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Specification for fiber-reinforced polymers (FRP): FRP (Bars, Grids and sheet)

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Foreword

GCC Standardization Organization (GSO) is a regional Organization which consists of the National Standards Bodies of GCC member States. One of GSO main functions is to issue Gulf Standards /Technical regulations through specialized technical committees (TCs).

GSO through the technical program of committee TC No. (TC06) "GSO Technical Committee for Construction and Building Materials" has prepared this Standard. The Draft Standard has been prepared by State of Kuwait . The draft Standard has been prepared based on relevant ADMO, International and National foreign Standards and references.

This standard has been approved as a Gulf Standard by GSO Technical Council in its meeting No.(37), held on 10-11/3/1437h (21-22/12/2015) .

Specification for fiber-reinforced polymers (FRP): FRP (Bars, Grids and sheet)

1. Scope

1.1 This standard covers the manufacturing process requirements of fibre-reinforced Polymer (FRP) bars or bars that are part of a grid for use in non-prestressed internal Reinforcement of concrete components of structures (e.g. bridges, buildings, and marine structures).

1.2 This standard covers FRPs comprised of
(a) Glass, carbon, or aramid fibres; and
(b) isophthalic polyester, vinylester, or epoxy resins.

1.3 This standard covers FRP bars having nominally circular or square cross-section.

1.4 This standard does not include FRP bars made of more than one type of fibre.

1.5 In this standard, FRPs are classified on the basis of their fibers, strength, stiffness, and durability.

1.6 In this standard, "shall' is used to express a requirement, i.e., a provision that the user is obliged to satisfy in order to comply with the standard; "should" is used to express a recommendation or that which is advised but not required; and “may” is used to express an option or that which is permissible within the limits of the standard . Notes accompanying a clause is to separate from the text explanatory or informative material. Notes to tables and figures are considered part of the table or figure and may be written as requirements.
Annexes are designated normative (mandatory) or informative (non-mandatory) to define their application.

2. Reference documents

This Standard refers to the following publications, and where such reference is made, it shall be to the edition listed below, including all amendments published thereto.

CSA (Canadian Standard Association)
CAN/CSA-ISO 9001-08
Quality Management Systems-Requirements
CAN/CSA-S806-02(R2007)
Design and construction of building components with fibre-reinforced polymers
ACI (American Concrete Institute)
440.3R-04
Guide Test Methods for Fibre-Reinforced Polymers (FRPs) for reinforcing or Strengthening Concrete Structures
B.3- Test Method for Bond Strength of FRP Bars y Pullout Testing
B.4 -Test Method for Transverse Shear Strength of FRB Bars
B.5- Test Method for Strength of FRP Bent Bars and Stirrups at Bend Locations
B.6- Accelerated Test Method for Alkali Resistance of FRP Bars
B.7- Test Method for Tensile Fatigue of FRP Bars
B.8- Test Method for Creep Rupture of FRP Bars

3. Definitions

The following definitions shall apply in this Standard:
Additve – a material added to another material to improve the properties of latter or to improve the manufacturing process.

Bar – a non – prestressed FRP element, with nominally rectangular or circular cross-section, used to reinforce a concrete component.

Note: *The bar can be an independent bar or part of a grid.*

Batch – see production lot.

Coefficient of variation (cov) – the ratio f the standard deviation of the mean.
Creep – the time – dependent change in the length of a component under nearly constant stress.

Cure – the process of causing an irreversible change in the properties of a thermosetting resin by chemical reaction.

Durability – the capability of a component, product, or structure to maintain its function for at least a specified period of time with appropriate maintenance.

Epoxy- a thermoset resin made of epichlorohydrin and bisphenol A or a similar compound.

Fibre content – see **fibre volume fraction**.

Fibre-reinforced polymer (FRP)-a fibre-reinforced composite with a polymeric matrix and continuous fibre reinforcement of aramd, carbon, or glass.

Fibre volume fraction- the ratio of the volume of fibers to the volume of fibre-reinforced composite.

Filler- an inert material added to the matrix to reduce the volume of polymer without significantly changing the properties of the FRP.

Glass transition temperature (Tg)-the midpoint of the temperature range over which an amorphous material changes from a brittle and vitreous state to a plastic state, or vice versa.

Grid- a prefabricated planar assembly consisting of bars in an orthogonal arrangement.

Isophthalic polyester resin- a thermosetting resin made with isophthalic acid and a monomer through glycol reaction.

Longitudinal axis--- the axis selected for coupon sampling and testing.

Low shrink /low profile additive--a special thermoplastic resin added to a thermosetting resin to reduce its shrinkage and to provide a smoother finish.

Manufacturer- a person ،or persons, representing the organization that manufactures the FRP.

Manufacturing---a process that includes the following methods:
(a)placing and arranging the fibres and fibre forms;
(b) Introducing the matrix into and around the fibres; and
(c) Activating the resin to produce acured FRP.

Matrix---a homogeneous polymer in which the fibre system of an FRP is embedded.

Mechanical properties---properties of a material related to the interaction between stresses and strains.

Owner---a person, or persons, having responsibility for and control of the structure in which the FRPs are used.

Owner's quality assurance tests---- tests that are conducted by the owner, AR an agent of the owner, to determine whether an individual production lot of materials conforms to the specifications of the owner.

Polymer--a substance consisting of molecules characterized by the repetition of one or more types of monomeric units.

Primary fibre—a fibre material added to the matrix that significantly controls the mechanical properties of the FRP.

Production lot---product manufactured from the same nominal raw materials under the same conditions.

***Note**: Typically, a production lot should begin and end every time a new set-up is made on the production line and/or each time the production lot number of any raw materials is changed.*

Physical properties ---properties of a material other than those related to chemical change and the interaction stresses and strains.

