

Harmonization of Material Specifications for FRP Reinforcing Bars

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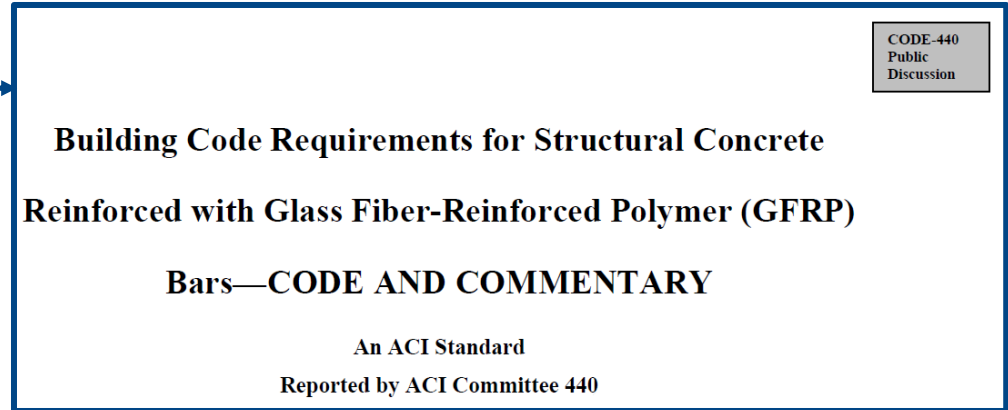
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1. Building Codes related to FRP design reference different materials specifications,

- USA, upcoming ACI 440 code.
- Europe, EU Code – CE (precursor EAD).
- Canada, CSA S806 & S807



2. Identify differences and points in common when evaluating the performance.

Research Significance

Variations in materials specifications for FRP bars may cause complexity and increase customer's costs.

Why harmonization?

International FRP providers

- Compliance with specifications of different countries
- Increase material verification costs
- Extends processes and makes them complex

Researchers, contractors, owners, & designers

- Lack of consistency
- Technical differences
- Statistical significance



Advantages

A
harmonized
database that
satisfies
reqs. of all
specs.

Decrease
material
verification
costs

Decrease
process time
&
complexity

No more
confusions

FRP Properties

1. Physical

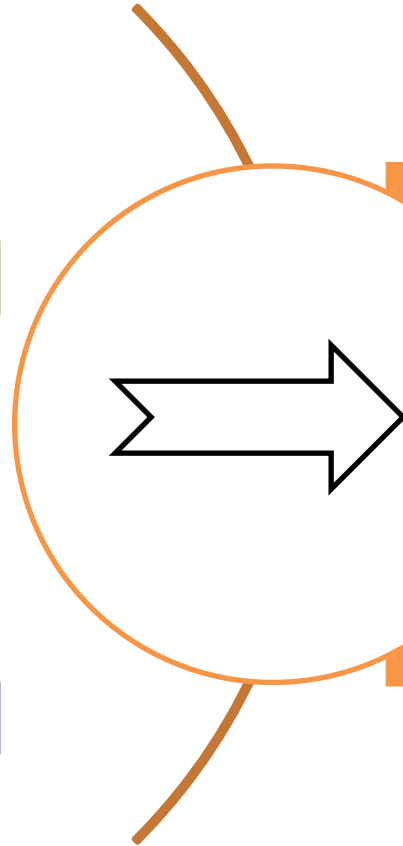
- Fiber content
- Glass transition temperature
- Degree of cure
- Moisture absorption to saturation

2. Mechanical

- Ultimate tensile force
- Tensile modulus of elasticity
- Tensile strength
- Bond strength
- Shear strength

3. Durability

- Tensile fatigue
- Creep failure
- Alkali resistance



Differences and similarities

- No. of specimens
- Size of specimens
- Limits criteria (Min. and Max. values)
- Loading rates

ASTM D7957

AC454

AC521

CSA S807:19

EAD

FDOT Sec
932-3

This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.



Designation: D7957/D7957M – 22

Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement¹

This standard is issued under the fixed designation D7957/D7957M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reappraisal. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reappraisal.



