Standard Test Method for
Monotonic Compressive Strength of Advanced Ceramics at Ambient Temperature[1]

This standard is issued under the fixed designation C 1424; 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 test method covers the determination of compressive strength including stress-strain behavior, under monotonic uniaxial loading of advanced ceramics at ambient temperature. This test method is restricted to specific test specimen geometries. In addition, test specimen fabrication methods, testing modes (load or displacement), testing rates (load 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. Monotonic loading refers to a test conducted at a constant rate in a continuous fashion, with no reversals from test initiation to final fracture.

1.2 *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.*

1.3 This test method is intended primarily for use with advanced ceramics that macroscopically exhibit isotropic, homogeneous, continuous behavior. While this test method is intended for use on monolithic advanced ceramics, certain whisker- or particle-reinforced composite ceramics as well as certain discontinuous fiber-reinforced composite ceramics may also meet these macroscopic behavior assumptions. Generally, continuous fiber ceramic composites (CFCCs) do not macroscopically exhibit isotropic, homogeneous, continuous behavior and, application of this test method to these materials is not recommended.

1.4 Values expressed in this test method are in accordance with the International System of Units (SI) and Practice E 380.

2. Referenced Documents

2.1 *ASTM Standards:*
C 773 Test Method for Compressive (Crushing) Strength of Fired Whiteware Materials[2]
C 1145 Terminology on Advanced Ceramics[3]

D 695 Test Method for Compressive Properties of Rigid Plastics[4]
E 4 Practices for Force Verification of Testing Machines[5]
E 6 Terminology Relating to Methods of Mechanical Testing[5]
E 83 Practice for Verification and Classification of Extensometers[5]
E 337 Test Method for Measured Humidity with Psychrometer (the Measurement of Wet-and Dry-Bulb Temperatures)[6]
E 380 Practice for Use of International System of Units (SI) (the Modernized Metric System)[7]
E 1012 Practice for Verification of Specimen Alignment Under Tensile Loading[5]

3. Terminology

3.1 *Definitions*—The definitions of terms relating to compressive testing appearing in Terminology E 6, Test Method D 695, and Terminology C 1145 may apply to the terms used in this test method. Pertinent definitions as listed in Practice E 1012, Terminology C 1145, and Terminology E 6 are shown in the following with the appropriate source given in parentheses. Additional terms used in conjunction with this test method are defined in the following.

3.1.1 *advanced ceramic, n*—a highly engineered, high-performance predominately nonmetallic, inorganic, ceramic material having specific functional attributes. **(C 1145)**

3.1.2 *axial strain, n [L/L]*—the average longitudinal strains measured at the surface on opposite sides of the longitudinal axis of symmetry of the specimen by two strain-sensing devices located at the mid length of the reduced section. **(E 1012)**

3.1.3 *bending strain, n [L/L]*—the 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 test specimen. **(E 1012)**

3.1.4 *breaking load, n [F]*—the load at which fracture occurs. **(E 6)**

3.1.5 *compressive strength, n [F/L²]*—the maximum compressive stress which a material is capable of sustaining.

Compressive strength is calculated from the maximum load during a compression test carried to rupture and the original cross-sectional area of the specimen. **(E 6)**

3.1.6 *gage length, n [L]*—the original length of that portion of the specimen over which strain or change of length is determined. **(E 6)**

3.1.7 *modulus of elasticity, n [F/L^2]*—the ratio of stress to corresponding strain below the proportional limit. **(E 6)**

3.1.8 *percent bending, n*—the bending strain times 100 divided by the axial strain. **(E 1012)**

4. Significance and Use

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

4.2 Generally, resistance to compression is the measure of the greatest strength of a monolithic advanced ceramic. 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. Although tensile strength distributions of ceramics are probabilistic and can be described by a weakest link failure theory, such descriptions have been shown to be inapplicable to compressive strength distributions in at least one study **(1)**.[8] However, the need to test a statistically significant number of compressive test specimens is not obviated. Therefore, a sufficient number of test specimens at each testing condition is required for statistical analysis and design.

4.3 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 which may develop as the result of cumulative damage processes (for example, microcracking) which may be influenced by testing mode, testing rate, processing or compositional effects, microstructure, or environmental influences.