Pultrusion--the process of manufacturing FRPs by drawing resin-impregnated fibres through a die.

Qualification tests-a series of tests conducted under the supervision of independent qualified persons or organizations competent in the field in accordance with various standards conformance with this standard.

Quality control tests—a test, or series of tests, conducted by the manufacturer, or an agent of the manufacturer, to demonstrate the properties and the degree of uniformity to the requirements.

Resin---see **Matrix**

Secondary fibre---an inert the fibre material added to the matrix without significantly changing the properties of the FRP.

Ultimate tensile strength (UTS) ---- the mean strength.

Vinylester--a thermoset resin produced by reacting acrylic or methacrylic acid with an epoxy resin.

Void content --- the ratio of the volume of voids to the total volume of the FRP.

4. General requirements

4.1 Materials

4.1.1 General

Clause 4.1 specifies the constituent materials that may be used in fibre –

Reinforced polymers(FRPs)and the limits on additives and the fillers relative to the base resin content.

4.1.2 Polymers

The base polymer shall be 100% isophthalic polyester ,vinylester, or epoxy .Resins of the same type may be blended, but resins of different types shall not be blended.

4.1.3 Fibres

The following requirements shall apply to fibres:

(a) Only aramid, carbon, or glass fibres shall be used.

(b) Fibre treatments (sizings) shall be compatible with the resin used.

(c) Only continuous rovings or tows shall be used.

4.1.4 Fillers

Inorganic fillers and secondary fibers may be used, but their quantity shall not exceed 20%by weight of the base polymer resin specified in Clause 4.1.2.

4.1.5 Additives

4.1.5.1 General

Additives making up part of the cure system, or added for other reasons, maybe used but shall be limited as specified in Clauses 4.1.5.2 to 4.1.5.4 All additives shall be appropriate for the fibre and polymer resin used.

4.1.5.2 Diluents

Diluents(e.g., styrene) added to the base polymer at the time of production shall not exceed 10% by weight of the base polymer resin specified in Clause 4.1.2

4.1.5.3 Low –profile additives

Low –profile (shrink) additives shall not exceed 20% by weight of the base polymer resin specified in Clause 4.1.2.

4.1.5.4 Other additives

The following additives may be used:

a) Catalysts;
b) Coupling agents;
c) Fire retardants;
d) Foaming agents;
e) Hardeners;
f) Initiators;
g) Pigments;
h) Promoters;
i) Release agents;
j) UV agents; and
k) Wetting agents;

4.2 Manufacturing

4.2.1 Method

The method of manufacturing shall be an open or closed moulding process that produces a cured FRP.

4.2.2 Production Lot Size
The manufacturer shall define the production lot size for the production method used for the FRP(e.g.; by weight, area of cross-section , and linear measurement). The manufacturer shall record values for the amounts of materials used in each lot.

4.2.3 Production changes
If a production change is made to the constituent materials (e.g., resin , fiber type, additive, and filler) or manufacturing process (e.g. pultrusion , vacuum molding, and hand lay-up) of an FRP, new qualification tests shall be done for that product.

4.3 Quality control
The manufacturer shall maintain a formal quality control plan and make it available to the owner on demand.
***Note** : An example of a quality control plan is given in Annex C.*

5. Quality of work and finish
FRP bars and grids shall be uniform in diameter/size and free of defects that would be injurious to the mechanical and durability properties.
***Note**: Defects include exposed fibres, cracks, surface pitting, and discoloration.*

6. Handling and storage
Materials shall be handled and stored in accordance with the procedures specified in documents acceptable to the owner.

7. Packaging and marking
7.1 FRP bars and grads shall clearly marked to identify their designation in accordance with Table 1.
***Note:** See Annex B for on example of a marking system. This Standard aims to standardize this marking system in the long-term.*

7.2 In the case of bent bars, during manufacturing for a specific project, identification shall comply with the owner's requirements.

7.3 for delivery to the construction site, bars and grids shall be grouped and bundled according to the designation identified in Table 1 and tagged with the following information:
(a) Manufacture's symbol;
(b) Length of the bar or area of grid; and
(c) Production lot number.

FRPs shall be loaded, handled, and transported in such a manner so as to not cause damage to the bars or grids.

8. Classification of products

8.1 General

8.1.1 Individual FRP bars and bars in grids in grids shall be designated according to their fibers, minimum specified tensile strength, minimum specified modulus of elasticity, and durability as follows:

Xa-Eb-Dc
Where
X = aramid (A) carbon (C), or glass (G)

A = the tensile strength of the FRP (see Clause 8.2) Mpa
E = the modulus of elasticity. Gpa
B = the grade of the FRP (see Clause 8.3) MPa
D = durability
C = durability designation (see Clause 8.4)
***Note** : for example, a glass FRP bar with a minimum tensile strength of 600 MPa , minimum modulus of 40 GPa and moderate durability would be designated as G600-El-D2.*
The designated diameters and cross-sectional areas of individual FRP bars and bars in FRP grids shall comply with Table 1. These requirements shall apply only to bars with Table 1 . These requirements shall apply only to bars with nominally circular and square cross-sections.

8.1.2 In drawings,
(a) Individual FRP bars shall be identified by an uppercase letter followed by the designated bar diameter in mm:

i. A for aramid
ii. C for carbon; or
iii. G for glass.

Note: for example, a glass FRP bars with a diameter of 15 mm would be identified as G15.

(b) Bars in FRP grids shall use the same denomination specified in item (a) in each of two orthogonal directions, followed by @s, whereas is the centre-to- centre spacing of the bars in mm in the direction under consideration.
***Note:** for example, the 10 × 10 mm longitudinal bars at 200 mm centre-to- centre an a carbon grid would be specified as C10@200.*

8.2 Classification based on tensile strength
The minimum specified tensile strength, specified in Table 1 shall be taken as the mean value of the test strengths multiplied by f_t.

