INTERNATIONAL

Designation: ~~C1358 – 13~~ C1358 – 18

Standard Test Method for Monotonic Compressive Strength Testing of Continuous Fiber-Reinforced Advanced Ceramics with Solid Rectangular ~~Cross-Section~~ Cross Section Test Specimens at Ambient Temperatures[1]

This standard is issued under the fixed designation C1358; 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*~~Scope

1.1 This test method covers the determination of compressive strength, including stress-strain behavior, under monotonic uniaxial loading of continuous fiber-reinforced advanced ceramics at ambient temperatures. This test method addresses, but is not restricted to, various suggested test specimen geometries as listed in the ~~appendix.~~appendixes. In addition, test specimen fabrication methods, testing modes (force, displacement, or strain control), testing rates (force rate, stress rate, displacement rate, or strain rate), allowable bending, and data collection and reporting procedures are addressed. Compressive strength, as used in this test method, refers to the compressive strength obtained under monotonic uniaxial loading, where monotonic refers to a continuous nonstop test rate with no reversals from test initiation to final fracture.

1.2 This test method applies primarily to advanced ceramic matrix composites with continuous fiber reinforcement: ~~uni-directional (1–D), bi-directional (2–D), and tri-directional (3–D)~~unidirectional (1D), bidirectional (2D), and tridirectional (3D) or other multi-directional reinforcements. In addition, this test method may also be used with glass (amorphous) matrix composites with ~~1–D, 2–D, 3–D,~~1D, 2D, 3D, and other multi-directional continuous fiber reinforcements. This test method does not directly address discontinuous fiber-reinforced, whisker-reinforced, or particulate-reinforced ceramics, although the test methods detailed here may be equally applicable to these composites.

1.3 The values stated in SI units are to be regarded as the standard and are in accordance with ~~SI 10-02~~ IEEE/ASTM SI 10.

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~~ safety, health, and ~~health~~environmental practices and determine the applicability of regulatory limitations prior to use.* Refer to Section 7 for specific precautions.

1.5 *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]

C1145 Terminology of Advanced Ceramics
D695 Test Method for Compressive Properties of Rigid Plastics
D3379 Test Method for Tensile Strength and Young's Modulus for High-Modulus Single-Filament Materials
D3410/D3410M Test Method for Compressive Properties of Polymer Matrix Composite Materials with Unsupported Gage Section by Shear Loading
D3479/D3479M Test Method for Tension-Tension Fatigue of Polymer Matrix Composite Materials
D3878 Terminology for Composite Materials
~~D6856~~D6856/D6856M Guide for Testing Fabric-Reinforced "Textile" Composite Materials
E4 Practices for Force Verification of Testing Machines

[1] This test method 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.

***A Summary of Changes section appears at the end of this standard**

E6 Terminology Relating to Methods of Mechanical Testing
E83 Practice for Verification and Classification of Extensometer Systems
E337 Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)
E1012 Practice for Verification of Testing Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application
SI 10-02 IEEE/ASTM SI 10 American National Standard for Use of the International System of Units (SI): The Modern Metric SystemMetric Practice

3. Terminology

3.1 *Definitions:*

3.1.1 The definitions of terms relating to compressive testing, advanced ceramics, and fiber-reinforced composites,composites appearing in Terminology E6, Test Method D695, Practice E1012, Terminology C1145, Test Method D3410/D3410M, and Terminology D3878 apply to the terms used in this test method. Pertinent definitions are shown as follows, with the appropriate source given in parentheses. Additional terms used in conjunction with this test method are defined in 3.2.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *advanced ceramic, n*—highly engineered, high-performancehigh-performance, predominantly non-metallic, inorganic, ceramic material having specific functional attributes. **C1145**

3.2.2 *axial strain [LL^{-1}], n*—average longitudinal strains measured at the surface on opposite sides of the longitudinal axis of symmetry of the specimen by two strain-sensing strain sensing devices located at the mid length of the reduced section. **E1012**

3.2.3 *bending strain [LL^{-1}], n*—difference between the strain at the surface and the axial strain. In general, the bending strain varies from point to point around and along the reduced section of the specimen. **E1012**

3.2.4 *breaking force [F], n*—force at which fracture occurs. **E6**

3.2.5 *ceramic matrix composite, n*—material consisting of two or more materials (insoluble in one another), in which the major, continuous component (matrix component) is a ceramic, while the secondary component(s) (reinforcing component) may be ceramic, glass-ceramic, glass, metal, or organic in nature. These components are combined on a macroscale to form a useful engineering material possessing certain properties or behavior not possessed by the individual constituents.

3.2.6 *compressive strength [FL^{-2}], n*—maximum compressive stress which a material is capable of sustaining. Compressive strength is calculated from the maximum force during a compression test carried to rupture and the original cross-sectional area of the specimen. **E6**

3.2.7 *continuous fiber-reinforced ceramic matrix composite (CFCC), n*—ceramic matrix composite in which the reinforcing phase consists of a continuous fiber, continuous yarn, or a woven fabric.

3.2.8 *gage length [L], n*—original length of that portion of the specimen over which strain or change of length is determined. **E6**

3.2.9 *modulus of elasticity [FL^{-2}], n*—ratio of stress to corresponding strain below the proportional limit. **E6**

3.2.10 *percent bending, n*—bending strain times 100 divided by the axial strain. **E1012**

3.2.11 *proportional limit stress in compression [FL^{-2}], n*—greatest stress that a material is capable of sustaining without any deviation from proportionality of stress to strain (Hooke's law).

