cured, provided that the surface is roughened by sanding and is cleaned from dust and residue.

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Step-by-Step Installation Procedures

Step 1: If the use of CarbonBond™ 200P Adhesive Putty (filling putty) is specified, first prime the surface using a brush or roller with CarbonBond™ 300 Saturating Resin. If CarbonBond™ 200P is not specified, go directly to Step 3.

Step 2: Use CarbonBond™ 200P to smooth and level uneven surfaces and to fill holes. CarbonBond™ 200P also can be applied between layers of fabric that are saturated with CarbonBond™ 300 Saturating Resin to help prevent sagging. CarbonBond™ 200P Adhesive Putty is best applied with a trowel or putty knife.

Step 3: Apply CarbonBond™ 300 Saturating Resin to the cleaned surface, leaving at least 10ml thick resin on the surface before the dry fabric is applied. Pre-cut the fabric to specified lengths as shown on the drawings and apply the fabric to the epoxy-coated concrete surface. NOTE: DowAksa CarbonWrap® CFU10T and CFB10T can be applied dry onto the epoxy-coated surface, but DowAksa CarbonWrap® CFU20T, CFU40T and CFB20T must first be fully saturated with CarbonBond™ 300 Saturating Resin, either manually or by using an impregnating machine, before being applied to the epoxy-coated concrete surface. When either DowAksa CarbonWrap® CFU10T or CFB10T is applied (dry), it must be top coated with CarbonBond™ 300 Saturating Resin and fully saturated before the next layer is applied. Following full saturation of the fabric, at least 10ml thick resin should be applied on top of the fabric before the next fabric layer is applied. Pre-saturated DowAksa CarbonWrap® CFU20T, CFU40T or CFB20T can be applied in multiple layers without the application of additional coats of epoxy in between the layers. Using a spiked roller, apply sufficient pressure to the fabric to remove any trapped air and to ensure an intimate bond throughout the entire length of the fabric. For DowAksa CarbonWrap® CFB10T or CFB20T (bi-directional fabrics), press and smooth the fabric from the center to the edge, along the fiber directions in both directions. For DowAksa CarbonWrap® CFU10T, CFU20T and CFU40T (unidirectional fabrics), press and smooth the fabric only along the direction of the fibers. Pressing and smoothing the fabric in directions other than the primary fibers results in misalignment and wrinkling of the fabric. For multiple layer fabric applications, the subsequent layers must be applied while the previous layer is still tacky; otherwise the surface must be scuffed and cleaned again before the next ply of fabric is applied.

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Step 4: Apply paint or protective top coating onto the fabric as soon as it is tack-free. Cured, dry resin must be scuffed and the surface be cleaned for optimal bonding of the top coat or the paint. The paint or top coat must be extended at least 6 inches beyond the termination point of the fabric in all directions, if applicable.

Application of Pre-cured Laminates: The application of pre-cured laminate, DowAksa CarbonWrap® CFL-4-50, follows the basic principles of single-ply fabric installation. The pre-cured laminate should be cut to the desired length according to the construction documents and gently pressed onto the CarbonBond™ 200P Adhesive Putty coated surface. Rubber rollers may be used to slightly press the laminate and remove any entrapped air. The laminate should not be disturbed or moved while the resin is being cured.

Please refer to **DowAksa User Manual & Product Guide** for more details on installation and materials selection.

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Laboratory No. TL-619 | FRP Tensile Test | Report Date: 11/24/2015
Test Date: 11/21/2015

Client No. DACW-U20300HT | Project: DowAksa CarbonWrap | P.O. No: Dow Grant

Panel Fabrication Witnessed by: Dr.Ehsan Mahmoudabadi Company: University of Arizona

Has Annex A of ICC-ES AC178, or similar document, been completed by an inspector? ☐ Yes ☒ No

Description:

Test Type: Material Properties Tests (Tensile Strength/Modulus/Elongation)

Standard Test Method: ASTM D3039

Sample Preparation: 1”×12” Coupans were extracted from 24”×24” test panel fabricated and allowed to be cured at the testing facility location.

Material Type and Specification: Unidirectional 20 ounce Fabric (CFU-20T) Saturated by DowAksa Carbon bond 300 high temperature epoxy resin (CB300-HT)

Test Machine: MTS Load Frame 311.31, Model: 298-12C, S.N.: 0296674, 10 data points per Second at 0.05 inch/min test speed.

Sample ID	Width (in)	Thickness (in)	Average Area (in2)	Ultimate Load (lbf)	Force Per Unit Width (lbf/in)	Composite Strength (ksi)	Elong. (%)	Composite MOE (Msi)	Failure Mode
CFU-20T-M1	0.998	0.0345	0.0344	7990	8006	232.1	0.015	16.00	AGM
CFU-20T-M2	0.9985	0.0345	0.0344	6730	6740	195.36	0.015	16.44	AGM
CFU-20T-M3	1.000	0.0345	0.0345	7450	7450	215.94	0.016	15.52	SGM
CFU-20T-M4	0.998	0.0345	0.0344	7700	7715	223.64	0.015	16.09	SGM
CFU-20T-M5	0.997	0.036	0.0359	7210	7231	200.88	0.015	15.78	SGM
CFU-20T-M6	0.997	0.032	0.0319	7020	7041	220.035	0.015	16.66	LGM
CFU-20T-M7	0.997	0.0335	0.0334	7799	7822	233.51	0.016	16.63	AGM
CFU-20T-M8	0.998	0.037	0.0369	7780	7796	210.69	0.0147	16.48	M
CFU-20T-M9	0.994	0.0365	0.0363	8185	8234	225.6	0.0156	16.32	M
CFU-20T-M10	0.993	0.035	0.0347	7529	7582	216.6	0.017	16.48	LWT

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Laboratory No. TL-619 | FRP Tensile Test | Report Date: 11/24/2015
Test Date: 11/21/2015

Client No. DACW-U20300HT | Project: DowAksa CarbonWrap | P.O. No: Dow Grant

Sample ID	Width[1] (in)	Thickness[1] (in)	Average Area (in2)	Ultimate Load (lbf)	Force Per Unit Width (lbf/in)	Composite Strength (ksi)	Elong. (%)	Composite MOE (Msi)	Failure Mode
CFU-20T-M11	0.999	0.0325	0.0325	6820	6827	210.056	0.015	17.59	M
CFU-20T-M12	0.993	0.0375	0.0372	8360	8419	224.5	0.015	16.39	SGM
CFU-20T-M13	1.002	0.0365	0.0365	8240	8223	225.3	0.014	16.3	LGM
CFU-20T-M14	0.998	0.0355	0.0354	7990	8006	225.52	0.0165	16.4	XVV
CFU-20T-M15	0.995	0.036	0.0358	8000	8040	223.34	0.017	15.74	M
CFU-20T-M16	0.987	0.0365	0.036	7400	7497	205.41	0.015	16.51	LAT
CFU-20T-M17	0.997	0.037	0.0369	8920	8947	241.81	0.016	16.06	LGM
CFU-20T-M18	0.989	0.0345	0.0341	7530	7614	220.69	0.017	15.81	M
CFU-20T-M19	1.017	0.037	0.0376	7420	7296	197.19	0.0142	15.8	SGM
CFU-20T-M20	0.996	0.037	0.0368	7700	7731	208.94	0.0145	15.55	LAT
CFU-20T-M21	0.999	0.036	0.0359	6810	6817	189.36	0.0157	16.05	M
Average	0.997	0.0354	0.0353	7647	7668	216.5	0.0154	16.22	
Standard Deviation	0.0057	0.0015	0.00156	555.19	563.2	12.48	0.000896	0.47	
COV	0.57%	4.3%	4.4%	7.2%	5.98%	5.7%	5.8%	2.9%	

Results reported to DowAksa CarbonWrap.

Notes:

1- Based on average of three readings
- Panel Not conditioned.
- CarbobBond 300 was used for tab bonding.
- CFL-4-50 laminate was used for tabs.
- Extensometer was placed equidistant from tabs.

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Identification Number of the test report: DowAksa-BST-01 Report Date: 05.24.16

Test Report on DowAksa CFRP system

General:

This report is prepared in order to provide the necessary information and data to obtain approval of DowAksa Carbon Fiber Reinforcement Polymer (CFRP) System used as an externally bonded reinforcement for shear strengthening of concrete beams. The report contains experimental verification of design equations and assumptions outlined in the International Code Council Acceptance Criteria (ICC-ES-AC125) for the engineering analysis of the concrete and masonry structural members strengthened, using DowAksa CarbonWrap^{TM} fiber reinforced composite system.

The report complies with ICC-ES-AC85.

Laboratory Information:

The CEEM Structure Laboratory at the University of Arizona (TL-619) is an accredited laboratory complying with ISO/IES Standard 17025 by the international Accreditation Service (IAS). The scope of the laboratory's accreditation includes the specific type of testing covered in this report.

Laboratory accreditation certification is attached to the end of this report (Appendix I). Address and phone number of the lab is indicated on footer.

Standard Test Method: According to ICC-ES-AC125 criteria

Description of tested product:

- DowAksa CFU20T Carbon Fabric, Medium Weight Uniderectional Fabric,
- CarbonBond^{TM} 300-HT Saturant Resin System.

DowAksa CFU20T Carbon Fabric is attached to the soffit of the beam in order to increase the flexural capacity of the concrete member so that the sample fails in shear. This Fabric is attached to the concrete using DowAksa epoxy system called CarbonBond^{TM} 300-HT Saturant Resin System. Properties of these materials are attached to this report (Appendix II). This sample is considered as control sample. The shear strength of member can be improved by wrapping the FRP system around three sides of the member (U-wrap). DowAksa CFU20T Carbon Fabric is attached around three sides of the beam like a U-wrap for this purpose.
General installation instruction provided by DowAksa is also attached in Appendix III.

Test Description:

Concrete Beam Flexural Test, Group 1 of proposed plan

Test setup and Procedure:

The experimental justification consisted of casting four concrete beams with specification indicated in Figure.1 and Figure. 2.

Two samples with different compressive srengths were tested as control samples with four layers of CFU-20T on soffit (Figure. 1) and the remaining two were strengthened using DowAksa CFRP U-wrap (Figure. 2).