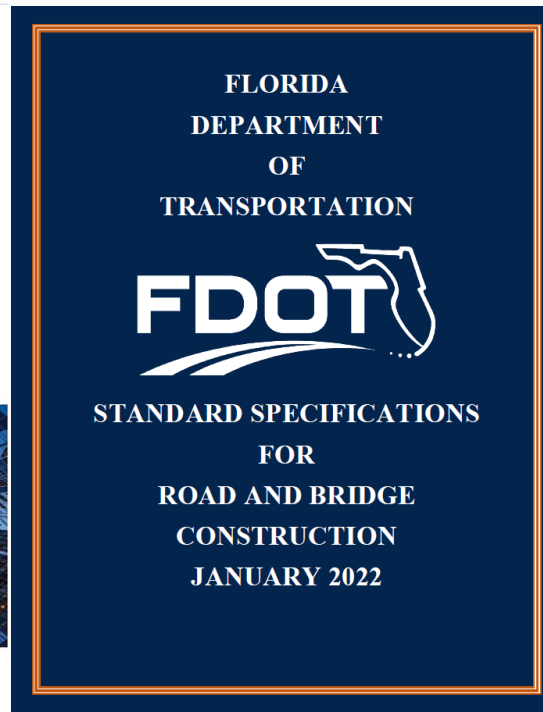
CSA S807:19
National Standard of Canada



Specification for fibre-reinforced polymers



Standards Council of Canada
Conseil canadien des normes



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ACCEPTANCE CRITERIA FOR FIBER-REINFORCED POLYMER (FRP) BARS FOR INTERNAL REINFORCEMENT OF CONCRETE MEMBERS

AC454

Proposed April 2021

Previously approved December 2020, June 2020, February 2017, June 2016, May 2015 and June 2014

(Previously editorially revised February 2021)



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ACCEPTANCE CRITERIA FOR FIBER-REINFORCED POLYMER (FRP) BARS AND MESHES FOR INTERNAL REINFORCEMENT OF NON-STRUCTURAL CONCRETE MEMBERS

AC521

Approved October 2020

(Editorially revised May 2021)

PREFACE



New ASTM (out for ballot)

- Covers GFRP and BFRP
- Straight cut lengths
- Includes two grades of FRP bars
- Two test methods for Glass Transition Temperature
- Uses “Mean” value for Transverse Shear and Bond Strength
- Bond strength limit increased to 1900 psi
- ...

Previous ASTM D7957

- Only for GFRP bars
- For straight bars and stirrups
- Provides property limits for different sizes
- Provides required specimen size and length
- Specifying test methods
- Includes 1 grade of FRP

Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement



- Only for GFRP bars
- For straight bars and stirrups
- Provides property limits for different sizes
- Provides required specimen size and length
- Specifying test methods

TABLE 1 Property Limits and Test Methods for Qualification^A

| Property | Limit | Test Method |
|---|--|--|
| Mean Glass Transition Temperature | Midpoint temperature ≥ 100 °C [212 °F] | ASTM E1356 |
| Mean Degree of Cure | ≥ 95 % | ASTM E2160 |
| Mean Measured Cross-Sectional Area | Table 3 | ASTM D7205/D7205M, subsection 11.2.5.1 |
| Guaranteed ^B Ultimate Tensile Force | Table 3 | ASTM D7205/D7205M |
| Mean Tensile Modulus of Elasticity | $\geq 44,800$ MPa [6 500 000 psi] | ASTM D7205/D7205M |
| Mean Ultimate Tensile Strain | ≥ 1.1 % | ASTM D7205/D7205M |
| Guaranteed ^B Transverse Shear Strength | ≥ 131 MPa [19 000 psi] | ASTM D7617/D7617M |
| Guaranteed ^B Bond Strength | ≥ 7.6 MPa [1100 psi] | ASTM D7913/D7913M |
| Mean Moisture Absorption to Saturation | ≤ 1.0 % to saturation at 50 °C [122 °F] | ASTM D570, subsection 7.4 |
| Mean Alkaline Resistance | ≥ 80 % of initial mean ultimate tensile force following 90 days at 60 °C [140 °F] | ASTM D7705/D7705M, Procedure A |
| Guaranteed ^B Ultimate Tensile Force of Bent Portion of Bar | ≥ 60 % of the values in Table 3 | ASTM D7914/D7914M |

^AFor the determination of the mean and guaranteed properties, at least 24 samples shall be obtained in groups of eight or more from three or more different production lots. The mean and guaranteed properties shall satisfy the limits.