3.2.11.1 *Discussion—*

Many experiments have shown that values observed for the proportional limit vary greatly with the sensitivity and accuracy of the testing equipment, eccentricity of loading, the scale to which the stress-strain diagram is plotted, and other factors. When determination of proportional limit is required, specify the procedure and sensitivity of the test equipment. **E6**

3.2.11 *percent bending, n*—bending strain times 100 divided by the axial strain. **E1012**

3.2.12 *slow crack growth (SCG), n*—subcritical crack growth (extension) which may result from, but is not restricted to, such mechanisms as environmentally-assisted environmentally assisted stress corrosion or diffusive crack growth. **C1145**

4. Significance and Use

4.1 This test method may be used for material development, material comparison, quality assurance, characterization, reliability assessment, and design data generation.

4.2 Continuous fiber-reinforced ceramic matrix composites (CFCCs) are generally characterized by fine-grain sized (<50 μm) (<50 μm) matrices and ceramic fiber reinforcements. In addition, continuous fiber-reinforced glass (amorphous) matrix composites can also be classified as CFCCs. Uniaxial-loaded Uniaxially loaded compressive strength tests provide information on mechanical behavior and strength for a uniformly stressed CFCC.

4.3 Generally, ceramic and ceramic matrix composites have greater resistance to compressive forces than tensile forces. Ideally, ceramics should be compressively stressed in use, although engineering applications may frequently introduce tensile stresses in the component. Nonetheless, compressive behavior is an important aspect of mechanical properties and performance. The compressive strength of ceramic and ceramic composites may not be ~~deterministic~~deterministic. Therefore, test a sufficient number of test specimens to gain an insight into strength distributions.

4.4 Compression tests provide information on the strength and deformation of materials under uniaxial compressive stresses. Uniform stress states are required to effectively evaluate any nonlinear stress-strain behavior that may develop as the result of cumulative damage processes (for example, matrix cracking, matrix/fiber debonding, fiber fracture, delamination, etc.) that may be influenced by testing mode, testing rate, effects of processing or combination of constituent materials, or environmental influences. Some of these effects may be consequences of stress corrosion or sub-critical (slow) crack growth which can be minimized by testing at sufficiently rapid rates as outlined in this test method.

4.5 The results of compression tests of test specimens fabricated to standardized dimensions from a particulate material or selected portions of a part, or both, may not totally represent the strength and deformation properties of the entire, full-size product or its in-service behavior in different environments.

4.6 For quality control purposes, results derived from standardized compressive test specimens may be considered indicative of the response of the material from which they were taken for given primary processing conditions and post-processing heat treatments.

4.7 The compressive behavior and strength of a CFCC are dependent on, and directly related to, the material. Analysis of fracture surfaces and fractography, though beyond the scope of this test method, are recommended.

5. Interferences

5.1 Test environment (vacuum, inert gas, ambient air, ~~etc.)~~etc.), including moisture content (for example, relative ~~humidity)~~humidity), may have an influence on the measured compressive strength. In particular, the behavior of materials susceptible to slow crack growth will be strongly influenced by test environment, testing rate, and test temperature. Conduct tests to evaluate the maximum strength potential of a material in inert environment or at sufficiently rapid testing rates, or both, to minimize slow crack growth effects. Conversely, conduct tests in environments or at test modes, or both, and rates representative of service conditions to evaluate material performance under use conditions. Monitor and report relative humidity and ambient temperature when testing is conducted in uncontrolled ambient air with the intent of evaluating maximum strength potential. Testing at humidity levels >65 % relative humidity (RH) is not recommended.

5.2 Surface preparation of test specimens, although normally not considered a major concern in CFCCs, can introduce fabrication flaws that may have pronounced effects on compressive mechanical properties and behavior (for example, shape and level of the resulting stress-strain curve, compressive strength and strain, proportional limit stress and strain, ~~etc.)~~etc.). Machining damage introduced during test specimen preparation can be either a random interfering factor in the determination of ultimate strength of pristine material (that is, increased frequency of surface-initiated fractures compared to volume-initiated fractures), or an inherent part of the strength characteristics to be measured. Surface preparation can also lead to the introduction of residual stresses. Universal or standardized test methods of surface preparation do not exist. In addition, the nature of fabrication used for certain composites (for example, chemical vapor infiltration or hot pressing) may require the testing of test specimens in the as-processed condition (that is, it may not be possible to machine the test specimen faces without compromising the in-plane fiber architecture). Final machining steps ~~may,~~may or may ~~not,~~not negate machining damage introduced during the initial machining. Thus, report test specimen fabrication history since it may play an important role in the measured strength distributions.

5.3 Bending in uniaxial compressive tests can introduce eccentricity, leading to geometric instability of the test specimen and buckling failure before true compressive strength is attained. In addition, if deformations or strains are measured at surfaces where maximum or minimum stresses occur, bending may introduce over or under measurement of strains, depending on the location of the ~~strain-measuring~~ strain measuring device on the test specimen. Bending can be introduced from, among other sources, initial load train misalignment, misaligned test specimens as installed in the grips, warped test specimens, or load train misalignment introduced during testing due to low lateral machine/grip stiffness.