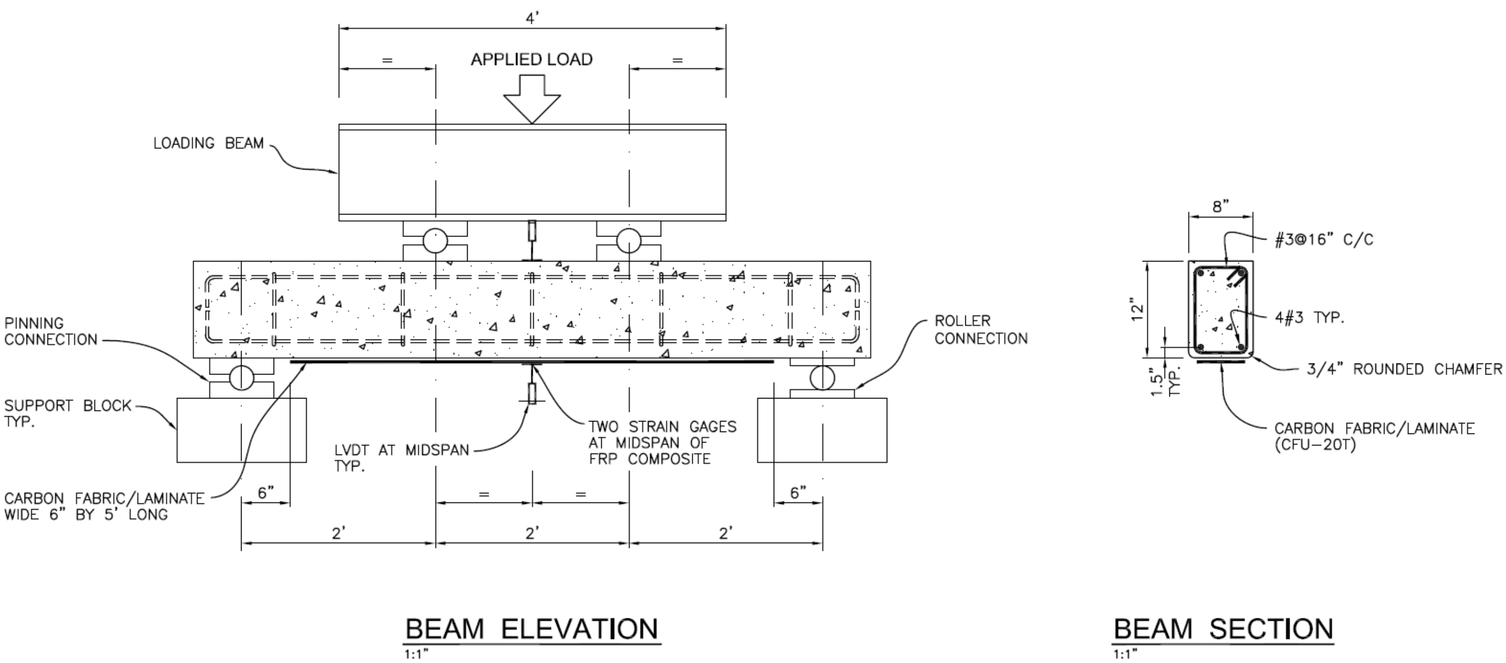

Figure 1. Beam specification for shear test, Control Sample

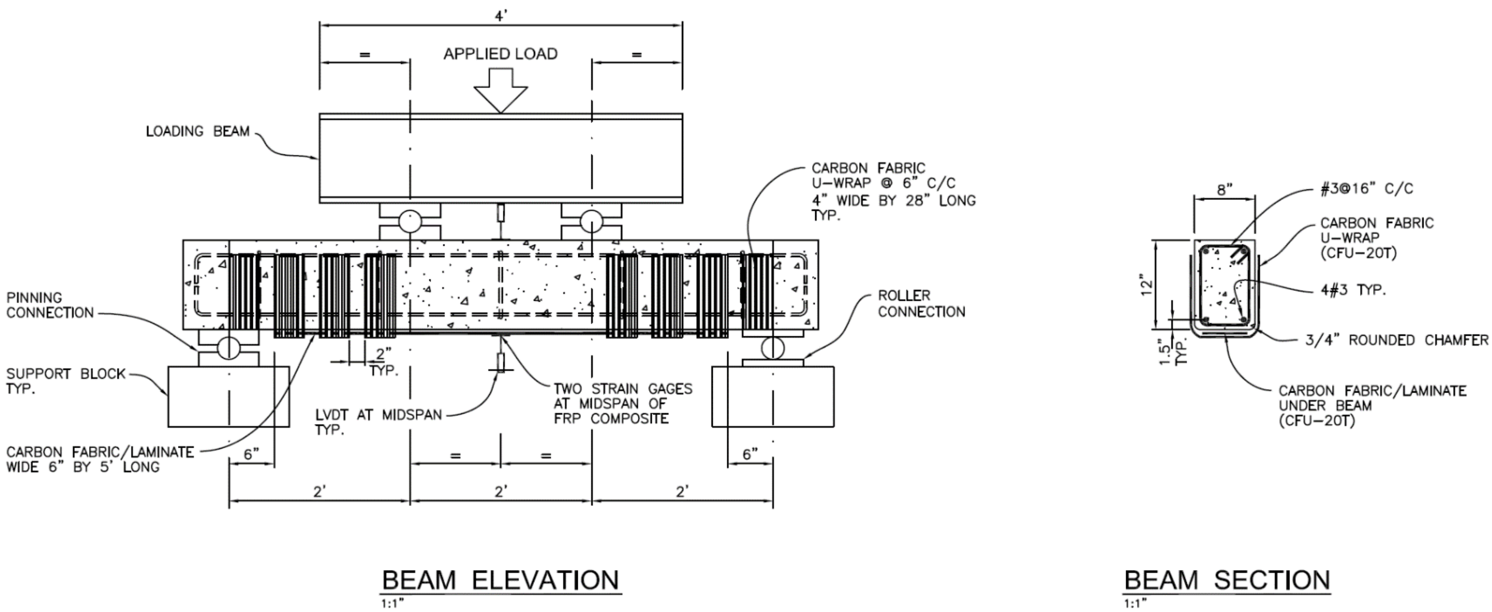

Figure 2. Beam specification for shear test, Strengthened Sample

Specimens were loaded continuously and without shock. Load was applied at a rate that constantly increases the maximum stress on the tension face at 150 psi/min. (According to ASTM C78, this rate should be between 0.9 and 1.2 MPa/min [125 and 175 psi/min] until rupture occurs.)

The loading rate is calculated using the following equation:

$$r = \frac{Sbd^2}{L} \qquad \text{(ASTM C78-10)}$$

where:

r = loading rate, N/min [lb/min],

S = rate of increase in maximum stress on the tension face, MPa/min [psi/min],

b = average width of the specimen as oriented for testing, mm [in.],

d = average depth of the specimen as oriented for testing, mm [in.], and

L = span length, mm [in.].

So, Considering S=150 psi/min, the load rating used in this test is 1.8 kip/min.

Notation:

f_y : Specified yield strength of nonprestressed steel reinforcement

ε_s : Strain level in nonprestressed steel reinforcement

ε_y : Strain corresponding to yield strength of nonprestressed steel reinforcement

E_s : Modulus of Elasticity of steel

f_c' : Specified compressive strength of concrete

E_c : Modulus of elasticity of concrete

α_1 : Multiplier on f_c' to determine intensity of an equivalent rectangular stress distribution for concrete

β_1 : Ratio of depth of equivalent rectangular stress block to depth of the neutral axis

b : width of compression face of member

c : Distance from extreme compression fiber to the neutral axis

ε_{cu} : Ultimate axial strain of unconfined concrete

ε_c' : Maximum strain of unconfined concrete corresponding to f_c'

ε_s' : Strain level in nonprestressed steel reinforcement on top of the section

A_s : Area of nonprestressed steel reinforcement

$A_{s'}$: Area of nonprestressed steel reinforcement on top of the section

f_s' : Stress level of steel reinforcement on top of the section

b_f : Width of fabric

t_f : Thickness of fabric

A_f : Area of fabric

E_f : Modulus of elasticity of fabric

ε_{fd} : Debonding strain of externally bonded FRP reinforcement

ε_{fe} : Effective strainlevel in FRP reinforcement attained at failure

ε_{fu} : Design rupture strain of FRP reinforcement

Ψ_f : FRP Strength reduction factor

Sample Information:

Sample ID#: ICC 2a.1

Date of Testing: 04.29.2016

Temperature at the time of testing: 69°F

Average Width of Beam (3 measurements): 8.00 inch

Average Depth of Beam (3 measurements): 12.05 inch

Clear Span Length: 72 inch

Concrete Compressive Strength:

Test Specimen	Proposal information
Average Compressive Strength of five sample (f_c'): 3025 psi	3000±500

Steel rebar grade: 60

f_y= 60,000 ksi, f_u= 90,000 ksi

CFRP properties:

Type: DowAksa Unidirectional 20 ounce Fabric Saturated with DowAksa CarbonBond 300HT epoxy system

Thickness = 0.0354 inch

Modulus of Elasticity = 14800 ksi

Width of fabric = 6 inch

ε_{fu}= 1.3%

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Design Criteria and minimum acceptable level:

$\varepsilon_y = \frac{f_y}{E_s}$ = 60,000/29,000,000=0.00207

$f_c' = 3025$ psi → β_1=0.85 → a=β_1.c

Assume:

- Concrete reaches ε_{cu} before FRP reaches ε_{fd}.
- Steel yields before concrete crushes.

From Equilibrium Equation:

$$\sum Compression\ forces = \sum Tension\ forces$$

0.85*f_c'*b*a+f_s'*$A_{s'}$ = f_y*A_s+ $(b_f.t_f).\ \varepsilon_{fe}.E_f$ Where ε_{fe}= 0.003$\frac{d_f-c}{c}$

Solving for c → c = 4.14 inch

a = 0.85*2.451= 3.519 inch

From Strain Diagram: $\frac{\varepsilon_{cu}}{c} = \frac{\varepsilon_s'}{c-d'} \rightarrow \varepsilon_s' = 0.003 * \frac{1.5-4.14}{4.14} = 0.0019 < \varepsilon_y$ O.K.

$$\varepsilon_{fd} = 0.083\sqrt{\frac{f_c'}{n.E_f.t_f}} = 0.083\sqrt{\frac{3.025}{4*14800*0.0354}} = 0.003153 < 0.9\ \varepsilon_{fu} = 0.0117$$

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From Strain diagram:

ε_{fe}=0.003$\frac{d_f-c}{c}$ = 0.003*$\frac{12-4.14}{4.14}$ = 0.0057 $>$ ε_{fd}=0.003153 N.G.

