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Standard Classification for
Fiber Reinforced Carbon-Carbon Composite Structures[1]

This standard is issued under the fixed designation C1836; 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 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 2-D (*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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.7 *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.*

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 (Withdrawn 2017)[3]

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

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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 2-D or 3-D 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 3-D 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 °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 *laminate, 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 2-D 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 2-D 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 *1-D, 2-D, and 3-D 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 1-D structure, all of the fibers are oriented in a single longitudinal (x) direction. In a 2-D 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 3-D 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 °F to 5450 °F (1900 °C 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 perform 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.

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

5. Carbon-Carbon Composites

5.1 Carbon-carbon composites are composed of carbon/graphite fiber reinforcement in a carbon/graphite matrix. The combination of fibers and carbon matrix, the fiber architecture (the shape and morphology of the fiber preform, multidimensional fiber distribution, and volume content of the fiber reinforcement), the matrix phase composition, microstructure and the composite density and porosity are engineered to give the desired performance properties for the composite. The fibers may have a surface treatment to improve fiber/fabric handleability or to control the bonding between the fiber and the matrix. (9-15)

5.2 The mechanical, thermal, and physical properties of carbon-carbon (C-C) composites are determined by the complex interaction of the constituents (fiber, matrix, porosity) in terms of the constituent chemistry, phase composition, microstructure, properties, and fractional content; the fiber architecture; the fiber-matrix bonding, and the effect of fabrication on the constituent properties, morphology and their physical interactions. Each of these factors can be tailored to produce a structure/component with the desired mechanical, physical, and thermal properties. The C-C composite properties can be tailored for directional properties by the anisotropic architecture of the carbon fiber reinforcement. (9-15)

5.3 Carbon/graphite fibers are commonly small diameter (5 μm to 20 μm) continuous filaments produced from polyacrylonitrile, pitch, or rayon precursors. The mechanical and thermal properties of the carbon fibers are strongly dependent on the carbon content, the crystal structure, and the crystallite size and orientation in the fibers. These factors are determined by the precursor chemistry and the processing (spinning, carbonization, and graphitization) conditions. Typically, carbon fibers are classified as either high strength (tensile strength ~ 3 GPa to 5 GPa, elastic modulus ~ 200 GPa to 400 GPa) or high modulus (elastic modulus >500 GPa, tensile strength <3 GPa). Often the carbon fibers have marked differences in mechanical and thermal properties in the axial direction, compared to the radial direction, because of crystal structure anisotropy. (8, 9)

5.4 The carbon fibers are commonly consolidated into high count multifilament tows which can be wrapped or layed-up into 1-D structures, woven/layed-up/braided/knitted into 2-D structures, or woven/braided/knitted/stitched into 3-D structures. Each of these fiber structures are fabricated with defined fiber architectures, offering a wide range of bulk fiber content. Different fiber architectures may have marked reinforcement anisotropy, depending on the relative fiber content in each orthogonal direction.

Note 1—Many commercially available carbon-carbon composites have a two dimensional woven fabric architecture, consisting of stacked plies. The C-C composite is densified to produce a final structure with orthotropic or quasi-isotropic mechanical and thermal properties.

5.5 The carbon matrix in C-C composites is commonly produced by either of two methods: an iterative liquid infiltration/pyrolysis process or a chemical vapor infiltration process (1-6). The two matrix formation processes use different precursors and different processing conditions, which produce differences in the chemistry, crystallinity, morphology, and microstructure (density, pores, and cracks) in the carbon matrix. These two matrix densification processes may be combined for a hybrid carbon matrix.

5.6 In some C-C composite applications an inorganic surface seal coating is applied to the outer surface of the composite to protect against high temperature oxidation and corrosion attack or to improve wear and abrasion resistance. Such coatings are commonly hard, impermeable ceramic coatings.

5.7 The interaction of these three variable factor sets [(*1*) carbon fiber type, properties, coatings; (*2*) fiber content, tow structure, and architecture; (*3*) matrix phase composition and properties, crystallinity, density, morphology, and porosity] can produce C-C composites with a wide range of mechanical and physical properties, along with tailored anisotropic properties in the major directions.

6. Classification of Carbon-Carbon Composites

6.1 *General*—Carbon-carbon composites are classified by fiber type, architecture class, matrix grade, physical properties, and mechanical properties.

6.2 *Fiber Types*—The carbon-carbon composites are *type* classified based on the type of carbon fiber.
6.2.1 *Type A*—Polyacrylonitrile (PAN)-based carbon fibers;
6.2.2 *Type P*—Pitch-based carbon fibers;
6.2.3 *Type R*—Rayon-based carbon fibers; and
6.2.4 *Type H*—A hybrid/blend of two or more types (PAN-, pitch-, or rayon-based) of carbon fibers.

6.3 *Architecture Class*—The carbon-carbon composites are *class* identified based on the fiber reinforcement architecture.
6.3.1 *Class 1*—One-dimensional (1-D) filament winding or 1-D layups of uniaxial tape;
6.3.2 *Class 2*—Laminates of two-dimensional (2-D) fabric plies, 0-90 cross-ply lay-ups of uniaxial tape, or 2-D braids/knits; and
6.3.3 *Class 3*—Three-dimensional (3-D) fiber woven, braided, or knitted fiber preforms.

Note 2—Some two dimensional laminates are reinforced by limited (<5 % by fiber volume) through-thickness stitching/needling with fiber tows, sometimes called a 2.5-D architecture. For the purposes of this specification, stitched/needled (2.5-D) architectures are considered Class 3 (3-D) composites.

6.4 *Matrix Grade*—The carbon-carbon composites are *grade* classified based on the method of matrix densification.
6.4.1 *Grade S*—Matrix based on infiltration and pyrolysis of thermosetting resins;
6.4.2 *Grade P*—Matrix based on infiltration and pyrolysis of thermoplastic resins (pitch);
6.4.3 *Grade C*—Matrix based on chemical vapor infiltration/deposition with hydrocarbons; and
6.4.4 *Grade H*—Matrix based on a hybrid/combination of resin infiltration (S and/or P) and chemical vapor infiltration (C).

6.5 Table 1 summarizes the classification codes for type, class, and grade of carbon-carbon composites.