Where

$$F_t = \frac{1-1.645v}{1+\frac{1.645v}{\sqrt{n}}}$$

where
v = the coefficient of variation (COV) of the tensile strength obtained from qualification tests
n = the number of samples
***Note:** Table 1 also gives the minimum tensile strength for all glass FRP bars and grids and part of the carbon FRP bars and grids (diameters 6 to 20 mm).*

8.3 Classification based on minimum modulus of elasticity

Depending on the values of their longitudinal modulus of elasticity, E , individual FRP bars and bars in a grid shall be classified as Grade 1 , 11, or lll (see Table 2).
Note: Grade FRPs have the lowest value of E and Grade lll FRPs have the have the highest value of E.
When the COV of the modulus of elasticity is smaller than 5 % the minimum specified modulus of elasticity (see Table 2) shall be taken as the mean value of the test modulus; alternatively E may be taken as the mean value of test modulus multiplied by $F_{e,}$

Where

$$F_e = \frac{1-1.645v}{1+\frac{1.645v}{\sqrt{n}}}$$

Where :
V = the COV of the modulus of elasticity obtained from qualification tests
n = the number of samples.

8.4 Classification based on durability

Depending on the physical and durability properties defined in Table 4
(a) FRPs with high durability shall be classified as D1;
(b) FRPs with moderate durability shall be classified as D2 ;
(c) FRPs made with vinylester and epoxy shall be classified as D1 or D2 ; and
(d) FRPs made with polyester matrix shall be classified as D2.

9. Inspection

9.1 Quality control during manufacturing

9.1.1 The manufacturer shall have in place a standardized quality control program that includes routine sampling, inspection, and testing of all constituent materials and FRPs.
9.1.2 The manufacturer shall keep detailed records on
(a) Quantity of resin and fibers used during each production run;
(b) Mixture proportions;
(c) Identification of all components;
(d)ambient temperature;
(e) Humidity; and
(f) Other factors affecting the resin properties.

9.1.3 Test reports (See Clause 11) shall be made available by the manufacturer for production lot produced for a specific project.
***Note** : An example of a manufacturer's quality control plan in Annex C.*

9.2 Owner's quality assurance testing and inspection

The owner may complete quality assurance testing and inspection of manufacturing facilities to confirm that the FRPs being furnished for a specific project comply with this standard and that the properties of the FRPs upon receipt match those reported in the qualification tests and the manufacturer's quality control test reports. The manufacturer shall afford the owner unhindered access to the manufacturing facilities and assist the owner in carrying out the inspection shall be conducted an a manner that will not unnecessarily interfere with the operation of the facilities.

9.3 Qualification testing

Qualification testing shall be performed on the mechanical , physical , and durability properties relating to both short – and long – term performance of FRPs. For qualification testing to be valid , there shall be quality control of the manufacturing process to ensure consistent quality. This quality control process shall be confirmed by third party organizations or qualified persons acceptable to the owners.
Note : Examples of third party organizations include CAN/CSA- ISO 9001 or a person qualified as Certified as Certified Composites Technician (instructor)by the American Composite Manufacturers Association, or if preapproved by the owner.

10. Determination of properties

10.1 Number of samples

To determine the mechanical, physical and durability properties for qualification testing , the minimum number of samples shall be 24 with a minimum of eight samples from each of three different production lots.

To determine the mechanical, physical and durability properties for the manufacturer's quality control test and for the owner's quality assurance tests, the minimum number of samples shall be five form each production lot. The production lot shall be rejected it a test value of any sample is beyond the specified limit in Tables 1, 3 and 4.

10.2 Mechanical properties

Mechanical properties of FRPs shall be determined as specified in Table 3. The limits of the various properties shall be as specified in Table 3. When the number of test samples is greater than 20, one test result may be beyond the specified limit.

Note: Same of the bent shapes are not conducive to performing tests (e.g. bent bars of small sizes). Samples can be produced at the same time as the bent bars using the same resin production lot and procedure as that of the production lot produced for a specific project.

10.3 Physical and durability properties

Physical and durability properties of straight, bent, and other FRP bard shall be determined as specified in Table 4. The limits of the various properties shall be as specified in Table 4. Most of the test methods and limits of various properties specified in Table 4 are for straight bars; when test methods and limits are not available for bent and other bars, alternative test methods and limits may be used as long as they are consistent with the test methods and limits specified in Table 4. When the number of test samples is greater than 20 , one test result may be beyond the specified limit.

11. Reporting

11.1 Confirmation and test reports

11.1.1 Confirmation

The manufacturer shall confirm to the owner that each production lot has been manufactured in accordance with this standard and that all qualification tests have been conducted.

11.1.2 Test report

For each tested bar and grid, the test report shall contain the information specified in Clause 11.3 The manufacturer shall sign and date all test reports and shall provide two copies of the signed test report at the time the material is delivered.

11.2 Reports

11.2.1 Qualification reports

The manufacturer shall confirm that all the qualification tests have been carried out in accordance with this Standard and that requirements of this standard have been met.

11.2.2 Mechanical property reports

For the relevant mechanical properties specified in Table 3 a complete report on the tests conducted in accordance with Table 3 shall be provided.

11.2.3 Physical and durability property reports

For the relevant physical and durability properties specified in Table 4 a complete report on the tests conducted in accordance with Table 4 shall be provided.