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

4.5 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.

5. Interferences

5.1 Test environment (vacuum, inert gas, ambient air, and so forth) including moisture content (for example, relative humidity) may have an influence on the measured compressive strength. Testing to evaluate the maximum strength potential of a material can be conducted in inert environments or at sufficiently rapid testing rates, or both, so as to minimize any environmental effects. Conversely, testing can be conducted in environments, test modes, and test rates representative of service conditions to evaluate material performance under use conditions. When testing is conducted in uncontrolled ambient air with the intent of evaluating maximum strength potential, relative humidity and temperature must be monitored and reported.

5.2 Fabrication of test specimens can introduce dimensional variations which may have pronounced effects on compressive mechanical properties and behavior (for example, shape and level of the resulting stress-strain curve, compressive strength, induced bending, and so forth). Machining effects introduced during test specimen preparation can be an interfering factor in the determination of ultimate strength of pristine material (that is, increased frequency of loading block related fractures (see Fig. 1) compared to volume-initiated fractures). Surface preparation can also lead to the introduction of residual stresses. Universal or standardized test methods of surface preparation do not exist. It should be understood that final machining steps may or may not negate machining damage introduced during the initial machining. Note that final compressive fracture of advanced ceramics can be attributed to the interaction of large numbers of microcracks that are generated in the volume of the material and ultimately lead to loss of structural integrity. **(1,2)**. Therefore, although surface roughness in the gage section of the test specimen is not as critical for determining maximum strength potential as it is for flexure or tension tests of advanced ceramics, test specimen fabrication history may play an important role in the measured compressive strength distributions and should be reported. In addition, the nature of fabrication used for certain advanced ceramics (for example, pressureless sintering, hot pressing) may require the testing of test specimens with gage sections in the as-processed condition (that is, it may not be possible or desired/required to machine some test specimen surfaces not directly in contact with test fixture components). For very rough or wavy as-processed surfaces eccentricities in the stress state due to nonsymmetric cross sections as well as variation in the cross-sectional
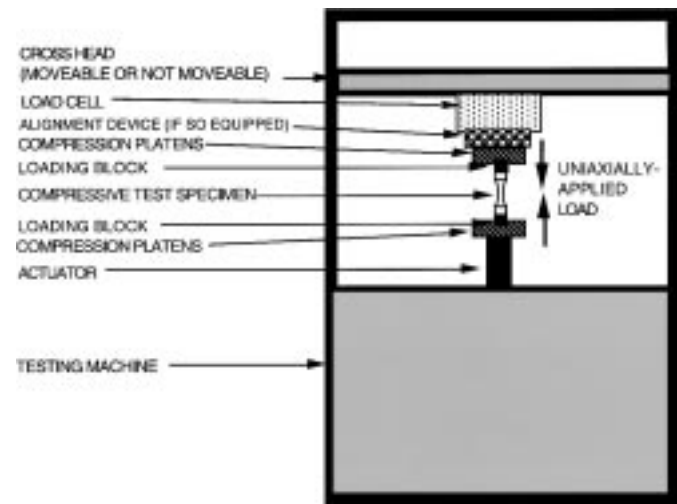
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[8] The boldface numbers in parenthesis refer to the list of references at the end of this test method

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

dimensions may also interfere with the compressive strength measurement. Finally, close geometric tolerances, particularly in regard to flatness, concentricity, and cylindricity of test specimen surfaces or geometric entities in contact with the test fixture components) are critical requirements for successful compression tests.

5.3 Bending in uniaxial compression tests can introduce eccentricity leading to geometric instability of the test specimen and buckling failure before valid 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 device on the test specimen.

5.4 Fractures that initiate outside the uniformly stressed gage section or splitting of the test specimen along its longitudinal centerline may be due to factors such as stress concentrations or geometrical transitions, extraneous stresses introduced by the load fixtures, misalignment of the test specimen/loading blocks, nonflat loading blocks or nonflat test specimen ends, or both, or strength-limiting features in the microstructure of the test specimen. Such non-gage section fractures will normally constitute invalid tests.

