CERTIFIED TEST REPORT

EVALUATION OF GLASS FIBER REINFORCED POLYMER (GFRP) BARS FOR INTERNAL REINFORCEMENT OF CONCRETE MEMBERS
- Per ASTM D7957 -

Report Number: R-5.10_GAL-G_ASTM-D7957.1
Date: October 25, 2018

REVISION 1

REPORT PREPARED FOR:

Galen Panamerica LLC
Attn: Vladimir Nevidomy
1206 Sterling Road, Suite 6A
Dania Beach, FL 33004

PROJECT:

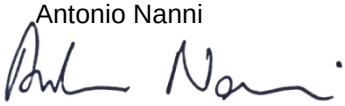
Independent Report for GFRP bar Qualification for Saudi Aramco

Quality System: The Structures and Materials Laboratory (SML) maintains a quality system in compliance with ISO 17025-2017, accredited under International Accreditation Service (IAS), testing laboratory TL-478 and qualified laboratory by the Florida Department of Transportation (FDOT) number ISM028.

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

Test Data: All the test results presented herein are linked through unbroken chain to the raw data files recorded on the day of the test. Analyzed data is obtained directly from the recorded raw data during testing, from which the test results are presented. This report contains analyzed tabulated data results of each test.

Controls:	
Superseded Report	R-5.10_GAL-G_ASTM-D7957
Reason for Revision Effective Date	Strength of bend bar test results updated. October 25, 2018
Superseded Report	n/a
Reason for Revision Effective Date	New report July 27, 2018

Test Report Approval Signatures:	
Quality review Approval	I indicate that I have reviewed this Test Report and agree with the contents it presents, and find it meets all applicable laboratory requirements and policies. I approve for its release to the customer. Name: Francisco De Caso Signature:  Date: October 25, 2018
Technical review Approval	I indicate that I have reviewed this Test Report and agree with the technical contents it presents, and find it meets all applicable laboratory requirements and policies. I approve for its release to the customer. Name: Antonio Nanni Signature:  Date: October 25, 2018

EXECUTIVE SUMMARY

This certified test report is issued for the internal procedures as requested by Saudi Aramco, to confirm that the nominal size M13 (#4) GFRP rebar produced by Galen Panamerica LLC qualifies as specified here in in compliance with the standard international specification provided within ASTM D7956-17, 'Glass Fiber Reinforced Polymer (GFRP) reinforcement bar (rebar) for concrete structures.'

Based on the results presented herein, it can be concluded that M13 (#4) GFRP rebar produced by Galen Panamerica LLC is in compliance with the international specification provided within ASTM D7956-17, and has passed the GFRP property limits for qualification purposes per the test methods specified within Table 1.

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

Sincerely,

Antonio Nanni, SML Director

SUMAMRY OF CERTIFIED FRP REBAR QUALIFICATION RESULTS

ASTM TEST METHOD	Property	Limit	
ASTM D7957	Bar Designation No.	SI US	M13 #4
ASTM E1356	Mean Glass Transition Temperature (DSC)	°C °F	104 219
ASTM E2160	Mean Degree of Cure	%	97
ASTM D7205	Guaranteed Ultimate Tensile Force	kN kip	119 26.8
	Mean Tensile Modulus of Elasticity	GPa Msi	56.3 8.17
	Mean Ultimate Tensile Strain	%	1.67
	Mean Measured Cross-Sectional Area	mm^2 $inch^2$	159 0.247
ASTM D7913	Guaranteed Bond Strength	MPa ksi	13.7 2.0
ASTM D7617	Guaranteed Transverse Shear Strength	MPa ksi	188.5 27.3
ASTM D2584	Fiber Mass Content	%	85
ASTM D570	Mean Moisture Absorption to Saturation at 50°C Moisture Absorption in 24 hrs. at 50°C	%	0.56 0.10
ASTM D7914	Guaranteed Strength of the bent portion of bar	MPa ksi	457 66.3

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1. INTRODUCTION

1.1. PURPOSE

This laboratory test report presents certified test results and other relevant information for the nominal size M13 (#4) GFRP rebar produced by Galen Panamerica LLC for the qualification testing of Glass Fiber Reinforced Polymer (GFRP) reinforcement bar (rebar) for concrete structures as per ASTM D7957-17, Table 1.

1.2. STRUCTURES AND MATERIALS LABORATORY (SML)

All tests presented in this report, including material sampling and specimen preparation, were performed by and under the supervision of the University of Miami, College of Engineering, Structures and Materials Laboratory, herein referred to as SML. This testing laboratory has met the requirements of the International Accreditation Service (IAS) AC89 (Accreditation Criteria for Testing Laboratories), has demonstrated compliance with ANS/ISO/IEC Standard 17025 / 2017, "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 PRODUCT/S UNDER EVALUATION

The Glass Fiber-Reinforced Polymer (GFRP) composite reinforcing bar (rebar) product/s under evaluation per ASTM D7957-17 are summarized as follows:

1.3.1. Galen Panamerica GFRP rebar M13 [#4] (GAL-G4)

GFRP M13 [#4] composite rebar straight or bend bar, with sand coated surface enhancement, herein referenced as, GAL-G4; is designed for use as internal reinforcement of concrete for the construction of structures and elements in residential, commercial, industrial, road and civil engineering. Refer to the manufacture's technical data sheet for additional information.

1.4. CLIENT INFORMATION

The test report has been requested for the internal procedures as requested by Saudi Aramco as is issued to:

Galen Panamerica LLC
Attn: Vladimir Nevidomy
1206 Sterling Road, Suite 6A
Dania Beach, FL 33004

2. TESTING OF REPRESENTATIVE PRODUCTS

2.1. PRODUCT SAMPLING

2.1.1. Sampling Guidelines

Sampling was conducted in accordance with the SML standard operating procedures.

2.1.2. Product Sampling

Sampling for the GFRP bars under evaluation was performed under the supervision of the Structures and Materials Laboratory. Overall the products tested are truly representative of the standard manufactured products for which recognition is being sought.

2.2. ACKNOWLEDGED AND INSPECTION OF PRODUCTS

Upon arrival of the products for evaluation to the testing laboratory, the samples 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 procedure.

2.3. PRODUCT MANUFACTURING REFERENCE NUMBER

Table 2.1 provides a summary of the unique manufacturing reference identification (ID) numbers for the products under evaluation. The unique manufacturing ID numbers are provided herein for simplicity purposes. Each unique ID number references a specific production lot for each rebar size to ensure traceability of produced product. The following manufacturing parameters comprise the ID: Product name: AKS ROCKBAR; Nominal diameter/bar size: 13 Diam. #4; Lot number: 11/20. Refer to Figure 2.1.

Table 2.1 - Manufacturing ID of products under evaluation

Product	Lot #	Unique Manufacturing ID Number
GAL-G4	01	AKS ROCKBAR 13 Diam. #4 Lot11/17
GAL-G4	02	AKS ROCKBAR 13 Diam. #4 Lot11/20
GAL-G4	03	AKS ROCKBAR 13 Diam. #4 Lot11/22
GAL-G4	01	AKS ROCKBAR BEND 3 Diam. #4 Lot08/30 - 2.49 ft x 1.15 ft
GAL-G4	02	AKS ROCKBAR BEND 13 Diam. #4 Lot08/31- 2.49 ft x 1.15 ft
GAL-G4	03	AKS ROCKBAR BEND 13 Diam. #4 Lot08/29 - 2.49 ft x 1.15 ft

Figure 2.1 – AKS ROCKBAR #4 rebar

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.

3.2. ANALYZED DATA

Analyzed data is obtained directly from the recorded raw data during testing, from which the test results are presented. This report contains analyzed tabulated data results 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.

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.

3.4. PRODUCT HANDLING

All the products were handled based on the manufacturer's specifications and laboratory internal procedures, where handling and storage considerations where provided as needed before products were used to fabricate specimens.

3.5. 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:

CCCCPLL_MMM_EE_XX

Where, CCCC refers to company name, P refers to the products (or specimen) under evaluation, LL refers to the production lot number of the product, MMM refers to the test type or mechanical property, EE refers to the type of exposure, DD refers to the duration of the exposure, and XX is the specimen repetition number. The detailed description of the nomenclature is reported in Table 3.2.

Table 3.2 – Specimen label for characterization tests

General Information	Detail	ID
CCC, Company name	Applications and Technologies for Polymeric composites	GAL-G
PP, Product / Specimen	Rebar M13 [#4]	4
LL, Production Lot	First production lot of sampled bars	L1
	Second production lot of sampled bars	L2
	Third production lot of sampled bars	L3
Test Type	Fiber Content	FC
	Glass Transition Temperature	TG
	Degree of Cure (Total Enthalpy of Polymerization)	TEP
	Measured Cross Sectional Area	MXA
	Tensile Strength	TNS
	Transverse Shear Strength	TSS
	Bond Strength	BS
	Moisture/Water Absorption	MA
	Strength of Bent Portion of Bar	SOB
EE, Exposure	None (control/benchmark tests) if applicable	CC
	Alkaline Resistance	AR

4. FIBER CONTENT – ASTM D2584

4.1. TEST SUMMARY

4.1.1. ASTM D7957 Specification Property

Section 6.1 Fiber Mass Content.

4.1.2. Reference Standard/s

ASTM D2584-11, Standard Test Method for Ignition Loss of Cured Reinforced Resins.

4.1.3. Test Objective

Determine the fiber content by mass of the composite re-bar under evaluation.

4.1.4. Product/s under Evaluation

AKS ROCKBAR 13 Diam. #4

4.1.1. Test Location

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

4.1.2. Laboratory Technician/s

Guillermo Claure, Roger Solis, and Guan Wang

4.1.3. 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 Data Sheet number TDS_GAL-G_FC.

4.2. TEST MATRIX

4.2.1. Specimen Number

A total of 24 tests are reported, eight tests from three different production lots, refer to Table 4.1.

4.2.2. Specimen ID Nomenclature

Specimens are identified throughout the report using the format described in Section 3.5 of this document.

4.2.3. Test Matrix Table

Table 4.1 –Test matrix for fiber content

Specimen ID	Specimen Preparation mm/dd/yy	Test Date mm/dd/yy
GAL-G4L1_FC_01 to 08	03/27/18	03/29/18
GAL-G4L2_FC_01 to 08	03/20/18	03/22/18
GAL-G4L3_FC_01 to 08	03/30/18	04/02/18

4.3. SPECIMEN PREPARATION

4.3.1. Specimen Size

25.0 mm (1.0 in.) long segment cut and conditioned at different locations from the rebar. Specimen are shown after testing in Figure 4.1.

4.3.2. Preparation Procedure

The specimens were cut to the prescribed dimensions using a high precision blade saw.

4.3.3. Specimen Conditioning

All specimens were conditioned under laboratory ambient conditions for at least 40 hrs. at room temperature 23 ± 3°C (73 ± 6°F) and 50 ± 10% relative humidity.

Figure 4.1 – Fiber content test samples post ignition

4.4. TEST SET-UP

4.4.1. Set-up

Specimens were placed in pre-heated crucibles and placed in a furnace at 565 ± 28°C (1050 ± 50°F) until all carbonaceous material disappeared, as see in Figure 4.2. Weight measurements in a high precision micro-scale were taken to the nearest 0.0001 g (2.2×10^{-7} lbs.) before and after to determine the fiber content as per ASTM D2584, where a desiccator was used to place the specimens while cooling down to avoid absorption of air moisture by the dry fibers.

