

CERTIFIED TEST REPORT

EVALUATION OF GLASS FIBER REINFORCED POLYMER (GFRP) BARS FOR INTERNAL REINFORCEMENT OF CONCRETE MEMBERS - Per ICC-ES AC454 / ASTM D7957 -

Report Number: R-5.10_07-21-21_KBAR

Date: December 18, 2021

REPORT PREPARED FOR:



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REFERENCE:

Preliminary validation tests per ICC-ES AC454 / ASTM D7957

Quality System: The University of Miami, 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 recognized by the ILAC mutual recognition arrangement (ilac-MRC), and is also a qualified laboratory by the Florida Department of Transportation (FDOT), number ISM028. All the test results presented herein are linked through unbroken chain data. Analyzed data is obtained directly from the recorded raw data during testing, from which the test results are presented. This report contains analyzed tabulated data results.

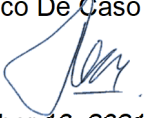
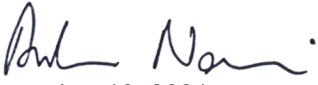
Procedures: All tests and services are done in accordance with the SML Quality Manual (Version 6.0) revised November 30, 2019; relevant standard operating procedures (SOPs); and with the applicable requirements of the reference standard test methods, unless otherwise stated.

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Decision Rule: Unless otherwise specified and if applicable, conformance to requirements is judged based on the actual value reported or the statistically derived value (median or mean) for replicate measurements even if the uncertainty (error band) of the value falls outside of the range.

Certified Test Report

| Controls: | |
|---------------------|-------------------|
| Superseded Report | New report |
| Reason for Revision | n/a |
| Effective Date | December 18, 2021 |

| Test Report Approval Signature: | |
|--|--|
| Quality review Approval | <p>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.</p> <p>Name: Francisco De Caso Signature:  Date: December 18, 2021</p> |
| Technical review Approval | <p>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.</p> <p>Name: Antonio Nanni Signature:  Date: December 18, 2021</p> |

1. EXECUTIVE SUMMARY

The glass fiber reinforced polymer (GFRP) bar was tested per the requirements set forth in ASTM D7957-17, 'Standard Specification For Solid Round Glass Fiber Reinforced Polymer Bars For Concrete Reinforcement' and ICC-ES 454, "Acceptance Criteria for Fiber-Reinforced Polymer (FRP) Bars for Internal Reinforcement of Concrete Members".

As a point of clarification, the GFRP bar evaluated is identified as a M8 (i.e 8 mm or 0.31 in. nominal diameter). This is not a nominal size included in ASTM D7957, nevertheless based on the results it meets the classification of a M6 (6 mm) or No. 2 (0.25 in.) nominal diameter bar. Based on the results provided here in, the specifications per ASTM D7957 have been met, except as reported herein.

Refer to Section 2 the material sample information; Section 3 for the summary test results and Section 4 for the individual tabulated results. Testing provided within this report is for initial validation purposes and does not represent full qualification testing requirements.

2. BAR SAMPLE INFORMATION

| Sample No.* | Manufacturing Lot/ID/Ref. | Sample ID Nominal Bar Denomination | Material type |
|-------------|---------------------------|--|------------------|
| 1 | TBD | M8 Straight bar | GFRP bar |



Scale in inches (in.).

*Sampling: Provided by client. Samples received on 10/25/2021.

3. SUMMARY TEST RESULTS

| SAMPLE No. 1: M8 | | | | | | |
|------------------|----------------------|--|-----------------|----------------------------------|------------|-------------|
| Test ID | Standard Test Method | Test Description | Units | Acceptance Criteria ^c | Test Value | Test Result |
| DSC | ASTM E2160 | Average Degree of Cure | % | ≥ 95 | 100 | Pass |
| | ASTM D3418 | Average Glass Transition Temp. | °F | ≥ 212 | 204 | Fail |
| FC | ASTM D2584 | Average Fiber Content (by weight) | % | ≥ 70 | 82 | Pass |
| MA | ASTM D570 | Average Moisture Absorption (24 hours) | % | ≤ 0.25 | 0.18 | Pass |
| MXA | ASTM D792 | Average Measured Cross-Sectional Area | in ² | 0.046 to 0.085 | 0.079 | Pass |
| | | Guaranteed Tensile Load* | kips | ≥ 6.1 | 10.8 | Pass |
| TNS | ASTM D7205 | Average Tensile Modulus of Elasticity | Msi | ≥ 6.5 | 7.8 | Pass |
| | | Mean Ultimate Tensile Strain | % | ≥ 1.1 | 2.1 | Pass |
| TSS | ASTM D7617 | Guaranteed Transverse Shear Strength* | ksi | ≥ 19 | 25 | Pass |
| BS | ASTM D7913 | Guaranteed Bond Strength* | ksi | ≥ 1.1 | TBD | - |