11.3 Manufactacturer's quality control tests

11.3.1 General

The manufacturer shall confirm to the owner that each production lot for every product has been manufactured in accordance with this standard. for each tested bar , the test report shall contain the information specified in clauses 11.3.2 to 11.3.5 The manufacturer shall sign and date all test reports and shall provide two copies of the signed test report at the time the material is delivered. The manufacturer shall retain individual test results for at least 5 years after the date of manufacturer and shall provide this data if requested by the owner.

11.3.2 Materials

The manufacturer's quality control test report shall include the following information on materials:

(a) Bar diameter and grade supplied;
(b) type of resin;
(c) primary fiber type ; and
(d) Fiber content by volume for primary and secondary fibred separately.

11.3.3 Production

The manufacturer's quality control test report shall include the following information on production:

(a) type of manufacturing process used (e.g. ,pultrusion);
(b) the identification of a production lot ;
Note: *for example. a production lot can be identified by a change by a change in the additives supplier.*
(c) Total linear metres produced in each production lot ; and
(d) The date of beginning and end of production for each production lot of material.

11.3.4 Product characterization

The manufacturer's quality control test report shall include the following information on characterization:

(a) Number of samples tested;
(b) The result of every test and their average;
(c) The standard deviation;

(d) Minimum tensile strength , if applicable (see Clause 8.2) ;
(e) Mode of failure , if applicable;
(f) Any deviations from the standard test method; and
(g) A statement explaining whether the FRP tested meets the requirements of this standard for each property measured.

11.3.5 Test set-up

The manufacturer's quality control test report shall include the following information on test set – up, if applicable:

(a) Details of the apparatus used to perform tests, capacity of the test machine and date of calibration ;
(b) The type of instrumentation used to perform the tests for tensile modulus of elasticity ; and
(c) Lengths of the samples, the free length, and anchor length used.

Table 1
Designation of FRP individual bars and bars in a grid
(See Claus 7.1, 7.3, 8.1.1 m 10.1, and B.1 and Tables 3 and 4)

Fibre	Designated diameter of bar with circular cross-section or width of bar with nominally square cross-section , mm	Nominal cross-sectional area (mm^2)	Minimum specified tensile strength , MPa	Designation
Aramid	6	32	*	Aa-Eb-Dc
	8	50	*	
	10	71	*	
	13	129	*	
	15	199	*	
	20	284	*	
	22	387	*	
	25	510	*	
	30	645	*	
	32	819	*	
	36	1006	*	
Carbon	6	32	1450	Ca-Eb-Dc
	8	50	1350	
	10	71	1300	
	13	129	1170	
	15	199	1100	
	20	284	1100	
	22	387	*	
	25	510	*	
	30	645	*	
	32	819	*	
	36	1006	*	
Glass	6	32	750	Ca-Eb-Dc
	8	50	750	
	10	71	750	
	13	129	650	
	15	199	650	
	20	284	600	
	22	387	550	
	25	510	550	
	30	645	500	
	32	819	450	
	36	1006	450	

* To be provided by the manufacture**.**
Note: The nominal cross-sectional area is not based on designated diameter of width. These values should be used for the determination of properties

Table 2
Grades of FRP bars and grids corresponding to their
Minimum modulus of elasticity . GPa
(See Clause 8.3 and Table 3)

Designation	Grade 1		Grade II		Grade III	
	Individual Bars	Bars in a grid	Individual Bars	Bars in a grid	Individual Bars	Bars in a grid
AFRP	50	40	70	60	90	80
CFRP	80	70	110	100	140	130
GFRP	40	30	50	40	60	50

Table 3
Determining mechanical properties of FRPs
(all bar sizes for qualification and manufacturer's QC)
(See Clauses 10.1 Clauses 10.2 and 11.2.2)

Property	No. and details of test specimens required					
	Qualification	Manufacturer's QC	Owner's QA	Provided at request	Test method	Specified Limits
Cross-sectional area	N/A	N/A	N/A	5 tests	CAN/CSA-S806, Annex A	N/A
Longitudinal tensile strength for bars	24 tests from 3 production lots 10,13,15,20,25 and 32 mm or only the sizes manufactured by the supplier	5 tests for each bar size used on project	5 tests for each bar size used on project	N/A	ASTM D 7205/D7205 M; or CAN/CSA-S806, Annex C	Minimum values defined in Table 1
Longitudinal tensile modulus and ultimate elongation	24 tests from 3 production lots 10,13,15,20,25 and 32 mm or only the sizes manufactured by the supplier	5 tests for each bar size used on project	5 tests for each bar size used on project	N/A	ASTM D 7205/D7205 M; or CAN/CSA-S806, Annex C	Minimum values tensile modulus specified in Table 2 ; the ultimate elongation shall be not less than 1.2 %

Table 3 (Continued)

Property	No. and details of test specimens required					
	Qualification test	Manufacturer's QC	Owner's QA	Provided at request	Test method	Specified Limits
Bond strength	24 tests from 3 production lots 10,15,20 and 25 mm or only the sizes manufactured by the supplier	N/A	5 tests for each bar size used on project	N/A	ACI 440.3R, Test Method B.3	≥ 8 MPa
Transverse Shear strength (if applicable)	24 tests from 3 production lots 15,20,25,32 and 36 mm or only the sizes manufactured by the supplier	5 tests for each bar size used on project	5 tests for each bar size used on project	N/A	ACI 440.3R, Test Method B.4	≥ 160 MPa
Strength of FRP bent bars and stirrups and bend locations (if applicable)	24 tests from 3 production lots 10,13,15 and 20 mm or only the sizes manufactured by the supplier	N/A	5 tests for each bar size used on project	N/A	ACI 440.3R, Test Method B.5; or CAN/CSA-S806,Annex E	Minimum strength at the bend shall be at least 45% of the minimum strength of straight FRP bars manufactured by the same process as the bent bars
Longitudinal tensile properties at cold temperature	24 tests from 3 production lots 10,15 and 20 mm or only the sizes manufactured by the supplier	N/A	N/A	N/A	Specimens shall be conditioned according to ASTM D618 until – 40 ° C the temperature should remain constant during the tensile test conducted according to ASTM D7205/D7205M or CAN/CSA-S80D, Annex C	As compared to properties at room temperature the loss of properties at specified low temperatures shall be less than 5%
Flexural Strength and modulus	N/A	N/A	N/A	5 tests all bar sizes	ASTM D790; or ASTM D4476	N/A
Compressive strength and modulus	N/A	N/A	N/A	5 tests on bar size requested	ASTM D695; or ASTM D3410/D3410M	N/A