5.4 Fractures that initiate outside the uniformly stressed gage section of a test specimen may be due to factors such as stress concentrations or geometrical transitions, extraneous stresses introduced by gripping, or strength-limiting features in the microstructure of the test specimen. Such non-gage section fractures will normally constitute invalid tests. In addition, for frictional face-loaded geometrics, gripping pressure is a key variable in the initiation of fracture. Insufficient pressure can shear the outer plies in laminated ~~CFCCs;~~CFCCs, while too much pressure can cause local crushing of the CFCC and may initiate fracture in the vicinity of the grips.

5.5 Lateral supports are sometimes used in compression tests to reduce the tendency of test specimen buckling. However, such lateral supports may introduce sufficient frictional stress so as to artificially increase the force required to produce compressive failure. In addition, the lateral supports and attendant frictional stresses may invalidate the assumption of uniaxial stress state.

When lateral supports are used, the frictional effect should be quantified to ensure that its contribution is small, and the means for doing so reported along with the quantity of the frictional effect.

6. Apparatus

6.1 *Testing Machines*—Machines used for compressive testing shall conform to Practices E4. The forces used in determining compressive strength shall be accurate to within ±1 % at any force within the selected force range of the testing machine as defined in Practices E4. A schematic showing pertinent features of one possible compressive testing apparatus is shown in Fig. 1.

6.2 *Gripping Devices:*

6.2.1 *General*—Various types of gripping devices may be used to transmit the measured force applied by the testing machine to the test specimens. The brittle nature of the matrices of CFCCs requires a uniform interface between the grip components and the gripped section of the test specimen. Line or point contacts and nonuniform pressure can produce Hertzian-type stresses, leading to crack initiation and fracture of the test specimen in the gripped section.

6.2.1.1 The primary recommended gripping system for compressive testing CFCCs employs active grip interfaces that require a continuous application of a mechanical, hydraulic, or pneumatic force to transmit the force applied by the test machine to the test specimen. These types of grip interfaces (that is, frictional face-loaded grips) cause a force to be applied normal to the surface of the gripped section of the test specimen. Transmission of the uniaxial force applied by the test machine is then accomplished by friction between the test specimen and the grip faces. Thus, important aspects of active grip interfaces are uniform contact between the gripped section of the test specimen and the grip faces and constant coefficient of friction over the grip/specimen interface.

6.2.1.2 For flat test specimens, frictional face-loaded grips, either by direct lateral pressure grip faces (**1**)[3] or by indirect wedge-type grip faces, act as the grip interface (**2, 3**) as illustrated in Fig. 2 and Fig. 3, respectively. Generally, close tolerances are required for the flatness and parallelism as well as for the wedge angle of the wedge grip faces. In addition, the thickness, flatness, and parallelism of the gripped section of the test specimen must be within similarly close tolerances to promote uniform contact at the test specimen/grip interface. Tolerances will vary depending on the exact configuration as shown in the appropriate test specimen drawings.

6.2.1.3 Sufficient lateral pressure must be applied to prevent slippage between the grip face and the test specimen. Grip surfaces that are scored or serrated with a pattern similar to that of a single-cut file have been found satisfactory. A fine serration appears to be the most satisfactory. Keep the serrations clean and ~~well-defined~~ well defined but not overly sharp. The length and width of the grip faces shall be equal to or greater than the respective length and width of the gripped sections of the test specimen.

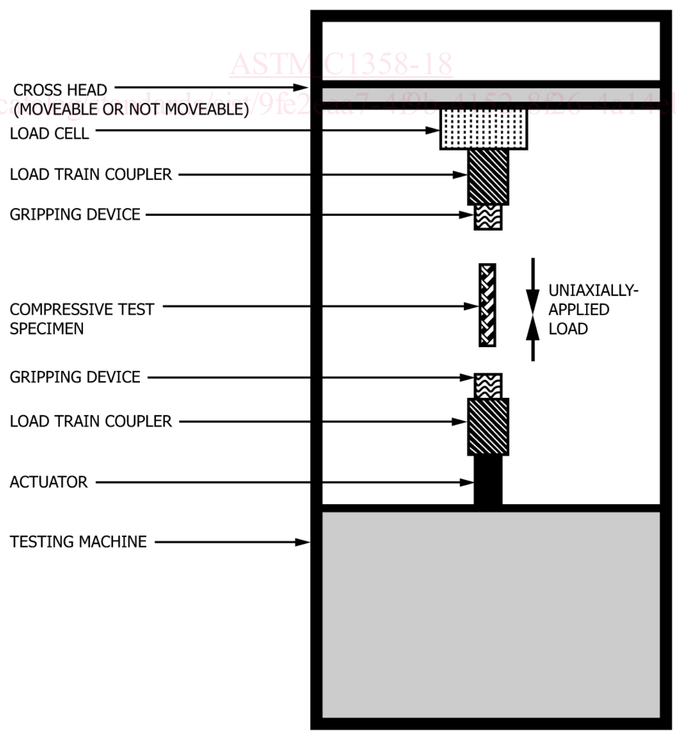


FIG. 1 Schematic Diagram of One Possible Apparatus for Conducting a ~~Uniaxially-Loaded~~ Uniaxially Loaded Compression Test

[3] The boldface numbers given in parentheses refer to a list of references at the end of the text.