NOTES:

*Guaranteed value is defined as the average minus three standard deviations, derived from a sample size of at least three different production lots and eight tests per lot (total of 24 test repetitions). This guaranteed value is based on a limited sample size and is provided for reference purposes

^cCriteria imposed for M6 [2] nominal bar size per specification requirements in ICC-ES AC454 / ASTM D7957-17

4. SPECIFIC TEST DATA

Test data is uniquely identified in this report using the following nomenclature: "XXXY-Z" where 'XXX' refers to the test ID as referenced in the first column of Section 3; 'Y' refers to the sample number as referenced in the first column of Section 2; and Z is the test sample repetition number. Note dates referenced within this report use the *mm/dd/yyyy* format.

4.1. ENTHALPHY OF POLYMERIZATION (DSC)

Test Standard Method: [ASTM E2160-04 \(2018\)](#), Standard test method for heat of reaction of thermally reactive materials by differential scanning calorimetry, and [ASTM D3418-15](#), Transition temperatures and enthalpies of fusion and crystallization of polymers by differential scanning calorimetry.

Test Description: Determine the degree of cure (DC) and glass transition temperature (T_{mg}) via differential scanning calorimetry (DSC), with a single heat run, where the heat of reaction is determined on the first run and the glass transition temperature on the second run.

Technician/Analyst: Karla Pabellon and Juan Manuel Palacios

Test Date: 10/22/2021

Specimen Size: Slice of the bar cross-section yielding a minimum of 5 mg of material

Test Result: PASS: DC \geq 95%

FAIL: Acceptance criteria is $T_{mg} \geq 212^{\circ}\text{F}$

Test Data:

| Sample ID | Specimen ID | Initial Mass | Mass Change | Degree of Cure, DC* | Glass Transition Temperature, T_{mg} | |
|-----------|----------------|--------------|-------------------|---------------------|--|--------------------|
| | | M_i mg | M_{Δ} % | % | $^{\circ}\text{C}$ | $^{\circ}\text{F}$ |
| M8 | DSC1-01 | 18.70 | 0.002 | 100.0 | 94.0 | 201.2 |
| | DSC1-02 | 26.12 | -0.003 | 100.0 | 95.6 | 204.0 |
| | DSC1-03 | 33.89 | 0.004 | 100.0 | 96.4 | 205.5 |
| | Average | | | 100.0 | 95.3 | 203.5 |
| | S_{n-1} | | | 0.0 | 1.2 | 2.2 |
| | CV (%) | | | 0.0 | 1.3 | 1.1 |

* Note that the total heat of reaction (H_t), which is derived from the unreacted resin system (neat resin), is conservatively assumed value of 100 J/g to compute the degree of cure.

Certified Test Report**4.2. FIBER CONTENT (FC)**

Test Standard Method: [ASTM D2584-18](#), Standard Test Method for Ignition Loss of Cured Reinforced Resins.

Test Description: Determine the fiber content (FC) by weight (mass).

Technician/Analyst: Leonardo Ramos

Test Date: 10/25/2021

Specimen Size: Straight bar: 25.0 mm (1.0 in.) long segment cut at different locations.

Test Result: PASS: FC \geq 70% by weight

Test Data:

| Sample ID | Specimen ID | Weight of Specimen W_1 g | Weight of residue W_2 g | Fiber Content FC % |
|-----------|----------------|----------------------------------|---------------------------------|--------------------------|
| M8 | FC1-01 | 2.506 | 2.088 | 83.3 |
| | FC1-02 | 2.538 | 2.088 | 82.3 |
| | FC1-03 | 2.607 | 2.130 | 81.7 |
| | FC1-04 | 2.425 | 1.987 | 81.9 |
| | FC1-05 | 2.655 | 2.183 | 82.2 |
| | Average | | | |
| S_{n-1} | | | | 0.6 |
| CV (%) | | | | 0.7 |

4.3. MOISTURE ABSORPTION (MA)

Test Standard Method: [ASTM D570 - 98 \(2018\)](#), Standard Test Method for Water Absorption of Plastics, Procedure 7.1 and, [ASTM D5229/D5229M-14](#), Standard Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials (Procedure B).

Test Description: Determine the short-term (24 hrs) and long-term (saturation) level of moisture absorption when immersed in distilled water at 122°F \pm 3°F.

Technician/Analyst: Leonardo Ramos

Test Date: 10/27/2021

Specimen Size: Straight bar: 25.0 mm (1.0 in.) long segment cut at different locations.

