CERTIFIED TEST REPORT

EVALUATION of RockRebar™ per ICC-ES Acceptance Criteria 454 and FDOT Section 932-3, Fiber Reinforced Polymer (FRP) Reinforcing Bars

Report Number: IR-5.10_NRR_AC454/932

April 13, 2016

REPORT PREPARED FOR:

Raw Energy Materials Corp.
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Chairman
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http://www.newrebar.com/

Quality System: The Structures and Materials Laboratory (SML) maintains a quality system in compliance with ISO 17025-2005, accredited under International Accreditation Service (IAS), testing laboratory, TL-478 and qualified laboratory by the Florida Department of Transportation (FDOT).

Procedures: All tests and services are done in accordance with the SML Quality Manual (Version 2.2) revised March 18, 2013; 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Superseded Report	n/a
Reason for Revision Effective Date	New report April 13, 2016

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: April 13, 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: April 13, 2016

EXECUTIVE SUMMARY

This interim certified test report presents summary average results to determine the physical and mechanical behavior of basalt fiber reinforced polymer (BFRP) bars, under the trade name RockRebar^{TM}, for used as internal reinforcement of concrete members. The nominal BFRP bars under evaluation include #3, #4, #5 and #8, and a stirrup #4.

Based on the results presented herein, RockRebar^{TM} longitudinal sizes #3, #4, #5 and #8, and a stirrup #4 meet the criteria required by:

- The International Building Code (IBC) as per the International Code Council Evaluation Service (ICC-ES) acceptance criteria AC454 June 2014, 'ACCEPTANCE CRITERIA FOR GLASS FIBER–REINFORCED POLYMER BARS FOR INTERNAL REINFORCEMENT OF CONCRETE MEMBERS' and
- Florida Department of Transportation (FDOT) SECTION 932 'NONMETALLIC ACCESSORY MATERIALS FOR CONCRETE PAVEMENT AND CONCRETE STRUCTURES, subsection 932-3 Fiber Reinforced Polymer (FRP) Reinforcing Bars.

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1. INTRODUCTION

1.1. PURPOSE

This certified test report presents experimental test results and other relevant information to characterize and verify the requirements for fiber reinforced polymer reinforcement bars (rebars) for concrete under the International Code Council Evaluation Service (ICC-ES) for RockRebar™ as required by AC454 June 2014 (ACCEPTANCE CRITERIA FOR FIBER–REINFORCED POLYMER BARS FOR INTERNAL REINFORCEMENT OF CONCRETE MEMBERS), as well as required by the Florida Dept. of Transportation (FDOT) 932-3 Fiber Reinforced Polymer (FRP) Reinforcing Bars, of Section 932 (NONMETALLIC ACCESSORY MATERIALS FOR CONCRETE PAVEMENT AND CONCRETE STRUCTURES) for the products described in Section 1.3 of this document.

The test sample numbers for each property provided within this report do not meet the complete test repetition requirements of AC454. The results are intended to provide a preliminary evaluation to determine RockRebar™ properties and evaluate if such properties meet the requirements set forth by AC454 and FDOT 932-3. Further testing is currently ongoing.

1.2. STRUCTURES AND MATERIALS LABORATORY (SML)

All tests presented in this report, including material sampling and specimen preparation, were performed by and under the supervision of the University of Miami, College of Engineering, Structures and Materials Laboratory, herein referred to as SML. This testing laboratory has met the requirements of the International Accreditation Service (IAS) AC89 (Accreditation Criteria for Testing Laboratories), has demonstrated compliance with ANS/ISO/IEC Standard 17025:2005, "General requirements for the competence of testing and calibration laboratories," and has been accredited for the test methods listed in the approved scope of accreditation under Testing Laboratory #TL-478; and is a District 6 qualified laboratory by the Florida Department of Transportation (FDOT).

1.3. DESCRIPTION OF PRODUCTS UNDER EVALUATION

RockRebar™ is a round solid Basalt Fiber-Reinforced Polymer (BFRP) composite reinforcing bar (re-bar) made from continuous basalt fibers, in an epoxy matrix/resin and a quartz sand coasted surface. The nominal rebar sizes under evaluation include:

1.3.1 *RockRebar™* #3

BFRP 3/8-in.nominal diameter, #3 size (D10) rebar.

1.3.2 RockRebar™ *#4.*

BFRP 1/2-in.nominal diameter, #4 size (D13) rebar.