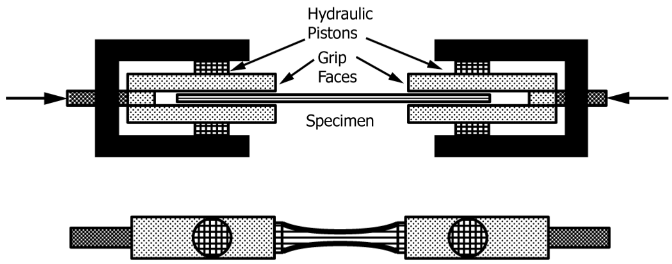


FIG. 2 Example of a Direct Lateral Pressure Grip Face for a Face-Loaded Grip Interface

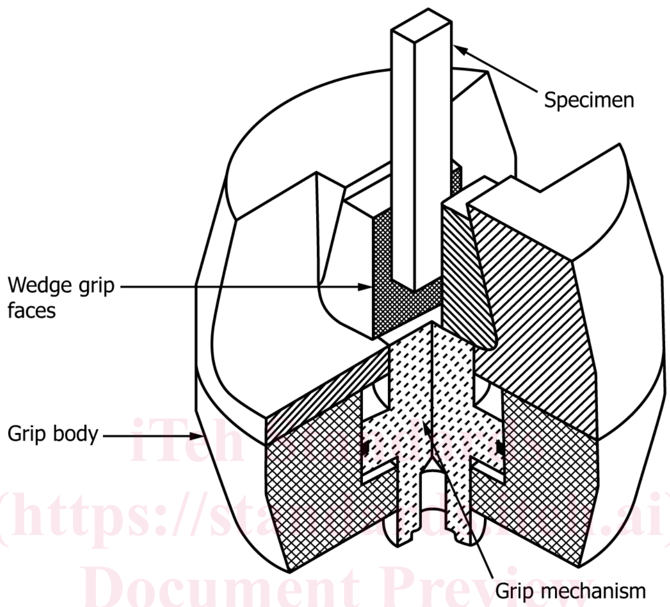


FIG. 3 Example of aan Indirect Wedge-Type Grip FacesFace for a Face-Loaded Grip Interface

6.2.1.4 An alternative recommended gripping system for compressive testing CFCCs employs passive grip interfaces whichthat employ lateral supports and loading anvils to transmit the applied force to the compressive test specimen. The lateral supports prevent both buckling of the test specimen in the gage section and splitting and brooming of the 'grip' section. Transmission of the force applied by the test machine is then accomplished by a directly applied uniaxial force to the test specimen ends. Thus, important aspects of this type of grip interface are uniform contact between the loading anvil and the test specimen and good contact between the test specimen and lateral supports.

6.2.1.5 For flat test specimens, a controlled, face-supported fixture **(4)** as illustrated in Fig. 4 can be used. Generally, close tolerances are required for the flatness and parallelism. In addition, the thickness, flatness, and parallelism of the supported section of the test specimen must be within similarly close tolerances to promote uniform contact at the test specimen/lateral support interface. Tolerances will vary depending on the exact configuration as shown in the appropriate test specimen drawings.

6.3 *Load Train Couplers:*

6.3.1 *General*—Various types of devices (load train couplers) may be used to attach the active or passive grip interface assemblies to the testing machine. The load train couplers, in conjunction with the type of gripping device, play major roles in the alignment of the load train and thus subsequent bending (that is, eccentricity) imposed in the test specimen. Fixed,Fixed but adjustable load train couplers are primarily recommended for compression testing CFCCs to ensure a consistently well-aligned load train for the entire test. The use of well-alignedwell-aligned, fixed couplers does not automatically guarantee low bending (that is, eccentricity) in the gage section of the compressive test specimen. Well-alignedWell-aligned, fixed couplers provide for well-aligned load trains, but the type and operation of grip interfaces, as well as the as-fabricated dimensions of the compressive test specimen, can add significantly to the final bending (that is, eccentricity) imposed in the gage section of the test specimen.

6.3.1.1 AsAt a minimum, verify the alignment of the testing system at the beginning and end of a test series, unless the conditions for verifying alignment are otherwise met. An additional verification of alignment is recommended, although not required, at the middle of the test series. Use either a dummy or actual test specimen. Allowable bending requirements are discussed in 6.5. See Practice E1012 for discussions of alignment and Appendix X1 for suggested procedures specific to this test method. A test series is interpreted to mean a discrete group of tests on individual test specimens conducted within a discrete period

