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Standard Classification for Fiber Reinforced Carbon-Carbon Composite Structures¹

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1. Scope

1.1 This classification covers fiber reinforced carbon-carbon (C-C) composite structures (flat plates, rectangular bars, round rods, and tubes) manufactured specifically for structural components. The carbon-carbon composites consist of carbon/graphite fibers (from PAN, pitch, or rayon precursors) in a carbon/graphite matrix produced by liquid infiltration/pyrolysis or by chemical vapor infiltration, or both.

1.2 The classification system provides a means of identifying and organizing different C-C composites, based on the fiber type, architecture class, matrix densification, physical properties, and mechanical properties. The system provides a top-level identification system for grouping different types of C-C composites into different classes and provides a means of identifying the general structure and properties of a given C-C composite. It is meant to assist the ceramics community in developing, selecting, and using C-C composites with the appropriate composition, construction, and properties for a specific application.

1.3 The classification system produces a classification code for a given C-C composite, which shows the type of fiber, reinforcement architecture, matrix type, fiber volume fraction, density, porosity, and tensile strength and modulus (room temperature).

1.3.1 For example, Carbon-Carbon Composites Classification Code, C3-A2C-4C2*-32—classification of a carbon-carbon composite material/component (C3) with PAN based carbon fiber (A) in a 2D (2) fiber architecture with a CVI matrix (C), a fiber volume of 45 % (4), a bulk density of 1.5 g/cc (C), an open porosity less than 2 % (2*), an average ultimate tensile strength of 360 MPa (3), and an average tensile modulus of 35 GPa (2).

1.4 This classification system is a top level identification tool which uses a limited number of composite properties for high level classification. It is not meant to be a complete, detailed material specification, because it does not cover the full range of composition, architecture, physical, mechanical,

fabrication, and durability requirements commonly defined in a full design specification. Guide C1783 provides extensive and detailed direction and guidance in preparing a complete material specification for a given C-C composite component.

1.5 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.6 *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 ASTM Standards:²

- C242 Terminology of Ceramic Whitewares and Related Products
- C559 Test Method for Bulk Density by Physical Measurements of Manufactured Carbon and Graphite Articles
- C709 Terminology Relating to Manufactured Carbon and Graphite
- C838 Test Method for Bulk Density of As-Manufactured Carbon and Graphite Shapes
- C1039 Test Methods for Apparent Porosity, Apparent Specific Gravity, and Bulk Density of Graphite Electrodes
- C1198 Test Method for Dynamic Young's Modulus, Shear Modulus, and Poisson's Ratio for Advanced Ceramics by Sonic Resonance
- C1259 Test Method for Dynamic Young's Modulus, Shear Modulus, and Poisson's Ratio for Advanced Ceramics by Impulse Excitation of Vibration
- C1275 Test Method for Monotonic Tensile Behavior of Continuous Fiber-Reinforced Advanced Ceramics with Solid Rectangular Cross-Section Test Specimens at Ambient Temperature
- C1773 Test Method for Monotonic Axial Tensile Behavior of Continuous Fiber-Reinforced Advanced Ceramic Tubular Test Specimens at Ambient Temperature

¹ This classification is under the jurisdiction of ASTM Committee C28 on Advanced Ceramics and is the direct responsibility of Subcommittee C28.07 on Ceramic Matrix Composites.

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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.

- C1783** Guide for Development of Specifications for Fiber Reinforced Carbon-Carbon Composite Structures for Nuclear Applications
- D3878** Terminology for Composite Materials
- D4850** Terminology Relating to Fabrics and Fabric Test Methods
- D6507** Practice for Fiber Reinforcement Orientation Codes for Composite Materials
- E6** Terminology Relating to Methods of Mechanical Testing
- E111** Test Method for Young's Modulus, Tangent Modulus, and Chord Modulus
- E1309** Guide for Identification of Fiber-Reinforced Polymer-Matrix Composite Materials in Databases (Withdrawn 2015)³

3. Terminology

3.1 *General Definitions*—Many of the terms in this classification are defined in the terminology standards for graphite articles (**C709**), composite materials (**D3878**), fabrics and fabric test methods (**D4850**), and mechanical testing (**E6**).

3.1.1 *apparent porosity, n*—the volume fraction of all pores, voids, and channels within a solid mass that are interconnected with each other and communicate with the external surface, and thus are measurable by gas or liquid penetration. (Synonym – open porosity) **C242**

3.1.2 *braided fabric, n*—a woven structure produced by interlacing three or more ends of yarns in a manner such that the paths of the yarns are diagonal to the vertical axis of the fabric.