Figure 4.2 – Fiber content furnace test set

4.5. TEST RESULTS

4.5.1. Results Summary

Based on the experimental tests presented herein the average fiber content is summarized in Table 4.2, which meets the requirements of ASTM D7957, stating that the fiber content shall not be less than 70 percent by mass.

Table 4.2 – Average summary results for fiber content by mass

Specimen ID	Fiber Content %	Specification Limit
GAL-G4_FC	85.42	Pass

4.5.2. Calculations

The results reported herein have been computed per ASTM D2584 using the parameters defined in Table 4.3. Note that sand granules were separated from the calculation, so that only the dry fiber weight after ignition was measured in order to obtain the actual fiber content, as seen in Figure 4.1.

Table 4.3 - Definitions for fiber content calculations

Symbol	Parameter	Description
W_c	Weight measurement	Weight of crucible after being heated for minimum of 10min in furnace.
W_i		Initial weight of specimen and crucible, prior ignition.
W_f		Final weight of specimen and crucible, post furnace.
W_1		Weight of rebar specimen
W_2		Weight of residue, fibers only
RC	Resin content	Ignition loss = $[(W1 - W2)/W1]*100$
FC	Fiber content	$100 - [(W1 - W2)/W1]*100$

4.5.3. Tabulated Results

Table 4.4 contains the tabulated summary results for the fiber content of the products under evaluation. Average, standard deviation (S_{n-1}) and coefficient of variance (CV) values are also reported for the group of results under evaluation.

Table 4.4 - Tabulated results for fiber content by mass, per ASTM D2584

Specimen ID	W_c	W_i	W_f	W_1	W_2	RC	FC*
	g	g	g	g	g	%	%
GAL-G4L1_FC_01	40.260	47.105	46.128	6.845	5.868	14.27	85.73
GAL-G4L1_FC_02	39.641	48.452	47.149	8.811	7.508	14.79	85.21
GAL-G4L1_FC_03	40.267	48.872	47.626	8.605	7.359	14.48	85.52
GAL-G4L1_FC_04	40.264	49.182	47.861	8.918	7.597	14.81	85.19
GAL-G4L1_FC_05	40.258	49.386	48.071	9.128	7.813	14.41	85.59
GAL-G4L1_FC_06	40.379	47.521	46.483	7.142	6.104	14.53	85.47
GAL-G4L1_FC_07	37.806	46.806	45.480	9.000	7.674	14.73	85.27
GAL-G4L1_FC_08	39.664	49.223	47.823	9.559	8.159	14.65	85.35
GAL-G4L2_FC_01	40.058	49.743	48.290	9.685	8.232	15.00	85.00
GAL-G4L2_FC_02	40.645	49.901	48.559	9.256	7.914	14.50	85.50
GAL-G4L2_FC_03	40.118	49.463	48.079	9.345	7.961	14.81	85.19
GAL-G4L2_FC_04	40.035	49.409	48.011	9.374	7.976	14.91	85.09
GAL-G4L2_FC_05	40.743	49.751	48.435	9.008	7.692	14.61	85.39
GAL-G4L2_FC_06	39.869	49.833	48.392	9.964	8.523	14.46	85.54
GAL-G4L2_FC_07	40.207	49.172	47.851	8.965	7.644	14.74	85.26
GAL-G4L2_FC_08	39.661	49.579	48.112	9.918	8.451	14.80	85.20
GAL-G4L3_FC_01	39.529	48.216	46.942	8.687	7.413	14.66	85.34
GAL-G4L3_FC_02	39.471	48.829	47.492	9.358	8.021	14.29	85.71
GAL-G4L3_FC_03	39.656	48.977	47.632	9.322	7.976	14.43	85.57
GAL-G4L3_FC_04	37.790	44.743	43.736	6.953	5.947	14.47	85.53
GAL-G4L3_FC_05	40.253	50.068	48.640	9.816	8.387	14.55	85.45
GAL-G4L3_FC_06	40.275	48.502	47.281	8.227	7.006	14.84	85.16
GAL-G4L3_FC_07	40.271	49.494	48.144	9.223	7.872	14.64	85.36
GAL-G4L3_FC_08	40.265	48.714	47.494	8.449	7.228	14.44	85.56
					Average	**14.62**	**85.38**
					Sn-1	0.20	0.20
					CV (%)	1.34	0.24

*Condition of acceptance for fiber content (FC) shall not be less than 70% by mass

5. GLASS TRANSITION TEMPERATURE – ASTM E1356

5.1. TEST SUMMARY

5.1.1. ASTM D7957 Specification Property

Section 6.2 Glass Transition Temperature.

5.1.2. Reference Standard/s

ASTM E1356-08(2014), Standard Test Method for Assignment of the Glass Transition Temperatures by Differential Scanning Calorimetry.

5.1.3. Test Objective

Determine the glass transition temperature (T_g) of the rebar under evaluation based on differential scanning calorimetry (DSC) method.

5.1.4. Product/s under Evaluation

AKS ROCKBAR 13 Diam. #4

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

Guillermo Claure, Roger Solis, and Guan Wang

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 Data Sheet number TDS_GAL-G_TG.

5.2. TEST MATRIX

5.2.1. Specimen Number

A total of 24 tests are reported, eight tests from three different production lots, refer to Table 5.1.

5.2.2. Specimen ID Nomenclature

Specimens are identified throughout the report using the format described in Section 3.5 of this document.

5.2.3. Test Matrix Table

Table 5.1 – Test matrix for glass transition temperature

Specimen ID	Specimen Preparation mm/dd/yy	Test Date mm/dd/yy
GAL-G4L1_TG_01 to 08	05/15/18	05/17/18
GAL-G4L2_TG_01 to 08	05/18/18	05/21/18
GAL-G4L3_TG_01 to 08	05/22/18	05/29/18

5.3. SPECIMEN PREPARATION

5.3.1. Specimen Size

A disk specimen was extracted with a high precision blade saw from the cross-section of the bar, to then extract a portion of the disk with a high precision blade to provide a specimen with a mass between 5 and 20 mg, as seen in Figure 5.1.

5.3.1. Preparation Procedure

The specimens were cut to the prescribed dimensions using a high precision blade saw, avoiding grinding to reduce the thermal effects that may affect the specimen's thermal history properties.

5.3.2. 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 72 hrs. prior testing.

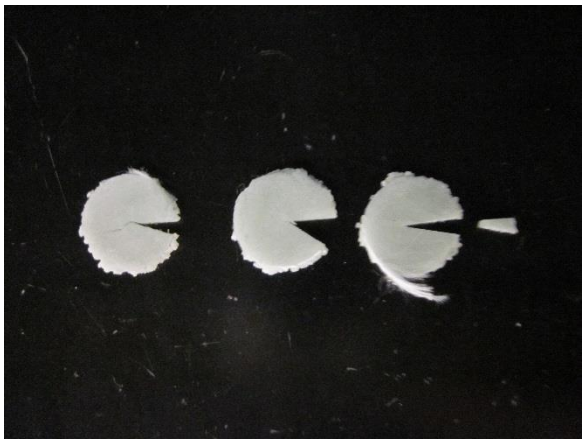


Figure 5.1 – Test specimen for glass transition temperature

5.4. TEST SET-UP

5.4.1. Set-up

A differential scanning calorimeter (DSC), TA instruments Q20 capable of programing, measuring and recording heat flow as a function of temperature and time with a dedicated test chamber was use, as seen in Figure 5.2. The specimen was placed in the chamber and program as needed for the temperature rate heating and cooling.

5.4.2. Rate and Method of Loading

A heating/cooling rate of 20°C/min was applied until the glass transition temperature was determined. An initial thermal program was done prior testing flowing nitrogen in the chamber at a rate of 10°C/min to laboratory conditions to remove potential environmental thermal history.

Figure 5.2 – Glass transition temperature DSC test set-up and chamber

5.5. TEST RESULTS

5.5.1. Results Summary

Based on the experimental tests presented herein the average, glass transition temperature, T_g of the rebars under evaluation are summarized in Table 5.2, which meets the requirements of ASTM D7957, stating that the T_g shall not be less than 100°C (212°F).

Table 5.2 – Average tests result for glass transition temperature

Specimen ID	Glass Transition Temperature T_g		Specification Limit
	°C	°F	
GAL-G4_TG	104	219	Pass

5.5.2. Calculations

The T_g is extrapolated numerically by the DCS from the heat flow versus temperature reaction curve, corresponding to range at which the observed material transitions from the hard, brittle region to the soft, rubbery region.

5.5.3. Graphical Representation of Results

Figure 5.3 shows a representative graphical response and the computed T_g.

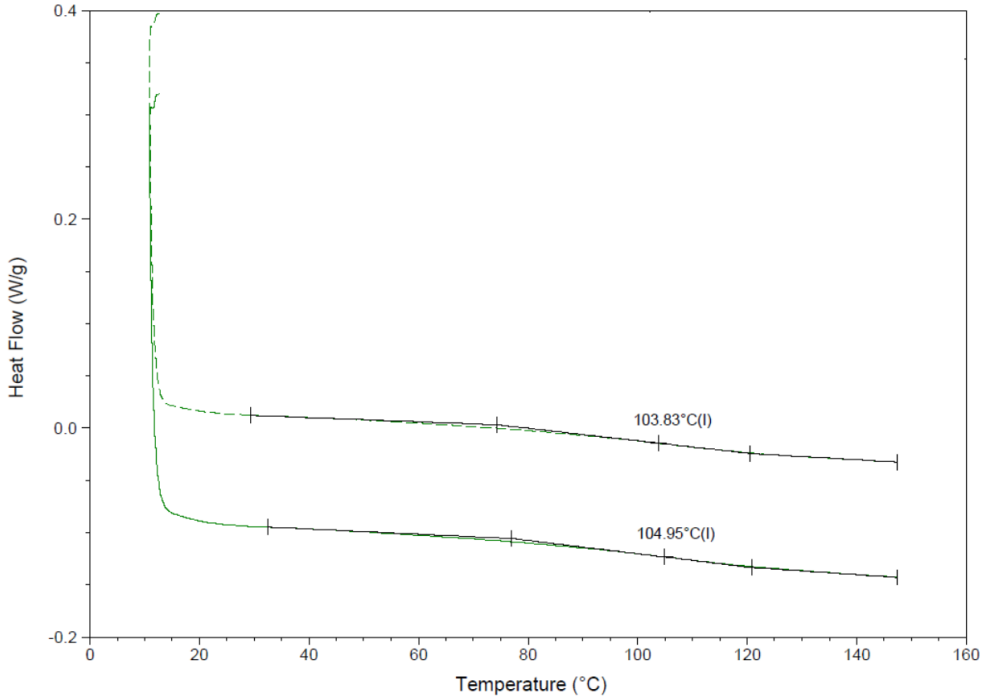


Figure 5.3 – Heat flow versus temperature response graph for representative tests

5.5.4. Tabulated Results

Table 5.3 contains the tabulated summary results for the glass transition temperature (T_g). Average, standard deviation (S_{n-1}) and coefficient of variance (CV) values are also reported for the group of results under evaluation.