1.3.3 *RockRebar™* #5

BFRP 5/8-in.nominal diameter, #5 size (D16) rebar.

1.3.4 *RockRebar™* #8

BFRP 1-in.nominal diameter, #8 size (D25) rebar.

Refer to Table 1.1, for the summary of products under evaluation and the reference name of the products within this report. Figure 1 shows RockRebar™ BFRP composite rebar under evaluation with the different sizes.

Table 1.1 - Summary of RockRebar™ products under evaluation with the report reference ID.

FRP products under evaluation	Report Reference Name
RockRebar™ #3 (Ø 3/8 in.)	03
RockRebar™ #4 (Ø 4/8 in.)	04
RockRebar™ #5 (Ø 5/8 in.)	05
RockRebar™ #8 (Ø 6/8 in.)	08

Figure 1 – RockRebar™ Basalt Fiber-Reinforced Polymer (BFRP) composite reinforcing bar under evaluation, from left to right #3, #4, #5 and #8.

1.4. CLIENT INFORMATION

The test report has been requested by:

Raw Energy Materials Corp.
Attn: Don Smith
Chairman
don@rawenergytec.com
http://www.newrebar.com/

2. TEST DATA

2.1. 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.

2.2. 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.

2.3. REPORT PRESENTATION OF TEST RESULTS

Test results are presented in the subsequent chapters of this report (indicated with X in Table 2.1), structured in the following chapter sub-sections:

Table 2.1 – 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	SPECIMEN PREPERATION	Contains specimen size, layout (if applicable), and relevant specimen preparation procedures and conditioning parameters as needed.
X.3	TEST SET-UP	Contains test set-up information as well as the rate and method of loading.
X.4	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.

2.4. 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.

3. GLASS TRANSITION (T_g) TEMPERATURE – ASTM E1640

3.1. TEST SUMMARY

3.1.1. AC454 Section/s

Section 4.1.2. Glass Transition Temperature

3.1.2. Reference Standard/s

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

3.1.3. Test Objective

Determine the glass transition temperature (T_g) of the re-bar under evaluation based on dynamic mechanical analysis (DMA) method.

3.1.4. Test Location

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

3.1.5. Laboratory Technician/s

Zahra Karim and Francisco De Caso

3.2. SPECIMEN PREPARATION

3.2.1. 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.

3.2.2. Preparation Procedure

Segments of randomly selected bars were cut to then cut the glass transition temperature specimens to the prescribed dimensions using a high precision blade saw from the core of the rebar.

3.2.3. 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.

3.3. TEST SET-UP

3.3.1. Set-up

A Dynamic Mechanical Analyzer (DMA), TA instruments Q800, was used with a flexural set up to apply a forced oscillation with constant amplitude at a fixed frequency. The change loss modulus with the increasing temperature is obtained by the analysis of the flexural mechanical response and plotted in a graph to determine the glass transition temperature, T_g based on two methodologies: i) storage modulus and ii) loss modulus. The test set-up is shown in Figure 3.1.

3.3.2. Rate and Method of Loading

A heating rate of 1°C/min (1°F/min) and a frequency of 1 Hz was applied.