Since $\varepsilon_{fe} > \varepsilon_{fd}$, CFRP strain governs the equations and controls the failure:

So,

ε_{fe} = ε_{fd} = 0.003153

From Strain Diagram: : $\frac{\varepsilon_{fe}}{\varepsilon_c} = \frac{12-c}{c}$ $\rightarrow$ ε_c = 0.003153 $\frac{c}{12-c}$

$\frac{\varepsilon_{fe}}{12-c} = \frac{\varepsilon_s'}{c-1.5}$ $\rightarrow$ ε_s' = 0.003153 $\frac{c-1.5}{12-c}$

$E_c\ (ksi)$ = 57$\sqrt{f_c'\ (psi)}$ = 57$\sqrt{3025}$ = 3135 ksi

Concrete Stress Block $\rightarrow$ ε_c' = $\frac{1.7f_c'}{E_c}$ = 0.00164

$$\beta_1 = \frac{4\varepsilon_c' - \varepsilon_c}{6\varepsilon_c' - 2\varepsilon_c}$$

$$\alpha_1 = \frac{3\varepsilon_c'\varepsilon_c - {\varepsilon_c}^2}{3\beta_1{\varepsilon_c'}^2}$$

From Equilibrium Equation:

$\alpha_1.f_c'.\beta_1.c.b + (E_s.\varepsilon_s').A_s = f_y.A_s + A_f.(E_f.\varepsilon_{fe})$

Solving for c:

c = 3.459 inch;

ε_c = 0.003153 $\frac{c}{12-c}$= 0.003153*$\frac{3.459}{12-3.459}$ = 0.001277

Calculate Moment Capacity of section:

M = f_y*A_s*(d - $\beta_1.c$ /2) + $\Psi_f.A_f.f_{fe}.(d-\beta_1.c$ /2) - $f_{s'}$*$A_{s'}$. (d' - $\beta_1.c$ /2)

M = 40.25 kip.ft

Based on test setup: Max Shear load = 20.12 kips

Section Properties:

$V_c = 2.\sqrt{f_c'}$.b.d = 2× $\sqrt{3025} \times 8 * 10.5$ = 9.24 kips

$V_s = \frac{A_v.f_{sd}.d}{s}$ = 0.22*60*10.5/16 = 8.66 kips

So, $V_n = 17.86$ kips

Max Shear = 20.12 kips > Shear capacity of section = 17.86 kips → Shear enhancement is needed.

Based on Analysis, Failure load of sample 2a.1 must be 17.86×2 = 35.72 kips

Mesured results:

Load at Failure: 36.11 kips

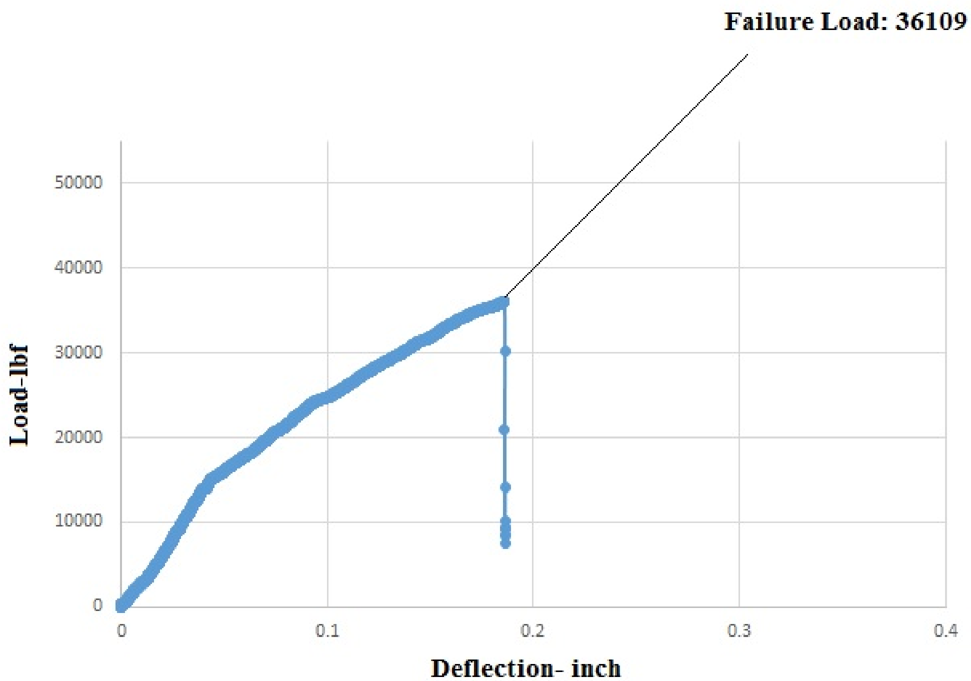


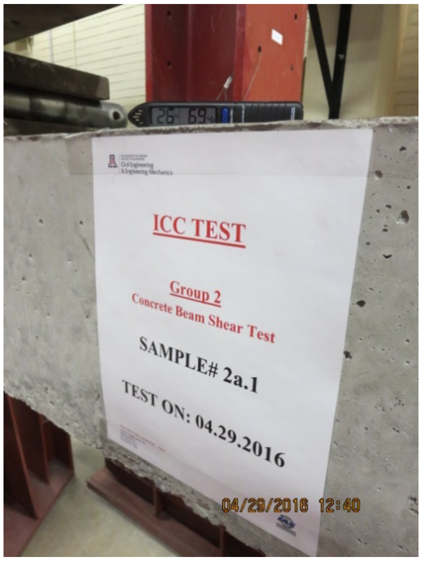
Figure 3. Load-Deflection Curve- ICC 2a.1 Sample

Failure Mode:

Shear Failure.

Mode of failure was confirmed.

Photographs:



(a)

(b)

(c)

Figure 4. (a) Sample ID #, (b) Test setup, (c) Failure of beam

Sample Information:

Sample ID#: ICC 2a.2

Temperature at the time of testing: 71.5°F

Date of Testing: 05.06.2016

Average Width of Beam: 8.0 inch

Average Depth of Beam: 12.0 inch

Clear Span Length: 72 inch

Concrete Compressive Strength:

Test Specimen	Proposal information
Average Compressive Strength of five sample (f_c'): 2804 psi	3000±500

Steel rebar grade: 60

f_y= 60,000 ksi, f_u= 90,000 ksi

CFRP properties:

Type: DowAksa Unidirectional 20 ounce Fabric Saturated with DowAksa CarbonBond 300HT epoxy system

Thickness = 0.0354 inch

Modulus of Elasticity = 14800 ksi

Width of fabric = 6 inch

ε_{fu}= 1.3%

Design Criteria and minimum acceptable level:

$\varepsilon_y = \frac{f_y}{E_s}$ = 60,000/29,000,000=0.00207

$f_c' = 2804$ psi → β_1=0.85 → a=β_1.c

Assume:

- Concrete reaches ε_{cu} before FRP reaches ε_{fd}.
- Steel yields before concrete crushes.

From Equilibrium Equation:

$$\sum Compression\ forces = \sum Tension\ forces$$

0.85*f_c'*b*a+f_s'*$A_{s'}$ = f_y*A_s+ $(b_f.t_f).\,\varepsilon_{fe}.E_f$ Where ε_{fe}= $0.003\frac{d_f-c}{c}$

Solving for c → c = 4.267 inch

a = 0.85*4.267= 3.627 inch

From Strain Diagram: $\frac{\varepsilon_{cu}}{c} = \frac{\varepsilon_s'}{c-d'} \rightarrow \varepsilon_s' = 0.003 * \frac{1.5-4.267}{4.267} = 0.00194 < \varepsilon_y$ O.K.

$$\varepsilon_{fd} = 0.083\sqrt{\frac{f_c'}{n.E_f.t_f}} = 0.083\sqrt{\frac{2.804}{4*14800*0.0354}} = 0.003036 < 0.9\ \varepsilon_{fu} = 0.0117$$

From Strain diagram:

ε_{fe}=0.003$\frac{d_f-c}{c}$ = 0.003*$\frac{12-4.267}{4.267}$ = 0.00544 $>$ ε_{fd}=0.003036 N.G.

Since $\varepsilon_{fe} > \varepsilon_{fd}$, CFRP strain governs the equations and controls the failure:

So,

ε_{fe} = ε_{fd} = 0.003036

From Strain Diagram: : $\frac{\varepsilon_{fe}}{\varepsilon_c} = \frac{12-c}{c}$ $\rightarrow$ ε_c = 0.003036 $\frac{c}{12-c}$

$\frac{\varepsilon_{fe}}{12-c} = \frac{\varepsilon'_s}{c-1.5}$ $\rightarrow$ ε'_s = 0.003036 $\frac{c-1.5}{12-c}$

$E_c\ (ksi)$ = 57$\sqrt{f'_c\ (psi)}$ = 57$\sqrt{2804}$ =3018 ksi

Concrete Stress Block → ε'_c = $\frac{1.7 f'_c}{E_c}$ = 0.001579

$$\beta_1 = \frac{4\varepsilon'_c - \varepsilon_c}{6\varepsilon'_c - 2\varepsilon_c}$$

$$\alpha_1 = \frac{3\varepsilon'_c\varepsilon_c - {\varepsilon_c}^2}{3\beta_1 {\varepsilon'_c}^2}$$

From Equilibrium Equation:

$\alpha_1 . f'_c . \beta_1 . c . b + (E_s . \varepsilon'_s) . A_s = f_y . A_s + A_f . (E_f . \varepsilon_{fe})$

Solving for c:

c = 3.538 inch;

ε_c = 0.003036 $\frac{c}{12-c}$= 0.003036*$\frac{3.538}{12-3.538}$ = 0.001269

Calculate Moment Capacity of section:

M = f_y*A_s*(d - $\beta_1 . c$ /2) + $\Psi_f . A_f . f_{fe} . (d - \beta_1 . c$ /2) - $f_{s'}$*$A_{s'}$. (d' - $\beta_1 . c$ /2)

M = 39 kip.ft

Analysis:

Based on specimen properties: Max Shear load = 19.5 kip

Section Properties:

$V_c = 2.\sqrt{f_c'}$.b.d = 2× $\sqrt{2804} \times 8 * 10.5$ = 8.89 kips

$V_s = \frac{A_v . f_{sd} . d}{s}$ = 0.22*60*10.5/16 = 8.66 kips

So, $V_n = 17.55$ kips

Max Shear = 19.5 kips > Shear capacity of section = 17.55 kips → External Shear enhancement is needed.