Table 5.3 - Tabulated results for glass transition temperature, per ASTM E1640

Specimen ID		Glass Transition Temperature T_g*	
		°C	°F
GAL-G4L1_TG_01		103.07	217.53
GAL-G4L1_TG_02		101.59	214.86
GAL-G4L1_TG_03		102.74	216.93
GAL-G4L1_TG_04		103.90	219.02
GAL-G4L1_TG_05		103.65	218.57
GAL-G4L1_TG_06		103.83	218.89
GAL-G4L1_TG_07		105.00	221.00
GAL-G4L1_TG_08		102.04	215.67
GAL-G4L2_TG_01		103.90	219.02
GAL-G4L2_TG_02		103.65	218.57
GAL-G4L2_TG_03		101.31	214.36
GAL-G4L2_TG_04		100.75	213.35
GAL-G4L2_TG_05		101.03	213.85
GAL-G4L2_TG_06		101.33	214.39
GAL-G4L2_TG_07		101.70	215.06
GAL-G4L2_TG_08		106.14	223.05
GAL-G4L3_TG_01		107.89	226.20
GAL-G4L3_TG_02		108.04	226.47
GAL-G4L3_TG_03		105.22	221.40
GAL-G4L3_TG_04		107.03	224.65
GAL-G4L3_TG_05		107.79	226.02
GAL-G4L3_TG_06		106.65	223.97
GAL-G4L3_TG_07		103.74	218.73
GAL-G4L3_TG_08		104.95	220.91
	Average	**104.04**	**219.27**
	S_{n-1}	2.3	4.1
	CV (%)	2.2	1.9

**Condition of acceptance is equivalent to T_g > 100°C (212°F)*

6. DEGREE OF CURE – ASTM E2160

6.1. TEST SUMMARY

6.1.1. ASTM D7957 Specification Property

Section 6.3 Degree of Cure (Total Enthalpy of Polymerization)

6.1.2. Reference Standard/s

ASTM E2160-04(2018), Standard test method for heat of reaction of thermally reactive materials by differential scanning calorimetry.

6.1.3. Test Objective

Determine the exothermic heat of reaction of thermally reactive chemicals or chemical mixtures, using milligram specimen sizes, by differential scanning calorimetry (DSC).

6.1.4. Product/s under Evaluation

AKS ROCKBAR 13 Diam. #4

6.1.5. Test Location

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

6.1.6. Laboratory Technician/s

Guillermo Claure, Roger Solis, and Guan Wang

6.1.7. 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 Data Sheet number TDS_GAL-G_TEP.

6.2. TEST MATRIX

6.2.1. Specimen Number

A total of 24 tests are reported, eight tests from three different production lots, refer to, refer to **Error! Reference source not found.**.

6.2.2. Specimen ID Nomenclature

Specimens are identified throughout the report using the format described in Section 3.5 of this document.

6.2.3. Test Matrix Table

Table 6.1 – Test matrix for degree of cure

Specimen ID	Specimen Preparation mm/dd/yy	Test Date mm/dd/yy
GAL-G4L1_TEP_01 to 08	06/05/18	06/07/18
GAL-G4L2_TEP_01 to 08	06/11/18	06/13/18
GAL-G4L3_TEP_01 to 08	06/15/18	06/18/18

6.3. SPECIMEN PREPARATION

6.3.1. Specimen Size

A disk specimen was extracted with a high precision blade saw from the cross-section of the bar, to then extract a portion of the disk with a high precision blade to provide a specimen with a mass between 1 to 10 mg, as seen in Figure 5.1.

6.3.2. Preparation Procedure

The specimens were cut to the prescribed dimensions using a high precision blade saw, avoiding grinding to reduce the thermal effects that may affect the specimen's thermal history properties.

6.3.3. 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.

6.4. TEST SET-UP

6.4.1. Set-up

A differential scanning calorimeter (DSC), TA instruments Q20 capable of programing, measuring and recording heat flow as a function of temperature and time with a dedicated sealed test chamber was use, as seen in Figure 6.1. The specimen was placed in the chamber, weighted and programed as needed for the temperature rate heating.

6.4.2. Rate and Method of Loading

A heating rate of 10±0.1°C/min to provide uniform controlled heating of the specimen and reference to a constant temperature within the temperature range of 25 to 200°C was applied.

Figure 6.1 – Degree of Cure test set-up

6.5. TEST RESULTS

6.5.1. Results Summary

Based on the experimental tests presented herein the average degree of cure of the rebars under evaluation are summarized in Table 6.2, which meets the requirements of ASTM D7957, stating that the degree of cure shall not be less than 95%.

Table 6.2 – Average tests result for degree of cure

Specimen ID	Degree of Cure DC %	Specification Limit
GAL-G4_TEP	97	Pass

6.5.2. Calculations

The degree of cure, DC is computed percentage of the fraction reacted, given by the difference between the total heat of reaction, H_t, and the normalized heat, H.

6.5.3. Graphical Representation of Results

Figure 6.2 shows representative graphical response for the degree of cure.

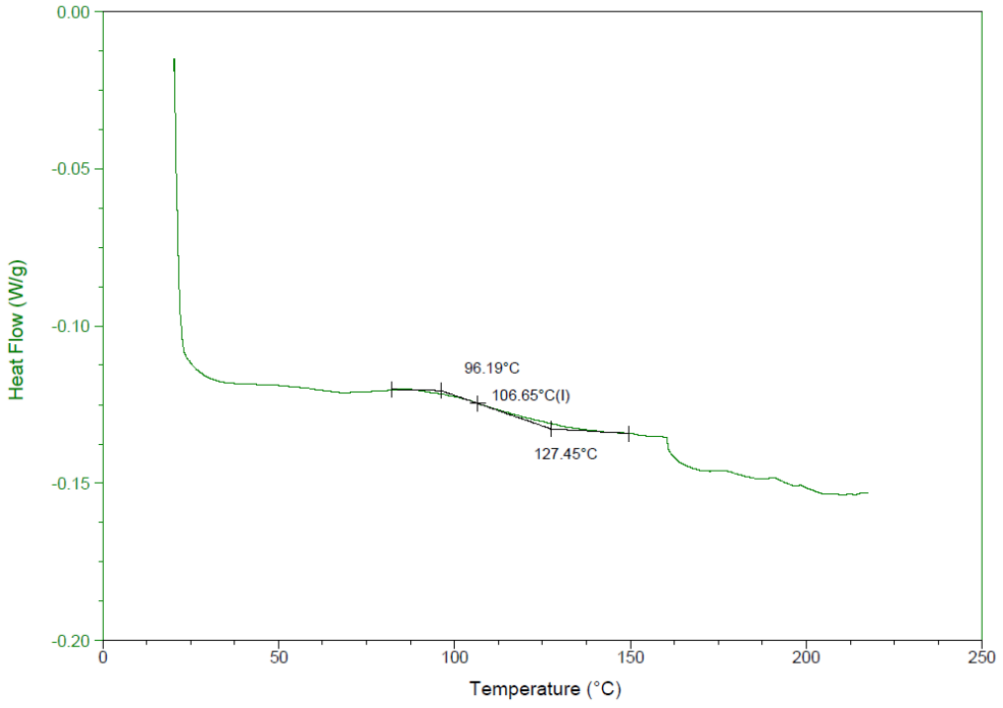


Figure 6.2 – Degree of Cure graph for a representative test specimen

6.5.4. Tabulated Results

Table 6.3 contains the tabulated summary results for the Total Enthalpy of Polymerization (TEP). Average, standard deviation and coefficient of variance (C.O.V.) values are also reported.

Table 6.3 - Tabulated results for degree of cure, per ASTM E2160

Specimen ID		Degree of Cure DC* %
GAL-G4L1_TEP_01		98
GAL-G4L1_TEP_02		98
GAL-G4L1_TEP_03		96
GAL-G4L1_TEP_04		95
GAL-G4L1_TEP_05		96
GAL-G4L1_TEP_06		96
GAL-G4L1_TEP_07		97
GAL-G4L1_TEP_08		98
GAL-G4L2_TEP_01		97
GAL-G4L2_TEP_02		97
GAL-G4L2_TEP_03		98
GAL-G4L2_TEP_04		96
GAL-G4L2_TEP_05		97
GAL-G4L2_TEP_06		98
GAL-G4L2_TEP_07		98
GAL-G4L2_TEP_08		99
GAL-G4L3_TEP_01		98
GAL-G4L3_TEP_02		99
GAL-G4L3_TEP_03		97
GAL-G4L3_TEP_04		99
GAL-G4L3_TEP_05		98
GAL-G4L3_TEP_06		98
GAL-G4L3_TEP_07		97
GAL-G4L3_TEP_08		98
	Average	**97**
	S_{n-1}	1.1
	CV (%)	1.1

**Condition of acceptance DC ≥ 95%*

7. CROSS-SECTIONAL AREA – ASTM D7205/D792

7.1. TEST SUMMARY

7.1.1. ASTM D7957 Specification Property

Section 6.4.1, Measured Cross-sectional Area; and

Section 6.4.2, Size designation of bars

7.1.2. Reference Standard/s

ASTM D7205/D7205M-06(2016), Standard test method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars.

ASTM D792-13, Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement.

7.1.3. Test Objective

Determine the measured cross-sectional area by volume of water displacement method and size designation of the rebar products under evaluation.

7.1.4. Product/s under Evaluation

AKS ROCKBAR 13 Diam. #4

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

Guillermo Claure, Roger Solis, and Guan Wang

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 Data Sheet number TDS_GAL-G_MXA.

7.2. TEST MATRIX

7.2.1. Specimen Number

A total of 24 tests are reported, eight tests from three different production lots, refer to Table 7.1.

7.2.2. Specimen ID Nomenclature

Specimens are identified throughout the report using the format described in Section 3.5 of this document.

7.2.3. Test Matrix Table

Table 7.1– Test matrix for Cross-sectional Area

Specimen ID	Specimen Preparation mm/dd/yy	Test Date mm/dd/yy
GAL-G4L1_FC_01 to 08		
GAL-G4L2_FC_01 to 08	05/21/18	05/28/18
GAL-G4L3_FC_01 to 08		

7.3. SPECIMEN PREPARATION

7.3.1. Specimen Size

Nominal specimen length dimension was 50 mm (2.0 in.).

7.3.2. Preparation Procedure

The specimens were cut to the prescribed dimensions using a high precision blade saw.

7.3.1. Specimen Conditioning

All specimens were conditioned under laboratory ambient conditions for at least 40 hrs. at room temperature 23 ± 3°C (73 ± 6°F) and 50 ± 10% relative humidity.

7.4. TEST SET-UP

7.4.1. Set-up

A light-weight wire frame resting on a micro-balance, where the re-bar specimen is suspended from and then immersed into distilled water, was used as the test set up. Figure 7.1 illustrates the test set up, where additionally the container with the distilled water rests on a support that spans over the scale so that the weight of the container is dismissed.

(a) (b)

Figure 7.1 – Test set up for measurement of cross-sectional area (volume of water displacement), (a) test fixture with suspended specimen and (b) immersed specimen

7.5. TEST RESULTS

7.5.1. Results Summary

Based on the experimental tests presented herein the average measured cross-sectiona area is summarized in Table 7.2, which meets the requirements of ASTM D7957, stating that the measured rebar area shall be between 119 to 169 mm^2 (0.185 to 0.263 in^2).