Test Result: PASS: $W_{24} \leq 0.25$ % and $W_s \leq 1.00$ %

Test Data:

| Sample ID | Specimen ID | Initial Mass M_i g | Final Mass M_{24} g | Short-term Absorption (24 hrs.) W_{24} % |
|-----------|----------------|----------------------------|-----------------------------|--|
| M8 | MA1-01 | 2.7337 | 2.7393 | 0.20 |
| | MA1-02 | 2.7545 | 2.7599 | 0.20 |
| | MA1-03 | 2.6865 | 2.6906 | 0.15 |
| | MA1-04 | 2.6187 | 2.6231 | 0.17 |
| | MA1-05 | 2.7813 | 2.7863 | 0.18 |
| | Average | | | |
| S_{n-1} | | | | 0.02 |
| CV (%) | | | | 11.7 |

Certified Test Report**4.4. CROSS-SECTIONAL AREA (MXA)**

Test Standard Method: [ASTM D7205/D7205M - 21 \(2021\)](#) Standard test method for Tensile Properties of Fiber Reinforced *Polymer* Matrix Composite Bars and, [ASTM D792-13](#) Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement

Test Description: Determine the measured of cross-sectional area by volume of water displacement method.

Technician/Analyst: Karla Pabellon, Leonardo Ramos, and Juan Manuel Palacios.

Test Date: Samples 1 to 4 tested on 10/25/2021. Sample 5 tested on 10/28/2021.

Specimen Size: Specimen nominal length dimensions were 50.8 mm (2.0 in.).

Test Result: PASS: 2S, A shall be between 0.046 in² to 0.085 in².

Test Data:

| Sample ID | Specimen ID | Ave. Length L | | Volume V | | Measured Area A | | Weight/unit length | |
|-----------|----------------|---------------|-------|-----------------|-----------------|-----------------|-----------------|--------------------|--------------|
| | | Mm | in. | mm ³ | in ³ | mm ² | in ² | kg/m | lbs/ft |
| M8 | MXA1-01 | 51.32 | 2.020 | 2609 | 0.16 | 50.84 | 0.079 | 0.106 | 0.071 |
| | MXA1-02 | 52.29 | 2.059 | 2648 | 0.16 | 50.65 | 0.079 | 0.106 | 0.071 |
| | MXA1-03 | 51.01 | 2.008 | 2591 | 0.16 | 50.80 | 0.079 | 0.106 | 0.071 |
| | MXA1-04 | 49.35 | 1.943 | 2531 | 0.15 | 51.29 | 0.079 | 0.106 | 0.071 |
| | MXA1-05 | 51.65 | 2.033 | 2595 | 0.16 | 50.24 | 0.078 | 0.105 | 0.070 |
| | Average | | | | | | 50.76 | 0.079 | 0.106 |
| | S_{n-1} | | | | | 0.38 | 0.001 | 0.000 | 0.000 |
| | CV (%) | | | | | 0.7 | 0.7 | 0.5 | 0.5 |

4.5. TENSILE PROPERTIES (TNS)

Test Standard Method: [ASTM D7205/D7205M - 21 \(2021\)](#) Standard test method for Tensile Properties of Fiber Reinforced *Polymer* Matrix Composite Bars.

Test Description: Determine the guaranteed tensile load, ultimate tensile load carrying capacity, tensile modulus of elasticity and computed ultimate strain based on an assumed linear elastic behavior.

Technician/Analyst: Leonardo Ramos and Juan Manuel Palacios

Test Date: 11/16/2021

Specimen Size: The specimens were cut to the prescribed dimensions. Steel pipe type anchors were installed as indicated in ASTM D7205 using expansive grout after machining the ends of the bar as to center the bars in the anchors.

Test Result: **PASS:**
 $E \geq 6.5 \text{ Msi}$ and $\epsilon \geq 1.1\%$
 For each specimen P_{\max} shall be:
 $2S \geq 6.1 \text{ kips}$.

Test Data:

| Sample ID | Specimen ID | Peak Load P_{\max} | | Nominal Area A | | Ultimate Tensile Strength f_{tu} | | Modulus of Elasticity E | | Strain ϵ |
|--------------------|----------------|----------------------|-------------|-----------------|-----------------|------------------------------------|-------------|-------------------------|------|-------------------|
| | | kN | kips | mm ² | in ² | GPa | ksi | GPa | Msi | % |
| M8 | TNS1-01 | 57.38 | 12.9 | 50.3 | 0.08 | 1140.3 | 165.4 | 53.4 | 7.75 | 2.13 |
| | TNS1-02 | 52.70 | 11.8 | | | 1047.2 | 151.9 | 53.5 | 7.76 | 1.96 |
| | TNS1-03 | 58.20 | 13.1 | | | 1156.6 | 167.7 | 54.7 | 7.94 | 2.11 |
| | TNS1-04 | 55.54 | 12.5 | | | 1103.7 | 160.1 | 54.2 | 7.86 | 2.04 |
| | TNS1-05 | 60.64 | 13.6 | | | 1205.0 | 174.8 | 53.6 | 7.78 | 2.25 |
| | Average | 56.89 | 12.8 | 1130.5 | 164.0 | 53.9 | 7.82 | 2.10 | | |
| | S_{n-1} | 2.97 | 0.7 | 59.1 | 8.6 | 0.6 | 0.08 | 0.11 | | |
| CV (%) | 5.2 | 5.2 | 5.2 | 5.2 | 1.0 | 1.0 | 5.2 | | | |
| Guaranteed* | 48.0 | 10.8 | | | | | | | | |

*Guaranteed value is defined as the average minus three standard deviations, derived from a sample size of at least three different production lots and eight tests per lot (total of 24 test repetitions). This guaranteed value is based on a limited sample size and is provided for reference purposes.

4.6. TRANSVERSE SHEAR STRENGTH (TSS)

Test Standard Method: [ASTM D7617/D7617M-11\(2017\)](#) Standard Test Method for Transverse Shear Strength of Fiber-Reinforced Polymer Matrix Composite Bars.

Test Description: Determine the guaranteed transverse shear strength.

Technician/Analyst: Leonardo Ramos

Test Date: 10/28/2021

Specimen Size: Specimen nominal length dimensions were 229 mm (9.0 in.).

Test Result: PASS: $\tau_u \geq 19$ ksi

Test Data:

| Bar Size | Specimen ID | Peak Transverse Force, P_{max} | | Nominal Area A_{nom} | | Shear Strength τ_u | |
|--------------------|----------------|----------------------------------|-------------|------------------------|-----------------|-------------------------|--------------|
| | | kN | lbs | mm ² | in ² | Mpa | ksi |
| M8 | TSS1-01 | 20.63 | 4635 | 50.32 | 0.08 | 204.94 | 29.71 |
| | TSS1-02 | 19.39 | 4358 | | | 192.69 | 27.94 |
| | TSS1-03 | 19.12 | 4296 | | | 189.95 | 27.54 |
| | TSS1-04 | 19.17 | 4308 | | | 190.48 | 27.62 |
| | TSS1-05 | 18.66 | 4194 | | | 185.44 | 26.88 |
| | Average | 19.39 | 4358 | | | 192.70 | 27.94 |
| | S_{n-1} | 0.74 | 166 | 7.33 | 1.06 | | |
| | CV (%) | 3.8 | 3.8 | 3.8 | 3.8 | | |
| Guaranteed* | | | | | | 170.70 | 24.75 |

*Guaranteed value is defined as the average minus three standard deviations, derived from a sample size of at least three different production lots and eight tests per lot (total of 24 test repetitions). This guaranteed value is based on a limited sample size and is provided for reference purposes.

Certified Test Report

4.7. BOND STRENGTH (BS)

Test Standard Method: [ASTM D7913-14 \(2020\)](#) Standard Test Method for Bond Strength of Fiber-Reinforced Polymer Matrix Composite Bars to Concrete by Pullout Testing.

Test Description: To determine the guaranteed bond strength to concrete by pullout test method.

Technician/Analyst: TBD

Test Date: TBD

Specimen Size: Nominal bonded area was based on a bonded length of five times the nominal bar diameter. The samples were embedded in solid plain concrete cubes 205 mm (8.00 in.). Specimens were prepared simultaneously from one single batch of concrete 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), and equal to 32.15 Mpa (4660 psi).

Test Result: TBD: $\tau_g \geq 1.1$ ksi

Test Data:

| Lot and Nominal Rebar Size | Specimen ID | Nominal Bonded Area | | Peak Tensile Force | | Maximum Bond Strength | |
|----------------------------|---------------------------------------|--------------------------|-----------------|--------------------|-----|-----------------------|-----|
| | | A_L mm ² | in ² | P_{max} kN | kip | τ Mpa | ksi |
| M8 | BS1-01 | | | | | | |
| | BS1-02 | TBD | TBD | TBD | TBD | TBD | TBD |
| | BS1-03 | | | | | | |
| | Average S_{n-1} CV (%) | | | | | | |
| Guaranteed* | | | | | | | |

*Guaranteed value is defined as the average minus three standard deviations, derived from a sample size of at least three different production lots and eight tests per lot (total of 24 test repetitions). This guaranteed value is based on a limited sample size and is provided for reference purposes.

◆ **END OF TEST REPORT** ◆