3.1.2.1 *Discussion*—Braided structures can have 2D or 3D architectures. **D4850**

3.1.3 *bulk density, n*—the mass of a unit volume of material including both permeable and impermeable voids. **C559**

3.1.4 *fabric, n—in textiles*, a planar structure consisting of yarns or fibers. **D4850**

3.1.5 *fiber, n*—a fibrous form of matter with an aspect ratio >10 and an effective diameter <1 mm. (Synonym – filament)

3.1.5.1 *Discussion*—A fiber/filament forms the basic element of fabrics and other textile structures. **D3878**

3.1.6 *fiber content/fraction (volume or weight), n*—the amount of fiber present in a composite, expressed either as a percent by weight or a percent by volume. **D3878**

3.1.7 *fiber preform, n*—a preshaped fibrous reinforcement, normally without matrix, but often containing a binder to facilitate manufacture, formed by distribution/weaving of fibers to the approximate contour and thickness of the finished part. **D3878**

3.1.8 *graphite, n*—allotropic crystalline form of the element carbon, occurring as a mineral, commonly consisting of a hexagonal array of carbon atoms (space group P 63/mmc) but also known in a rhombohedral form (space group R 3m). **C709**

3.1.9 *graphitization, n—in carbon and graphite technology*, the solid-state transformation of thermodynamically unstable

amorphous carbon into crystalline graphite by a high temperature thermal treatment in an inert atmosphere.

3.1.9.1 *Discussion*—The degree of graphitization is a measure of the extent of long-range 3D crystallographic order as determined by diffraction studies only. The degree of graphitization affects many properties significantly, such as thermal conductivity, electrical conductivity, strength, and stiffness.

3.1.9.2 *Discussion*—A common, but incorrect, use of the term graphitization is to indicate a process of thermal treatment of carbon materials at $T > 2200^{\circ}\text{C}$ regardless of any resultant crystallinity. The use of the term graphitization without reporting confirmation of long range three dimensional crystallographic order determined by diffraction studies should be avoided, as it can be misleading. **C709**

3.1.10 *hybrid, n—for composite materials*, containing at least two distinct types of matrix or reinforcement. Each matrix or reinforcement type can be distinct because of its (a) physical or mechanical properties, or both, (b) material form, or (c) chemical composition. **D3878**

3.1.11 *knitted fabric, n*—a fiber structure produced by interlooping one or more ends of yarn or comparable material. **D4850**

3.1.12 *laminated, n*—any fiber- or fabric-reinforced composite consisting of laminae (plies) with one or more orientations with respect to some reference direction. **D3878**

3.1.13 *lay-up, n*—a process or fabrication involving the placement of successive layers of materials in specified sequence and orientation. **D6507, E1309**

3.1.14 *matrix, n*—the continuous constituent of a composite material, which surrounds or engulfs the embedded reinforcement in the composite and acts as the load transfer mechanism between the discrete reinforcement elements. **D3878**

3.1.15 *ply, n—in 2D laminar composites*, the constituent single layer as used in fabricating, or occurring within, a composite structure. **D3878**

3.1.16 *tow, n—in fibrous composites*, a continuous, ordered assembly of essentially parallel, collimated continuous filaments, normally without twist. (Synonym – roving) **D3878**

3.1.17 *unidirectional composite, n*—any fiber reinforced composite with all fibers aligned in a single direction. **D3878**

3.1.18 *woven fabric, n*—a fabric structure produced by the interlacing, in a specific weave pattern, of tows or yarns oriented in two or more directions.

3.1.18.1 *Discussion*—There are a large variety of 2D weave styles, e.g., plain, satin, twill, basket, crowfoot, etc.

3.1.19 *yarn, n—in fibrous composites*, a continuous, ordered assembly of essentially parallel, collimated filaments, normally with twist, and of either discontinuous or continuous filaments.

3.1.19.1 *single yarn, n*—an end in which each filament follows the same twist. **D3878**

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *1D, 2D, and 3D reinforcement, n*—a description of the orientation and distribution of the reinforcing fibers and yarns in a composite.

3.2.1.1 *Discussion*—In a 1D structure, all of the fibers are

³ The last approved version of this historical standard is referenced on www.astm.org.

oriented in a single longitudinal (x) direction. In a 2D structure, all of the fibers lie in the x-y planes of the plate or bar or in the circumferential shells (axial and circumferential directions) of the rod or tube with no fibers aligned in the z or radial directions. In a 3D structure, the structure has fiber reinforcement in the x-y planes and in the z-direction in the plate or bar and in the axial, circumferential, and radial directions in a tube or rod.

3.2.2 *axial tensile strength, n*—for a composite tube or solid round rod, the tensile strength along the long axis of the rod or tube. For a composite flat plate or rectangular bar, the tensile strength along the primary structural axis/direction.