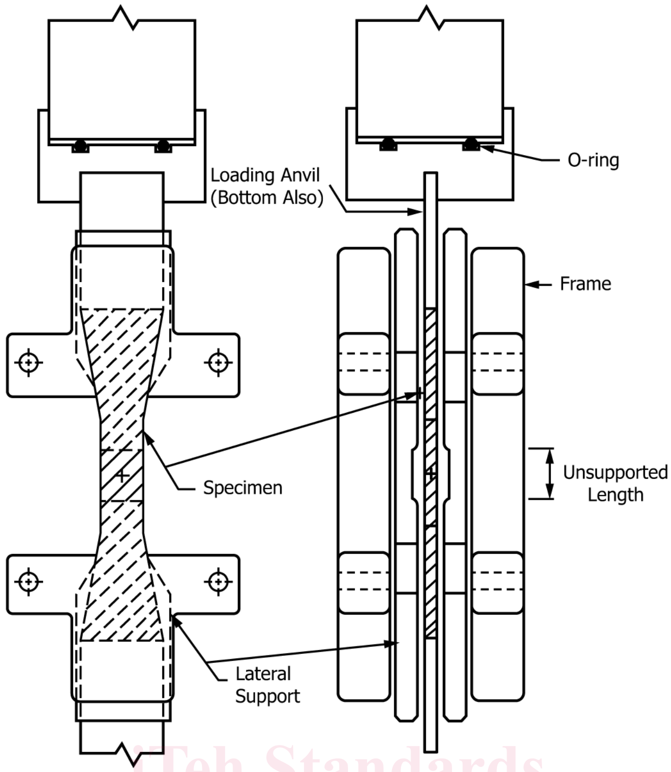


FIG. 4 Example of a ~~Controlled Face Supported Fixture (4)~~Controlled, Face-Supported Fixture (4)

of time on a particular material configuration, test specimen geometry, test condition, or other uniquely definable qualifier (for example, a test series composed of material A comprising ten test specimens of geometry B tested at a fixed rate in strain control to final fracture in ambient air).

NOTE 1—Compressive test specimens used for alignment verification should be equipped with a recommended eight separate longitudinal strain gages to determine bending contributions from both eccentric and angular misalignment of the grip heads. Ideally, the verification test specimen should be of identical material to that being tested. However, in the case of CFCCs, the type of reinforcement or degree of residual porosity may complicate the consistent and accurate measurement of strain. Therefore, use an alternate material (isotropic, homogeneous, continuous) with similar elastic modulus, elastic strain capability, and hardness to the test material. In addition, dummy test specimens used for alignment ~~verification,~~verification should have the same geometry and dimensions of the actual test specimens, as well as similar mechanical properties as the test material to ensure similar axial and bending stiffness characteristics as the actual test specimen and material.

6.3.2 Fixed load train couplers may incorporate devices which require either a one-time, ~~pretest~~pre-test alignment adjustment of the load train which remains constant for all subsequent tests or an ~~*in situ,*~~*in-situ,* ~~pretest~~pre-test alignment of the load train which is conducted separately for each test specimen and each test. Such devices ~~(2)~~**(2)** usually employ angularity and concentricity adjusters to accommodate inherent load train misalignments. Regardless of which method is used, perform an alignment verification as discussed in 6.3.1.1.

6.4 *Strain Measurement*—Determine strain by means of either a suitable extensometer or strain gages.

6.4.1 Extensometers used for compressive testing of ~~CFCCs~~CFCC test specimens shall satisfy Practice E83, Class B-1 requirements and are recommended to be used in place of strain gages for test specimens with gage lengths of ≥25 mm, and shall be used for high-performance tests beyond the range of strain gage applications. Calibrate extensometers periodically in accordance with Practice E83. For extensometers which mechanically contact the test specimen, the contact shall not cause damage to the test specimen surface. However, shallow grooves (0.025 to 0.051 mm deep) machined into the surfaces of CFCCs to prevent extensometer slippage have been shown to not have a detrimental effect on failure strengths ~~(4).~~**(4).** In addition, support the weight of the extensometer so as not to introduce bending greater than that allowed in 6.5.

6.4.2 An additional recommendation, but not ~~requirement~~ a requirement, for the actual testing is strain determined directly from strain gages. Two strain gages, one mounted on each of the opposite faces of the width surfaces, can be used to monitor incidences of bending eccentricity and, hence, tendency to buckling. Buckling can be detected when the strain on one face reverses (decreases) while the strain on the other face increases rapidly.

NOTE 2—If Poisson's ratio is to be determined, instrument the test specimen to measure strain in both longitudinal and lateral directions at the same position on the test specimen. Either a stacked, biaxial strain gage or two suitably oriented uniaxial strain gages (attached as close to each other as possible) are suitable for this ~~purposes.~~purpose.

NOTE 3—Unless it can be shown that strain gage readings are not unduly influenced by localized strain events such as fiber crossovers, strain gages should not be less than 9 to 12 mm in length for the strain-measurement direction and not less than 6 mm in width for the direction normal to strain measurement. Larger strain gages than those recommended here may be required for fabric reinforcements to average the localized strain effects of the fiber crossovers. Choose the strain gages, surface preparation, and bonding agents so as to provide adequate performance on the subject materials. Employ suitable strain recording equipment. Many CFCCs may exhibit high degrees of porosity and surface roughness and therefore require surface preparation, including surface filling, before the strain gages can be applied.

