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Standard Specification for Carbon Fiber Thermoset Polymer Matrix Composite Core (CFC) for use in Overhead Electrical Conductors[1]

This standard is issued under the fixed designation B987/B987M; 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 reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers carbon fiber reinforced thermoset matrix composite core strength members for use in reinforcing or supporting overhead electrical conductors.

1.2 This specification covers carbon fiber core diameters from 0.180 to 0.500 in. [4.57 to 12.7 mm], inclusive.

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 The following documents of the issue in effect on date of material purchase form a part of this specification to the extent referenced herein.

2.2 *ASTM Standards:*[2]

D792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement

D3916 Test Method for Tensile Properties of Pultruded Glass-Fiber-Reinforced Plastic Rod

D5117 Test Method for Dye Penetration of Solid Fiberglass Reinforced Pultruded Stock

D5423 Specification for Forced-Convection Laboratory Ovens for Evaluation of Electrical Insulation

D7028 Test Method for Glass Transition Temperature (DMA Tg) of Polymer Matrix Composites by Dynamic Mechanical Analysis (DMA)

E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *CFC (carbon fiber composite core/thermoset matrix), n*—consisting of continuous carbon fiber tows held together by a polymer matrix where the polymer is specifically a thermosetting polymer. The carbon fiber composite core is protected with a galvanic protection barrier layer.

3.1.2 *core, n*—see **CFC**.

3.1.3 *design validation tests, n*—the purpose of these tests is to verify the suitability of the CFC design, materials, and method of manufacturing to meet the requirements in this specification. To ensure compliance with this specification, these tests shall be performed on composite core samples at the time of manufacture and be repeated whenever the design, manufacturing method or the materials have changed. The results of design validation tests are to be recorded and are considered valid for the whole class of CFC.

3.1.4 *DMA (dynamic mechanical analyzer), n*—a device that measures the T_g of a polymer matrix or composite by subjecting the sample to an oscillating stress while heating the specimen at a given heating rate.

3.1.5 *galvanic protection barrier layer, n*—a layer that prevents the carbon fiber of the composite core from making contact with the aluminum strands used in the conductor.

3.1.6 *glass transition temperature (T_g), n*—a temperature where the polymer matrix properties transition from a hard, glassy state to a rubbery state. This temperature is defined to be the temperature at which a curve defined by plotting loss modulus versus temperature reaches its peak value.

3.1.7 *loss modulus, n*—represents the viscous portion of the polymer matrix response to the simultaneous application of heat and stress; is proportional to the energy dissipated as heat by the composite sample in the DMA and reaches a maximum value when the polymer matrix in the composite transitions from the glassy to the rubbery state (T_g).

[1] This specification is under the jurisdiction of ASTM Committee B01 on Electrical Conductors and is the direct responsibility of Subcommittee B01.07 on Conductors of Light Metals.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.1.8 *lot, n*—unless otherwise specified in the contract or order, a lot shall consist of all coils of CFC of the same diameter, produced from one continuous run of a fiber setup, submitted for inspection at the same time.

3.1.9 *matrix volume fraction, n*—the amount of matrix resin relative to fiber in a composite core. The matrix volume fraction is calculated by subtracting the area of the glass and carbon fibers from the total area of the part and then dividing by the total area of the part.

3.1.10 *polymer matrix, n*—a high molecular weight organic material consisting of repeating chemical structures.

3.1.11 *production unit, n*—a reel, spool, or other package of CFC that represents a single usable length.

3.1.12 *routine tests, n*—tests that are performed by the manufacturer, and are intended to prove conformance to the specific requirements.

3.1.13 *sample, n*—a length of composite core removed from the start or end of a CFC lot, and considered to have properties representative of the lot.

3.1.14 *specimen, n*—a length of composite core taken from a lot of CFC for testing purposes.

3.1.15 *tow, n*—a bundle, containing multiple fibers. Tow sizes range from 1 K (1000 fibers per bundle) to 50 K (50 000 fibers per bundle).

3.1.16 *rated* T_g—the minimum T_g value guaranteed by the supplier of the CFC.