6. Apparatus

6.1 *Testing Machines*—Machines used for compression testing shall conform to the requirements of Practices E 4. The loads used in determining compressive strength shall be accurate within ±1 % at any load within the selected load range of the testing machine as defined in Practices E 4. A schematic showing pertinent features of one possible compressive testing apparatus is shown in Fig. 1. Check that the expected breaking load for the desired test specimen geometry and test material is within the capacity of the test machine and load cell. Advanced ceramic compression test specimens require much greater loads to fracture than those usually encountered in tension or flexure test specimens of the same material.

6.2 *Loading Fixtures*:

6.2.1 *General*—Compression loading fixtures are generally composed of two parts: (*1*) basic steel compression fixtures (for example, platens) attached to the test machine and (*2*) loading blocks which are non-fixed and act as the interface between the compression platens and the test specimen. An assembly drawing of such a fixture and a test specimen is shown in Fig. 2. The brittle nature of advanced ceramics requires a uniform interface between the loading fixtures and the test specimen. Line or point contact stresses lead to crack initiation and fracture of the test specimen at stresses less than the actual compressive strength (that is, where actual strength is the intrinsic strength of the material not influenced by the test or test conditions). In addition, large mismatches of Poisson's ratios or elastic moduli between the loading fixture and test specimen, or both, can introduce lateral tensile loads leading to splitting of the compression test specimen. Similarly, plastic deformation of the load fixture can induce lateral tensile loads with the same effect.

6.2.1.1 Hardened (>48 HR_c) steel compression platens shall be greater in diameter (≥25.4 mm) than the loading blocks and shall be at least 25.4 mm in thickness. The loading surfaces of
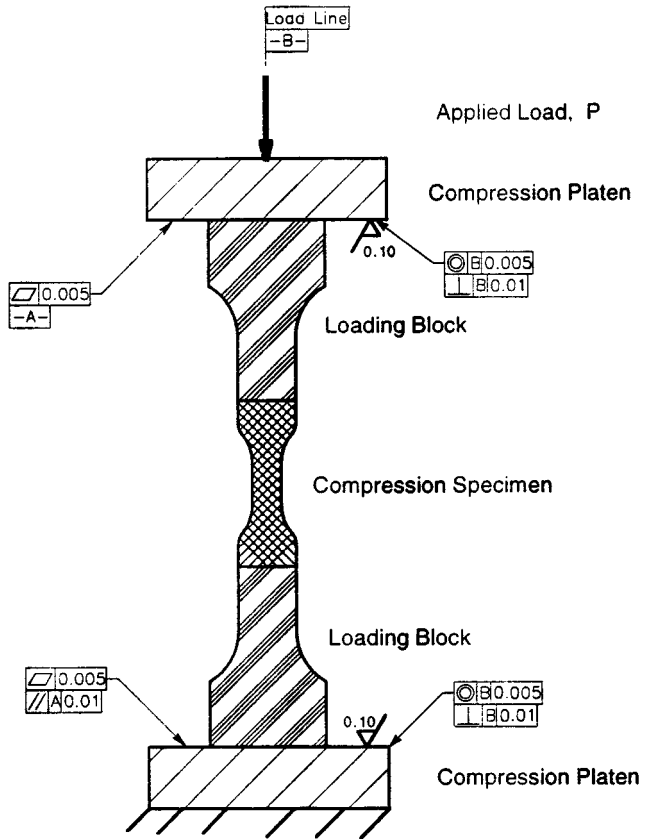

FIG. 2 Example of Basic Fixturing and Test Specimen for Compression Testing

the compression platens shall be flat to 0.005 mm. In addition, the two loading surfaces (loading face used to contact the loading blocks and bolted face used to attach the platen to the test machine) shall be parallel to 0.005 mm. When installed in the test machine, the loading surfaces of the upper and lower compression platens shall be parallel to each other within 0.01 mm and perpendicular to the load line of the test machine to within 0.01 mm (**2**). The upper and lower compression platens shall be concentric within 0.005 mm of each other and the load line of the test machine. Angular and concentricity alignments have been achieved with commercial alignment devices or by using available hole tolerances in commercial compression platens in conjunction with shims (**2**).