***Note** : Some of the bent shapes are not conducive to performing tests (e.g. bent bars of small sizes) Test specimens can be produced at the same time as the bent bars using the same resin production lot and procedure as that of the production lot produced for a specific project.*

Table 4
Determining physical and durability properties of FRPs
(All sizes for qualification and manufacturer's QC)
(See Clauses 8.4, 10.1, 10.3 and 11.2.3)

Property	No. and details of test specimens required					
	Qualification test	Manufacturer's QC	Owner's QA	Provided at request	Test method	Specified Limits
Fibre content	9 tests from 3 production lots 10,15,20 and 25 mm or only the sizes manufactured by the supplier	3 tests for bar size used on project	3 tests for bar size used on project	N/A	The relevant of the following : (a) bars with glass fibre : ASTM D2584 or ASTM E1131; (b) bars with carbon fiber: ASTM E1131; or (c) bars with aramid fiber : no method is available; provide the theoretical content	Fibre volume Fraction $\geq$ 55 % for FRP bars ; Fibre volume Fraction $\geq$ 35 % for FRP Grids ; for ASTM D2584 , glass fibre Fraction $\geq$ 70 % by weight
Longitudinal coefficient of thermal expansion	N/A	N/A	N/A	3 tests on bar size requested	ASTM E831 at temperature = 0.1-0.3 T_{gi} or ASTM D696	N/A
Transverse coefficient of thermal expansion	9 tests from 3 production lots 10,15,20 and 25 mm or only the sizes manufactured by the supplier	N/A	3 tests for each bar size used on project	N/A	ASTM E831 at temperature = 0.1-0.3 T_{gi} or ASTM D696	Transverse coefficient of thermal expansion $\leq 40 \times 10^{-6\,\circ c-1}$
Density	N/A	N/A	N/A	3 tests on bar size requested	ASTM D792	N/A
Void content	9 tests * from 3 production lots 10,15,20 and 25 mm or only the sizes manufactured by the supplier	3 tests for each bar size used on project	3 tests for each bar size used on project	N/A	ASTM D2734 (do not use for hollow fibers); or ASTM D5117	$\leq$ 1% (ASTM D2734); Or if no voids or longitudinal cracks are observed after 15 min of the ASTM D5117 test. this criterion shall be deemed to have been met

Water absorption	15 tests [t] from 3 production lots 10,15,20 and 25 mm or only the sizes manufactured by the supplier	5 tests [t] for each bar size used on project	5 tests [t] for each bar size used on project	N/A	ASTM D570	For long – term immersion till full saturation : ≤ 1% For D2 FRP bars and grids; <0.75% for D1 bars and grids; for immersion (24h): ≤ 0.35% for D1 FRP bars and grids; ≤ 0.25 % For D1 bars and grids
Cure ration	15 tests [s] from 3 production lots 10,15,20 and 25 mm or only the sizes manufactured by the supplier	5 tests for each bar size used on project	5 tests for each bar size used on project	N/A	Test method described in Annex A	≥ 93 % FOR D2 bars and grids; > 95 % for D1 bars and grids
Glass transition temperature	15 tests from 3 production lots 10,15,20 and 25 mm or only the sizes manufactured by the supplier	5 tests for each bar size used on project	5 tests for each bar size used on project	N/A	ASTM E1356; ASTM D3418; or ASTM E1640 (samples to determine glass transition temperature shall be saturated in accordance with ASTM D570 water absorption tests , except that the temperature of 50 ° C shall be used for conditioning)	For D2 bars and grids : DMA : 90 ° C ; DSC: 80 ° C for D1 bars and grids : DMA: 110 ° C DSC: 100 ° C
Fouier transform infrared spectroscopy (FTIR)	N/A	N/A	N/A	5 tests on size requested	ASTM E1252; or ASTM E168	N/A
Energy dispersive X-ray (EDX)	N/A	N/A	N/A	5 tests on size requested	ASTM E1508	N/A
Alkali resistance in high p^H solution (without load)	24 tests [**] from 3 production lots 10,13,15,20,25 and 32 mm or only the sizes manufactured by the supplier	N/A	N/A	N/A	ACI 440.3R, Test Method B.6; or CAN/CSA – S806 , Annex O (test duration :3 months)	Tensile capacity retention ≥ 70 % UTS for D 2 bars and grids : tensile capacity