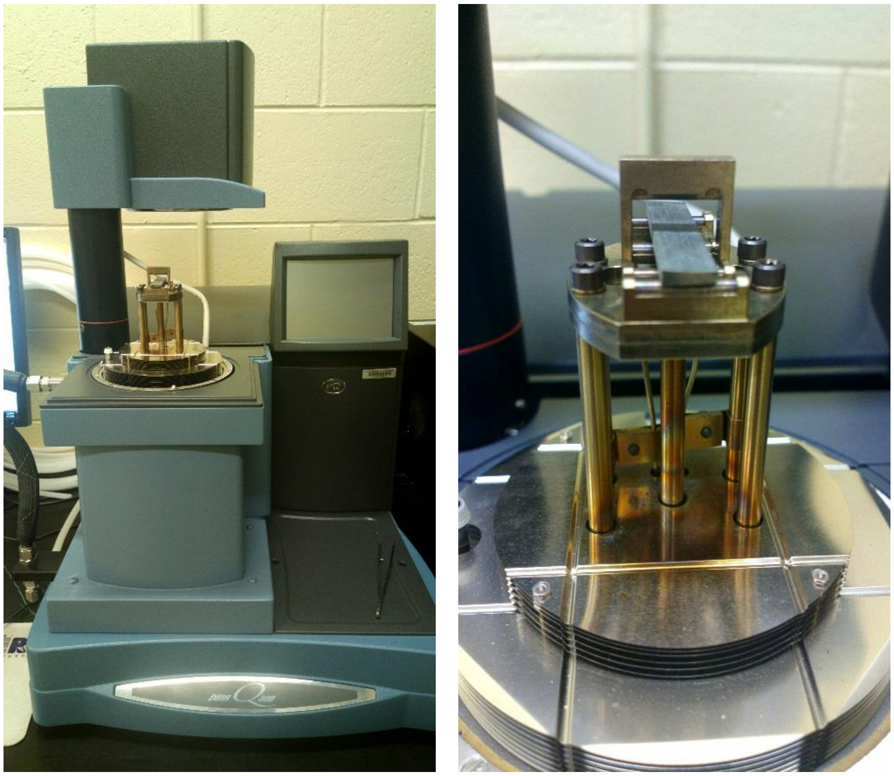

Figure 3.1 – T_g test set-up

3.4. TEST RESULTS

3.4.1. Results Summary

Based on the experimental tests presented herein the average T_g of the re-bars under evaluation are summarized in Table 3.1. The T_g meets the conditions of acceptance of AC454, which states that the T_g shall not be less than 100°C (212°F).

Table 3.1 – Average tests result for T_g

	Storage Modulus, T_g*		***Loss Modulus, T_g****		***Tan Delta T_g****		***AC454 criteria***
	°C	***°F***	***°C***	***°F***	***°C***	***°F***	
TG	109.1	149.8	120.0	161.6	129.5	171.8	PASS

3.4.2. Calculations

The T_g is determined by the extrapolated onset to the sigmoidal change in the loss modulus, storage modulus and tan delta observed in going from the hard, brittle region to the soft, rubbery region of the material under evaluation.

3.4.3. Graphical Representation of Results

Figure 3.2 shows a typical graphical result for the determination of T_g.