6.2.1.2 Loading blocks as shown in Fig. 3 shall have the same diameter as the test specimen ends at their interface. Parallelism and flatness of faces as well as concentricity of the loading blocks shall be as given in Fig. 3. The material for the loading blocks shall be chosen to meet the following requirements. Generally, cobalt-sintered tungsten carbide (Co-WC) has worked satisfactorily for this purpose in compression tests of a variety of advanced ceramics (**2**). However, for some high-performance advanced ceramics, other loading block materials may be required to meet the requirements of 6.2.1.2.1 and 6.2.1.2.2.

6.2.1.2.1 Lateral strain in the loading block (ϵ_{LB}) at the loading block/test specimen interface shall be less than the lateral strain in the compression test specimen end (ϵ_{SE}) at the loading block/test specimen interface to prevent lateral splitting in the test specimen such that:
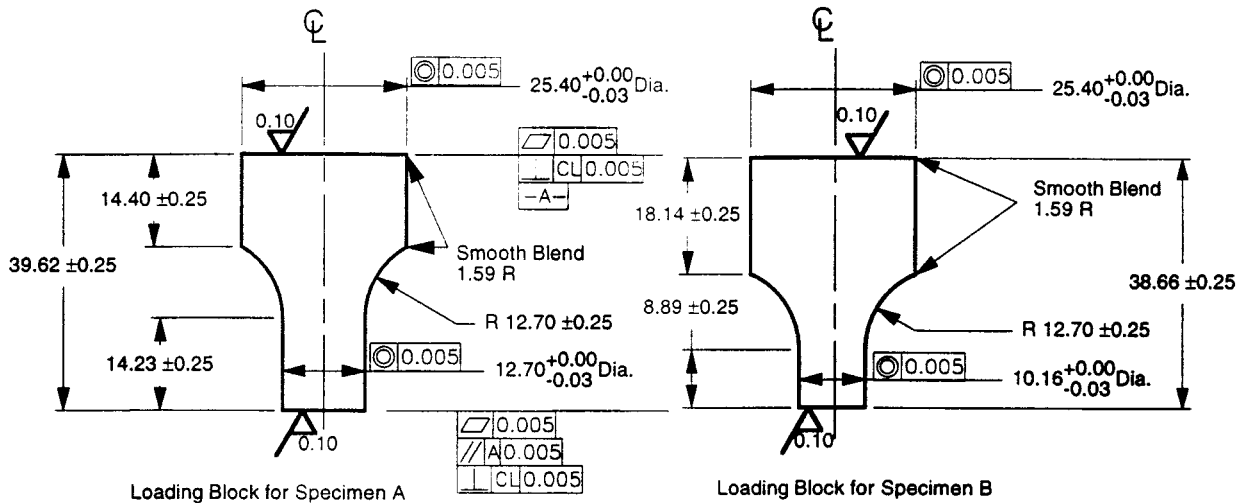
NOTE 1—Dimensions in millimetres; surface finish in micrometres.
FIG. 3 Loading Blocks for Recommended Compression Test Specimen Sizes A and B

$$\epsilon_{LB} < \epsilon_{SE} \qquad (1)$$

where:

ϵ_{LB} = $-\nu_{LB}\sigma_{LB}/E_{LB}$ (ν_{LB} = Poisson's ratio of the loading block material, σ_{LB} = longitudinal stress in the loading block at the loading block/test specimen interface, and E_{LB} = elastic modulus of the loading block material) and

ϵ_{SE} = $-\nu_S\sigma_{SE}/E_S$ (ν_S = Poisson's ratio of the compression test specimen material, σ_{SE} = longitudinal stress in the compression test specimen at the loading block/test specimen interface, and E_S = elastic modulus of the compression test specimen material).

Since, $\sigma_{LB} = \sigma_{SE}$ are presumably equal at the loading block/test specimen interface, Eq 1 can be rewritten as:

$$\frac{\nu_{LB}}{E_{LB}} < \frac{\nu_S}{E_S} \qquad (2)$$

6.2.1.2.2 The mean compressive strength of the loading block material, $\bar{S}_{UC-LB}$, shall be greater than the anticipated mean compression strength of the compression test specimen material, $\bar{S}_{UC-S}$, such that:

$$\bar{S}_{UC-LB} > \bar{S}_{UC-S} \qquad (3)$$

6.3 *Alignment*—Although limits on angularity and concentricity of loading fixtures are given in 6.2.1.1, other variables may affect final nonuniformity of the stress in the specimen gage section. As a result, quantification of this nonuniformity (that is, bending) is accomplished using a well-accepted and documented parameter, percent bending. Therefore, at a minimum, quantify and verify alignment of the testing system at the beginning and end of a test series unless the conditions for verifying alignment as detailed in A1.1 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 and the alignment verification procedures detailed in the appendix. Allowable bending requirements are discussed in 6.5. Equip compression test specimens used for alignment verification with a recommended four separate longitudinal strain gages located circumferentially on a single cross-sectional plane to determine bending contributions from both eccentric and angular misalignment of the loading fixtures. Ideally, the material of the verification test specimen should be identical to that being tested. In addition, dummy test specimens used for alignment 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.

NOTE 1—A test series is interpreted to mean a discrete group of tests on individual test specimens conducted within a discrete period 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 five test specimens of Geometry B tested at a fixed rate in displacement control to final fracture in ambient air).

6.4 *Strain Measurement*—Although strain measurements are not required in this test method, if measured on the actual test specimen, determine strain by means of either expendable strain gages attached to the test specimen or noncontacting extensometry. Since fracture of test specimens in compression is spectacular, conventional contacting extensometers would in all likelihood be damaged or destroyed and are therefore not recommended. If Poisson's ratio is to be determined, instrument the test specimen to measure strain in both longitudinal and lateral directions. Stacked, biaxial strain gages are recommended for this purpose. Choose the strain gages, surface preparation, and bonding agents so as to provide adequate performance on the subject material without introducing spurious surface damage which may affect the test results. In addition, employ suitable strain gage conditioning and recording equipment.

6.4.1 If contacting extensometers are used to record strain in the initial (that is, linear) part of the stress-strain curve, remove the extensometer prior to test specimen fracture. All extensometers, whether contacting or noncontacting, shall be in accordance with Practice E 83, Class B-1 requirements. Extensometers shall be calibrated periodically in accordance with

Practice E 83. For contacting extensometers, the contact should cause no damage to the test specimen surface. In addition and if applicable, support the weight of the extensometer so as not to introduce bending greater than that allowed in 6.5'.

6.4.2 Although buckling is minimized when using the recommended test specimens of this test method, an additional recommendation but not requirement for the actual testing is to monitor possible buckling using strain determined directly from strain gages. Four strain gages mounted 90° apart around the circumference of the test specimen can be used to monitor incidences of bending or eccentricity and, hence, tendency to buckle. Buckling can be detected when the strain on one side of the test specimen reverses (decreases) while the strain on the other side increases rapidly.

6.5 *Allowable Bending*—Although the test specimens in Fig. 4 are designed to minimize incidences of load-induced buckling **(2)**, axial misalignment or the introduction of bending, due either to eccentricity or angular misalignment, will produce a geometric instability in the compressive test specimen leading to buckling and measured compressive strengths less than the actual compressive strength. Bending can be measured using either strain gages or other strain measurement devices located around the circumference of the test specimen or can be inferred from evidence in fractured test specimens that exhibit vertical cracking (splitting) due to tensile stresses which develop at the ends leading to chipping and cracking of the test specimen.

6.5.1 Actual studies of the effect of bending on the compressive strength distributions of advanced ceramics do not exist, although the test specimen and fixture tolerances given in this test method are intended to minimize non-uniaxial and nonuniform stresses. Until such information is forthcoming for advanced ceramics, this test method adopts a conservative recommendation of the lowest achievable percent bending for compressive testing. Therefore, in this test method the maximum allowable percent bending determined either at fracture or during an alignment verification is 2.5 **(3)** although the

maximum recommended percent is 1. However, it should be noted that unless all test specimens are properly strain gaged and percent bending monitored up to fracture, there will be no record of percent bending at the onset of fracture for each test specimen (although test specimens which exhibit vertical splitting are good indicators of excessive bending). Therefore, verify the testing system using a procedure such as the one detailed in the appendix such that percent bending does not exceed 2.5 at the average strain equal to either one half the anticipated strain at fracture or a strain of –0.0005 (that is, –500 microstrain) whichever is greater. At a minimum, conduct this verification at the beginning and end of each test series in accordance with 6.3. An additional verification of alignment is recommended, although not required, at the middle of the test series.