^BGuaranteed property is defined in 3.2.5.

TABLE 2 Property Limits and Test Methods for Quality Control and Certification^{A,B}

| Property | Limit | Test Method |
|-------------------------------|---|--|
| Fiber Mass Content | ≥ 70 % | ASTM D2584 or ASTM D3171 |
| Glass Transition Temperature | Midpoint temperature ≥ 100 °C [212 °F] | ASTM E1356 |
| Degree of Cure | ≥ 95 % | ASTM E2160 |
| Measured Cross-Sectional Area | Table 3 | ASTM D7205/D7205M, subsection 11.2.5.1 |
| Ultimate Tensile Force | Table 3 | ASTM D7205/D7205M |
| Tensile Modulus of Elasticity | $\geq 44 800$ MPa [6 500 000 psi] | ASTM D7205/D7205M |
| Ultimate Tensile Strain | ≥ 1.1 % | ASTM D7205/D7205M |
| Moisture Absorption in 24 h | ≤ 0.25 % in 24 h at 50 °C [122 °F] | ASTM D570, subsection 7.4 |

^AFor the determination of each of the property limits, five random samples shall be obtained from each production lot. Each individual sample shall satisfy the property limits.

^BFor bent bars, the tests are performed on the straight portion of the bars.

Acceptance Criteria for Fiber-Reinforced Polymer (FRP) Bars for Internal Reinforcement of Concrete Members

- For GFRP and BFRP bars
- Test methods, property limits, and specimen size are similar to ASTM D7957
- For straight bars, stirrups, and ties
- Considering accelerated environmental exposures
- Evaluating FRP under exposure to fire

TABLE 1—SUMMARY OF TESTS FOR FRP BARS*

| PROPERTY | TEST OR CALCULATION METHOD |
|---|---|
| Fiber mass content | ASTM D2584 |
| Mean glass transition temperature | ASTM E1640 (DMA) ASTM E1356 (DSC) |
| Mean total enthalpy of polymerization (resin) | ASTM E2160 |
| Mean degree of cure | ASTM D2160 |
| Mean measured cross-sectional area | ASTM D7205/D7205M ASTM D792 |
| Guaranteed ultimate tensile force | ASTM D7205/D7205M |
| Tensile modulus of elasticity | |
| Guaranteed transverse shear strength (+ to the Bar) | ASTM D7617 |
| Mean horizontal shear strength (of straight bar)** | ASTM D4475 |
| Guaranteed bond strength | ASTM D7913 |
| Mean moisture absorption (24 hours) | ASTM D570 |
| Mean moisture absorption to saturation | |
| Mean alkaline resistance | ASTM D7705 (A or B) |
| Guaranteed ultimate tensile force of bent portion of bar | ASTM D7914 |
| Tensile force of straight portion of bent bar, or mean horizontal shear strength (// to the bar) of straight portion of bent bar, and fiber mass content of bend portion | ASTM D7205 or ASTM D4475 and ASTM D2584 |

* Specimen selection and number of specimens shall comply with ASTM D7957.

** Test applicable to straight portion of bent bars, refer to Section 4.4.4.

Acceptance Criteria for Fiber-Reinforced Polymer (FRP) Bars and Meshes for Internal Reinforcement of Non-structural Concrete Members

- GFRP and BFRP bars & meshes
- For temperature and shrinkage reinforcement in non-structural members
- Provides requirements for meshes
- For solid continuous circular cross-sections
- Test methods, property limits, and No. of specimens similar to ASTM D7957
- Concrete footings, plain concrete, and slabs-on-grade