To increase shear capacity of section, DowAksa Carbon fiber, CFU-20T was used with properties as below:

U-wrap:

Type: DowAksa Unidirectional 20 ounce Fabric Saturated with DowAksa CarbonBond 300HT epoxy system

Thickness = 0.0354 inch

Modulus of Elasticity = 14800 ksi

Width of strips = 4 inch

Center-to-center spacing between strips = 6 inch

Number of strips layers = 1 layer

ε_{fu}= 1.3%

Shear Contribution of the FRP to shear strength

$$V_f = \frac{A_{fv} f_{fe}(\sin\alpha + \cos\alpha) d_{fv}}{s_f}$$

Where A_{fv}=2n$t_f w_f$ = 2×1×0.0354*4 = 0.2832 in^2

$f_{fe} = \varepsilon_{fe} E_f$

$\varepsilon_{fe} = \kappa_v . \varepsilon_{fu} \leq 0.004$ for 3-sides (U-wrapped) members

$$\kappa_v = \frac{k_1 k_2 L_e}{486\varepsilon_{fu}} \leq 0.75$$

$$k_1 = \left(\frac{f_c'}{4000}\right)^{2/3} = \left(\frac{2804}{4000}\right)^{2/3} = 0.789$$

$$k_2 = \frac{d_{fv} - L_e}{d_{fv}} \text{ for U-wrapped}$$

$$L_e = \frac{2500}{(n_f t_f E_f)^{0.58}} = \frac{2500}{(1*0.0354*14800)^{0.58}} = 1.204 \rightarrow \quad k_2 = \frac{d_{fv} - L_e}{d_{fv}} = \frac{8.5 - 1.204}{8.5} = 0.8583$$

$$\rightarrow \kappa_v = \frac{k_1 k_2 L_e}{486\varepsilon_{fu}} = \frac{0.789 \times 0.8583 \times 1.204}{486 \times 0.013} = 0.129 \leq 0.75 \quad \text{O.K.}$$

$\rightarrow \varepsilon_{fe} = \kappa_v . \varepsilon_{fu} = 0.129 \times 0.013 = 0.00167 \leq 0.004$ O.K.

$V_f = \frac{A_{fv} f_{fe} (sin\alpha + cos\alpha) d_{fv}}{s_f} = \frac{0.2832 \times (0.00167 \times 14800) \times 1 \times 8.5}{6} = 9.91$ kips

Controls:

$V_s + V_f$ =8.66 kips + 9.91 kips =18.57 kips $\leq 8 . \sqrt{f_c'}$.b.d =8$\times \sqrt{2804} \times 8 \times 10.5$ =35.58 kips O.K.

Center-to-center spacing between strips = 6 inch $< \frac{d}{4}$ + width of the strip=$\frac{10.5}{4} + 4 = 6.625$ inch O.K.

$V_c + V_s + \Psi_f V_f$ = 8.89+8.66+0.85*9.91= 25.97 > shear capacity of section with 4-layers of CFU-20T = 19.5 kips O.K.

Analysis

Load at failure = 39 kips

Measured Results:

Load at Failure: 39.1 kips

Load-Deflection curve:

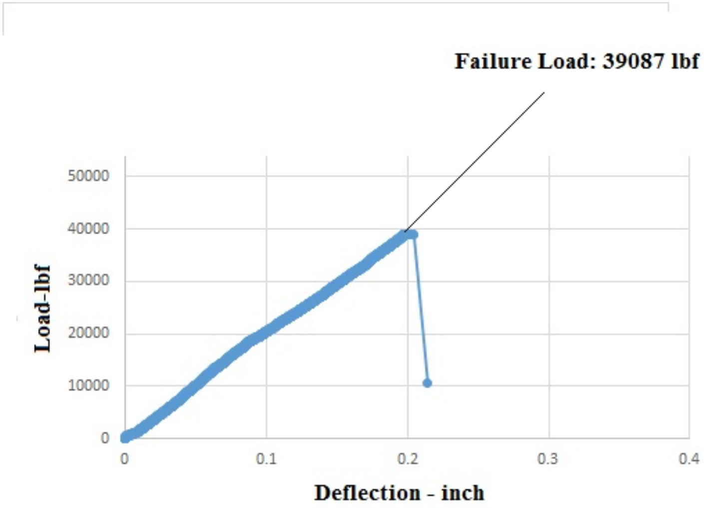


Figure 5. Load-Deflection Curve- ICC 2a.2 Sample

Failure Mode:

Mode of failure was confirmed.

FRP controled the failure/ Cover delamination.

Photographs:

(a)

(b)

(c)

Figure 6. (a) Sample ID #, (b) Test setup, (c) Failure of beam

Sample Information:

Sample ID#: ICC 2b.1

Date of Testing: 05.09.2016

Temperature at the time of testing: 76.3°F

Average Width of Beam (3 measurements): 8.00 inch

Average Depth of Beam (3 measurements): 12.0 inch

Clear Span Length: 72 inch

Concrete Compressive Strength:

Test Specimen	Proposal information
Average Compressive Strength of five sample (f_c'): 5610 psi	6000$\pm$500

Steel rebar grade: 60

f_y= 60,000 ksi, f_u= 90,000 ksi

CFRP properties:

Type: DowAksa Unidirectional 20 ounce Fabric Saturated with DowAksa CarbonBond 300HT epoxy system

Thickness = 0.0354 inch

Modulus of Elasticity = 14800 ksi

Width of fabric = 6 inch

ε_{fu}= 1.3%

Design Criteria and minimum acceptable level:

$\varepsilon_y = \frac{f_y}{E_s}$ = 60,000/29,000,000=0.00207

$f_c' = 5610$ psi → β_1=0.7695 → a=β_1.c

Assume:

- Concrete reaches ε_{cu} before FRP reaches ε_{fd}.
- Steel yields before concrete crushes.

From Equilibrium Equation:

$$\sum Compression\ forces = \sum Tension\ forces$$

0.85*f_c'*b*a+f_s'*$A_{s'}$ = f_y*A_s+ $(b_f.t_f).\ \varepsilon_{fe}.E_f$ Where ε_{fe}= $0.003\frac{d_f - c}{c}$

Solving for c → c = 3.373 inch

a = 0.7695*3.373= 2.596 inch

From Strain Diagram: $\frac{\varepsilon_{cu}}{c} = \frac{\varepsilon_s'}{c-d'} \rightarrow \varepsilon_s' = 0.003 * \frac{1.5-3.373}{3.373} = 0.00166 < \varepsilon_y$ O.K.

$$\varepsilon_{fd} = 0.083\sqrt{\frac{f_c'}{n.E_f.t_f}} = 0.083\sqrt{\frac{5.610}{4*14800*0.0354}} = 0.00429 < 0.9\ \varepsilon_{fu} = 0.0117$$

From Strain diagram:

ε_{fe}=0.003$\frac{d_f-c}{c}$ = 0.003*$\frac{12-3.373}{3.373}$ = 0.00767 $>$ ε_{fd}=0.00429 N.G.

Since $\varepsilon_{fe} > \varepsilon_{fd}$, CFRP strain governs the equations and controls the failure:

So,

ε_{fe} = ε_{fd} = 0.00429

From Strain Diagram: : $\frac{\varepsilon_{fe}}{\varepsilon_c} = \frac{12-c}{c}$ → ε_c = 0.00429 $\frac{c}{12-c}$

$\frac{\varepsilon_{fe}}{12-c} = \frac{\varepsilon_s'}{c-1.5}$ → ε_s' = 0.00429 $\frac{c-1.5}{12-c}$

$E_c\ (ksi)$ = 57$\sqrt{f_c'\ (psi)}$ = 57$\sqrt{5610}$ = 4269 ksi

Concrete Stress Block → ε_c' = $\frac{1.7f_c'}{E_c}$ = 0.00223

$$\beta_1 = \frac{4\varepsilon_c' - \varepsilon_c}{6\varepsilon_c' - 2\varepsilon_c}$$

$$\alpha_1 = \frac{3\varepsilon_c'\varepsilon_c - {\varepsilon_c}^2}{3\beta_1{\varepsilon_c'}^2}$$

From Equilibrium Equation:

$\alpha_1 . f_c' . \beta_1 . c . b + (E_s . \varepsilon_s') . A_s = f_y . A_s + A_f . (E_f . \varepsilon_{fe})$

Solving for c:

c = 2.89 inch;

ε_c = 0.00429 $\frac{c}{12-c}$= 0.00429*$\frac{2.89}{12-2.89}$ $= 0.00136$

Calculate Moment Capacity of section:

M = f_y*A_s*(d - $\beta_1 . c$ /2) + $\Psi_f . A_f . f_{fe} . (d - \beta_1 . c$ /2) - $f_{s'}$*$A_{s'}$

M = 52.2 kip.ft

Based on test setup and specimen properties: Max Shear load = 26.1 kips

Section Properties:

$V_c = 2.\sqrt{f_c'}$.b.d = 2× $\sqrt{5610} \times 8 * 10.5$ = 12.58 kips

$V_s = \frac{A_v . f_{sd} . d}{s}$ = 0.22*60*10.5/16 = 8.66 kips

So, $V_n = 21.24$ kips

Max Shear = 26.1 kips > Shear capacity of section = 21.24 kips → External Shear enhancement is needed.