Table 7.2 – Average measured Cross-sectional Area results

Specimen ID	Measured Area A		Specification Limit
	mm^2	in^2	
GAL-G4_MXA	159	0.247	Pass

7.5.2. Calculations

The results reported herein have been computed as per ASTM D792, as referenced by ASTM D7205, where the parameters are as follows:

Symbol	Parameter	Description
a	Mass	Apparent mass of specimen, without wire/string or sinker, in air (i.e. dry conditioned specimen)
(a+s)	Mass	Apparent mass of specimen, with wire/string or sinker, on frame fixture in air (i.e. specimen and holding fixture)
b	Mass	Apparent mass of specimen (and of sinker, if used) completely immersed and of the string partially immersed in water, with holding fixture on scale.
w	Mass	(a+s) - b
L	Length	Average length of specimen based on three measurements
∆ M	Change in mass	a-w
SG	Specific gravity	Specific gravity of specimen
P	Density	Density of specimen
V	Volume	Volume of specimen
A	Area	Measured (experimental) cross-sectional Area of specimen

7.5.3. Tabulated Results

Table 7.3 contains the tabulated summary results of the measured cross-sectional area, including: the length of the specimen, water displaced weight, cross-sectional area maximum measured dimensions. Average, standard deviation (S_{n-1}) and coefficient of variance (CV) values are also reported for the group of results under evaluation.

Table 7.3 – Tabulated results for measured cross-sectional area, per ASTM D792

Specimen ID	Mass M				Average Length		Weight Change	Specific Gravity	Density	Volume	Cross-section Area*	
	a	a+s	b	w	L		∆ M	SG	P	V	A	
	g	g	g	g	mm	in.	g	g/g	kg/m³	mm³	mm²	in.²
GAL-G4L1_MXA_01	15.907	21.865	14.593	7.272	2.163	54.94	8.635	1.842	1836.757	8660	157.6	0.244
GAL-G4L1_MXA_02	15.087	21.045	14.187	6.858	2.022	51.35	8.229	1.833	1828.947	8249	160.7	0.249
GAL-G4L1_MXA_03	14.754	20.711	13.943	6.769	1.969	50.02	7.985	1.848	1843.404	8004	160.0	0.248
GAL-G4L1_MXA_04	14.597	20.554	13.888	6.666	1.981	50.31	7.931	1.841	1836.549	7948	158.0	0.245
GAL-G4L1_MXA_05	14.010	19.967	13.584	6.384	1.881	47.77	7.626	1.837	1833.340	7642	160.0	0.248
GAL-G4L1_MXA_06	15.715	21.673	14.445	7.228	2.147	54.54	8.487	1.852	1846.102	8513	156.1	0.242
GAL-G4L1_MXA_07	15.846	21.804	14.013	7.791	2.015	51.17	8.055	1.967	1962.130	8076	157.8	0.245
GAL-G4L1_MXA_08	15.025	20.983	14.459	6.524	2.135	54.23	8.501	1.767	1762.989	8522	157.2	0.244
GAL-G4L2_MXA_01	15.994	21.951	14.050	7.901	2.004	50.90	8.093	1.976	1971.276	8114	159.4	0.247
GAL-G4L2_MXA_02	15.548	21.505	13.752	7.753	1.939	49.25	7.795	1.995	1989.472	7815	158.7	0.246
GAL-G4L2_MXA_03	15.320	21.277	14.502	6.775	2.113	53.67	8.545	1.793	1788.642	8565	159.6	0.247
GAL-G4L2_MXA_04	15.681	21.639	14.221	7.418	2.021	51.33	8.263	1.898	1893.136	8283	161.4	0.250
GAL-G4L2_MXA_05	15.112	21.069	14.132	6.937	2.038	51.77	8.175	1.849	1844.085	8195	158.3	0.245
GAL-G4L2_MXA_06	15.047	21.004	13.952	7.052	1.987	50.47	7.995	1.882	1877.473	8014	158.8	0.246
GAL-G4L2_MXA_07	15.463	21.421	14.208	7.213	2.022	51.36	8.250	1.874	1869.895	8269	161.0	0.250
GAL-G4L2_MXA_08	15.903	21.860	14.567	7.293	2.114	53.70	8.610	1.847	1841.745	8635	160.8	0.249
GAL-G4L3_MXA_01	14.705	20.663	13.971	6.692	1.974	50.13	8.013	1.835	1830.166	8035	160.3	0.248
GAL-G4L3_MXA_02	14.342	20.300	13.781	6.520	1.920	48.76	7.822	1.833	1828.689	7843	160.8	0.249
GAL-G4L3_MXA_03	15.179	21.134	14.243	6.892	2.028	51.51	8.287	1.832	1827.553	8306	161.2	0.250
GAL-G4L3_MXA_04	15.783	21.741	14.503	7.238	2.130	54.10	8.545	1.847	1842.014	8568	158.4	0.245
GAL-G4L3_MXA_05	14.608	20.566	13.906	6.660	1.961	49.80	7.948	1.838	1833.797	7966	160.0	0.248
GAL-G4L3_MXA_06	16.068	22.026	14.741	7.285	2.168	55.08	8.783	1.829	1824.987	8804	159.9	0.248
GAL-G4L3_MXA_07	14.476	20.434	13.818	6.617	1.955	49.66	7.859	1.842	1837.429	7878	158.6	0.246
GAL-G4L3_MXA_08	14.063	20.020	13.620	6.400	1.891	48.02	7.663	1.835	1830.819	7681	159.9	0.248
Average											**159.3**	**0.247**
S_{n-1}											1.4	0.002
CV (%)											0.88	0.88

***Condition of acceptance, area range within 0.185 to 0.263 in²*

8. TENSILE PROPERTIES – ASTM D7205

8.1. TEST SUMMARY

8.1.1. ASTM D7957 Specification Property

Section 7.1, Ultimate Tensile Load,

Section 7.2, Mean Tensile Modulus of Elasticity, and

Section 7.3, Ultimate Tensile Strain

8.1.2. Reference Standard/s

ASTM D7205/D7205M-06(2016), Standard test method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars.

8.1.3. Test Objective

Determine the ultimate and guaranteed tensile load carrying capacity, mean tensile modulus of elasticity and mean ultimate tensile strain.

8.1.4. Product/s under Evaluation

AKS ROCKBAR 13 Diam. #4

8.1.5. Test Location

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

8.1.6. Laboratory Technician/s

Guillermo Claure, Roger Solis, and Guan Wang

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 Data Sheet number TDS_GAL-G_TNS.

8.2. TEST MATRIX

8.2.1. Specimen Number

A total of 24 tests are reported, eight tests from three different production lots, refer to Table 8.1.

8.2.2. Specimen ID Nomenclature

Specimens are identified throughout the report using the format described in Section 3.5 of this document.

8.2.3. Test Matrix Table

Table 8.1 – Test matrix for tensile properties tests

Specimen ID	Specimen Preparation mm/dd/yy	Test Date mm/dd/yy
GAL-G4L1_TNS_CC_01 to 08	04/03/18	04/12/18
GAL-G4L2_TNS_CC_01 to 08	04/06/18	04/13/18
GAL-G4L3_TNS_CC_01 to 08	04/11/18	04/18/18

8.3. SPECIMEN PREPARATION

8.3.1. Specimen Size and Layout

Nominal specimen dimensions as reflected in Figure 8.1, and summarized in Table 8.2.

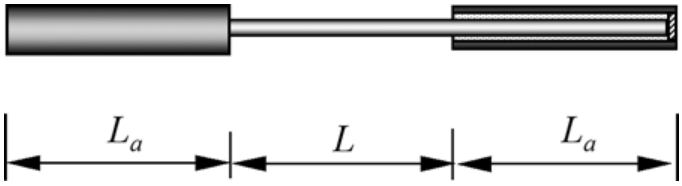


Figure 8.1 – Tensile specimens' geometry

Table 8.2 – Nominal tensile test specimen dimensions

Specimen ID	Length anchors (steel pipe) L_a		Free length between anchors L		Diameter of steel pipe D_{pipe}	
	mm	in.	mm	in.	mm	in.
GAL-G4 _TNS_CC_00	300	12	1525	60	25.4	1.00

8.3.2. Preparation Procedure

The specimens were cut to the prescribed dimensions using a high precision blade saw. Steel pipe type anchors were installed as indicated in ASTM D7205 using expansive grout by laboratory personnel after machining the ends of the rebar specimens to center the bar within the anchors. All specimens where left cure for a minimum period of 7 days to ensure the grout reached its maximum internal pressure ensuring proper gripping of the rebar.

8.3.3. 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 a minimum of 72 hrs. prior testing.

8.4. TEST SET-UP

8.4.1. Set-up

Uniaxial tensile load was applied to all specimens. Tensile testing was performed using a screw-driven universal test frame with a maximum capacity of 889 kN (200 kip). Tensile load was measured with the internal frame load cell 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 100 mm (4.0 in.) gauge length, placed at mid-length of the free length between the anchors. The extensometer was removed half way during the test to avoid damage of the instrument. Specimen's anchors were gripped with mechanical wedge type grips. The test set up is shown is Figure 8.2. All data was gathered using a National Instruments data acquisition system at a rate of 100 Hz.

Figure 8.2 - Tensile test set-up

8.4.2. Rate and Method of Loading

Load was applied in displacement control to effect a near constant strain rate in the gauge section, producing failure within 1 to 10 minutes, as per ASTM D7205 requirements.

8.5. TEST RESULTS

8.5.1. Results Summary

All specimens behaved linear elastically until failure. Based on the experimental tests presented herein the guaranteed ultimate tensile force (P_G), mean tensile modulus (E), the mean computed ultimate tensile strain (ε_u) as summarized in Table 8.3, met the requirements of ASTM D7957, where the minimum P_G shall be 96 kN (21.6 kip); minimum E shall be 44.8 GPa (6.5 Msi); and minimum ε_u shall be 1.1%.

Table 8.3 – Average summary results for tensile tests

Specimen ID	Guaranteed Ultimate Tensile Force P_G		Mean Tensile Modulus of Elasticity E		Mean Ultimate Tensile Strain ε_u	Specification Limit
	kN	kip	MPa	Msi	%	
GAL-G4_TNS	119	26.8	56.3	8.2	1.67	Pass

8.5.2. Modes of Failure

The mode of failure for all bars was by tensile rupture of the re-bar as seen in Figure 8.3.

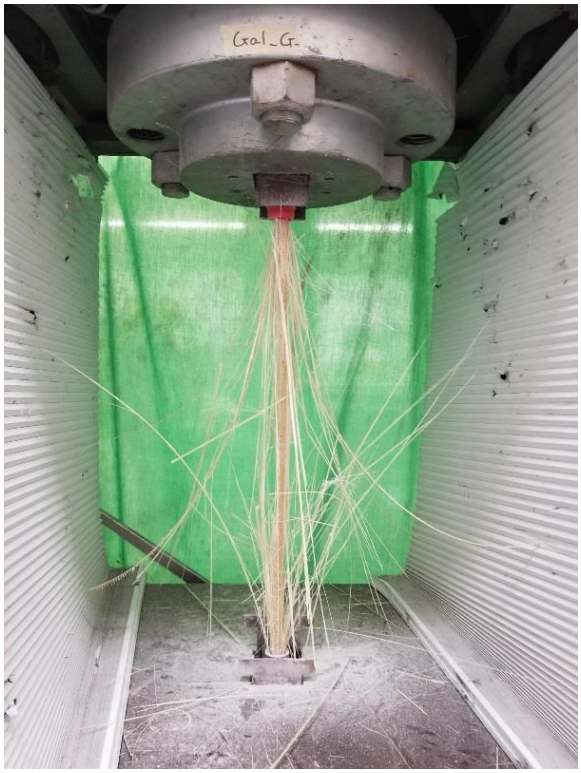


Figure 8.3 – Representative failure mode of tensile test

8.5.3. Calculations

The results reported herein have been computed per ASTM D7205 based on the nominal area of the rebar. Refer to Table 8.4 for definitions and calculations.