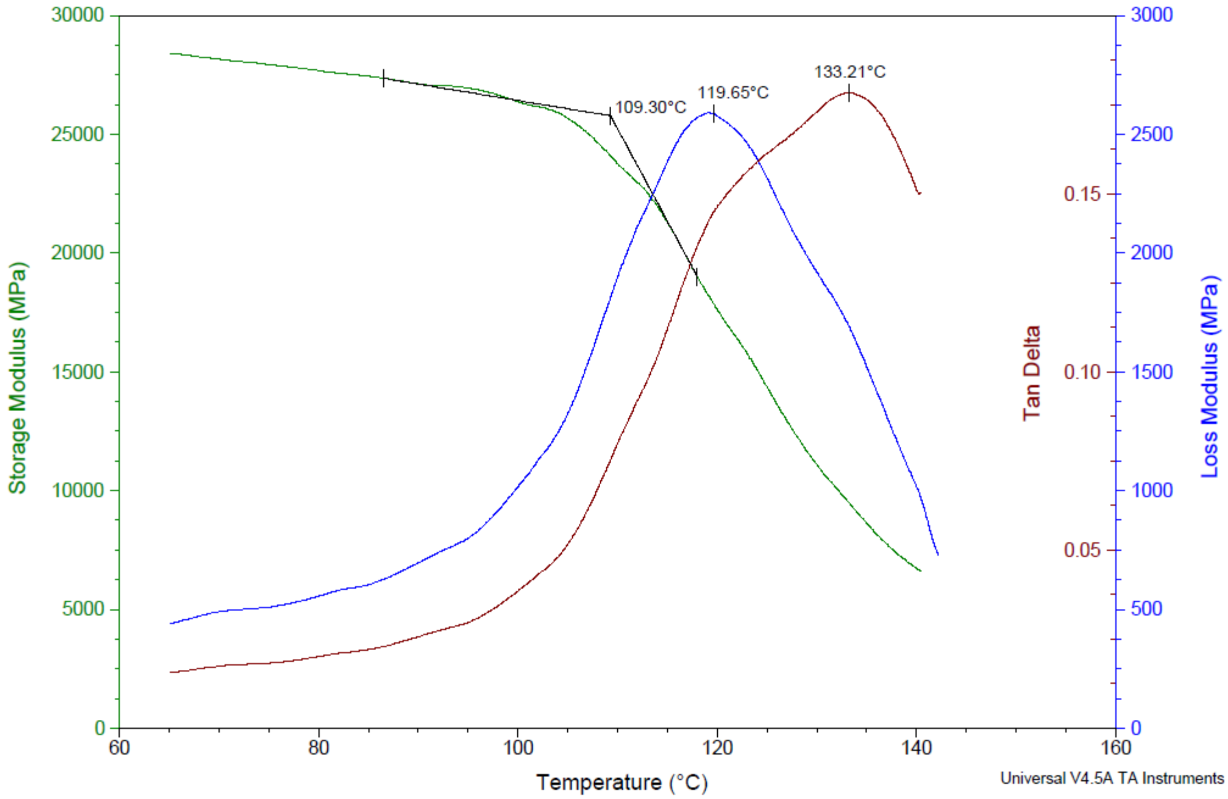

Figure 3.2 – Storage modulus / loss modulus vs temperature response graph for a representative test.

4. CROSS-SECTIONAL AREA – ASTM D792

4.1. TEST SUMMARY

4.1.1. AC454 Section/s

Section 4.1.3, Measured Cross-sectional Area; and

4.1.2. Reference Standard/s

ASTM D7205/D7205M - 06 (2011) 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.

4.1.3. Test Objective

Determine the measured cross-sectional area by volume of water displacement method of the re-bar products under evaluation.

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 and Francisco De Caso

4.1.3. Specimen Size

Nominal specimen length dimensions were 100 mm (4.0 in.).

4.1.4. Preparation Procedure

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

4.1.1. 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.

4.2. TEST SET-UP

4.2.1. 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.

4.3. TEST RESULTS

4.3.1. Results Summary

Based on the experimental tests presented herein summarized in Table 4.1, the average cross-sectional areas of the rebar sizes under evaluation meet the ranges listed in column 1 of Table 1 of AC454, and stated below.

Table 4.1 – Average cross-sectional area and Maximum dimension results

Specimen ID	Acceptance Criteria AC454 Area Range		Average Measured Area		*AC454 criteria*
	mm²	**in²**	***mm²***	**in²**	
03_MXA_CC_00	67.10 to 103.87	0.104 to 0.161	97.206	0.151	PASS
04_MXA_CC_00	119.35 to 169.68	0.185 to 0.263	157.314	0.244	PASS
05_MXA_CC_00	185.81 to 250.32	0.288 to 0.388	218.290	0.338	PASS
08_MXA_CC_00	476.13 to 589.03	0.738 to 0.913	572.424	0.887	PASS

4.3.2. Calculations

The results reported herein have been computed as per ASTM D792, 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). Mass of fixture, ‘s’ predetermined.
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
Δ M	Change in mass	Δ M = 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

5. TENSILE PROPERTIES – ASTM D7205

5.1. TEST SUMMARY

5.1.1. AC454 Section/s

Section 4.2.1, Ultimate Tensile Load,

Section 4.2.2, Mean Tensile Modulus of Elasticity, and

Section 4.2.4, Calculated Ultimate Tensile Strain

5.1.2. Reference Standard/s

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

5.1.3. Test Objective

Determine the ultimate tensile load carrying capacity, tensile modulus of elasticity and computed ultimate strain for each re-bar size, based on an assumed linear elastic behavior.

5.1.4. Test Location

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

5.1.5. Laboratory Technician/s

Keith Holmes and Francisco De Caso

5.2. SPECIMEN PREPARATION

5.2.1. Specimen Size and Layout

Nominal specimen dimensions as reflected in Figure 5.1,

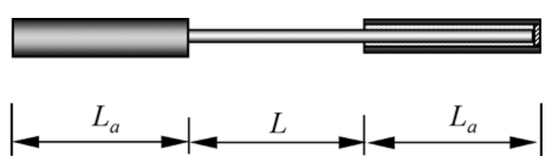

Figure 5.1 – Tensile specimen geometry

Table 5.1 – Nominal tensile test specimen dimensions

Specimen ID	Length anchors (steel pipe) L_a		Free length between anchors L		Diameter of steep pipe D_{pipe}	
	mm	*in.*	*mm*	*in.*	*mm*	*in.*
03_TNS_CC_00	300	12			25.4	1.00
04_TNS_CC_00	300	12	915	36	25.4	1.00
05_TNS_CC_00	300	12			25.4	1.00
08_TNS_CC_00	460	18	765	30	31.8	1.25

5.2.2. 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 re-bar specimens so as to center the bar specimens in 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 re-bar specimen.