Based on Analysis, Failure load of sample 2b.1 must be 21.24×2 = 42.4 kips

Mesured results:

Load at Failure: 42.1 kips

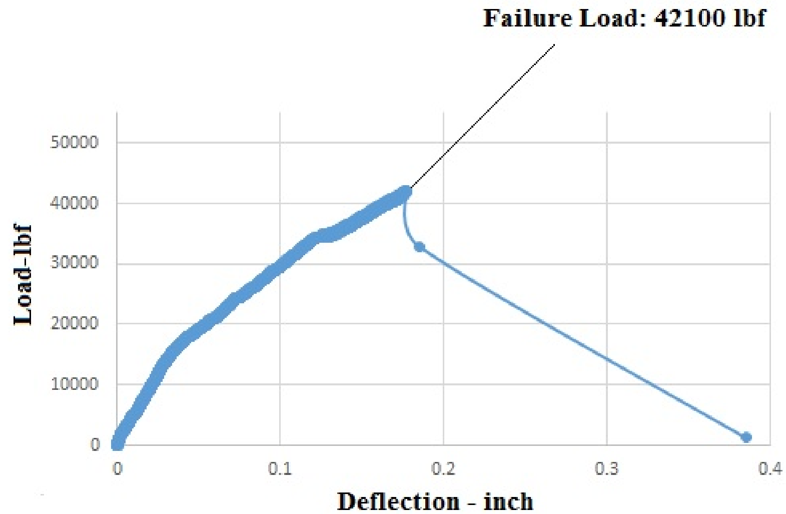


Figure 7. Load-Deflection Curve- ICC 2b.1 Sample

Failure Mode:

Shear Failure.

Mode of failure was confirmed.

<u>Photographs:</u>

(a)

(b)

(c)

Figure 8. (a) Sample ID #, (b) Test setup, (c) Failure of beam

Sample Information:

Sample ID#: ICC 2b.2

Temperature at the time of testing: 75.8°F

Date of Testing: 05.10.2016

Average Width of Beam: 8.0 inch

Average Depth of Beam: 12.0 inch

Clear Span Length: 72 inch

Concrete Compressive Strength:

Test Specimen	Proposal information
Average Compressive Strength of five sample (f_c'): 5517 psi	6000±500

Steel rebar grade: 60

f_y = 60,000 ksi, f_u = 90,000 ksi

CFRP properties:

Type: DowAksa Unidirectional 20 ounce Fabric Saturated with DowAksa CarbonBond 300HT epoxy system

Thickness = 0.0354 inch

Modulus of Elasticity = 14800 ksi

Width of fabric = 6 inch

ε_{fu} = 1.3%

Design Criteria and minimum acceptable level:

$\varepsilon_y = \frac{f_y}{E_s}$ = 60,000/29,000,000=0.00207

$f_c' = 5517$ psi → β_1= 0.774 → a=β_1.c

Assume:

- Concrete reaches ε_{cu} before FRP reaches ε_{fd}.
- Steel yields before concrete crushes.

From Equilibrium Equation:

$$\sum Compression\ forces = \sum Tension\ forces$$

0.85*f_c'*b*a+f_s'*$A_{s'}$ = f_y*A_s+ $(b_f.t_f).\varepsilon_{fe}.E_f$ Where ε_{fe}= 0.003$\frac{d_f-c}{c}$

Solving for c → c = 3.388 inch

a = 0.774*3.388= 2.622 inch

From Strain Diagram: $\frac{\varepsilon_{cu}}{c} = \frac{\varepsilon_s'}{c-d'} \rightarrow \varepsilon_s' = 0.003 * \frac{1.5-3.388}{3.388} = 0.00167 < \varepsilon_y$ O.K.

$$\varepsilon_{fd} = 0.083\sqrt{\frac{f_c'}{n.E_f.t_f}} = 0.083\sqrt{\frac{5.517}{4*14800*0.0354}} = 0.00426 < 0.9\ \varepsilon_{fu} = 0.0117$$

From Strain diagram:

ε_{fe}=0.003$\frac{d_f - c}{c}$ = 0.003*$\frac{12-3.388}{3.388}$ = 0.00762 $>$ ε_{fd}=0.00426 N.G.

Since $\varepsilon_{fe} > \varepsilon_{fd}$, CFRP strain governs the equations and controls the failure:

So,

ε_{fe} = ε_{fd} = 0.00426

From Strain Diagram: : $\frac{\varepsilon_{fe}}{\varepsilon_c} = \frac{12-c}{c}$ $\rightarrow$ ε_c = 0.00426 $\frac{c}{12-c}$

$\frac{\varepsilon_{fe}}{12-c} = \frac{\varepsilon_s'}{c-1.5}$ $\rightarrow$ ε_s' = 0.00426 $\frac{c-1.5}{12-c}$

$E_c\ (ksi)$ = 57$\sqrt{f_c'\ (psi)}$ = 57$\sqrt{5517}$ =4233.76 ksi

Concrete Stress Block → ε_c' = $\frac{1.7 f_c'}{E_c}$ = 0.00221

$$\beta_1 = \frac{4\varepsilon_c' - \varepsilon_c}{6\varepsilon_c' - 2\varepsilon_c}$$

$$\alpha_1 = \frac{3\varepsilon_c'\varepsilon_c - {\varepsilon_c}^2}{3\beta_1 {\varepsilon_c'}^2}$$

From Equilibrium Equation:

$$\alpha_1 . f_c' . \beta_1 . c . b + (E_s . \varepsilon_s') . A_s = f_y . A_s + A_f . (E_f . \varepsilon_{fe})$$

Solving for c:

c = 2.9035 inch;

ε_c = 0.00426 $\frac{c}{12-c}$= 0.00426*$\frac{2.9035}{12-2.9035}$ = 0.001359

Calculate Moment Capacity of section:

M = f_y*A_s*(d - $\beta_1 . c$ /2) + $\Psi_f . A_f . f_{fe} . (d - \beta_1 . c$ /2) - $f_{s'}$*$A_{s'}$. (d' - $\beta_1 . c$ /2)

M = 51.8 kip.ft

Analysis:

Based on specimen properties: Max Shear load = 25.9 kip

Section Properties:

$V_c = 2.\sqrt{f_c'}$.b.d = 2× $\sqrt{5517} \times 8 * 10.5$ = 12.48 kips

$V_s = \frac{A_v . f_{sd} . d}{s}$ = 0.22*60*10.5/16 = 8.66 kips

So, V_n = 21.13 kips

Max Shear = 25.9 kips > Shear capacity of section = 21.13 kips → External Shear enhancement is needed.

To increase shear capacity of section, DowAksa Carbon fiber, CFU-20T was used with properties as below:

U-wrap:

Type: DowAksa Unidirectional 20 ounce Fabric Saturated with DowAksa CarbonBond 300HT epoxy system

Thickness = 0.0354 inch

Modulus of Elasticity = 14800 ksi

Width of strips = 4 inch

Center-to-center spacing between strips = 6 inch

Number of strips layers = 1 layer

ε_{fu}= 1.3%

Shear Contribution of the FRP to shear strength

$$V_f = \frac{A_{fv} f_{fe}(sin\alpha + cos\alpha) d_{fv}}{s_f}$$

Where A_{fv}=2n$t_f w_f$ = 2×1×0.0354*4 = 0.2832 in^2

f_{fe}= $\varepsilon_{fe} E_f$

$\varepsilon_{fe} = \kappa_v . \varepsilon_{fu} \leq 0.004$ for 3-sides (U-wrapped) members

$$\kappa_v = \frac{k_1 k_2 L_e}{486 \varepsilon_{fu}} \leq 0.75$$

$$k_1 = \left(\frac{f'_c}{4000}\right)^{2/3} = \left(\frac{5517}{4000}\right)^{2/3} = 1.239$$

$$k_2 = \frac{d_{fv} - L_e}{d_{fv}} \text{ for U-wrapped}$$

$$L_e = \frac{2500}{(n_f t_f E_f)^{0.58}} = \frac{2500}{(1*0.0354*14800)^{0.58}} = 1.204 \rightarrow \quad k_2 = \frac{d_{fv} - L_e}{d_{fv}} = \frac{8.5-1.204}{8.5} = 0.8583$$

$$\rightarrow \kappa_v = \frac{k_1 k_2 L_e}{486 \varepsilon_{fu}} = \frac{1.239 \times 0.8583 \times 1.204}{486 \times 0.013} = 0.2 \leq 0.75 \quad \text{O.K.}$$

$\rightarrow \varepsilon_{fe} = \kappa_v . \varepsilon_{fu} = 0.2 \times 0.013 = 0.00263 \leq 0.004$ O.K.

$V_f = \frac{A_{fv} f_{fe} (sin\alpha + cos\alpha) d_{fv}}{s_f} = \frac{0.2832 \times (0.00263 \times 14800) \times 1 \times 8.5}{6} = 15.64$ kips

Controls:

$V_s + V_f$ =8.66 kips+15.64 kips =24.3 kips $\leq 8.\sqrt{f_c'}$.b.d =8$\times \sqrt{5517} \times 8 \times 10.5$ =49.9 kips O.K.

Center-to-center spacing between strips = 6 inch $< \frac{d}{4}$ + width of the strip=$\frac{10.5}{4} + 4 = 6.625$ inch O.K.

$V_c + V_s + \Psi_f V_f$ = 12.48+8.66+0.85*15.64= 34.43 > shear capacity of section with 4-layers of CFU-20T = 25.9 kips O.K.

Analysis

Load at failure = 51.8 kips

Measured Results:

Load at Failure: 51.5 kips

Load-Deflection curve:

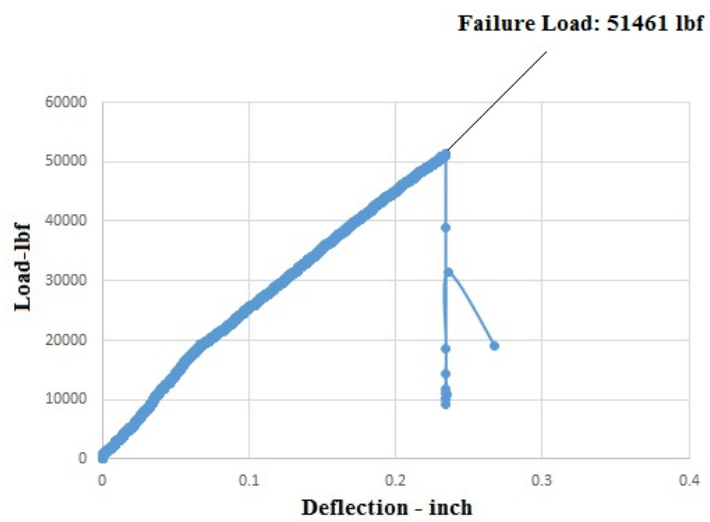


Figure 9. Load-Deflection Curve- ICC 2b.2 Sample

Failure Mode:

Mode of failure was confirmed.