3.2 *Product Code*—Defines the strength grade for product produced to this specification: Standard Strength (Code CFC1); High Strength (Code CFC2); and Extra High Strength (Code CFC3).

4. Classification

4.1 CFC is furnished in grades, either, standard designated CFC1, high strength designated CFC2, or extra high strength designated as CFC3 as specified, in conformance with the requirements of Sections 9 – 19, and meets the minimum requirements shown in Table 2. (see Explanatory Note 1).

5. Ordering Information

5.1 Orders for material under this specification shall include the following information:

5.1.1 Quantity and lengths of each size,

5.1.2 CFC diameter in inches or millimeters (Section 12),

5.1.3 Grade (either standard strength, high strength, or extra high strength),

5.1.4 Certification (Section 23),

5.1.5 Test report, if required (Section 23),

5.1.6 Package type (Section 24), and

5.1.7 Order example: Five (5) lengths of 24 000 ft [7300 m] each, 0.375 in. [9.53 mm] CFC, high strength grade, packaged onto wood nonreturnable reels, with certified test report.

6. Materials and Manufacture

6.1 The CFC shall consist of carbon fibers of suitable type that are combined with a suitable heat resistant thermoset polymer matrix, and encased in a galvanic protection barrier layer.

6.1.1 The galvanic protection barrier shall meet the requirements set forth in this specification including thickness, minimum bending diameter, and dye penetrant after bending.

6.2 The CFC shall meet the requirements set forth in this specification, including tensile strength, glass transition temperature (T_g) and minimum bending diameter.

7. Classes of CFC

7.1 The classes of CFC products shall be designated by the individual manufacturer and are designs that meet the specified strength grade, and are further defined as having cores with the following properties:

7.1.1 Meet the specified grade of strength.

7.1.2 The area ratio of carbon fiber plus matrix resin to galvanic protection layer is held within ±10 %.

7.1.3 The nominal matrix volume fraction is held within ±3 % in a given strength grade of CFC.

7.1.4 Use the same thermoset polymer matrix resin (including any fillers that are added to the polymer matrix) and same galvanic protection system (including any fillers).

7.1.5 Have a core diameter within ±15 % of the baseline diameter used for design validation tests (see Explanatory Note 2).

8. Test Classifications and Number of Tests and Retests

8.1 Test requirements are classified as either design validation tests or routine tests as indicated in Table 1.

TABLE 1 Design Validation and Routine Test Classifications

Test	Design Validation Test	Routine Test
Tensile Test	X	X
Glass Transition Temperature	X	X
Density	X	X
Dimensions	X	X
Heat Exposure	X	
Heat/Stress Test	X	
Bending Test	X	
Dye Penetrant after Bending Test	X	
Tensile Test after Bending Test	X	
Galvanic Protection Barrier Layer Thickness Test	X	X

8.2 *Design Validation Tests:*

8.2.1 The manufacturer shall provide to the purchaser test reports that support the CFC meets the requirements in these sections.

8.3 *Routine Tests:*

8.3.1 The manufacturer shall test each production lot using samples of core of sufficient length to run all testing and potential retests. The samples shall be taken from the start and end of the lot. Specimens from each sample shall be subjected to the required testing.

8.3.2 Upon request from purchaser, the manufacturer shall provide test reports that support the CFC meets the requirements in these sections.

8.4 *Retesting:*

TABLE 2 Physical Properties[A] (see Explanatory Note 1)