6.5 *Allowable Bending*—Axial misalignment ~~of~~with the introduction of ~~bending,~~ bending stresses, due either to eccentricity or angular misalignment, ~~will~~may produce a geometric instability in the compressive test specimen, leading to buckling and measured compressive strengths less than the true compressive strength. One study on polymeric composites has indicated that a misalignment of even 2.5 % bending, as defined in Practice E1012, will cause an apparent strength drop to only 87 % of the ultimate compressive strength ~~(5).~~**(5).**

6.5.1 Actual studies of the effect of bending on the compressive strength distributions of CFCCs do not exist. Until such information is forthcoming for CFCCs, this test method adopts a conservative recommendation of the lowest achievable percent bending for compressive testing CFCCs. Therefore, the maximum allowable percent bending at the onset of the cumulative fracture process (for example, ~~non linearity~~ nonlinearity in the compressive stress-strain curve) for test specimens tested under this test method shall not exceed ~~five,~~5 %, with ~~one~~1 % recommended, measured at a mean strain equal to either ~~one half~~ one-half the anticipated strain at the onset of the cumulative fracture process (for example, ~~non linearity~~ nonlinearity in the compressive stress-strain curve) or a strain of −0.0005 (that is, −500 ~~microstrain)~~microstrain), whichever is greater. Unless all test specimens are properly strain gaged and percent bending monitored until the onset of the cumulative fracture process, there will be no record of percent bending at the onset of fracture for each test specimen. Therefore, verify the alignment of the testing system. See Practice E1012 for discussions of alignment and Appendix X1 for suggested ~~procedure~~procedures specific to this test method.

NOTE 4—Lateral stiffness of the grip/machine (in addition to misaligned grips/load train, test specimens misaligned in the grips, or misshapen test specimens) will influence load train alignment and the resulting eccentricity introduced in the test specimen. Therefore, unlike a tension test which may produce a certain amount of self-alignment at increasing forces in a compliant load train, a compression test may produce a certain amount of misalignment at increasing forces in a compliant load train. Therefore, lateral grip/machine stiffnesses as high as possible are recommended for compression tests. Increasing bending with increasing force as measured in the alignment verification is an indication of a low lateral stiffness of the grip/machine (among other sources).

6.6 *Data Acquisition*—Obtain, at ~~the~~ minimum, an autographic record of applied force and gage section deformation (or strain) versus time. Either analog chart recorders or digital data acquisition systems can be used for this purpose, although a digital record is recommended for ease of later data analysis. Ideally, use an analog chart recorder or plotter in conjunction with the digital data acquisition system to provide an immediate record of the test as a supplement to the digital record. Recording devices shall be accurate to within ±1 % of the selected range for the testing system including readout unit, as specified in Practices E4, and should have a minimum data acquisition rate of 10 Hz, with a response of 50 Hz deemed more than sufficient.

6.6.1 Record strain or deformation of the gage section, or both, either similarly to the force or as independent variables of force. ~~Cross-head~~Crosshead displacement of the test machine may also be recorded but should not be used to define displacement or strain in the gage section.

6.7 ~~*Dimension-Measuring*~~ *Dimension Measuring Devices*—Micrometers and other devices used for measuring linear dimensions shall be accurate and precise to at least ~~one half~~ one-half the smallest unit to which the individual dimension is required to be measured. Measure cross-sectional dimensions to within 0.02 mm using dimension-measuring devices with accuracies of 0.01 mm.

7. Precautionary Statement

7.1 During the conduct of this test method, the possibility of flying fragments of broken test material may be high. The brittle nature of advanced ceramics and the release of strain energy contribute to the potential release of uncontrolled fragments upon fracture. Means for containment and retention of these fragments for safety, as well as later fractographic reconstruction and analysis, is highly recommended.

7.2 Exposed fibers at the edges of CFCC test specimens present a hazard due to the sharpness and brittleness of the ceramic fiber. Inform all those required to handle these materials of such conditions and the proper handling techniques.

8. Test Specimen

8.1 *Test Specimen Geometry:*

8.1.1 *General*—Unlike tensile tests, in which test specimens with reduced (or contoured) gage sections are used to minimize non-gage section failures, in compressive tests anisotropy and sensitivity to the geometric instability of buckling may discourage the use of contoured test specimens. Generally, straight-sided test specimens are recommended for compression tests. However, contoured compressive test specimens have been used successfully to test some types of CFCCs ~~(4).~~**(4).**

NOTE 5—The final dimensions of compressive test specimens are dependent on the ultimate use of the compressive strength data. For example, if the compressive strength of an as-fabricated component is required, the dimensions of the resulting compressive test specimen may reflect the thickness, width, and length restrictions of the component. If it is desired to evaluate the effects of interactions of various constituent materials for a particular CFCC manufactured via a particular processing route, then the size of the test specimen and resulting gage section will reflect the desired volume to be sampled.

8.1.1.1 The following paragraphs discuss recommended test specimen geometries, although any geometry is acceptable if it meets the gripping, fracture location, and bending requirements of this test method. Deviations from the recommended geometries may be necessary depending upon the particular CFCC being evaluated. Conduct stress analyses of untried test specimen geometries to ensure that stress concentrations, thatwhich can lead to undesired fractures outside the gage sections, do not exist. Contoured test specimens by their nature contain inherent stress concentrations due to geometric transitions. Stress analyses can indicate the magnitude of such stress concentrations while revealing the success of producing a uniform compressive stress state in the gage section of the test specimen.

8.1.1.2 Fig. 5 shows the nomenclature and an example of a straight-sided test specimen (**3**) that can be used in either the frictional, face-loaded grips or the controlled, face-supported fixture. Important tolerances for this geometry include parallelism and flatness of faces, all of which will vary depending on the exact configuration as shown in the appropriate test specimen drawing.

8.1.1.3 Fig. 6 shows the nomenclature and an example of a contoured, "bow-tie" "bow tie" test specimen (**4**)(**4**) that can be used in either the frictional, face-loaded grips ofor the controlled, face-supported fixture. Important tolerances for the face-loaded geometry include parallelism and flatness of faces, which will vary depending on the exact configuration as shown in the appropriate test specimen drawing.