						retention ≥ 80 % UTS for D 1 bars and grids
Alkali resistance in high p^H solution (with load)	24 tests [ff] from 3 production lots	N/A	N/A	N/A	ACI 440.3R, Test Method B.6; or CAN/CSA – S806 , Annex O (The sustained tensile stress should be set to induce a tensile strain equal to 3000 micro-strain; test duration:3 months)	Tensile capacity retention ≥ 60 % UTS for D 2 bars and grids : tensile capacity retention ≥ 70 % UTS for D 1 bars and grids
Creep rupture strength	24 tests from 3 production lots ; tests on one size bar	N/A	N/A	N/A	ACI 440.3R, Test Method B.8; or CAN/CSA – S806 , Annex l	Creep rupture strength : ≥ 35 % UTS (Glass) ; ≥ 75 % UTS (Carbon) ; ≥ 45% UTS (Aramid)
Creep	N/A	N/A	N/A	tests on one size bar	ACI 440.3R, Test Method B.8; or CAN/CSA – S806 , Annex l (two sustained tensile stress levels to be used : 20 and 40 % of UTS for CFRP ; 30 and 50 % for AFRP for a test duration of 10000h)	Report Creep strain values at 1000 h ; 3000 h ; and 10000 h
Fatigue strength	N/A	N/A	N/A	tests on one size bar	ACI 440.3R, Test Method B.7; or CAN/CSA – S806 , Annex L	Fatigue strength at 2 million cycles: > 35 % UTS (Carbon) ; > 45 % UTS (Aramid only for applications in which fatigue is a consideration)

** the density and content of the component in the FRP should be reported by the manufacturer to determine the void content; for example X% of fibres (density 2.54) and Y% matrix (density 1.11) the matrix is the phase containing the resin and the additives (fillers , etc.) the density of the matrix can be different than the resin density.*

F The qualification test shall be conducted in accordance with procedure 7.4 Long-Term immersion. Of ASTM D 570 except that a water temperature of 50 ° C shall be used for straight and bars and grids.
ǂ These tests shall be conducted in accordance with procedure 7.1 Twenty-four hour immersion, of. ASTM D 570 except that a water temperature of 50 ° C shall be used for both straight and bent bars and grids.
(a) The neat resin content (by mass) should be reported by the manufacture or supplier.
(b) The value of enthalpy of polymerization of the neat resin used an the FRP should be reported by the manufacturer.
These two values are requested to determine the cure ration the DSC.
*** If these conditions are satisfied by durability tests with load on a particular size bar these tests are not required for that bar.*
ff these tests can be carried out on alternative size bars , as specified in Table 1 , and results averaged between the two tested bars.

Annex A (normative)
Test |Method for determination of cure ratio for FRP bars by DSC

***Note** : This Annex is normative (mandatory) part of this Standard*

A.1 Scope

This Test Method describes the procedure used to determine the cure ratio of fibre – reinforced polymers (FRP) in the form of rods using differential scanning calorimetry (DSC).

A.2 Principle

When a thermoset resin matrix cures, an exothermic reaction (polymerization) occurs in a specific temperature range. The enthalpy of polymerization (i.e., the amount of energy created during the reaction) is constant for each type of resin matrix formulation. When a DSC measurement is performed on a non-polymerized resin matrix, a broad period peak corresponding to the enthalpy of polymerization, H_{total} occurs in the aforementioned temperature rang. At the end of the scanning (when the heat flow signal reaches the baseline) the resin matrix is fully cured and H_{total} is a calculated.

***Note** : The resin matrix is the blend of resin, hardeners, fillers used to wet the fibres during the manufacturing process.*

To determine the cure ratio of FRP material, the following information is needed:

(a) The resin matrix content of the material;
(b) The enthalpy of polymerization of the resin matrix ; and
(c) The residual enthalpy of polymerization of the material.

A.3 Apparatus

The DSC shall be capable of heating spectating at a controlled rate between 10 ° C /min and 20 ° C /min and of automatically the differential heat flow. The calorimeter shall have a computerized interface managing automatic axis scales and display. The calculation is obtained through programmed procedures using the algorithms of the interface.

A.4 Sampling

FRP rods and specimens shall be kept indoors at room temperature before testing. The number of specimens shall be not less than three. Since core of the FRP rods could be cured less than the outer part, the specimens shall be taken in the material using a saw equipped with a diamond blade. The sawing shall be slow enough So that the specimen not heated appreciably.

A.5 Procedure

A.5.1 Summary

The procedure consists of three steps:

(a) The first step is the determination of the resin matrix content of the material by weight (see clause A.5.2) If it has been provided by the manufacturer or if it has already been measured by a previous test, the procedure may be started at the second step.
(b) The second step is the determination of the enthalpy of the resin matrix of the material (see clause A.5.3) If it has been provided by the manufacturer or if it is measured by a previous test, the procedure may be started at the third step.
(c) The third step is the determination of the residual enthalpy of polymerization of the material (see clause A.5.4).

A.5.2 Determination of the resin matrix content

A.5.2.1 the resin matrix content of a glass FRP rod shall be determined either by thermogravimetry (TGA) (see clause A.5.2.2) or by ignition loss (see clause A.5.2.3) for a carbon FRP rod ignition loss shall be carried out under an inert atmosphere to avoid oxidizing the fibres. The specimen shall be representative of the core of the FRP rod and any form of coating shall be discarded before sampling the FRP material.

A.5.2.2 The thermogravimetry method shall be as follows:

(a) Cut the samples form the core of the FRP rod ensuring their weight is between 20 and 75 mg.
(b) Measure the weight loss. W_m , at 550 ° C.
(c) Correct the calculated resin matrix content by adding the weight ratio W_f of inorganic fillers found in the material (data issued form the manufacture of the FRP rods).
(d) Calculate the resin matrix content W_n using the following equation:

$W_r = W_m + W_f$

If the FRP material is free of inorganic filler, then $W_r = W_m$

A.5.2.3 The ignition loss method shall be as follows:

i. Measure the initial weight of the specimen P_u to an accuracy of $\pm$ 1 %.
ii. Heat the specimen between 500 ° C for 30 min or until all carbonaceous material has disappeared.
iii. Cool the specimen to room temperature in a room desiccator.
iv. Thoroughly wash the fibres with acetone and stir to remove filler particles from the surface of the fibres.
v. Discard the acetone and repeat item (d) until the fibers bathe in clear acetone.
vi. Once the fibers are cleaned, evaporate the acetone in an oven set to 70 ° C before weighing the specimen P_f to an accuracy of $\pm$ 1 %.
vii. Calculate the resin matrix content , W_t using the following equation:

$$W_r = 100 - \frac{p_f}{p_t}$$

A.5.3 Determination of the enthalpy of polymerization of the resin

The enthalpy of polymerization of the resin shall be determined as follows:

(a) Using a balance capable of weighing to an accuracy of $\pm$ 0.1 mg, weigh a sample of 5 to 10 mg of the liquid resin matrix used in the FRP material in a clean metal pan that is hermetically sealed to ensure there is no off gassing.
(b) Place the pan on the appropriate heating element of the calorimeter. Ensure the element is a clean and the surface even for intimate thermal exchanges with the pan.
(c) Set up the heating rate of the calorimeter between 10 ° C/min and 20 ° C/min choose the start and stop temperatures of the cycle to highlight the heat flow baseline before and after the exothermal reaction.
(d) Set up the purging gas (nitrogen) flow between 50 ML/min and 80 ML/min.
(e) Start and record the cycle.
(f) Using the analysis interface of the calorimeter, calculate the enthalpy of polymerization of the resin matrix, ΔH_{total} (l/g) . Include the exothermal peak in the integration limits. Choose the start and stop temperatures of integration as the beginning and end of the exothermic reaction, defined as a deviation from the baseline of the heat flow (see figure A.1).

A.5.4 Determination of the residual enthalpy of polymerization

The residual enthalpy of polymerization shall be determined as follows:

(a) Using a balance capable of weighing to an accuracy of ± 0.1 mg weigh a sample of 5 to 75 mg of the specimen , P_s .

(b) Calculate the net weight , P_r of the resin matrix using the following equation:
$P_r = P_s \times w_r$
Where w_r is determined as per Clause A.5.2
Use p_r as the weight input in the interface of the calorimeter

(c) Place the sample in the pan and execute items © to (f) of Clause A.5.3.

(d) Using the analysis interface of the calorimeter, calculate the residual enthalpy of polymerization of the specimen , ΔH_R (l/g) . Include the exothermal peak in the integration limits. (see figure A.2). Choose the start and stop temperatures of the integration as the beginning and the end of the reaction exothermic, defined as a deviation from the baseline of the heat flow.

Note: *A fully cured specimen will show no residual reaction. In such a case, the value of the residual enthalpy is considered to be equal to O l/g (see figure A.3)*

A.6 Calculation

The cure ration shall be calculated using the following equation:

$$C\ \% = \frac{\Delta H_{total} - \Delta H_R}{\Delta H_{totol}} \times 100$$

Where:
C% - cure ratio, %
ΔH_{total} = enthalpy of polymerization of the resin matrix l/g
ΔH_R = residual enthalpy of polymerization of the specimen, l/g
Note : The interface of the calorimeter may automatically calculate C% when using this function, the previously determined ΔH_{total} should be used as an input to the interface.

A.7 Report

The report shall include the following information:

(a) Complete identification and description of the material tested:
  i. bar diameter and grade supplied;
  ii. type of resins;
  iii. primary fibre type;
  iv. secondary fibre type , if any;
  v. fibre content as determined by Clause A.5.2;
  vi. enthalpy of polymerization as determined by Clause A.5.3; and
  vii. production lot number;

(b) description of the calorimeter and test parameters used for the tests:
  i. brand name and model;
  ii. type of the sensor head; and
  iii. heating rate;

(c) value of the cure ratio (C%) calculated as per Clause A.6 for each specimen and the average value; and

(d) Thermograms obtained from Clause A.5.4.

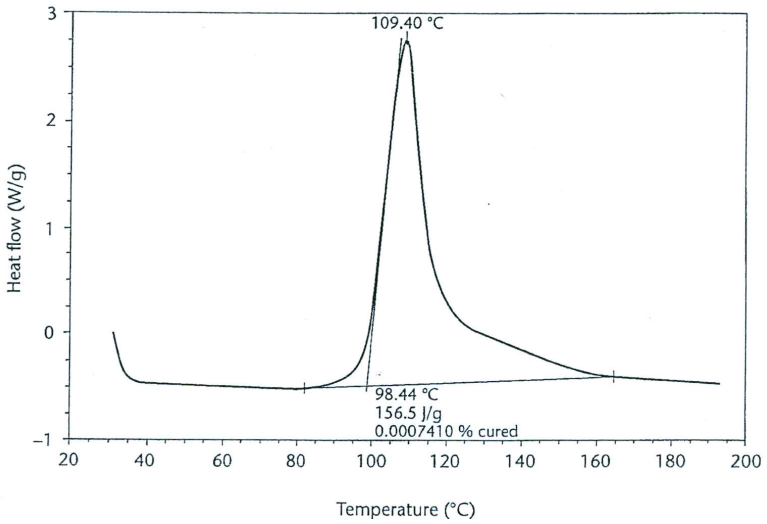

Figure A.1
Exothermal peak of resin matrix
(See Clause A.5.3)