Property	Standard Strength Grade	High Strength Grade	Extra High Strength Grade
Ultimate Tensile Strength, min	250 ksi (1724 MPa)	310 ksi (2137 MPa)	375 ksi (2586 MPa)
Thermoset Polymer Matrix T_g, min	355°F [180°C] to 482°F [250°C]	355°F [180°C] to 482°F [250°C]	355°F [180°C] to 482°F [250°C]
Galvanic Layer Thickness, min	0.020 in. [0.50 mm]	0.020 in. [0.50 mm]	0.020 in. [0.50 mm]
Heat Exposure Capacity, min	95 % retention of rated tensile strength after 52 weeks of heat exposure	95 % retention of rated tensile strength after 52 weeks of heat exposure	95 % retention of rated tensile strength after 52 weeks of heat exposure
Bending Diameter, min	100 times diameter of CFC	50 times diameter of CFC	60 times diameter of CFC
Tensile Modulus[B]	16.2 Msi (111.7 GPa)	16.2 Msi (111.7 GPa)	21.2 Msi (146 GPa)
Thermal Expansion Coefficient[A]	manufacturer's nominal value ±5 %	manufacturer's nominal value ±5 %	manufacturer's nominal value ±5 %
Density at 20°C[A]	manufacturer's nominal value ±5 %	manufacturer's nominal value ±5 %	manufacturer's nominal value ±5 %
Maximum continuous operating temperature	heat exposure capability temperature temperature minus 35°F [20°C]	heat exposure capability temperature temperature minus 35°F [20°C]	heat exposure capability temperature temperature minus 35°F [20°C]

[A] Properties listed are before stranding values.
[B] For informational purposes only; see manufacturer for specific values.

8.4.1 Should one or more of the test specimens from the sample fail any of the tests specified, the nonconforming lot may be subjected to retesting (see Explanatory Note 3).

8.4.2 For retest purposes, three (3) additional specimens may be cut from the original samples from the nonconforming lot and tested for the property in which the original specimen from the lot failed to comply. Retests shall be performed using the area (start or end) of the lot that failed.

8.4.3 Should any of the retest specimens fail to meet the property specified, the lot represented by the test specimen shall be rejected.

9. Tensile Test

9.1 The CFC shall conform to the tensile strength requirements prescribed in Table 2.

9.2 Tensile tests on the finished CFC shall be conducted in accordance with the test methods and definitions section of Test Method D3916 (see Explanatory Note 4).

9.3 Calculation of tensile properties shall be based on the total cross sectional area of the core including the galvanic protection layer.

10. Glass Transition Temperature (T_g) Test

10.1 The glass transition temperature (T_g) shall be determined in accordance with Test Method D7028.

10.2 The CFC DMA specimen shall be machined into a rectangular shape that meets the requirements described in Test Method D7028.

10.3 Prior to measurement in the DMA, the specimens shall be preconditioned in accordance with Test Method D7028 to determine the dry T_g of the CFC. If the test specimen is within 2 weeks of the date of manufacture, the preconditioning may be reduced to 24 h at 221°F [105°C]. The specimen should be kept in a desiccator after preconditioning until testing, in accordance with Test Method D7028.

10.4 The peak in the loss modulus shall be used to determine the T_g (see Explanatory Note 5). The T_g value shall meet the requirements in Table 2.

11. Density

11.1 For the purpose of calculating mass per unit length, cross-sections and so forth, the actual density of the CFC shall be used in the determination. Density may be calculated from mass divided by volume or determined in accordance with Test Method D792.

12. Dimensions and Permissible Variations

12.1 The specified diameter of the CFC shall be expressed in decimal fractions of an inch to three decimal places, or in millimeters to two decimal places.

12.2 The diameter shall be the average of the largest and smallest measured diameters at the same cross section, rounded to the nearest 0.001 in. [0.01 mm] in accordance with the rounding method of Practice E29. Measurements shall be evenly spaced around the circumference of the cross section and a minimum of three measurements shall be taken.

12.3 The average diameter shall not differ by more than ±0.002 in. [0.05 mm] from the nominal diameter of the CFC.

13. Bending Test (See Explanatory Note 6)

13.1 Perform one test each on the start and end of the lot. Test specimens shall not fracture, including the galvanic protection barrier, when the CFC is wrapped 180 degrees around a cylindrical mandrel, and the force on the composite core is brought to 7.5 % of the composite core's rated tensile strength and held for 60 s.

13.1.1 The diameter of the cylindrical mandrel shall be equal to the minimum bending diameter in Table 2.

13.1.2 The section of the composite core that is in direct contact with the mandrel shall be marked so that after the bending test, this section can be easily identified to perform post testing analysis.