FRP controled the failure/ Cover delamination.

Photographs:

(a)

(b)

(c)

Figure 10. (a) Sample ID #, (b) Test setup, (c) Failure of beam

Conclusion:

Testing data reported here verified the design equations and assumptions outlined in the International Code Council Acceptance Criteria (ICC-ES-AC125) for the engineering analysis of concrete beams strengthened for shear, using DowAksa CarbonWrap^{TM} fiber reinforced composite system.

Appendix 1

INTERNATIONAL ACCREDITATION SERVICE®

CERTIFICATE OF ACCREDITATION

This is to attest that

CEEM STRUCTURE LABORATORY AT THE UNIVERSITY OF ARIZONA

1209 E. 2ND STREET, ROOM NO. 118
TUCSON, ARIZONA 85721-0072

Testing Laboratory TL-619

has met the requirements of the IAS Accreditation Criteria for Testing Laboratories (AC89), has demonstrated compliance with ISO/IEC Standard 17025:2005, *General requirements for the competence of testing and calibration laboratories*, and has been accredited, commencing January 11, 2016, for the test methods listed in the approved scope of accreditation.

(see laboratory's scope of accreditation for fields of testing and accredited test methods)

This accreditation certificate supersedes any IAS accreditation bearing an earlier effective date. The certificate becomes invalid upon suspension, cancellation or revocation of accreditation. See http://iasonline.org/More/search.html for current accreditation information, or contact IAS at 562-364-8201.

ilac-MRA

IAS ACCREDITED

C.P. Ramani, P.E., C.B.O
President

INTERNATIONAL ACCREDITATION SERVICE®

SCOPE OF ACCREDITATION

IAS Accreditation Number	TL-619
Accredited Entity	Ceem Structure Laboratory at the University of Arizona
Address	1209 E. 2nd Street, Room No. 118 Tucson, Arizona 85721-0072
Contact Name	Dr. Ehsan Mahmoudabadi
Telephone	(520) 621-0745
Effective Date of Scope	January 11, 2015

FIELDS OF TESTING	ACCREDITED TEST METHODS
Construction Materials Testing	ASTM C 39
	ASTM C 78
	ASTM C 293
	ASTM C 617
	ASTM C 1609
	Test methods referenced in Section 5.0 of ICC ES AC125 (Sections 5.1 to 5.8)
	Test methods referenced in Section 9 of ICC ES AC178
	Test methods referenced in Sections 3.0, 4.2.3, 4.3.4, 4.3, 4.7 and 5.0 of ICC ES AC434
Composites	ASTM D 3039
	ASTM D 7205
	ASTM D 7565
	ACI 440.3R (Except Part B.6)
Physical Testing of Structural Assemblies	ASTM D 2344
	ASTM D 3165
	ASTM D 3528
	ASTM D 4541
	Test methods referenced in Section 5.0 of ICC ES AC125 (Sections 5.1 to 5.8)
	Test methods referenced in Section 9 of ICC ES AC178
	Test methods referenced in Sections 3.0, 4.2.3, 4.2.4, 4.3, 4.7 and 5.0 of ICC ES AC434

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IAS ACCREDITED

Appendix 2

DOWAKSA

Product Technical Information

DowAksa CFU20T Carbon Fabric

Medium Weight Unidirectional Fabric

Description

DowAksa CFU20T is a medium weight, high tensile strength unidirectional carbon fabric. It easily wets out with CarbonBond™ 300-HT Saturant Resin System and can be installed using the "wet lay-up" technique. This fabric has excellent mechanical properties as listed below. This system is a NSF/ANSI Standard 61 listed product for drinking water systems (see water system requirements below).

Applications

CFU20T Carbon Fabric is designed to fabricate on-site composite reinforcements to a variety of structures and substrates:

- Flexural and shear reinforcement of beams
- In-plane and out-of-plane reinforcement of concrete and masonry walls
- Column wrapping and reinforcement of slab
- Structural steel applications

CFU20T Carbon Fiber (Composite Laminate Properties)

Property(1)	Average Value	Design Value	Method
Tensile Strength (Ksi)	216.5	179.06	ASTM D3039
Elongation at Break (%)	1.5	1.3	
Tensile Modulus (Msi)	16.2	14.8	
Thickness (in)	0.035		
Longitudinal Coefficient of Linear Thermal Expansion $(10^{-6}\ F^{-1})$	0.5		ASTM E831
Trasnverse Coefficient of Linear Thermal Expansion $(10^{-6}\ F^{-1})$	29.7		
Water Adsorption (%)			ASTM D570
24 Hours	0.29%		
168 Hours	0.70%		
Hardness, Shore D	85		ASTM D2240
Glass Transition (°F)	210		ASTM E1640
HDT (°F)	572		ISO 75-1

1) Typical values and should not be construed as specifications.

Page 1 of 2 CFU20T Carbon Fabric

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CFU20T Carbon Fiber (Dry Fiber Properties)

Property[1]	Value	Method
Avg. Tensile Strength (Ksi)	710	
Elongation at Break (%)	2.0	ISO 10618
Avg. Tensile Modulus (Msi)	34.8	
Density (lbs/in^3)	0.065	ISO 10119
Weight (oz/yd^2)	20	

(1) Typical values and should not be construed as specifications.

NSF/ANSI Standard 61 Requirments

This system is certified NSF/ANSI Standard 61 compliant only for use in drinking water systems with:

CarbonBond™ 300 Saturant Resin (Slow Cure System)

Minimum Diameter Pipe Size (Static Flow): 48 in

Minimum Tank Size: 10,000,000 gallons

Minimum Cure Times: 72 hours

Please contact DowAksa USA LLC for other requirments.

How Supplied (net weight)

CFU20T 24 in. wide, at 1 roll 50LY, 300 sq. ft.

DowAksa

Contact information:
North America: 520-292-3109
Toll Free: 866-380-1269
Emergency: 800-535-5053
http://www.dowaksausa.com

Technical Data Sheet

DowAksa CarbonWrap™

CarbonBond™ 300-HT Saturant Resin System
CarbonBond™ 300A-HT Saturant Resin - Part A
CarbonBond™ 300B-HT Hardener - Part B

Description

The CarbonBond™300-HT Saturant Resin System consists of an epoxy resin and an amine hardener formulated for saturating fiber reinforced composites. The CarbonBond™300-HT Saturant Resin System provides an excellent balance of viscosity, pot life and cure development. The low viscosity of the CarbonBond™300-HT Saturant Resin System results in excellent flow properties and fiber wetting while enhancing the toughness of the cured system without sacrificing the thermal resistance of the cured product.

Applications

CarbonBond™ 300-HT Saturant Resin System is designed for use with the CarbonBond™ 100 Primer, CarbonBond™ 200P Adhesive Putty and Carbon Fiber Fabrics to fabricate on-site composite reinforcements to a variety of structures and substrates.

CarbonBond™ 300-HT Saturant Resin System is recommended for the manufacture of fiber reinforced structural composites for diverse applications including Construction, Marine and Infrastructure Repair.

Mixing and Handling

Accurate proportioning and thorough mixing are essential to achieve full performance properties. Manually mix resin, hardener and catalyst components together for approximately 5 minutes while making sure to scrape the sides, bottom and corners of the mixing container. When automated meter mixing equipment is used, it should be tested for accuracy on a regular basis.

	Part A	Part B	Mix
	Parts	Parts	A:B
By Weight	100	32.4	3.1:1
By Volume	100	36.3	2.75:1

Hardener and the mixed system (epoxy resin and hardener) are hygroscopic and any absorbed moisture will moderately shorten the pot life of the system. This can be minimized by keeping containers of the hardener and the mixed system covered while transferring, dispensing and impregnating. For large applications, it is a good practice to mix and use several small batches rather than one large batch.

The epoxy resin and amine hardener used in this system will readily react with each other at ambient temperatures. This reaction is exothermic and, depending on the mass, can result in a significant temperature rise or fire. The utmost care must be taken to avoid inadvertent mixing of the system components. Refer to the Safety and Handling section for additional information.

Application and Curing Conditions

The recommended application conditions are between 20°C and 25°C with a maximum relative humidity (RH) of 70%. It is recommended that the minimum application temperature should be at least 3°C above the dew point temperature.

Higher temperatures will shorten the pot life and lower temperatures will increase the viscosity, significantly affecting the fiber wetting characteristics at the system.

Generally, with cure temperatures between 20°C and 30°C, mechanical property development will peak after about 2 weeks. To accelerate the mechanical property development and heat resistance of the resin system, an elevated temperature post cure is required. A post cure schedule can be started after the material has cured at ambient temperatures for a minimum of 24 hours. In order to obtain a full cure, the product must be kept at 110°C for at least 2 hours. Post cure schedules can be tailored for each application. If the post cure temperature is limited to 90°C for instance, the time should be increased to approximately 6 hours. Accordingly, times, temperatures, and ramp rates should be adjusted such that the entire composite article receives sufficient heat history to attain full properties.

Under cool / humid / damp conditions – the cured material may produce an oily film or exudate on the surface. See also the Dow technical bulletin entitled, Amine Blushing and Blooming of Epoxy Systems, Form No. 296-01656. This surface contaminant may affect the bonding of subsequent layers or materials. Should this occur, one must prepare the surface for secondary bonding by abrading the surface with coarse abrasive paper or similar treatments.

Safety and Handling

DowAksa USA, LLC provides its customers with a product specific Safety Data Sheet (SDS) to cover potential health effects, safe handling, storage, use and disposal information. DowAksa strongly encourages its customers to review the SDS on its products and other materials prior to their use.