TABLE 1 — SUMMARY OF REQUIRED TESTS FOR FRP BARS AND MESHES

| PROPERTY TO REPORT | TEST OR CALCULATION METHOD | NUMBER OF TEST SPECIMENS |
|--|---|--|
| Physical | | |
| Fiber Content | ASTM D2584 | For each bar/mesh size: total 24 (8 from 3 separate lots) |
| Mean Glass Transition Temperature | ASTM E1640 (DMA) ASTM E1356 (DSC) | Total 15: 5 from smallest, median and largest bar/mesh size each |
| Mean Total Enthalpy of Polymerization (Resin) | ASTM E2160 | For the neat resin system: total 3 |
| Mean Degree of Cure | ASTM E2160 | For each bar/mesh size: total 9 (3 from 3 separate lots) |
| Mean Measured Cross-Sectional Area | ASTM D7205 ASTM D792 | For each bar/mesh size: total 24 (8 from 3 separate lots) |
| Permissible Variation in Diameter (Mesh only) | Section 4.1.6 | For each mesh size: total 24 (8 from 3 separate lots) |
| Mean Moisture Absorption to Saturation | ASTM D570 or ASTM D5229 | For each bar/mesh size: total 24 (8 from 3 separate lots) |
| Mechanical | | |
| Guaranteed Ultimate Tensile Force | ASTM D7205 | For each bar/mesh size: total 24 (8 from 3 separate lots) |
| Mean Tensile Modulus of Elasticity | ASTM D7205 | |
| Guaranteed Transverse Shear Strength (+ to the Bar) | ASTM D7617 | |
| Mean Horizontal (Inter-laminar) Shear Strength | ASTM D4475 | |
| Mean Ultimate Tensile Strain | Tensile Strength to Modulus of Elasticity Ratio | |
| Guaranteed Bond Strength (Bar only) | ASTM D7913 | Total 15 (5 from smallest, median and largest bar size each) |
| Mean Shear Strength of Mesh Intersection (Mesh only) | ASTM A1064 | For each mesh size: total 24 (8 from 3 separate lots) |
| Shrinkage Cracking | ASTM C1579 | For each bar/mesh size: total 9 (3 from 3 separate lots) |

Specification for Fiber-Reinforced Polymers

- For GFRP, CFRP, AFRP, and BFRP bars or bars part of a grid
- Provides property limits based on fiber types and bar sizes
- Test methods for cross-sectional area and tensile properties are based on CSA S806
- Considers three grades of FRP
- No. of test specimens is different
- Solid circular or rectangular cross-section
- Limitations for hybrid FRP

Table 7
Determining mechanical properties of FRPs
 (See Clauses 4.2.2, 10.1, 10.2, and 11.2.2 and Table 8.)

| Property | Number and details of test specimens required | | | Provided if needed for special applications† | Test method |
|---|--|---|---|--|---|
| | Qualification test | Manufacturer's QC | Owner's QA | | |
| Cross-sectional area* | 24 tests from 3 production lots for all bar sizes | 5 tests for each bar size per lot used on project | 5 tests for each bar size per lot used on project | 5 tests | CSA S806, Annex A The submerged section of bar shall retain all surface bonding mechanisms such as sand coating, undulations, etc. |
| Longitudinal tensile strength for bars* | 24 tests from 3 production lots for 10, 13, 15, 20, 25, and 32 mm or only the sizes manufactured by the supplier | 5 tests for each bar size per lot used on project | 5 tests for each bar size per lot used on project | N/A | CSA S806, Annex C |
| Longitudinal tensile modulus and ultimate elongation* | 24 tests from 3 production lots for 10, 13, 15, 20, 25, and 32 mm or only the sizes manufactured by the supplier | 5 tests for each bar size per lot used on project | 5 tests for each bar size per lot used on project | N/A | CSA S806, Annex C |

Carbon, glass, basalt and aramid FRP bars as reinforcement of structural elements



- For CFRP, GFRP, BFRP, & AFRP bars
- Based on ISO standards
- Performance of FRP bars is assessed based on essential characteristics
- No. of specimen is different from ASTM.
- Bars can be straight or bent into different shapes, circular or flat.
- ISO is more conservative than ASTM to estimate ultimate tensile force.