6.6 *Data Acquisition*—At the minimum, obtain an autographic record of applied load 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, an analog chart recorder or plotter should be used 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 should be accurate to within ± 1 % of the selected range for the testing system including readout unit, as specified in Practices E 4, 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 load or as independent variables of load. Cross-head 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 Devices*—Micrometers and other devices used for measuring linear dimensions shall be accurate and precise to at least one half the smallest unit to which the individual dimension is required to be measured. For the
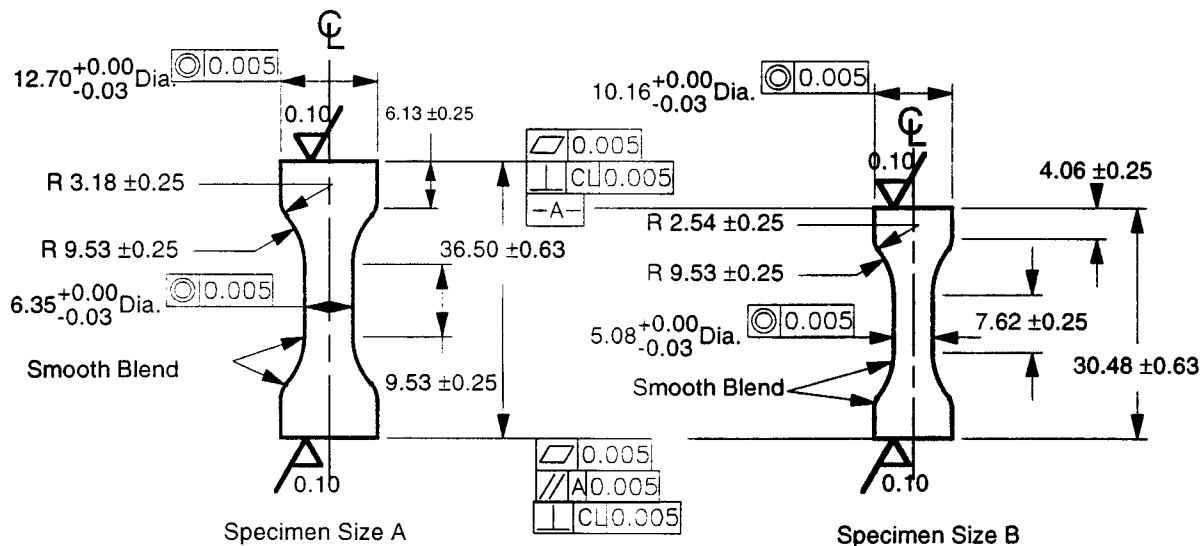
NOTE 1—Dimensions in millimetres; surface finish in micrometres.
FIG. 4 Recommended Compressive Test Specimen Sizes A and B

purposes of this test method, cross-sectional dimensions should be measured to within 0.01 mm requiring dimension-measuring devices with accuracies of 0.005 mm.

7. Precautionary Statement

7.1 Fractures of compressively loaded advanced ceramics occur at much greater loads and strain energies than in tensilely loaded advanced ceramics. Compressive fracture in high-strength advanced ceramics will generate the release of many uncontrolled fragments. Thick (6 to 13 mm) polycarbonate shielding or equivalent is recommended for operator safety.

7.2 To limit the uncontrolled motion of the compression fixture parts, temporarily bind the loading blocks to the compression platen using a strip or strips of adhesive tape around the loading block and adhered to the compression platen (see Fig. 1). Do not place any substance between the loading block and the compression platen contact surfaces.

7.3 Compression fractures often create fine particles which may be a health hazard. Materials containing whiskers, small fibers, or silica particles may also cause health hazards when compression tested. For such materials, the operator is advised to consult the material safety data sheet for guidance prior to testing. Suitable ventilation or masks may be warranted.