13.2 After completion of the bending test, the specimen shall be checked visually for fracturing, such as peeling of the fibers from the surface of the composite or a compressive type of failure. These types of fractures constitute failure.

13.3 If the specimens exhibit no visible fractures as described in 13.2, then the test specimens shall be subjected to the additional testing described in Sections 14 and 15.

14. Dye Penetrant Testing After Bending Test

14.1 One specimen taken from either of the two bending tests described in Section 13 shall be subjected to the dye penetrate test. Specimens for dye penetrate testing shall be taken from the part of the bending test specimen that was in direct contact with the mandrel (where the highest stresses would occur).

14.1.1 To detect the presence of any cracks that may have formed inside the composite core during the bending test, a minimum of five specimens shall be tested in accordance with Test Method D5117.

14.1.2 Specimens shall be placed in the dye penetrant bath in the vertical position, with the bottom surface submerged in the dye penetrant.

14.1.3 At the completion of the test, the presence of a few, very small, separated, wicking dots on the top surface would not constitute failure. When there are cracks in the CFC, the dye penetrate will wick quickly to the top surface. If the dots merge and the top surface of the CFC becomes covered in dye penetrant to a level of 50 % surface area or greater during the test period, then the sample has sustained damage and has failed the test.

15. Tensile Test After Bending Test

15.1 One specimen taken from either of the two bending tests described in Section 13, shall be subjected to the tensile test. The specimen for the tensile test shall be selected from the part of the sample that was in direct contact with the mandrel (where the highest stresses would occur), and subjected to the tensile testing as described in Section 9.

16. Heat Exposure Test

16.1 The purpose of this test is to determine the thermal endurance of polymer matrix resin system to resist degradation that can lead to loss of tensile strength. The test can be performed on any class of CFC that uses the same polymer matrix resin system to qualify the resin system for all classes.

16.2 Three CFC test specimens shall be exposed to a temperature equal to the rated T_g minus 10°F [5°C] for 52 weeks, in air circulating ovens that meet the specifications for Specification D5423 Type I forced air circulating ovens with no tensile stress applied.

16.3 The specimens shall be cut to a length that can be used for tensile testing after exposure, and all specimens in a test group shall be heat exposed at the same time.

16.4 The ends of the composite core specimens are allowed to extend 6 in. [150 mm] outside the oven walls.

16.5 At the end of the exposure time:

16.5.1 The CFC shall show no signs of cracking or wrinkling after exposure.

16.5.2 The CFC specimens shall be tensile tested in accordance with Section 9. The CFC shall retain 95 % of its rated tensile strength, in accordance with Table 2.

17. Heat/Stress Test

17.1 A specimen of CFC of sufficient length (see Explanatory Note 4) shall be subjected to a 1000 h test where the core is continuously loaded at 25 % of the rated tensile strength and continuously exposed to a temperature of the rated T_g minus 10°F [5°C].

17.2 The CFC shall be gripped according to the manufacturer's suggested gripping method.

17.3 At the end of the heat exposure the CFC shall be tested in accordance with Section 9. The CFC shall retain at least 95 % of its rated tensile strength, in accordance with Table 2.

17.4 The CFC shall show no signs of cracking or wrinkling after exposure.

18. Galvanic Protection Barrier Layer Thickness

18.1 Determination of the minimum thickness of the galvanic protection barrier layer shall be done by microscopic examination. Specimens shall be polished and the minimum thickness determined using an optical comparator.

18.1.1 The minimum thickness shall be at least 0.015 in. [0.38 mm].

19. Joints

19.1 No joints shall be made in the finished CFC (see Explanatory Note 7).

19.2 During the production run, splicing of the galvanic protection barrier is allowed, provided diameter specifications are maintained.

19.3 Splicing of the carbon fiber is not allowed; fibers are fully continuous over the entire length of the composite core.

20. Workmanship, Finish, and Appearance

20.1 The CFC shall be smooth, continuous and free of imperfections consistent with good manufacturing practices.

21. Inspection

21.1 The manufacturer shall be responsible for the performance of all inspection and test requirements specified, unless otherwise specified in the contract or purchase order.