Table 8.4 - Definitions of calculations for tensile tests

Symbol	Parameter	Description
P_{max}	Maximum force at failure	Peak load recorded during test
A_{nom}	Nominal cross-section area	Cross-section area per ASTM D7957, Table 3
F^{tu}_{nom}	Nominal ultimate tensile strength	$F^{tu}_{nom} = P_{max} / A_{nom}$
ε_u	Computed ultimate strain based on linear elastic behaviour	$\varepsilon_u = (P_{max} - 3\sigma) / (E_{ave} * A_{nom})$
E	Tensile modulus of elasticity	As per Section 13.3.1 ASTM D7205 – computed by experimental stress difference at the equivalent strain range between 1000 and 3000 με; divided by the difference between the two strain points (Δε), nominally 0.002 $E = \Delta F^{tu}_{nom} / \Delta\varepsilon$

8.5.4. Tabulated Results

Table 8.5 contains the tabulated summary results for the tensile properties for the rebar products under evaluation. Average, standard deviation (S_{n-1}) and coefficient of variance (CV) values are also reported for the group of results under evaluation.

Table 8.5 - Tabulated results for tensile test, per ASTM D7205

Specimen ID	P_{max}		A_{nom}		F^{tu}_{nom}		E_{nom}		$\varepsilon_{u\text{-}nom}$
	kN	lbs	mm^2	in^2	MPa	ksi	GPa	Msi	%
GAL-G4L1_TNS_CC_01	146.5	32940			1157.3	167.8	56.47	8.19	1.78
GAL-G4L1_TNS_CC_02	135.9	30544			1073.1	155.6	57.35	8.32	1.61
GAL-G4L1_TNS_CC_03	144.3	32438			1139.6	165.3	56.71	8.22	1.74
GAL-G4L1_TNS_CC_04	138.9	31225			1097.0	159.1	56.52	8.20	1.67
GAL-G4L1_TNS_CC_05	124.2	27932			981.3	142.3	56.65	8.22	1.46
GAL-G4L1_TNS_CC_06	145.4	32692			1148.6	166.6	55.59	8.06	1.79
GAL-G4L1_TNS_CC_07	140.0	31462			1105.3	160.3	57.59	8.35	1.66
GAL-G4L1_TNS_CC_08	144.4	32456			1140.3	165.4	57.60	8.35	1.72
GAL-G4L2_TNS_CC_01	135.2	30395			1067.8	154.9	56.63	8.21	1.62
GAL-G4L2_TNS_CC_02	139.4	31343			1101.2	159.7	55.30	8.02	1.72
GAL-G4L2_TNS_CC_03	140.7	31626			1111.1	161.2	55.74	8.08	1.72
GAL-G4L2_TNS_CC_04	139.4	31339	126.61	0.196	1101.0	159.7	56.13	8.14	1.69
GAL-G4L2_TNS_CC_05	143.0	32143			1129.3	163.8	54.23	7.87	1.80
GAL-G4L2_TNS_CC_06	136.7	30736			1079.8	156.6	58.80	8.53	1.58
GAL-G4L2_TNS_CC_07	134.8	30303			1064.6	154.4	58.32	8.46	1.56
GAL-G4L2_TNS_CC_08	134.4	30219			1061.7	154.0	55.67	8.07	1.63
GAL-G4L3_TNS_CC_01	131.8	29621			1040.7	150.9	53.54	7.77	1.66
GAL-G4L3_TNS_CC_02	128.4	28857			1013.8	147.0	52.51	7.62	1.64
GAL-G4L3_TNS_CC_03	126.2	28367			996.6	144.5	54.88	7.96	1.54
GAL-G4L3_TNS_CC_04	138.3	31100			1092.6	158.5	52.83	7.66	1.78
GAL-G4L3_TNS_CC_05	147.7	33198			1166.3	169.2	59.77	8.67	1.70
GAL-G4L3_TNS_CC_06	145.6	32743			1150.3	166.8	58.97	8.55	1.69
GAL-G4L3_TNS_CC_07	145.5	32721			1149.6	166.7	58.66	8.51	1.70
GAL-G4L3_TNS_CC_08	139.0	31252			1097.9	159.2	55.78	8.09	1.70
Average	**138.6**	**31152**			**1094.5**	**158.7**	**56.34**	**8.17**	**1.67**
S_{n-1}	6.4	1444			50.7	7.4	1.90	0.3	0.1
CV (%)	4.6	4.6			4.6	4.6	3.4	3.4	5.0
Guaranteed Tensile Load	**119.3**	**26821**							

**Condition of acceptance is equivalent to minimum guaranteed tensile load > 96 kN (21.6 kip); E > 44.8 GPa (6.5 Msi) and $\varepsilon_{u\text{-}nom}$ > 1.1 %*

9. TRANSVERSE SHEAR STRENGTH – ASTM D7617

9.1. TEST SUMMARY

9.1.1. ASTM D7957 Specification Property

Section 7.4, Transverse Shear Strength (Perpendicular to the Bar).

9.1.2. Reference Standard/s

ASTM D7616/D7617M-11(2017), Standard Test Method for Transverse Shear Strength of Fiber–Reinforced Polymer Matrix Composite Bars.

9.1.3. Test Objective

Determine the ultimate and guaranteed transverse shear strength.

9.1.4. Product/s under Evaluation

AKS ROCKBAR 13 Diam. #4

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

Guillermo Claure, Roger Solis, and Guan Wang

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 Data Sheet number TDS_GAL-G_TSS.

9.2. TEST MATRIX

9.2.1. Specimen Number

A total of 24 tests are reported, eight tests from three different production lots, refer to

Table 9.1.

9.2.2. Specimen ID Nomenclature

Specimens are identified throughout the report using the format described in Section 3.5 of this document.

9.2.3. Test Matrix Table

Table 9.1– Test matrix for transverse shear specimens

Specimen ID	Specimen Preparation mm/dd/yy	Test Date mm/dd/yy
GAL-G4L1_TSS_CC_01 to 08 GAL-G4L2_TSS_CC _01 to 08 GAL-G4L3_TSS_CC _01 to 08	03/19/18	03/29/18

9.3. SPECIMEN PREPARATION

9.3.1. Specimen Size

Average nominal specimen length was 300 mm (12.0 in.).

9.3.2. Preparation Procedure

The specimens were cut to the prescribed dimensions using a high precision blade saw.

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

Transverse compressive load was applied to the bar using a fixture as per ASTM D7617, providing an evenly distributed load applied to the bar in a double shear configuration. The load was applied using a screw-driven 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 E4-10. The test set-up is shown is Figure 9.1.

Figure 9.1 – Transvers shear strength test set-up

9.4.2. Rate and Method of Loading

Load was applied in displacement control to effect a near constant strain rate in the gauge section, producing failure within 1 to 10 minutes, as per ASTM D7617 requirements.

9.5. TEST RESULTS

9.5.1. Results Summary

Based on the experimental tests presented herein the guaranteed transverse shear strength of the rebars under evaluation meet the requirements of ASTM D7957 being at least 131 MPa, (19.0 ksi), as summarized in Table 9.2.

Table 9.2 – Average summary results for transverse shear strength tests

Specimen ID	Guaranteed Transverse Shear Strength T_G		Specification Limit
	MPa	ksi	
GAL-G4_TSS	188.5	27.3	Pass

9.5.2. Modes of Failure

The mode of failure was by double shear, as reflected in Figure 9.2 for all specimens.

Figure 9.2 –Transverse shear strength representative failure mode

9.5.3. Calculations

The results reported herein have been computed and summarized based on the definitions in Table 9.3

Table 9.3 - Definitions of calculations for transverse shear strength

Symbol	Parameter	Description
P_{max}	Maximum failure force	Peak load recorded during test
A_{nom}	Nominal cross-section area	Area per ASTM D7957, Table 3
$T_{u\text{-}nom}$	Nominal Transverse shear strength	$T_u = P_{max} / (2*A_{nom})$

9.5.4. Tabulated Results

Table 9.4 contains the tabulated summary results for the transverse shear strength properties for the rebar products under evaluation. Average, standard deviation (S_{n-1}) and coefficient of variance (CV) values are also reported for the group of results under evaluation.

Table 9.4 - Tabulated results for transverse shear strength as per ASTM 7617 (#3 rebar)

Specimen ID	Nominal Area A_{nom}		Shear Strength τ_u	
	mm^2	in^2	MPa	ksi
GAL-G4L1_TSS_CC_01			210.36	30.51
GAL-G4L1_TSS_CC_02			206.49	29.95
GAL-G4L1_TSS_CC_03			249.06	36.12
GAL-G4L1_TSS_CC_04			243.95	35.38
GAL-G4L1_TSS_CC_05			234.79	34.05
GAL-G4L1_TSS_CC_06			244.48	35.46
GAL-G4L1_TSS_CC_07			224.43	32.55
GAL-G4L1_TSS_CC_08			206.14	29.90
GAL-G4L2_TSS_CC_01			213.35	30.94
GAL-G4L2_TSS_CC_02			225.06	32.64
GAL-G4L2_TSS_CC_03			225.10	32.65
GAL-G4L2_TSS_CC_04	126.45	0.196	241.58	35.04
GAL-G4L2_TSS_CC_05			235.46	34.15
GAL-G4L2_TSS_CC_06			252.64	36.64
GAL-G4L2_TSS_CC_07			235.39	34.14
GAL-G4L2_TSS_CC_08			233.81	33.91
GAL-G4L3_TSS_CC_01			232.94	33.79
GAL-G4L3_TSS_CC_02			235.18	34.11
GAL-G4L3_TSS_CC_03			255.37	37.04
GAL-G4L3_TSS_CC_04			239.29	34.71
GAL-G4L3_TSS_CC_05			236.94	34.36
GAL-G4L3_TSS_CC_06			243.32	35.29
GAL-G4L3_TSS_CC_07			240.31	34.85
GAL-G4L3_TSS_CC_08			**232.19**	**33.7**
Average			14.57	2.11
S_{n-1}			6.3	6.3
CV (%)			210.36	30.51
Guaranteed Shear Strength			**188.5**	**27.3**

**Condition of acceptance is equivalent to τ_u >152 MPa (22ksi)*

10. BOND STRENGTH – ASTM D7913

10.1. TEST SUMMARY

10.1.1. ASTM D7957 Specification Property

Section 7.5, Bond Strength.

10.1.2. Reference Standard/s

ASTM D7913/D7913M-14, Standard Test Method for Bond Strength of Fiber-Reinforced Polymer Matrix Composite Bars to Concrete by Pullout Testing.

10.1.3. Test Objective

Determine the bond strength to concrete by pullout test method.

10.1.4. Product/s under Evaluation

AKS ROCKBAR 13 Diam. #4

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

Guillermo Claure, Roger Solis, and Guan Wang

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 Data Sheet number TDS_GAL-G_BS.

10.2. TEST MATRIX

10.2.1. Specimen Number

A total of 24 tests are reported, eight tests from three different production lots, refer to Table 10.1.

10.2.2. Specimen ID Nomenclature

Specimens are identified throughout the report using the format described in Section 3.5 of this document.