ANNEX A SUMMARY OF TEST SAMPLES

| | Essential characteristic | Minimum number of specimens | |
|------------|--------------------------------------|--|--|
| MECHANICAL | Tensile strength | For each bar size: total 25 (5 from 5 separate lots) | |
| | Tensile modulus of elasticity | | |
| | Ultimate strain | | |
| | Compressive strength | For each bar size: total 15 (3 from 5 separate lots) | |
| | Compressive modulus | | |
| | Bond strength by pull-out testing | Concrete strength C20/25 | Total 15 (5 from smallest, median and largest bar size each) |
| | | Concrete strength C50/60 | Total 5 (max diameter) |
| | Bond strength under high temperature | Total 15 (5 from smallest, median and largest bar size each) | |
| | Transverse shear strength | For each bar size: total 25 (5 from 5 separate lots) | |
| | Interlaminar shear strength | For each bar size: total 25 (5 from 5 separate lots) | |
| | Tensile Fatigue | At least 6 for each of the three test levels (18 from smallest, median and largest bar size each). | |
| | Creep failure | At least 3 for each of the 5 test levels (for smallest, median and largest bar size each). | |
| | Flexural tensile properties | At least 3 for each of the three test conditions (9 for smallest, median and largest bar size each). | |
| | Long-term relaxation | Total 15 (5 from smallest, median and largest bar size each) | |
| | Strength of FRP bent bars | Total 15 (5 from smallest, median and largest bar size each) | |

Fiber Reinforced Polymer (FRP) Reinforcing Bars



- For BFRP, GFRP, & CFRP bars
- Test methods are similar to ASTM
- Values of the maximum cross-sectional area slightly different from ASTM
- Vinyl ester or epoxy resin
- Number of test specimens are different
- Bent portion specimen sizes have requirements

Table 932-7
Physical and Mechanical Property Requirements for Straight FRP Reinforcing Bars

| Property | Test Method | Requirement | Specimens per LOT |
|--|---|---|-------------------|
| Fiber Mass Fraction | ASTM D2584 or ASTM D3171 | ≥70% | 5 ^a |
| Short-Term Moisture Absorption | ASTM D570, Procedure 7.1; 24 hours immersion at 122°F | ≤0.25% | 5 ^m |
| Long-Term Moisture Absorption | ASTM D570, Procedure 7.4; immersion to full saturation at 122°F | ≤1.0% | 5 ^m |
| Glass Transition Temperature (T _g) | ASTM D7028 (DMA) or ASTM E1356 (DSC; T _m)/ASTM D3418 (DSC; T _{mg}) | ≥230°F ≥212°F | 3 ^m |
| Total Enthalpy of Polymerization (Resin) | ASTM E2160 | Identify the resin system used for each bar size and report the average value of three replicates for each system | — |
| Degree of Cure | ASTM E2160 | ≥95% of Total polymerization enthalpy | 3 ^a |
| Measured Cross-Sectional Area | ASTM D7205 | Within the range listed in Table 932-6 | 10 ^a |
| Guaranteed Tensile Load ^a | | ≥ Value listed in Table 932-6 | |
| Tensile Modulus | | ≥ 6,500 ksi for BFRP and GFRP ≥ 18,000 ksi for CFRP (Type I) Bars ≥ 22,400 ksi for CFRP (Type II) Strands | |
| Alkali Resistance with Load | ASTM D7705; Procedure B, set sustained load to 30% of value in Table 932-6; 3 months test duration, followed by tensile strength per ASTM D7205 | ≥ 70% Tensile strength retention for BFRP & GFRP ≥ 95% Tensile Strength for Retention | 5 ^m |
| Transverse Shear Strength | ASTM D7617 | >22 ksi | 5 ^a |
| Horizontal Shear Strength ^p | ASTM D4475 | >5.5 ksi | 5 ^a |
| Bond Strength to Concrete, Block Pull-Out | ACI 440.3R, Method B.3 or ASTM D7913 | >1.1 ksi for Bars >0.9 for Strands | 5 ^m |

a – Guaranteed tensile load shall be equal to the average test result from all three lots minus three standard deviations. n – Tests shall be conducted for all bar sizes produced.
m – Tests shall be conducted for the smallest, median, and largest bar size produced.
p – Only required for BFRP bars.