3.2.3 *carbon-carbon composite, n*—a ceramic matrix composite in which the reinforcing phase consists of continuous carbon/graphite filaments in the form of fiber, continuous yarn, or a woven or braided fabric contained within a continuous matrix of carbon/graphite. **(1-6)**⁴

3.2.4 *carbon fibers, n*—inorganic fibers with a primary (>90 %) elemental carbon composition. These fibers are produced by the high temperature pyrolysis of organic precursor fibers (commonly, polyacrylonitrile (PAN), pitch, and rayon) in an inert atmosphere. (Synonym – graphite fibers) **(7, 8)**

3.2.4.1 *Discussion*—The term carbon is often used interchangeably with "graphite"; however, carbon fibers and graphite fibers differ in the temperature at which the fibers are made and heat-treated, the amount of elemental carbon produced, and the resulting crystal structure of the carbon. Carbon fibers typically are carbonized at about 2400°F (1300°C) and assay at 93 to 95 % carbon, while graphite fibers are graphitized at 3450 to 5450°F (1900 to 3000°C) and assay at more than 99 % elemental carbon. **(7, 8)**

3.2.5 *chemical vapor deposition or infiltration, n*—a chemical process in which a solid material is deposited on a substrate or in a porous preform through the decomposition or the reaction of gaseous precursors.

3.2.5.1 *Discussion*—Chemical vapor deposition is commonly done at elevated temperatures in a controlled atmosphere.

3.2.6 *infiltration and pyrolysis densification, n—in carbon matrix composites*, a matrix production and densification process in which a liquid organic precursor (thermosetting resin or pitch) is infiltrated/impregnated into the porous preform or the partially porous composite. The organic precursor is then pyrolyzed in an inert atmosphere to convert the organic to a carbon form with the desired purity and crystal structure. The infiltration/pyrolysis process may be iteratively repeated to fill the porosity and build up the density in the composite.

3.2.7 *primary structural axis, n—in a composite flat plate or rectangular bar*, the directional axis defined by the loading axis/direction with the highest required tensile strength. This is commonly the axis with the highest fiber loading. This primary structural axis may not be parallel with the longest dimensional axis of the plate/bar/structure.

3.2.8 *pyrolysis, n—in carbon matrix composites*, the controlled thermal process in which the hydrocarbon precursor is decomposed to elemental carbon in an inert atmosphere. (Synonym – carbonization)

3.2.8.1 *Discussion*—Pyrolysis commonly results in weight loss and the release of hydrogen and hydrocarbon vapors.

3.2.9 *rectangular bar, n*—a solid straight rod with a rectangular cross-section, geometrically defined by a width, a thickness, and long axis length.

3.2.10 *round rod, n*—a solid, straight elongated cylinder, geometrically defined by a outer diameter and an axial length.

3.2.11 *round tube, n*—a hollow elongated cylinder, geometrically defined by a outer diameter, an inner diameter, and an axial length.

3.2.12 *surface seal coatings, n*—an inorganic protective coating applied to the outer surface of a C-C composite component to protect against high temperature oxidation or corrosion or to improve wear and abrasion resistance. Such coatings are commonly hard, impermeable ceramic coatings.

4. Significance and Use

4.1 Composite materials consist by definition of a reinforcement phase/s in a matrix phase/s. The composition and structure of these constituents in the composites are commonly tailored for a specific application with detailed performance requirements. For fiber reinforced carbon-carbon composites the tailoring involves the selection of the reinforcement fibers (composition, properties, morphology, interface coatings etc), the matrix (composition, properties, and morphology), the composite structure (component fractions, reinforcement architecture, interface coatings, porosity structure, microstructure, etc.), and the fabrication conditions (assembly, forming, densification, finishing, etc.). The final engineering properties (physical, mechanical, thermal, electrical, etc) can be tailored across a broad range with major directional anisotropy in the properties. **(9-12)**

4.2 This classification system assists the designer/user/producer in identifying and organizing different types of C-C composites (based on fibers, matrix, architecture, physical properties, and mechanical properties) for structural applications. It assists the composites community in developing, selecting, and using C-C composites with the appropriate composition, construction, and properties for a specific application.

4.3 This classification system is a top level identification tool which uses a limited number of composites properties for high level classification. It is not meant to be a complete, detailed material specification, because it does not cover the full range of composition, architecture, physical, mechanical, fabrication, and durability requirements commonly defined in a full design specification. Guide **C1783** provides direction and guidance in preparing a complete material specification for a given C-C composite component.

5. Carbon-Carbon Composites

5.1 Carbon-carbon composites are composed of carbon/graphite fiber reinforcement in a carbon/graphite matrix. The

⁴ The boldface numbers in parentheses refer to the list of references at the end of this standard.