10.2.3. Test Matrix Table

Table 10.1– Test matrix for bond strength

Specimen ID	Specimen Preparation mm/dd/yy	Test Date mm/dd/yy
GAL-G4L1_BS_01 to 08		07/24/18
GAL-G4L2_BS_01 to 08	04/20/18	07/23/18
GAL-G4L3_BS_01 to 08		07/25/18

10.3. SPECIMEN PREPARATION

10.3.1. Specimen Size and Layout

The rebar specimens were installed within on solid plain concrete cubes 205 mm (8.00 in.), after applying a steel pipe anchor to one end of the rebar, as per the Table 8.2. The specimen layout is presented in Figure 10.1, where specimens had a de-bonded length to the concrete, so that the total bonded length to concrete was equivalent to five times the diameter of the rebar.

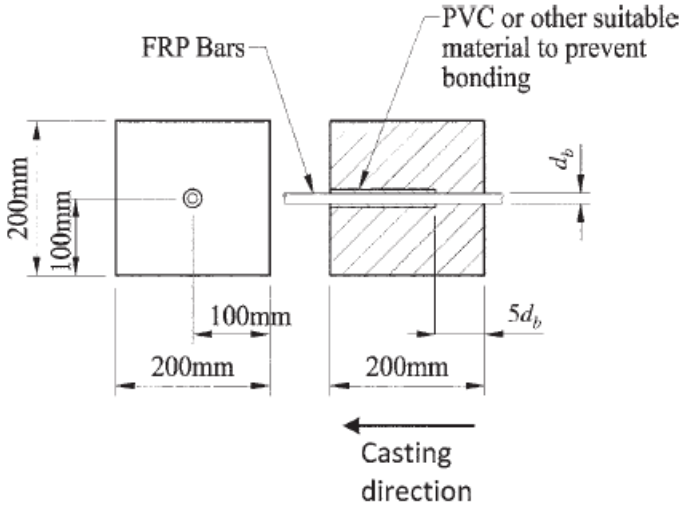


Figure 10.1 – Concrete pullout bond specimen layout

10.3.2. Preparation Procedure

The specimen anchor was installed in one end of the rebar as described in Section 8.3.2. All specimens were prepared simultaneously from one single batch of concrete on April 20, 2018 following ASTM C192/C192M-13a, Practice for Making and Curing Concrete Test Specimens in the Laboratory. The 28-day concrete compressive strength was then tested as per ASTM C39, (Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens) to ensure it met the requirements of 30 ± 3 MPa (4350 ± 435 psi). Summary results are presented in Table 10.2.

Table 10.2 – 28-day concrete compressive strength results (ASTM C39) for bond pull out tests

Specimen ID	Cylinder diameter d		Area A		Peak force P_{max}		Compressive Strength f'_c		Failure Mode
	mm	in	mm^2	in^2	kN	lbf	MPa	psi	
C1	102	4.027	8217	12.74	261	58580	32	4599	Type 3
C2	103	4.067	8383	12.99	262	58880	31	4532	Type 3
C3	102	4.033	8242	12.77	252	56700	31	4438	Type 3
C4	103	4.066	8378	12.99	262	58800	31	4528	Type 3
C5	102	4.031	8232	12.76	266	59910	32	4695	Type 3
Average					**261**	**58574**	**31**	**4558**	
S_{n-1}					5	1166	1	95	
CV (%)					2.0	2.0	2.1	2.1	

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

Uniaxial tensile load was applied to all specimens. Testing was performed using a screw-driven universal test frame. Tensile load was measured a load cell of capacity of 111 kN (25 kip) in compliance with ASTM E4-10 (Standard Practice for Force Verification of Testing Machines), while the extension (elongation) of the loaded and free end of the specimen was measured using a Liner Voltage Displacement Transducers (LVDTs) in accordance to ASTM E83-10a (Standard Practice for Verification and Classification of Extensometer Systems). The test set up is shown in Figure 10.2. All data was gathered using a National Instruments data acquisition system at a rate of 100 Hz.

Figure 10.2 - Bond test set-up

10.4.2. Rate and Method of Loading

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

10.5. TEST RESULTS

10.5.1. Results Summary

Based on the experimental tests presented herein the guaranteed bond strength of the rebars under evaluation meet the requirements of ASTM D7957, and was at least 7.6 MPa, (1.1 ksi), regardless of the rebar size or shape, as summarized in Table 10.3.

Table 10.3 – Average bond strength results

Specimen ID	Guaranteed bond strength, T^B_G		Specification Limit
	MPa	ksi	
GAL-G4_BS	13.7	2.0	Pass

10.5.2. Modes of Failure

The primary mode of failure was loss of bond via slippage between the bonded rebar and the concrete substrate due to pullout from concrete block. No concrete splitting was observed.

10.5.3. Calculations

The results reported herein have been computed as summarized in Table 10.4.

Table 10.4 - Definitions of calculations for bond strength

Symbol	Parameter	Description
d_b	Diameter	Nominal dimeter of rebar based on rebar nominal size
C_p	Circumference	Circumference of rebar based on nominal dimeter
L	Length	Length of bar bonded to concrete
Fu	Tensile load	Tensile load applied with the load device
A_L	Rebar Bond Area to Concrete	Lateral Area = Cp x L
T^B	Bond Strength	$T^B = F / A_L$

10.5.4. Tabulated Results

Table 10.5 contains the tabulated summary results for the bond strength for the rebar products under evaluation. Average, standard deviation (S_{n-1}) and coefficient of variance (CV) values are also reported for the group of results under evaluation.

Table 10.5 - Tabulated results for bond tests, per ASTM D7913

Specimen ID	Nominal Diameter d_b		Nominal Circumference C_b		Bonded length l		Nominal Bonded Area A_L*		Peak Load F_u		Maximum Bond Strength τ	
	mm	in.	mm	in.	mm	in.	mm^2	in^2	kN	Lbs	MPa	ksi
GAL-G4L1_BS_01									50.23	11.29	19.83	2.88
GAL-G4L1_BS_02									54.02	12.14	21.32	3.09
GAL-G4L1_BS_03									39.65	8.91	15.65	2.27
GAL-G4L1_BS_04									44.08	9.91	17.40	2.52
GAL-G4L1_BS_05									40.34	9.07	15.92	2.31
GAL-G4L1_BS_06									54.65	12.28	21.57	3.13
GAL-G4L1_BS_07									48.12	10.82	18.99	2.75
GAL-G4L1_BS_08									45.32	10.19	17.89	2.59
GAL-G4L2_BS_01									44.91	10.10	17.73	2.57
GAL-G4L2_BS_02									41.70	9.37	16.46	2.39
GAL-G4L2_BS_03									51.81	11.65	20.45	2.97
GAL-G4L2_BS_04	12.70	0.500	63.5	2.50	39.9	1.57	2533	3.93	48.28	10.85	19.06	2.76
GAL-G4L2_BS_05									48.56	10.92	19.17	2.78
GAL-G4L2_BS_06									50.82	11.43	20.06	2.91
GAL-G4L2_BS_07									49.19	11.06	19.41	2.82
GAL-G4L2_BS_08									53.59	12.05	21.15	3.07
GAL-G4L3_BS_01									53.24	11.97	21.01	3.05
GAL-G4L3_BS_02									51.53	11.59	20.34	2.95
GAL-G4L3_BS_03									48.42	10.89	19.11	2.77
GAL-G4L3_BS_04									44.18	9.93	17.44	2.53
GAL-G4L3_BS_05									41.82	9.40	16.51	2.39
GAL-G4L3_BS_06									46.28	10.40	18.27	2.65
GAL-G4L3_BS_07									50.45	11.34	19.91	2.89
GAL-G4L3_BS_08									51.83	11.65	20.46	2.97
Average									**48.04**	**10.80**	**18.96**	**2.75**
S_{n-1}									4.46	1.00	1.76	0.26
CV (%)									9.3	9.3	9.3	9.3
Guaranteed Bond Strength											**13.68**	**1.98**

Condition of acceptance is equivalent to T^B_G > 7.6 MPa (1.1 ksi)

11. MOISTURE ABSORPTION – ASTM D570

11.1. TEST SUMMARY

11.1.1. ASTM D7957 Specification Property

Section 8.1 Moisture Absorption.

11.1.2. Reference Standard/s

ASTM D570-98(2010)e1, Standard Test Method for Water Absorption of Plastics

11.1.3. Test Objective

Determine the short term (24hr) and long term (saturation) level of moisture absorption when immersed in at 50°C (122°F).

11.1.4. Product/s under Evaluation

AKS ROCKBAR 13 Diam. #4

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

Guillermo Claure, Roger Solis, and Guan Wang

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 Data Sheet number TDS_GAL-G_MA.

11.2. TEST MATRIX

11.2.1. Specimen Number

A total of 24 tests are reported, eight tests from three different production lots, refer to Table 11.1.

11.2.2. Specimen ID Nomenclature

Specimens are identified throughout the report using the format described in Section 3.5 of this document.

11.2.3. Test Matrix Table

Table 11.1 – Test matrix for water absorption specimens

Specimen ID	Specimen Preparation mm/dd/yy	Test Date Start mm/dd/yy	Test Date End mm/dd/yy
GAL-G4L1_MA_01 to 08 GAL-G4L2_MA_01 to 08 GAL-G4L3_MA_01 to 08	01/22/18	01/25/18	05/10/18

11.3. SPECIMEN PREPARATION

11.3.1. Specimen Size

Nominal specimen length dimensions were 25 mm (1.0 in.).

11.3.2. Preparation Procedure

The specimens were cut to the prescribed dimensions using a high precision blade saw.

11.3.3. Conditioning Parameters

The short and long-term moisture specimens tested in accordance with ASTM D570. They were conditioned and immersed in water for a 24-hour period at a temperature of 50°C (122°F). Similarly, the long-term specimens, till saturation, were tested and immersed in water, for an extended period of time until moisture equilibrium was reached at a temperature of 50°C (122°F).

11.4. TEST SET-UP

11.4.1. Set-up

An analytical balance with an accuracy of 0.0001 g was used to take readings of the specimens at the desired intervals, while a chamber capable of maintaining uniform temperatures of 50°C ± 3°C (122°F ± 6°F), was used for the conditioning portion of the short-term tests. All specimens had their surface wiped off with a dry cloth and weighted.

11.5. TEST RESULTS

11.5.1. Results Summary

Based on the experimental tests presented herein he average short moisture absorption and saturation content is summarized in Table 11.2, which meets the requirements of ASTM D7957, stating that the short term and long-term (saturation) moisture absorption levels of the rebars under shall be a maximum of 0.25% and 1.00% increase in mass, respectively.

Table 11.2 – Moisture Absorption results

Specimen ID	Short Term Immersion (24 hrs.) W_{24} %	Specification Limit	Long Term Immersion (Saturation) W_{15w} %	Specification Limit
GAL-G4_MA	0.10	PASS	0.56	Pass

11.5.2. Calculations

Refer to applicable calculations and analysis of data in tabulated results.

Table 11.3 - Definitions of calculations for moisture absorption tests

Symbol	Parameter	Description
W_d	Weight	Weight of condition specimen, prior immersion in water
W_w	Weight	Weight of specimen, post immersion in water
W_{24}	Weight	Increase in weight of specimen, post 24 hrs. period, $W_{24} = [W_w - W_d / W_d] *100$
W_s	Weight	Increase in weight of specimen, post saturation period $W_s = [W_w - W_d / W_d] *100$

11.5.3. Tabulated Results

Table 11.4, contains the tabulated summary results for moisture absorptions tests for the rebar products under evaluation. Average, standard deviation (S_{n-1}) and coefficient of variance (CV) values are also reported for the group of results under evaluation.