Packaging, Storage and Shelf Life

CarbonBond™ 300A-HT Saturant Resin Part A is packaged in 20 kg pails or 200 kg tight-head drums. The epoxy resin should retain its chemical properties for at least 24 months when stored in a dry place in its original closed packaging between 25°C and 35°C. For further storage information on liquid epoxy resins consult the Dow technical bulletin, Product Coding, Shelf-life and Storage Stability, Form No. 296-01657.

As with many liquid epoxy resins, CarbonBond™ 300A-HT Saturant Resin Part A may crystallize during storage. The potential for crystallization can be minimized by storing the resin in a controlled temperature environment between 25°C and 35°C. Crystallized resin can be reconstituted by heating

CarbonBond™ 300-HT Saturant Resin System

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Technical Data Sheet

to 60°C. For further details see the Dow technical bulletin, Crystallization of Liquid Epoxy Resins, Form No. 296-01652.

CarbonBond™ 300B-HT Hardener Resin Part B is supplied in 18 Kg pails or 180 kg tight-head drums. This hardener should retain its chemical properties for at least 24 months when stored in its original closed packaging, in a cool, dry environment, away from direct sunlight and at a temperature not over 35°C. If possible, provide nitrogen padding in the headspace of opened containers and bulk storage facilities.

CarbonBond™ 300HT-B Saturant Hardener is hygroscopic and will absorb moisture and carbon dioxide from the atmosphere if not stored properly. Be sure to close containers immediately after use. The absorption of moisture and/or carbon dioxide will affect the chemical behavior of the material and the performance properties of the final product. In addition, the reaction of amine hardeners with moisture and See also the Dow technical bulletin entitled, *Amine Blushing and Blooming of Epoxy Systems, Form No. 296-01656.*/or carbon dioxide will form a white precipitate; usually around the opening of the container. This precipitate is NOT soluble in the epoxy resin or the hardeners. To minimize the formation of this white precipitate, care should be taken to wipe away excess liquid material from around the opening of the container before closing it. To avoid contaminating the contents of the container with precipitate that may have formed, remove the precipitate BEFORE the container is opened.

Typical Properties of the System

Property[1]	Part A Epoxy Resin	Part B Hardener	Part A & B Combined	Method
Color	Clear	Clear Red	Clear Red	
Density @ 25°C (g/cc)	1.143	1.020	1.107	ASTM D4052
Brookfiled Viscosity @ 23°C LVT Spdl#3-30 rpm (mPa.s)	700	350	650	ASTM D2196
Gel Time 100 gm @ 23°C (min)			40-55	
Shelf Life (Months)[2]	24	24		

(1) Typical values and should not be construed as specifications.
(2) See Packaging, Storage and Shelf Life section for details.

Mechanical Properties of Cured System

Property(1)	After 14 days @ 23ºC	After 4hrs @100ºC	Method
Tensile Strength (Ksi)	10.15	10.88	
Elongation at Break (%)	2.3	8.1	ASTM D638
Tensile Modulus (Ksi)	536.64	435.12	
Flexural Strength (Ksi)	13.35	17.55	
Strain at Break (%)	2.8	>6	ASTM D790
Flexural Modulus (Ksi)	507.64	449.62	
Compression Strength (Ksi)	29.8		ASTM D695
Comprsive Modulus (Ksi)	508		
Glass Transition Temperature – DMA (ºF)	210	230	ASTM E1640
Shore D Hardness	85.7		ASTM D2240

(1) Typical values and should not be construed as specifications.

Food Contact Applications

This epoxy resin system is not intended for food or portable water contact applications.

Clean Up

Flush with water. Dispose of in accordance with local and federal regulations. Uncured material can be removed with approved solvents. Cured material can only be removed mechanically.

CarbonBond™ 300-HT Saturant Resin System

Appendix 3

DOWAKSA

Field Application and Installation Guidelines

Dow Aksa CarbonWrap® Systems for Concrete and Masonry Structures

Description

The DowAksa CarbonWrap® System for Concrete and Masonry Structures system provides a balance of properties most suitable for saturating carbon fiber fabrics predominantly applied to concrete structures as supplemental reinforcement or for the remediation of damaged structures. The low viscosity and thixotropic nature allow for fast and thorough wetting of the carbon fiber fabrics without drainage or sagging on vertical and overhead surfaces. The pot life and cure speed are balanced to allow for multiple applications or layers in a single day. Depending on temperature conditions, the system develops >95% of full properties in as little as 7 days. The system is designed with a colored hardener that makes it easy to identify and assess the thoroughness of the mixing process.

General

The integrity and quality of the DowAksa CarbonWrap® systems critically depend on a careful initial planning and evaluation of the project. All construction specifications, materials storage and handling, as well as installation steps, must be carefully reviewed by all those involved in the project and adhered to. The following sections describe various steps necessary for successful completion of the project.

Initial Planning

Because DowAksa CarbonWrap® materials can be affected by temperature and moisture during installation and curing, it is recommended that a careful plan for executing different stages of the project be put in place at the start of the project to assure a timely and efficient execution. Several important points to consider include, but are not limited to the following:

- Schedule: Plan installation dates and times
- Equipment: Provide all tools and equipment necessary for the particular project
- Materials: Provide sufficient lead time and order all materials from DowAksa to be ready at the site before the start of the work
- Workforce: Determine size, skill level and timeframe for the workforce
- On-Site Assistance: Work with DowAksa to determine if an on-site representative of DowAksa is required

Typical Tools and Equipment

The following are samples of tools required for installation:

- Heat gun, rags, measuring cups (1L)
- Scissors (4)
- Power generator
- Acetone (4 gallons)
- Silica-based dry sand
- Impregnating machine for automatically saturating the fabric
- Sand- or water-blasting equipment
- Grinder and wire wheel or wire brush
- Pressurized air and dust-removing tools
- Mixing and measuring containers (5 gallons and 2 gallons)
- Weight measuring scale
- Coveralls, chemical-resistant gloves and goggles
- Ventilation equipment
- Roller brush to apply resin, short-handled and long-handled
- Spiked wheel rollers to remove air pockets
- Industrial shears to cut the carbon fabric
- Jiffy or other rotary mixers and mixing paddles
- Rubber trowel or spatula to spread the putty
- Dropcloth and plastic sheets

Consult OSHA for appropriate safety equipment and measures for application of chemicals, resins and epoxies.

Page 1 of 6 CarbonWrap® System for Concrete and Masonry Structures

CarbonWrap® Systems, a Division of DowAksa

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Storage and Safe Handling

DowAksa CarbonWrap® epoxy and resin compounds must be stored in their unopened containers in temperatures between 10 °C and 38 °C (50 °F and 100 °F). Optimal storage temperature is between 18 °C and 29 °C (65 °F and 85 °F).

As with all chemicals, DowAksa CarbonWrap® epoxy and resin materials have a limited shelf life. In order to preserve their properties and reactivity, these materials should be stored in their unopened containers for periods of two years or less. Materials that have exceeded their shelf life and materials that have been stored improperly, as specified by DowAksa CarbonWrap®, must be disposed of in accordance with the disposal instructions given in the Clean Up and Disposal Section.

DowAksa CarbonWrap® fabrics and laminates have indefinite shelf life. Therefore, they can be stored indefinitely. All materials including the fabrics must be kept away from dust, moisture, chemicals, direct sunlight, physical damage and fire.

All DowAksa CarbonWrap® materials must be handled with care to avoid any physical damage and to avoid potential safety hazards. Those who are involved with handling and application of the epoxy compounds must be thoroughly informed of the safety hazards and potential dangers of the particular chemical they are handling. This includes access to and familiarity with the Safety Data Sheets (SDS). The SDS must be consistently placed in a familiar location and at all times be accessible to the work crew.

The contractor is responsible for providing SDS to all personnel and informing them of the potential safety hazards and other important characteristics of epoxies and resins. Furthermore, the contractor is responsible for making sure that all stages of the project are executed in accordance with federal, state and local environmental laws and regulations in addition to the OSHA requirements and laws to protect the safety of all workers.

When working with epoxy and resin compounds the work area must be very well ventilated. Safety goggles or glasses are necessary when working with epoxies. Coveralls and chemical-resistant gloves must be worn by all personnel in the work area. The gloves must have been tested for resistance to resins, epoxies and solvents.

Personal cleanliness is very important when working with chemical compounds. Involuntary habits such as eyeglass adjustment, face scratching and touching other objects, tools or equipment must be avoided. Eating, drinking or smoking must be avoided until the individual has washed up. Avoid unnecessary and prolonged handling of fabrics. Do not fold the fabrics as this may cause misalignment, pulling and/or breakage of the fibers.

Clean Up and Disposal

Any material that has exceeded its shelf life, is damaged or has not been stored according to the specified instructions, or is in excess or not used when opened must be disposed of in accordance with the SDS and all other federal, state and local laws.

The contractor must be thoroughly be familiar with the environmental laws and regulations governing the disposal of chemicals. He/she is responsible for the complete cleanup of the project site, including removal of excess and unused materials (waste), empty containers and other aesthetically unpleasing materials.

Surface Preparation

The effectiveness, integrity and performance of the DowAksa CarbonWrap® System critically depend on the preparation and soundness of the substrate. Therefore, preparing a clean and sound substrate is the most important part of the entire application process.

Removal of Damaged and Unsound Concrete: Environmental effects and corrosion of the reinforcing bars can cause damage to concrete or masonry. Any such concrete or masonry area that is determined by the engineer of record or other properly trained personnel to be damaged and unsound must be removed and repaired before DowAksa CarbonWrap® can be applied. Defects in concrete substrate can compromise the strength of the DowAksa CarbonWrap® System. Covering of carbonated or chloride-contaminated concrete with DowAksa CarbonWrap® without addressing the source of contamination will be detrimental to the effectiveness of the repair system. Special design consideration needs to be implemented by the engineer of record to address the possibilities of carbonation, alkali silica reactions or reactive aggregates. Careful attention must be paid when removing defective concrete to not damage the surrounding areas. The removal of defective concrete must be in accordance with the guidelines of ACI 546R-96 and ICRI No. 03730. Proper equipment such as chippers and electric jackhammers must be used to remove defective concrete at sufficient depth of at least 1/2 inch beyond the repair area to expose sound aggregates. If concrete removal exposes any pre-stressing or reinforcing steel that is corroded or de-bonded as a result of the removal of defective concrete, additional concrete shall be removed to a depth of 3/4 inch, or at least 1/4 inch larger than the largest aggregate size in the repair material, and repaired again before the application of DowAksa CarbonWrap®. Substrate must be cleaned and repaired before the application of DowAksa CarbonWrap®.