5.2.3. 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.

5.3. TEST SET-UP

5.3.1. 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 50 mm (2.0 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 5.2. All data was gathered using a National Instruments data acquisition system at a rate of 100 Hz.

Figure 5.2 - Tensile test set-up

5.3.2. *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.

5.4. TEST RESULTS

5.4.1. *Results Summary*

All specimens behaved linear elastically until failure. Based on the experimental tests presented herein the average ultimate force carrying capacity (P_{max}), tensile strength (F_{tu}), the computed average ultimate tensile strain (ε_u), and the average modulus of elasticity (E) meet the AC454 condition of acceptance as per Table 1, and Section 4.2 for the re-bar sizes under evaluation except as indicated in Table 5.2.

Table 5.2 – Average results for tensile tests

Specimen ID	***Peak load P_{max}***		***Guaranteed Tensile Load***		***Nominal Ult. Strain $\varepsilon_{u\text{-}nom}$***	***Modulus E***		***AC454 criteria***
	kN	**lbs**	**kN**	**lbs**	***%***	***GPa***	***Msi***	
03_TNS_CC_00	87.4	19660	77.6	17449	1.32	45.44	6.59	PASS
04_TNS_CC_00	130.3	29288	114.8	25818	1.70	48.79	7.08	PASS
05_TNS_CC_00	183.6	41271	158.7	35650	1.83	46.13	6.69	PASS
08_TNS_CC_00	439.9	98891	363.6	81741	1.70	45.20	6.56	PASS

**Condition of acceptance is equivalent to minimum guaranteed tensile load of:*

> 13.2 kips for #3;

> 21.6 kips for #4;

> 32.2 kips for #5;

> 70.6 kips for #8; and

E >45 GPa (6.5 Msi) regardless of bar size

5.4.2. Modes of Failure

The mode of failure for all bars was by tensile rupture of the re-bar as seen in Figure 5.3.

Figure 5.3 – Representative failure mode of tensile test

5.4.3. Calculations

The results reported herein have been computed as per ASTM D7205 and summarized in Table 5.3. Note that the results have been calculated using the computed area based on average of five specimens.

Table 5.3 - Definitions of calculations for tensile tests

Symbol	Parameter	Description
P_{max}	Maximum force at failure	Peak load recorded during test.
A	Measured experimental area	Cross-section area as per ASTM D792
A_{nom}	Nominal cross-section area	Cross-section area as per AC454 Table 1.
F^{tu}	Experimental ultimate tensile strength	$F^{tu} = P_{max} / A$
F^{tu}_{nom}	Nominal ultimate tensile strength	$F^{tu}_{nom} = P_{max} / A_{nom}$
ε_u	Experimental ultimate strain	$\varepsilon_u = F^{tu} / E$
$\varepsilon_{u\text{-}nom}$	Nominal ultimate strain	$\varepsilon_{u\text{-}nom}$ Strain calculated as per AC454 Section 4.2.4; $\varepsilon_u = (P_{max} - 3\sigma) / (E_{ave} * A_{nom})$
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 $E = \Delta F^{tu} / \Delta\varepsilon$
E_{nom}	Nominal tensile modulus	$E_{nom} = \Delta F^{tu}_{nom} / \Delta\varepsilon$

6. TRANSVERSE SHEAR STRENGTH – ASTM D7617

6.1. TEST SUMMARY

6.1.1. AC454 Section/s

Section 4.2.3, Mean Ultimate Shear Strength (Perpendicular to the Bar).

6.1.2. Reference Standard/s

ASTM D7616/D7616M-11, Standard Test Method for Transverse Shear Strength of Fiber–Reinforced Polymer Matrix Composite Bars.

6.1.3. Test Objective

Determine the ultimate shear strength for each bar size under evaluation.

6.1.4. Test Location

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

6.1.5. Laboratory Technician/s

Kyrah Williams and Francisco De Caso

6.2. SPECIMEN PREPARATION

6.2.1. Specimen Size

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

6.2.2. Preparation Procedure

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

6.2.3. 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.