Table 11.4 - Tabulated results for water/mositure absorption, per ASTM D570

Specimen ID	W_d	W_{24}	W_{24}^*	W_s	W_s^*
	g	g	%	g	%
GAL-G4L1_MA_01	9.1141	9.1217	0.08	9.1615	0.52
GAL-G4L1_MA_02	7.3670	7.3753	0.11	7.4038	0.50
GAL-G4L1_MA_03	6.9925	6.9940	0.02	7.0346	0.60
GAL-G4L1_MA_04	6.8238	6.8277	0.06	6.8628	0.57
GAL-G4L1_MA_05	6.7991	6.8053	0.09	6.8331	0.50
GAL-G4L1_MA_06	9.7639	9.7756	0.12	9.8205	0.58
GAL-G4L1_MA_07	7.3486	7.3567	0.11	7.3912	0.58
GAL-G4L1_MA_08	7.2089	7.2154	0.09	7.2457	0.51
GAL-G4L2_MA_01	7.4077	7.4151	0.10	7.4484	0.55
GAL-G4L2_MA_02	7.2241	7.2299	0.08	7.2631	0.54
GAL-G4L2_MA_03	7.4369	7.4436	0.09	7.4741	0.50
GAL-G4L2_MA_04	7.8240	7.8318	0.10	7.8741	0.64
GAL-G4L2_MA_05	7.4360	7.4434	0.10	7.4799	0.59
GAL-G4L2_MA_06	7.7231	7.7301	0.09	7.7718	0.63
GAL-G4L2_MA_07	7.5247	7.5330	0.11	7.5751	0.67
GAL-G4L2_MA_08	7.3936	7.4018	0.11	7.4396	0.62
GAL-G4L3_MA_01	7.4308	7.4395	0.12	7.4778	0.63
GAL-G4L3_MA_02	7.6821	7.6906	0.11	7.7213	0.51
GAL-G4L3_MA_03	7.2216	7.2307	0.13	7.2697	0.67
GAL-G4L3_MA_04	9.5876	9.5985	0.11	9.6357	0.50
GAL-G4L3_MA_05	6.4450	6.4507	0.09	6.4781	0.51
GAL-G4L3_MA_06	6.9605	6.9668	0.09	6.9951	0.50
GAL-G4L3_MA_07	7.4315	7.4426	0.15	7.4696	0.51
GAL-G4L3_MA_08	7.5039	7.5122	0.11	7.5452	0.55
Average			**0.10**		**0.56**
S_{n-1}			0.02		0.06
CV (%)			24.9		10.3

**Condition of acceptance for* $W_{24} < 0.25\%$, *and for* $W_s < 1.00\%$

12. STRENGTH OF BENT BAR – ASTM D7914

12.1. TEST SUMMARY

12.1.1. ASTM D7957 Specification Property

Section 9.0 Requirements for Bent Bars.

12.1.2. Reference Standard/s

ASTM D7914, Standard Test Method for Strength of Fiber Reinforced Polymer (FRP) Bent Bars in Bend Locations.

12.1.3. Test Objective

Determine the relative strength of the bent portion of the FRP bars under tensile stress when embedded in concrete.

12.1.4. Product/s under Evaluation

AKS ROCKBAR 13 Diam. #4

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

Guillermo Claure, Phil Lavonas and Roger Solis.

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 Data Sheet number TDS_GAL-G_SOB.

12.2. TEST MATRIX

12.2.1. Specimen Number

A total of 24 tests are reported, eight tests from three different production lots, refer to Table 12.1.

12.2.2. Specimen ID Nomenclature

Specimens are identified throughout the report using the format described in Section 3.5 of this document.

12.2.3. Test Matrix Table

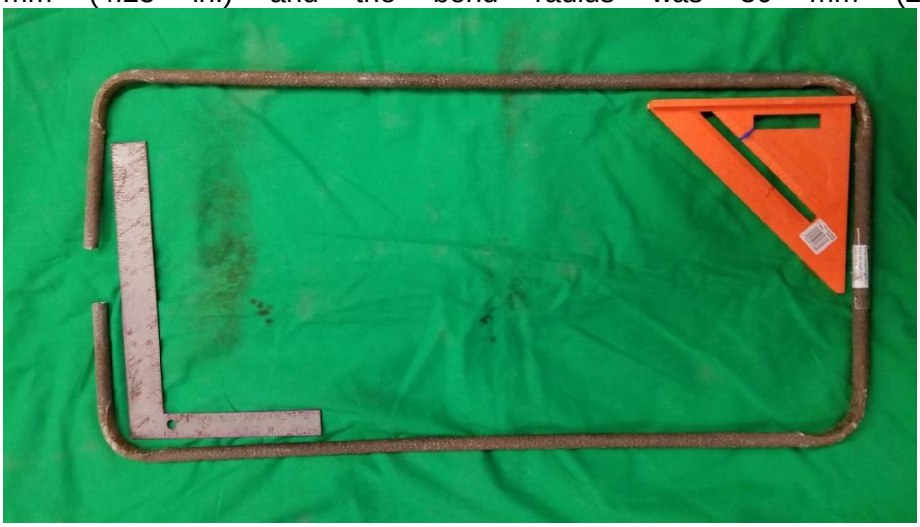
Table 12.1 – Test matrix for strength of bend tests

Specimen ID	Specimen Preparation mm/dd/yy	Test Date mm/dd/yy
GAL-G4L1_SOB_01 to 08	09/14/18	10/12/18
GAL-G4L2_SOB_01 to 08		10/16/18
GAL-G4L3_SOB_01 to 08		10/15/18

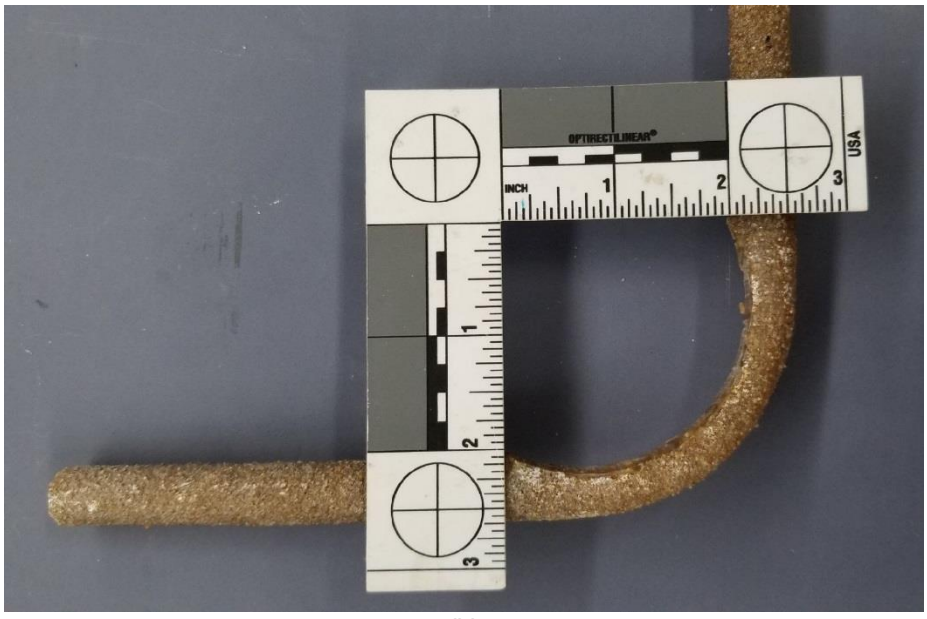
12.3. SPECIMEN PREPARATION

12.3.1. Specimen Size and layout

The bent rebar specimen was installed in two concrete blocks with overall dimensions of 300 x 300 x 500 mm (12 x 12 x 20 in.) with a free length between the blocks was 406 mm (16 in.); per ASTM D7914, as is presented in Figure 12.1. The overall dimensions of the bend bar specimen was 760.4 mm x 352.4 mm (29.94 x 13.88 in.) length by width, the tail length (free end) was 108.0 mm (4.25 in.) and the bend radius was 50 mm (2.0 in.) as seen in

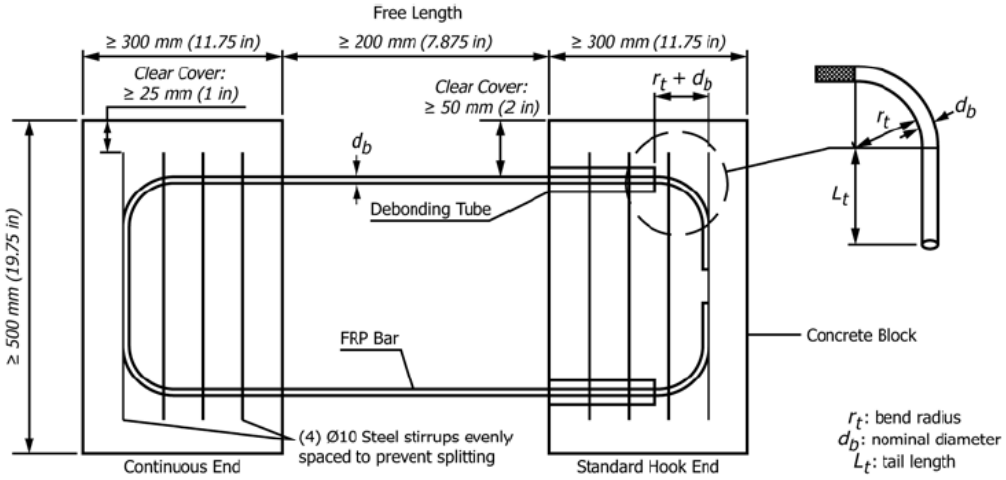


(a)



(b)

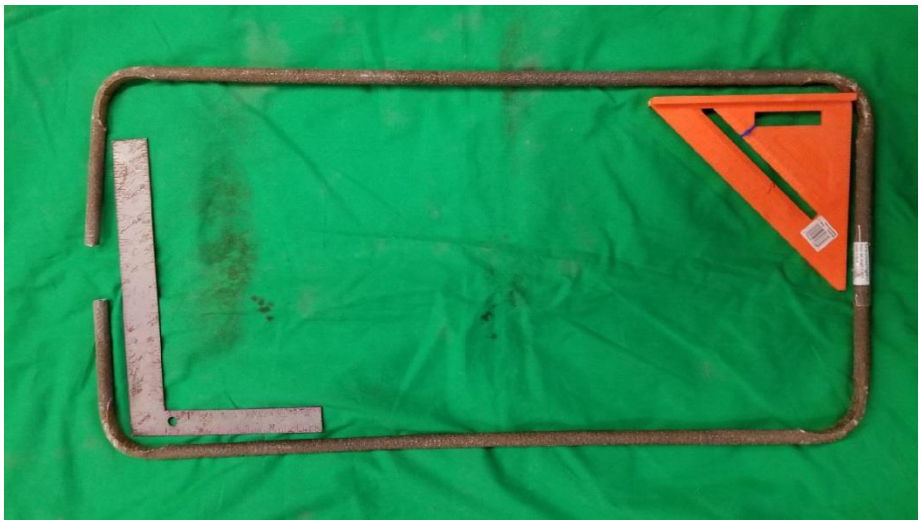
Figure 12.2. The debonded portion of bend specimen leg was located in the tail end ensuring no bond between concrete and rebar. The bonded portion of the bend bar included the tail length plus the bend radius and the nominal bar diameter length equal to 12.7 mm (0.5 in.) as indicated in in Figure 12.1.