Tensile modulus of elasticity (an example)

| ASTM D7957 | | | | | AC454 | | | | |
|------------------------------------|--------------------------------|--|------------------------|--|------------------------------------|--------------------------------|---|--|---|
| Equivalent Characteristic | Reference Standard/Test Method | No. of Specimens | Limit criteria | Comments / differences | Equivalent Characteristic | Reference Standard/Test Method | No. of Specimens | Limit criteria | Comments / differences |
| Mean Tensile Modulus of Elasticity | ASTM D7205/D7205M | At least 24 samples shall be obtained in groups of eight or more from three or more different productions lots | > 44800 MPa [6500 Ksi] | 1-Just covers GFRP 2- Straight bars and stirrups 3- Provides required specimens size and length 4-Specifies test method | Mean Tensile Modulus of Elasticity | ASTM D7205/D7205M | For each bar size: at least 24 samples in groups of 8 (or more) from 3 (or more) different production lots. | Table 1 of ASTM D7957 (>= 44800 MPa or 6500 ksi) | 1- Covers GFRP and FRP bars 2- Test methods, property limits, and specimen size are similar to ASTM D7957 3- Straight bars, stirrups, and ties 4- Considers accelerated environmental exposures 5- Evaluates FRP under exposure to fire |

The final harmonized document will include:

- Reference standard/test method
- Reference section/clause
- No. of specimens
- Limit criteria
- Comments/differences

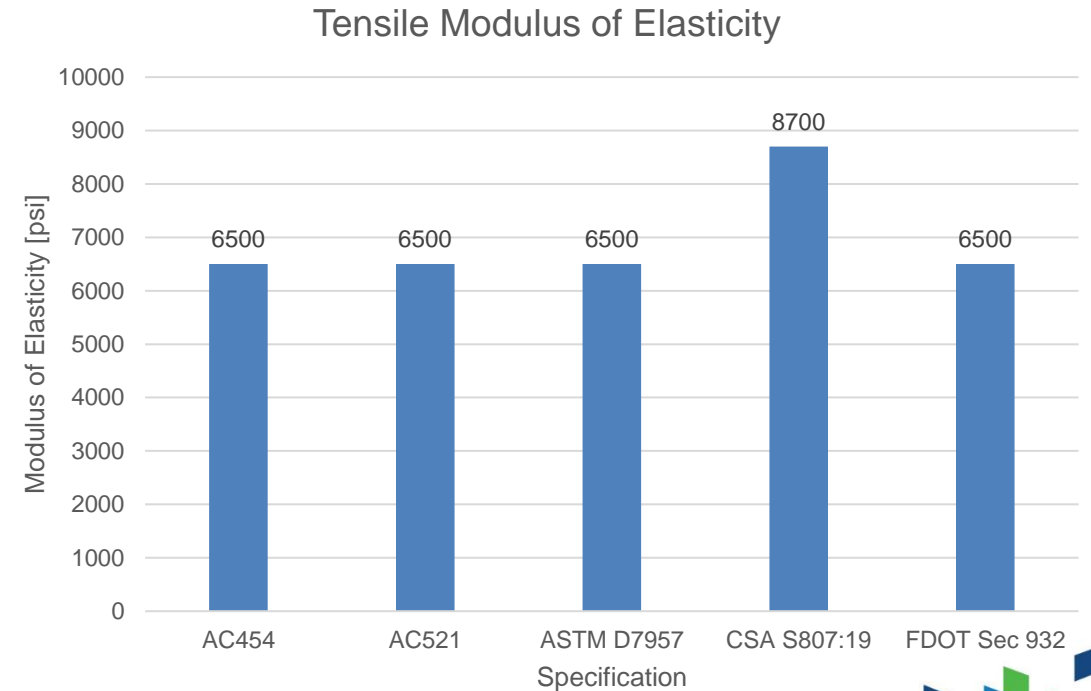
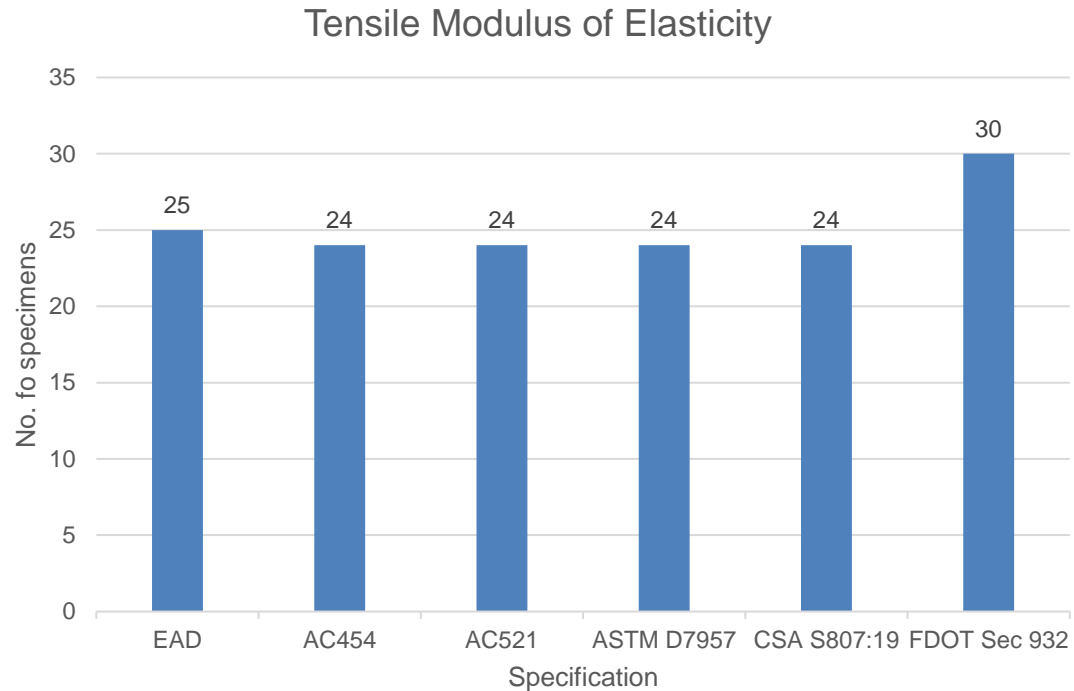
Tensile modulus of elasticity (an example)