21.2 All inspections and tests shall be made at the place of manufacture unless otherwise agreed upon between the manufacturer and the purchaser at the time of purchase.

21.3 The manufacturer shall afford the inspector representing the purchaser all reasonable access to manufacturer's facilities to satisfy him/her that the material is being furnished in accordance with this specification.

22. Rejection and Rehearing

22.1 Material that fails to conform to the requirements of this specification shall be rejected. Rejection should be reported to the producer or supplier promptly and in writing. In case of dissatisfaction with the results of the test, all parties may make a claim for a rehearing.

23. Certification

23.1 A producer's or supplier's certification shall be furnished to the purchaser showing that the material was manufactured, sampled, tested and inspected in accordance with this specification and is in accordance with the specification.

24. Packaging and Package Material

24.1 Package dimensions, kind of package (coils, reels or reel-less coils), and quantity (or length) of CFC in each package shall be agreed upon between the manufacturer and the purchaser. Length tolerances shall be 2 % unless otherwise specified by the purchaser.

24.2 Each package shall contain one continuous length of CFC.

24.3 There is a minimum bend radius required for the CFC to prevent damage. The drum diameter shall not be less than 36 in. [914 mm] for the reels used to transport the CFC.

24.4 The CFC wire shall be protected against damage in handling and shipping. A layer of paper shall be placed around the reel first. The paper is secured to the reel using a layer of 80 gauge stretch wrap. Finally, a protective sheet, (for example, ⅛ in. [3 mm] thick hardboard) shall be wrapped around the CFC on the reel and secured with plastic bands. A durable, weatherproof tag shall be securely attached to each package that displays the nominal core diameter, length, approximate weight, lot number and unit number (if necessary), CFC grade and purchaser's order number and the manufacturer's name and contact information.

25. Keywords

25.1 carbon fiber composite core; carbon fiber reinforced CFC; overhead conductors

EXPLANATORY NOTES

NOTE 1—The differences between the standard strength, high strength, and extra high strength grades are due to the types or amounts of the carbon fibers used in production of the CFC. The fiber types (different strength, modulus), and fiber volume fractions will lead to differences in characteristics such as density, tensile modulus and flexibility in the resulting composite. The manufacturer of the CFC must, at a minimum, meet the requirements set forth in this standard in order for the CFC to be qualified for supporting overhead conductors.

NOTE 2—If a new product configuration has a core diameter that deviates by more than 15 % from the baseline configuration the design validation tests shall be repeated using samples taken from the new core size.

NOTE 3—Should a failure occur, the manufacturer may retest if the cause of failure is suspected to be an error in the testing procedure, set-up, or factors other than non-conformance with the property being tested. For example, if a tensile test fails due to a break that occurs within the gripping region, the failure may be due to a gripping deficiency, and that would be a valid cause for retesting the lot.

NOTE 4—To sufficiently bring the CFC to its ultimate tensile strength, the purchaser should consult with the individual CFC manufacturer for the best gripping method to test and secure in the field or lab environment. The suggested length of the test specimen is 42 in. [1.1 m].

NOTE 5—The peak of the DMA loss modulus (T_g) that is used to determine if the CFC has achieved the appropriate amount of cure, differs from the method specified in Test Method D7028, which specifies the onset temperature be used. Due to the difficulty in choosing a low temperature point to determine the onset temperature, and to ensure consistency between different labs making measurements on the CFC, the loss modulus peak (T_g) is the preferred point in the DMA plot to determine if the minimum requirements specified in Section 10 have been met.

NOTE 6—The purpose of the bending test is to ensure the composite core has the appropriate flexibility. The flexibility will be dependent on the type and volume fraction of the fibers in the CFC. At installation, the composite core is subjected to both bending and tensile loads, often together. It is necessary to do this testing once to show that the CFC design has the appropriate flexibility to ensure typical installation practices will not cause a failure in the CFC.

NOTE 7—The maximum length of the composite core is primarily dictated by the length of the spools of carbon fiber that are being used as the reinforcement. The manufacturer shall specify to the customer the maximum length of composite core that can be produced with no joints in the carbon fiber in accordance with this standard.