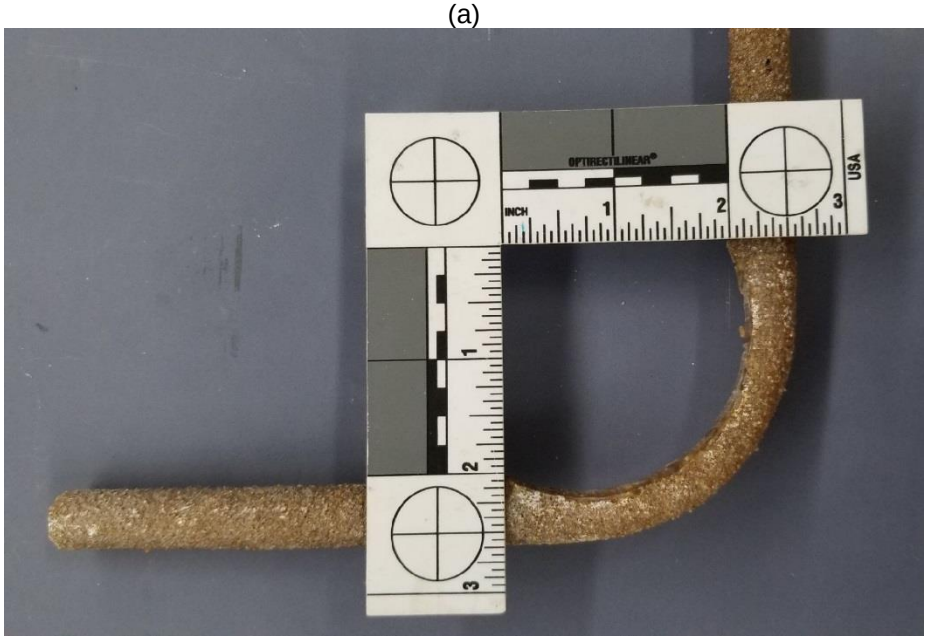
(a)

(b)

Figure 12.1 – (a) Bend bar test specimen layout; and (b) specimen prior casting



(a)



(b)

Figure 12.2 – (a) Overall bend bar specimen, and (b) detail of bend portion of specimen

12.3.2. Preparation Procedure

All bend bar specimens were prepared simultaneously from one single batch of concrete on September 14, 2018 following ASTM C192/C192M-13a. Steel stirrups where used in each block to avoid concrete slitting during testing per ASTM D7914 recommendations. The 28-day concrete compressive strength was then tested as per ASTM C39, to ensure it met the requirements of 30 ± 3 MPa (4350 ± 435 psi). Summary results are presented in

Table 12.2.

Table 12.2 – 28-day concrete compressive strength results (ASTM C39) for bend bar tests

Specimen ID	Cylinder diameter d		Area A		Peak force P_{max}		Compressive Strength f'_c		Failure Mode
	mm	in	mm^2	in^2	kN	lbf	MPa	psi	
B1	101.83	4.009	8143.9	12.62	267.5	60,147	32.85	4,765	Type 2
B2	103.36	4.069	8390.8	13.01	252.2	56,697	30.06	4,359	Type 2
B3	101.95	4.014	8162.8	12.65	245.7	55,244	30.10	4,366	Type 2
B4	102.29	4.027	8217.2	12.74	270.8	60,871	32.95	4,779	Type 2
B5	101.88	4.011	8152.0	12.64	249.1	56,007	30.56	4,432	Type 2
Average					**257.1**	**57,793**	**31.31**	**4,540**	
S_{n-1}					11.3	2,545	1.47	213	
CV (%)					4.4	4.4	4.7	4.7	

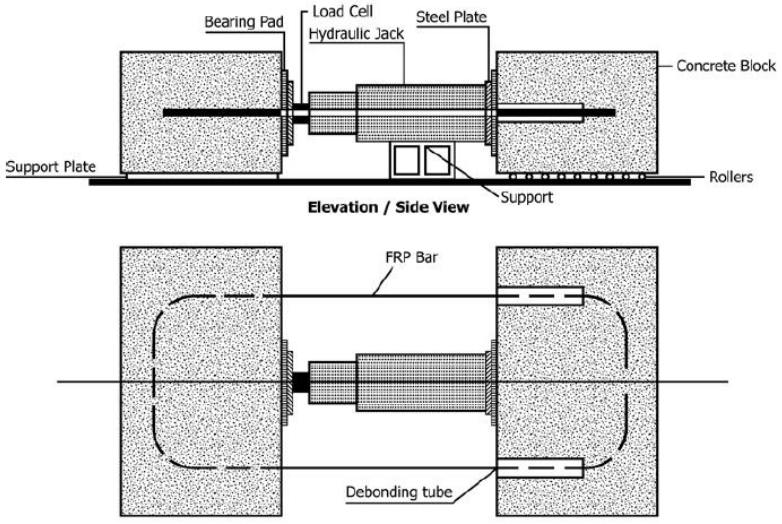
12.3.1. Conditioning Parameters

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

Uniaxial compressive force was applied between the two concrete blocks by means of a hydraulic jack position symmetrically in order to avoid bending or rotations of the blocks due to eccentricities. The block with the tail ends was placed on roller supports and a load cell with a capacity of 222 kN (50 kip) in compliance with ASTM E4-10 was place on the head of the jack to measure the applied axial force, additionally a pressure gauge was used as verification proposes. Steel plates were placed between the jack and concrete faces to provide a distributed load and avoid stress concentrations in the concrete. The test setup schematic and actual set up is shown in Figure 12.3.



(a)

(b)

Figure 12.3 – (a) Bend bar test set schematic and (b) test set up

12.4.2. Rate and Method of Loading

Load was applied in load control to effect a near constant strain rate avoiding shock, bending, vibration or other undesired load conditions until failure was reached, producing failure within 1 to 10 minutes.

12.5. TEST RESULTS

12.5.1. Results Summary

Based on the experimental tests presented herein the guaranteed ultimate tensile force of the benf portion of the bar under evaluation meet the requirements of ASTM D7957, and was at least 60% of the values reported in Table 3 of ASTM D7957, corresponding to the minimum guaranteed ultimate tensile force values, as summarized in Table 12.5Table 12.3.

Table 12.3 – Average strength of bent bar test results

Specimen ID	**Guaranteed Ultimate Tensile Strength of Bend Portion of Bar F_{fb}**		**Specification Limit**
	MPa	**psi**	
GAL-G4_SOB	457	66275	Pass

12.5.2. Modes of Failure

Two main modes of failure where observed which included: i) failure in the concrete most likely at the bend (not visible), and ii) failure in tension at the FRP leg in the free length (between the blocks), a representative failure mode in tension is provided in Figure 12.4.

Figure 12.4 – Representative failure mode of strength of bent bar test

12.5.3. Calculations

The results reported herein have been computed per ASTM D7914, as summarized in Table 12.4.

Table 12.4 - Definitions of calculations for strength of bend bar test

Symbol	Parameter	Description
P_{fb}	Applied load	Ultimate force measured in bend test
A	Area of leg	Nominal area of single leg of FRP bend bar
F_{fb}	Bend Strength	$F_{fb} = P_{fb} / 2*A$
χ	Reduction factor	Reduction factor based on load capacity used as acceptance criteria, which shall be > 0.6 (60% of values reported in Table 3 of ASTM D7957)
		$\chi = [P_{fb} / 2]$ / min. guaranteed load per ASTM D7957 Table 3), equal to 96 kN (21.6 kip) for #4.

12.5.4. Tabulated Results

Table 12.5 contains the tabulated summary results for the strength of the bend test for the rebar products under evaluation. Average, standard deviation (S_{n-1}) and coefficient of variance (CV) values are also reported for the group of results under evaluation including the guaranteed values.

Table 12.5 - Tabulated results for bend bar tests as per ASTM D7914

Specimen ID	Area, A		Maximum Applied force, P_{fb}		Force in each leg, $P_{fb}/2$		Bend Strength, F_{fb}		Reduction factor, χ	Failure Mode
	mm^2	in^2	N	lbs	N	lbs	MPa	psi		
GAL-G4L1_SOB_01	126.45	0.196	141599	31833	70800	15916	560	81206	0.74	Bend
GAL-G4L1_SOB_02			173841	39081	86921	19541	687	99697	0.90	Broken Rebar
GAL-G4L1_SOB_03			178539	40137	89270	20069	706	102391	0.93	Broken Rebar
GAL-G4L1_SOB_04			164147	36902	82073	18451	649	94137	0.85	Broken Rebar
GAL-G4L1_SOB_05			145417	32691	72709	16346	575	83396	0.76	Bend
GAL-G4L1_SOB_06			173698	39049	86849	19524	687	99615	0.90	Broken Rebar
GAL-G4L1_SOB_07			156165	35107	78083	17554	617	89559	0.81	Bend
GAL-G4L1_SOB_08			156489	35180	78245	17590	619	89745	0.81	Bend
GAL-G4L2_SOB_01			166408	37410	83204	18705	658	95434	0.87	Broken Rebar
GAL-G4L2_SOB_02			156248	35126	78124	17563	618	89607	0.81	Broken Rebar
GAL-G4L2_SOB_03			177598	39926	88799	19963	702	101851	0.92	Broken Rebar
GAL-G4L2_SOB_04			147196	33091	73598	16546	582	84416	0.77	Bend
GAL-G4L2_SOB_05			161916	36400	80958	18200	640	92858	0.84	Bend
GAL-G4L2_SOB_06			156277	35133	78139	17566	618	89624	0.81	Bend
GAL-G4L2_SOB_07			173443	38991	86721	19496	686	99468	0.90	Broken Rebar
GAL-G4L2_SOB_08			158921	35727	79460	17863	628	91140	0.83	Broken Rebar
GAL-G4L3_SOB_01			154059	34634	77030	17317	609	88352	0.80	Bend
GAL-G4L3_SOB_02			146958	33038	73479	16519	581	84279	0.76	Bend
GAL-G4L3_SOB_03			165026	37099	82513	18550	653	94641	0.86	Broken Rebar
GAL-G4L3_SOB_04			157729	35459	78864	17729	624	90456	0.82	Bend
GAL-G4L3_SOB_05			166439	37417	83220	18709	658	95452	0.87	Broken Rebar
GAL-G4L3_SOB_06			169492	38103	84746	19052	670	97203	0.88	Broken Rebar
GAL-G4L3_SOB_07			141339	31774	70669	15887	559	81057	0.74	Bend
GAL-G4L3_SOB_08			147698	33204	73849	16602	584	84704	0.77	Bend
Average			**159860**	**35938**	**79930**	**17969**	**632**	**91679**	**0.83**	
S_{n-1}			14765	3319	7383	1660	58	8468	0.08	
CV (%)			9.2	9.2	9.2	9.2	9.2	9.2	9.2	
Guaranteed Bend Strength					**57782**	**12990**	**457**	**66275**	**0.60**	

**Condition of acceptance is equivalent to 60% of corresponding values bar designation provided in Table 3 of ASTM D7957: 57.6 kN (12.96 kip)*

♦ END OF TEST REPORT ♦