| AC521 | | | | | CSA S807:19 | | | | |
|------------------------------------|--------------------------------|-----------------------------------|--|-------------------------|------------------------------|--------------------------------|---------------------------------|---|--|
| Equivalent Characteristic | Reference Standard/Test Method | No. of Specimens | Limit criteria | Comments / differences | Equivalent Characteristic | Reference Standard/Test Method | No. of Specimens | Limit criteria | Comments / differences |
| Mean Tensile Modulus of Elasticity | ASTM D7205/D7205M | Total 24 (8 from 3 separate lots) | Shall be equal to or greater than 6500 ksi (44.8 GPa). | 1- Covers GFRP and BFRP | Longitudinal tensile modulus | CSA S806, Annex C | 24 tests from 3 production lots | Minimum values defined in Tables 5 and 6. Maximum values shall not be larger than the next highest grade. | 1- Covers GFRP, BFRP, CFRP, and AFRP 2- Including Grades I & II |

| EAD | | | | | FDOT 932-3 | | | | |
|-------------------------------|--------------------------------|--|----------------|--|---------------------------|--------------------------------|-------------------------------|--|------------------------------|
| Essential characteristic | Reference Standard/Test Method | No. of Specimens | Limit Criteria | Comments / differences | Equivalent Characteristic | Reference Standard/Test Method | No. of Specimens | Limit criteria | Comments / differences |
| Tensile modulus of elasticity | ISO 10406-1 Clause 6 | For each bar size: total 15 (5 from 3 separate lots) | None | 1- Covers GFRP, BFRP, CFRP, and AFRP 2- Length of specimen not less than 300 mm and 40 times nominal diameter 3- Rate of loading shall be 0,5 % to 1,5 % strain per minute | Tensile Modulus | ASTM D7205 | 10 specimens per lot (3 lots) | ≥6,500 ksi - BFRP & GFRP ≥18,000 ksi - CRFP Type I Bars ≥22,400 ksi - CRFP Type II Strands | 1- COV Shall be less than 6% |

Example

Tensile modulus of elasticity



***Note:** The EAD has not mentioned limits for Tensile Modulus of Elasticity.

Conclusions

- Most of the properties have an equivalent method on each spec.
- Different standards on FRP materials and several points in common were found.
- Main differences are number, size of specimens, and loading rates.
- ASTM, AC454, & AC521 are more economical (in terms of No. of specimens for product qualification)
- Providing a key document for manufacturers and designers based on the harmonization of these standards that satisfies reqs. of all specs.

Thanks



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