8.2 The recommended minimum gage length of the test specimen is 25 mm, with the length of at least 50 mm of the gripped sections at each end of the test specimen. Recommended minimum width and minimum thickness are 10 and 3 mm, 3 mm, respectively. However, other combinations of gage length, width, and thickness can be used as long as the slenderness ratio, l/k, ≤30 **(6,7).(6, 7).**

8.2.1 The slenderness ratio can be calculated as:

$$\frac{l}{k} = \sqrt{12}\,\frac{l}{b} \tag{1}$$

where:

l = length of the gage section,
k = least radius of gyration of the cross section, and
b = thickness of the cross section.

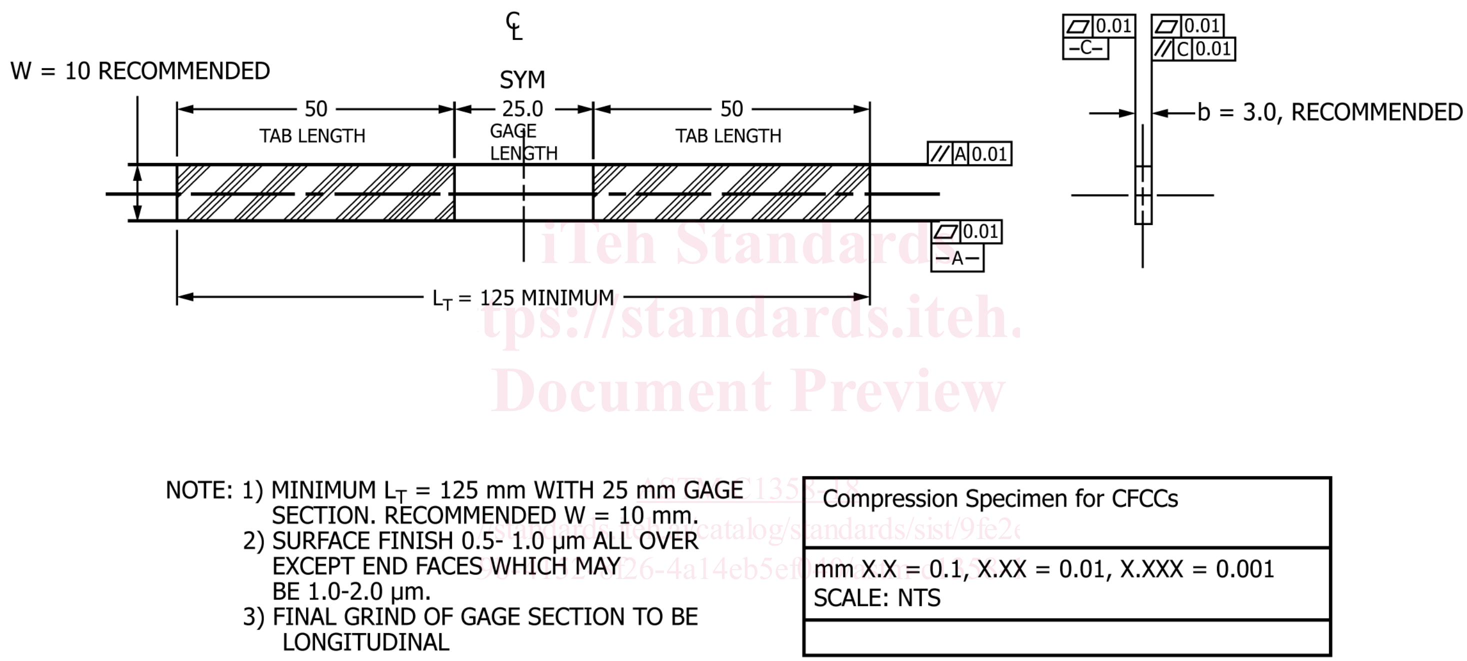
The investigations reported in Refs.Refs (**56**) and (**67**) indicate that measured compressive strengths of composites were independent of slenderness ratios (that is, presumably indicative of the true compressive strength) for $l/k \leq 30$.

8.2.2 When testing woven fabric laminate composites, it is recommended that the gage length and width equal, at a minimum, one length and one width of the weave unit cell. (Unit cell count = 1 across the given dimension.) Two or more weave unit cells are preferred across a given gage dimension.

NOTE 6—The weave unit cell is the smallest section of weave architecture required to repeat the textile pattern (see Guide D6856D6856/D6856M). The fiber architecture of a textile composite, which consists of interlacing yarns, can lead to inhomogeneity of the local displacement fields within the weave unit cell. The gage dimensions should be large enough so that any inhomogenities within the weave unit cell are averaged out across the gage. This is a particular concern for test specimens where the fabric architecture has large, heavy tows and/or open weaves or open weaves, or both, with large unit cell dimensions and the gage sections are narrow and/or short.or short, or both.