6.3. TEST SET-UP

6.3.1. 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 6.1.

Figure 6.1 – Transvers shear strength test set-up

6.3.2. 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.

6.4. TEST RESULTS

6.4.1. Results Summary

Based on the experimental tests presented herein the average mean transverse shear strength of the re-bars under evaluation meet the AC454 Section 4.2 and the condition of acceptance, and was at least 152 MPa, (22 ksi), regardless of the bar size or shape, as summarized in Table 6.1.

Table 6.1 – Average transverse shear strength results

Specimen ID	**$\tau_{u\text{-}nom}$ (Nominal)**		***AC454 criteria***
	MPa	***ksi***	
03_TSS_CC_00	198.1	28.7	PASS
04_TSS_CC_00	183.3	26.6	PASS
05_TSS_CC_00	152.4	22.1	PASS
08_TSS_CC_00	191.2	27.7	PASS

6.4.2. Modes of Failure

The mode of failure was by double shear.

6.4.3. Calculations

The results reported herein have been computed and summarized based on the definitions in Table 6.2

Table 6.2 - Definitions of calculations for transverse shear strength

Symbol	Parameter	Description
P_{max}	Maximum failure force	Peak load recorded during test
A_{exp}	Measured cross-section area	Area per ASTM D792
A_{nom}	Nominal cross-section area	Area per AC454 Table 1
τ_{u-exp}	Experimental Transverse shear strength	$\tau_u = P_{max} / (2*A_{exp})$
τ_{u-nom}	Nominal Transverse shear strength	$\tau_u = P_{max} / (2*A_{nom})$

7. VOID CONTENT - VISUAL

7.1. TEST SUMMARY

7.1.1. AC454 Section/s

Section 4.2.8 Mean Void Content or Longitudinal Wicking.

7.1.2. Reference Standard/s

Visual Inspection.

7.1.3. Test Objective

Determine if any unintentional continuous voids or crack exist within the products under evaluation.

7.1.4. Test Location

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

7.1.5. Laboratory Technician/s

Guillermo Claure and Francisco De Caso

7.2. SPECIMEN PREPARATION

7.2.1. Specimen Size and layout

25.0 mm (1.0 in.) long segment cut at different locations from the re-bar.

7.2.2. Preparation Procedure

The specimens were cut to the prescribed dimensions using a high precision blade saw, and the ends polished to ensure a clear surface was prepared for the visual inspection.

7.2.3. 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.

7.3. TEST SET-UP

7.3.1. Set-up

Specimens are placed under a high contrast background light, parallel and perpendicular to the axis of the bar to determine any inconsistent and unintentional contrast differences, indicating potential voids or longitudinal wicking. Furthermore high magnification electronic magnifying glass was used as needed for closer visual inspection when potential cracks may have been detected.

7.4. TEST RESULTS

7.4.1. Results Summary

Overall no unintentional continuous voids, or cracks or longitudinal wicking was detected in any of the products under evaluation, meeting the conditions of acceptance of AC454.

8. STRENGTH OF BENDS - ACI 440.3R, B.5

8.1. TEST SUMMARY

8.1.1. AC454 Section/s

Section 4.3.2, Mean Strength of Bends

8.1.2. Reference Standard/s

ACI 440.3R-12, Method B.5. Guide Test Methods for Fiber Reinforced Polymer (FRP) Composites for Reinforcing or Strengthening Concrete and Masonry Structures, Test method for bond strength of FRP bars, Test Method for Strength of FRP Bent Bars and Stirrups in Bend Locations.

8.1.3. Test Objective

Determine geometry characteristics of the bend radius, and the mean strength of the bend.

8.1.4. Test Location

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

8.1.5. Laboratory Technician/s

Keith Holmes and Francisco De Caso

8.2. SPECIMEN PREPARATION

8.2.1. Specimen Size and layout

Specimens where configured as per ACI 440.3R-12, Method B.5, by placing the pre-bend bar with the ends enchase in reinforced concrete blocks 500 by 300 by 300 mm (20 by 8 by 8 in.) length, width, depth; where a minimum length of 400 mm (15 in.) was left between the concrete blocks for placing the hydraulic jack. In addition, the open end of the bend bar and radius portion was the only part in contact, bonded to the concrete as seen in Figure 8.1, per ACI 440.3R-12, Method B.5 requirements, where the straight potion was covered to break the bond between the bar and the concrete.