Repair of Defective Reinforcement: The corroded reinforcement must be cleaned and repaired in accordance with ICRI No. 03730, and to the satisfaction of the engineer of record. DowAksa CarbonWrap® should not be applied to concrete having unrepaired corroded reinforcement. The corroded reinforcement shall be cleaned to expose the white metal (SSPC SPS-5). Defective steel that is deemed unrepairable by the engineer of record and/or other properly trained persons shall be removed and new steel be spliced in according to the construction documents before the surface is rebuilt.

Repair of Concrete Surface: The DowAksa CarbonWrap® System must be bonded only to clean and sound substrate as verified by the engineer of record or a properly trained person. The concrete surface must be built up to its original conditions and all voids greater than 1/2 inch in diameter be filled with repair materials that conform to ICRI No. 03733. The repair materials must have compressive strength greater than that of the original concrete, but not less than 4,500 psi and 5,000 psi at 7 days and 28 days, respectively. Furthermore, the bond strength of the repair materials shall be a minimum of 200 psi according to ASTM D4541 pull-off test. The repair materials shall be cured for a minimum of 7 days before installing the FRP system, unless it's curing and strength are verified by tests.

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Surface Preparation: All sharp fins, protrusions, surface irregularities and unevenness shall be ground to a smooth surface with less than 1/32 inch in deviation. Surface preparation shall promote continuous intimate contact between the DowAksa CarbonWrap® material and concrete by providing a clean and smooth flat or convex surface. Disk grinders or similar equipment may be used to remove paint, stains and other surface substances that may affect the bond. All surface voids greater than1/2 inch in diameter and 1/8 in depth must be filed before bonding DowAksa CarbonWrap®. Cracks in the concrete surface must be injected with epoxy as well. Any surface protrusions caused by crack injection must be removed before bonding DowAksa CarbonWrap®. Crack injection will prevent water from getting behind the DowAksa CarbonWrap® material. The surface must be completely cleaned of any dust, grease, oil, curing compounds, wax, stains, paint, surface lubricants, foreign particles, weathered layers or any other bond inhibiting materials. If water blast is used to clean the surface, the surface shall be allowed to dry completely before installing DowAksa CarbonWrap®.

Chamfering Corners: All corners and sharp edges shall be rounded or chamfered to a minimum radius of 3/4 inch or greater. Ridges and form lines larger than1/4 inch shall be ground down or filed with epoxy before installation of DowAksa CarbonWrap®.

Installation of the DowAksa CarbonWrap® System

This section discusses the mixing of the resin systems and the saturation and placement of the fabric or laminate.

Temperature and Moisture: The temperature and moisture recommendations provided in the DowAksa literature and on the product labels must be adhered to during the installation and curing of the DowAksa CarbonWrap® System. Do not apply any of the resin or epoxy compounds on damp or moist surfaces. At no time should the resin or epoxy compounds be applied on frozen surfaces. The application temperature must be between 10 ºC and 38 ºC (50 ºF and 100 ºF). A minimum temperature of 24 ºC (75 ºF) must be maintained for at least one week to allow full cure of the system. Higher temperatures promote faster cure (less than one week); colder temperatures extend the full cure time beyond one week. Auxiliary heat sources may be used to elevate temperature and cure the system faster. Concrete dryness is essential when using elevated temperature cure to prevent moisture vapor transmission. At temperatures of above 38 ºC (100 ºF), the system will cure in less than 24 hours. It is recommended that the minimum application temperature should be at least 3 ºC (37 ºF) above the dew point temperature.

Mixing of Epoxy Components: All resin and epoxy compounds manufactured by DowAksa CarbonWrap® are two-part systems, containing a Part A (resin) and a Part B (hardener). The mix ratios of Part A and Part B for different DowAksa CarbonWrap® epoxies are specified on the container label and the product data sheets. In all cases, it is crucial that the two parts are thoroughly mixed for proper development of the adhesives properties. All epoxy systems must be mixed at the specified temperature range using a Jiffy blade, or other power rotary tools and blades, for a minimum of 3 minutes, until a uniform color and consistency is achieved. No organic solvents or thinners should be used to thin the epoxies. Do not mix more resin than can be used during the pot life of the specific resin system. Any mixed resin that begins to generate heat or display increased viscosity should not be used and should be disposed of properly, according to the instructions (see the Clean-Up and Disposal section. Epoxy components are exothermic (heat up) when mixed and, if left alone, can catch on fire. Mix only small quantities in containers with a large surface area to volume ratio to allow heat dissipation and to prevent potential fire hazards. As an example, do not mix more than three gallons total of Parts A and B in a 5 gallon pail and use immediately following the mixing. The longer they are epoxy components are left in the pail, the more heat they generate, resulting in hardening and wasting of the epoxy.

Application of the Primer: If CarbonBond™ 200P Adhesive Putty Resin (putty used as a filler for spalled concrete areas) is specified, the concrete surface must first be primed with CarbonBond™ 300 Saturating Resin prior to the application of the putty. CarbonBond™ 300 Saturating Resin must be applied at ambient and surface temperatures between 10 ºC and 38 ºC (50 ºF and 100 ºF). The putty should be applied as soon as the primer becomes tacky. If the primer is cured, the surface must be slightly scuffed and cleaned before the putty is applied. The cleaned and prepared surfaces must be protected against recontamination until the DowAksa CarbonWrap® System is applied.

Alignment of Fibers: The fabrics and laminates provide the necessary strength in the primary direction of their fibers. Therefore, it is paramount that the plies and fibers in the fabric be oriented in the directions that are shown on the construction documents and drawings. Any deviation in the alignment of more than 5 degrees (1 inch/foot) is not acceptable and must be corrected. The installed fibers must be free of kinks, folds, waviness and misalignments.

Anchoring of Fabrics or Laminates: Anchoring of the fabrics or laminates shall follow the specific directions provided on the construction documents and drawings. Care should be taken to not damage the fabric or the laminate when installing clamps, fasteners or other mechanical anchoring systems.

Lap Joints: The fibers must be fully continuous or lapped in their primary direction to be effective. Whenever there is an interruption in the primary direction of the fibers, a lap joint must be designed and fibers need to be overlapped. This must be done as part of the design and be shown on the construction documents and drawings; in no case should such overlap be less than 6 inches. For greater structural reliability, the lap joints on multiple layers should be staggered. No lap joint is necessary for unidirectional fabrics or laminates in a direction perpendicular to the direction of the primary fibers, unless specified on the construction drawings.

Multiple Fabrics Plies: When multiple plies are installed, the sequence and stacking shall follow the special instructions in the construction documents. Each ply shall be installed before the onset of complete gelation of the previous layer. Multiple plies can also be applied on different days and after the previously applied ply is cured, provided that the surface is roughened by sanding and is cleaned from dust and residue.

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Step-by-Step Installation Procedures

Step 1: If the use of CarbonBond™ 200P Adhesive Putty (filling putty) is specified, first prime the surface using a brush or roller with CarbonBond™ 300 Saturating Resin. If CarbonBond™ 200P is not specified, go directly to Step 3.

Step 2: Use CarbonBond™ 200P to smooth and level uneven surfaces and to fill holes. CarbonBond™ 200P also can be applied between layers of fabric that are saturated with CarbonBond™ 300 Saturating Resin to help prevent sagging. CarbonBond™ 200P Adhesive Putty is best applied with a trowel or putty knife.

Step 3: Apply CarbonBond™ 300 Saturating Resin to the cleaned surface, leaving at least 10ml thick resin on the surface before the dry fabric is applied. Pre-cut the fabric to specified lengths as shown on the drawings and apply the fabric to the epoxy-coated concrete surface. NOTE: DowAksa CarbonWrap® CFU10T and CFB10T can be applied dry onto the epoxy-coated surface, but DowAksa CarbonWrap® CFU20T, CFU40T and CFB20T must first be fully saturated with CarbonBond™ 300 Saturating Resin, either manually or by using an impregnating machine, before being applied to the epoxy-coated concrete surface. When either DowAksa CarbonWrap® CFU10T or CFB10T is applied (dry), it must be top coated with CarbonBond™ 300 Saturating Resin and fully saturated before the next layer is applied. Following full saturation of the fabric, at least 10ml thick resin should be applied on top of the fabric before the next fabric layer is applied. Pre-saturated DowAksa CarbonWrap® CFU20T, CFU40T or CFB20T can be applied in multiple layers without the application of additional coats of epoxy in between the layers. Using a spiked roller, apply sufficient pressure to the fabric to remove any trapped air and to ensure an intimate bond throughout the entire length of the fabric. For DowAksa CarbonWrap® CFB10T or CFB20T (bi-directional fabrics), press and smooth the fabric from the center to the edge, along the fiber directions in both directions. For DowAksa CarbonWrap® CFU10T, CFU20T and CFU40T (unidirectional fabrics), press and smooth the fabric only along the direction of the fibers. Pressing and smoothing the fabric in directions other than the primary fibers results in misalignment and wrinkling of the fabric. For multiple layer fabric applications, the subsequent layers must be applied while the previous layer is still tacky; otherwise the surface must be scuffed and cleaned again before the next ply of fabric is applied.

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Step 4: Apply paint or protective top coating onto the fabric as soon as it is tack-free. Cured, dry resin must be scuffed and the surface be cleaned for optimal bonding of the top coat or the paint. The paint or top coat must be extended at least 6 inches beyond the termination point of the fabric in all directions, if applicable.

Application of Pre-cured Laminates: The application of pre-cured laminate, DowAksa CarbonWrap® CFL-4-50, follows the basic principles of single-ply fabric installation. The pre-cured laminate should be cut to the desired length according to the construction documents and gently pressed onto the CarbonBond™ 200P Adhesive Putty coated surface. Rubber rollers may be used to slightly press the laminate and remove any entrapped air. The laminate should not be disturbed or moved while the resin is being cured.

Please refer to **DowAksa User Manual & Product Guide** for more details on installation and materials selection.

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