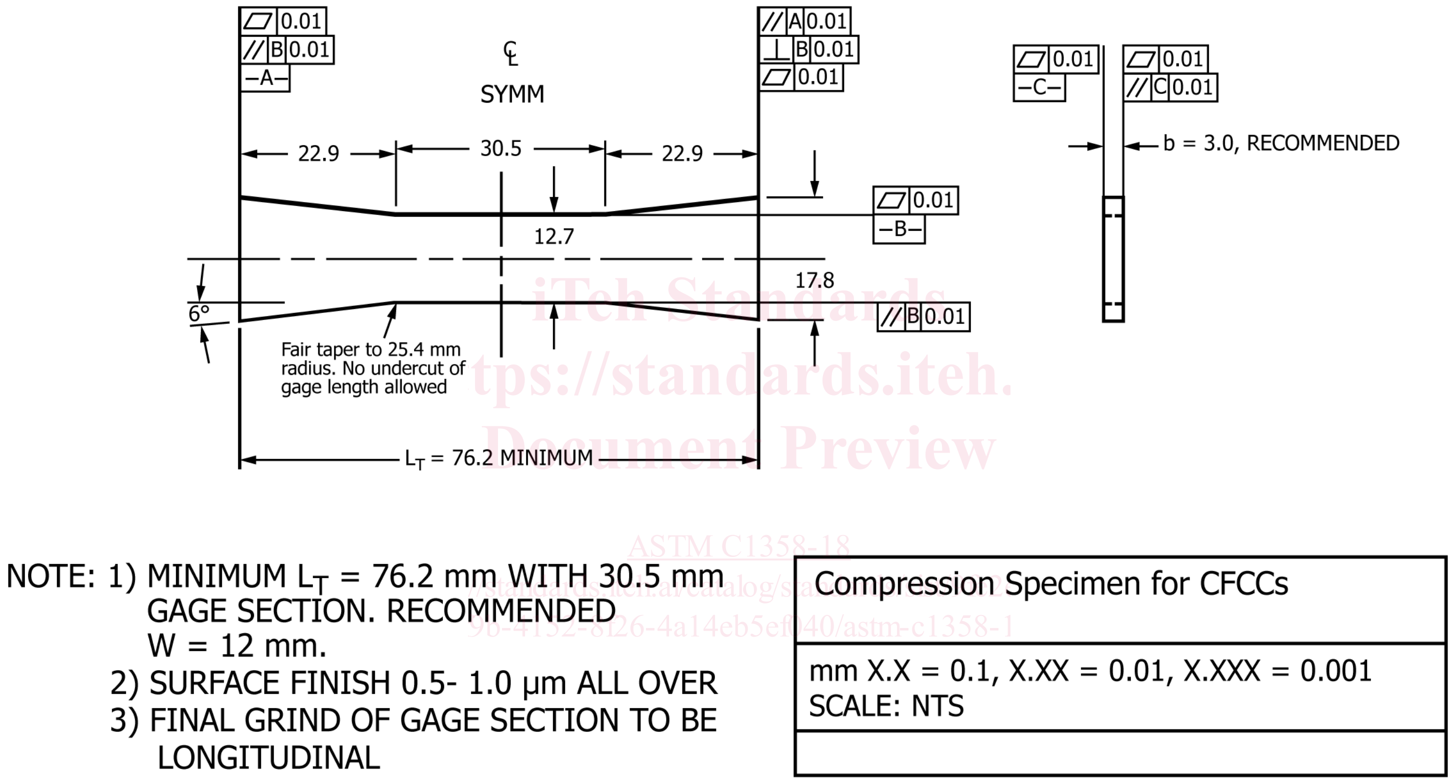
NOTE 7—Deviations from the recommended unit cell counts may be necessary depending upon the particular geometry of the available material. Such "small" gage sections should be noted in the test report and used with adequate understanding and assessment of the possible effects of weave unit cell count on the measured mechanical properties.

8.3 For the frictional, face-loaded grips, end tabs may be required to provide a compliant layer for gripping and to prevent splitting and brooming of the gripped ends of the test specimens. Balanced 0/90° cross-ply tabs made from unidirectional non-wovennonwoven E-glass have proven to be satisfactory for certain fiber-reinforced polymers. For CFCCs, tab materials comprised of fiber-glass reinforced fiberglass-reinforced epoxy, polymethylene resins (PMR), or carbon fiber-reinforced resins have been used successfully (**78**). However, metallic tabs (for example, aluminum alloys) may be satisfactory as long as the tabs are strain compatible (that is, having a similar bulk elastic modulus within ±10 % of that of the CFCC) with the CFCC material being tested. Each beveled tab (bevel angle <15°) should be a minimum of 50 mm long, the same width of the test specimen, and have the total thickness of the tabs on the order of the thickness of the test specimen. Any high-elongation (tough) adhesive system may be used with the length of the tabs determined by the shear strength of the adhesive, size of the test specimen, and estimated strength of the composite. In any case, if a significant fraction (≥20 %) of fractures occuroccurs within one test specimen width of the tab, re-examine the tab materials and configuration, gripping method, and adhesive, and make necessary adjustment to promote fracture within the gage section. Fig. 7 shows an example of a tab design modified to be used for compressive testing of CFCCs.



NOTE 1—Illustration not intended to be an engineering or production drawing, or both.

FIG. 5 Example of a Straight-Sided Compressive Test Specimen



Note 1—Illustration not intended to be an engineering or production drawing, or both.

FIG. 6 Example of a ~~'Bow-Tie'~~ "Bow Tie" Compressive Test Specimen ~~(4)~~(4)