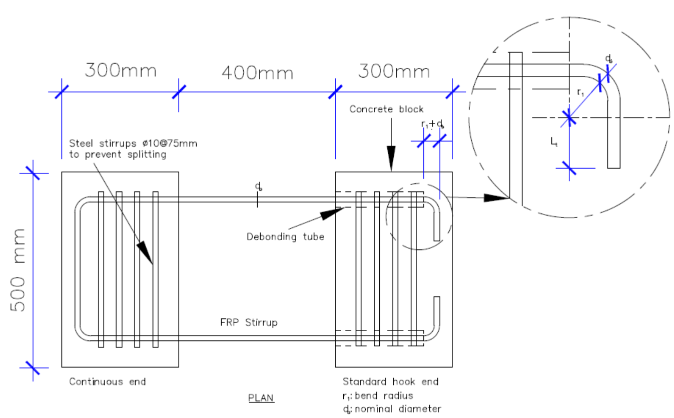

Figure 8.1 – Specimen layout for strength of bend tests.
Note: bend bars were not open, manufactured continuous closed stirrups were tested.

8.2.2. <u>Preparation Procedure</u>

The inside bend of the specimen was measure for compliance to compare the specified manufactures reported bend. All specimens were prepared simultaneously from one single batch of concrete on November 10, 2012, 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 with ACI 440.3R-12 Method B.3 at 30 ± 3 MPa (4350 ± 435 psi). Summary results are presented in Table 8.1.

8.2.3. <u>Conditioning Parameters</u>

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

8.3. TEST SET-UP

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

A hydraulic jack was used to apply the relative displacement between the two concrete blocks and a load cell in compliance with ASTM E4-10 to measure the applied load. Steel plates where used to between the concrete blocks and the loading apparatus and to distribute the applied load evenly to the surface of the concrete blocks, one of the blocks was placed on steel rollers to minimize the friction forces between the block and ground, refer to Figure 13.2.

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

Load was applied smoothly and continuously from start until failure of the specimen, where the load rate ensured that the specimen failure was reached between 1 and 10 minutes from the start of the test.

Figure 8.2 – Representative test setup for bend bar tests.

8.4. TEST RESULTS

8.4.1. Results Summary

Based on the experimental tests presented herein the geometry of the nominal #4 bend rebar and the average strength of the bend bars under evaluation met the AC454 condition of acceptance, where the bend strength meets and surpasses the required 60% over threefold of the mean tensile strength (χ_{nom} = 0.6) as reported in Section 5.4. Results are the Table 8.1. This is primarily due to the continuous close stirrup fabrication providing high performance.

Table 8.1 – Average tests result for Strength of Bend Bars

Bend Bar Strength	**Max Compressive force, Fub**		**Nomnial Area, Anom**		**Nomila Bend Capacity of FRP stirrup, fub-nom**		χ_{nom}
	kN	**lbs**	**mm2**	**in2**	**Mpa**	**ksi**	
AVERAGE	190.1	42740			1334.7	193.6	2.16
S_{n-1}	20.5	4605	71.22	0.110	143.8	20.9	0.23
CV((%)	10.8	10.8			10.8	10.8	10.8

8.4.2. Modes of Failure

The mode was by slip of the bend bar followed by concrete crushing.

8.4.3. Calculations

The results reported herein have been computed as per ACI 440.3R, method B.5. Definitions of the parameters used for calculation is provided in Table 8.2.

Table 8.2 - Definitions of calculations for strength of bend bars

Symbol	**Parameter**	**Description**
F_{ub}	Maximum force at failure	Ultimate load capacity according to bend test
A	Measured cross-section area	Cross-section area as per Section 0
A_{nom}	Nominal cross-section area	Cross-section area as per AC454 Table 1.
f_{ub}	Experimental Bend capacity	$f_{ub} = F_{ub} / (2^* A)$
f_{ub-nom}	Nominal Bend capacity	$f_{ub-nom} = F_{ub} / (2^* A_{nom})$
f_u	Ultimate tensile strength (parallel to the fibers)	As per Section 5.4, average result of group of data based on experimental or nominal data.
χ	Strength Reduction Factor	$\chi = f_{ub} / f_u$
χ_{nom}	Strength Reduction Factor	$\chi = f_{ub-nom} / f_{u-nom}$

♦ END OF TEST REPORT ♦