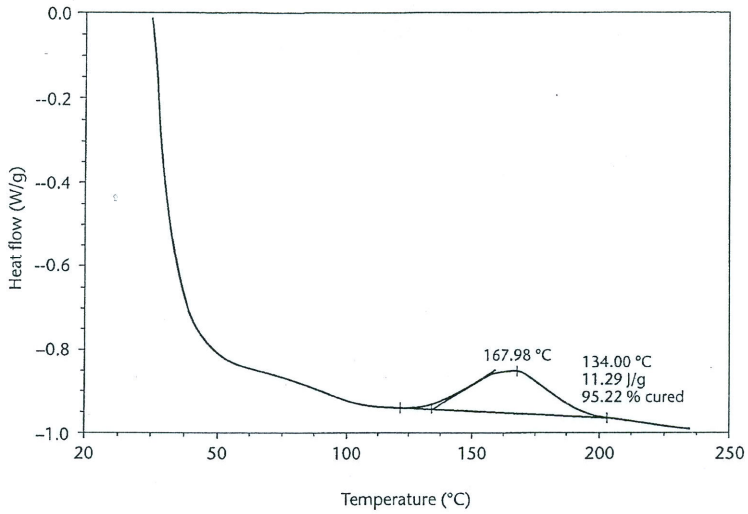

Figure A.2
Exothermal peak showing a residual enthalpy of polymerization
(See Clause A.5.4)

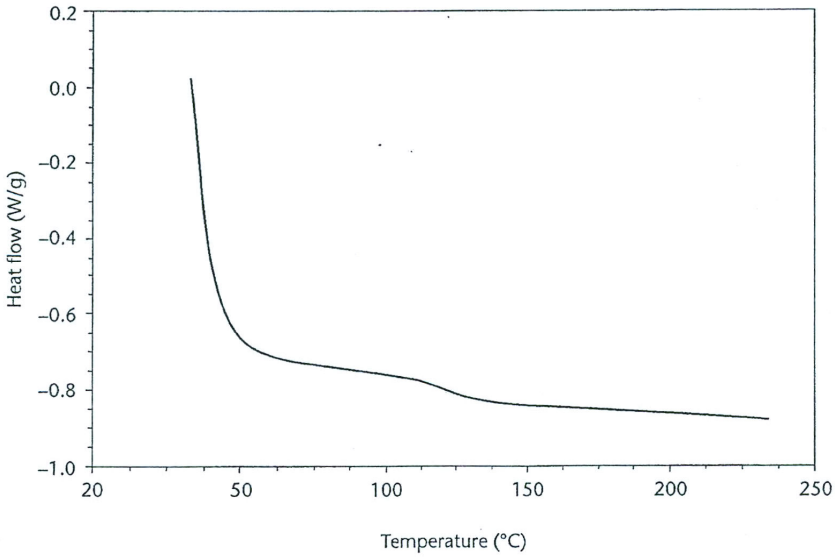

Figure A.3
Fully cured specimen showing no residual reaction
(See Clause A.5.4)

Annex (informative)
Example of manufacturer's quality control plan
Note : This Annex is not a mandatory part of this Standard

Operation	Determination of control	Documents	Test equipment	Inspection frequency	Specified requirements	Responsible	Records frequency	Record
1.	Raw material inspection	PG-10-01* PG-10-01*	PG-10-01*	PG-10-01*	PG-10-01*	QC	PG-10-01*	PG-10-01*
2.	Inspection of roving count	Mix recipe FO-09-31*	Manual count	Beginning halfway then shift and as needed	10-20 : ± 10% 21-50 : ± 5% 51 : ± 4%	Operator	100%	O-09-01 *
3.	Mix Recording	Mix recipe FO-09-31 *	Weigh scales	Each mix	See tolerance on mix recipe	Operator	100%	O-09-02 *
4.	Pull speed inspection	Mix recipe FO-09-31 *	Stop watch, tape measure , and/or inspection chart	Beginning halfway then shift and as needed	As per mix recipe	Operator	100%	O-09-01 *
5.	Length inspection	Mix recipe FO-09-31 * and part drawings	Tape measure or jig	100 %	As per drawing and client specifications	Operator	Nil	Nil
6.	Visual Inspection	IT-09-09-01 *	Visual	100 %	Sample parts	Operator	Nil	Nil
7.	Hardness	IT-09-09-02 *	Barcol	Each mix	Minimum hardness 40	Operator	100 %	O-09-02 *
8.	% of cure	Statistics (historical)	DSC	1 test/lot	To be established	QC	100 %	O-09-53 *

Operation	Determination of control	Documents	Test equipment	Inspection frequency	Specified requirements	Responsible	Records frequency	Record
9.	Glass %	Statistics (historical)	Muffle furnace	3 tests/lot Random	See SPC To be established	QC	100 %	O-09-53 *
10.	Surface prep.	N/A	Visual	Each rod	Complete sanding with on lustre	Operator	Nil	Nil
11.	Sand coating	IT-09-09-13 *	Visual	Each rod	Uniform coating of sand	Operator	Nil	Nil
12.	Linear weight	Statistics (historical)	Weigh scale	3 tests/lot	See SPC To be established	QC	100 %	O-09-53 *
13.	Tensile test (strength modulus)	ACI 440.3R	External Lab	5 tests/lot	According to ACI 440.3R SPC To be established	QC	100 %	External report
14.	Cut	Production card FO-09-30 *	Tape measure	100 %	$\pm$ 6.35 mm	Operator	Nil	Nil
15.	Packaging and final inspection	CLIENT SPECS	Visual	100 %	Client specs	QC	Nil	Nil

* Manufacturer's own standards.

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D618-08

Standard Practice for Conditioning Plastics for Testing
D695-08

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D696-08

Standard Test Method for Coefficient of Linear Thermal Expansion of Plastics Between -30°C and 30°C with a Vitreous Silica Dilatometer

D790-07e1
Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials

D792-08
Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastic by Displacement

D2584-08
Standard Test Method for Ignition Loss of Cured Reinforced Resins

D2734-09
Standard Test Method for Void Content of Reinforced Plastics

D3410/D3410M-03(2008)
Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials with Unsupported Gage Section by Shear Loading.

D3418-08
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