8. Test Specimen

8.1 *Test Specimen Geometries*:

8.1.1 Fig. 4 illustrates two contoured, cylindrical test specimens similar to those successfully used for compression tests of advanced ceramics (2-7). Contoured test specimens have been shown through finite element analyses (4) to have uniform stresses in the gage section with minimal stress concentrations at the geometric transitions and are therefore recommended in this test method. Although straight-sided test specimens (right circular cylinders) as recommended in Test Method C 773 for whitewares have been shown to produce nonuniform stresses with subsequent fracture at stresses not representative of actual compressive strengths (3,6), and are therefore not recommended in this test method for advanced ceramics, possible configurations for this geometry are discussed in Appendix X2. Specimen B as shown in Fig. 4 can be used when the load capacity of the test machine may be exceeded by use of Specimen A.

8.1.2 Contoured test specimen dimensions or geometries (2) other than those shown in Fig. 4 may be used, however the effect of any stress concentrations should be considered when developing a compressive test specimen geometry.

8.2 *Test Specimen Preparation*:

8.2.1 *Application-Matched Machining*—The gage section of the compressive test specimen will have the same surface/edge preparation as that given to a service component. Unless the process is proprietary, the report shall be specific about the stages of material removal, wheel grits, wheel bonding, amount of material removed per pass, and type of coolant used. Regardless of the application-matched procedure used to fabricate the surface of the gage section, the concentricity of the gage section as well as the surface roughness and flatness of the end faces shall be as specified in Fig. 4. This surface roughness can be achieved using lapping or a similar type of machining operation.

8.2.2 *Customary Practices*—In instances where a customary machining procedure has been developed that is completely satisfactory for a class of materials (that is, it induces no unwanted surface/subsurface damage or residual stresses), this procedure may be used to make the gage section of the compression test specimens. Unless the process is proprietary, the report shall be specific about the stages of material removal, wheel grits, wheel bonding, amount of material removed per pass, and the type of coolant used. Regardless of the customary machining procedure used to produce the surface of the gage section, the concentricity of the gage section as well as the surface roughness and flatness of the end faces shall be as specified in Fig. 4. This surface roughness can be achieved using lapping or a similar type of machining operation.

8.2.3 *Alternative Procedure*—In instances where 8.2.1 or 8.2.2 are not appropriate, 8.2.3.1-8.2.3.5 shall apply. The test report shall be specific about the stages of material removal, wheel grits, wheel bonding, amount of material removed per pass, and type of coolant used. Regardless of the alternative procedure used to fabricate the surface of the gage section, the concentricity of the gage section as well as the surface roughness and flatness of the end faces shall be as specified in Fig. 4. This surface roughness can be achieved using lapping or a similar type of machining operation.

NOTE 2—Final compressive fracture of advanced ceramics can be attributed to the interaction of large numbers of microcracks that are generated in the volume of the material and ultimately lead to loss of structural integrity (1,2). Therefore, surface roughness in the gage section of the test specimen is not as critical for determining maximum compressive strength potential as it is for flexural or tensile tests of advanced ceramics.

8.2.3.1 Perform all grinding or cutting with ample supply of appropriate filtered coolant to keep the workpiece and grinding wheel constantly flooded and particles flushed. Grinding can be done in at least two stages, ranging from coarse to fine rate of material removal. All cutting can be done in one stage appropriate for the depth of cut.

8.2.3.2 Stock removal rate shall not exceed 0.03 mm per pass up to the last 0.06 mm of material removed using diamond tools that have between 320 and 500 (or 600) grit. Remove equal stock from each surface where applicable.

8.2.3.3 Because of the axial symmetry of the contoured compressive test specimen, fabrication of the test specimens is generally conducted on a lathe-type apparatus. In some instances for tensile test specimens, the bulk of the material is removed in a circumferential grinding operation and a final, longitudinal grinding operation is then performed in the gage section. Such a final longitudinal grinding operation is not necessary for compressive test specimens because of the volume-related (that is, not surface-related) compressive strength mechanism.

8.2.3.4 Generally, computer numerical control (CNC) fabrication methods are necessary to obtain consistent test specimens with the proper dimensions within the required tolerances. A necessary condition for this consistency is the complete fabrication of the test specimen without removing it from the grinding apparatus, thereby avoiding introducing unacceptable tolerances into the finished test specimen.

8.2.3.5 Formed, diamond-impregnated wheels may be necessary both to fabricate critical shapes (for example, gage section transition radius) and to minimize grinding vibrations and subsurface damage in the test material. Formed wheels may require periodic dressing and shaping (truing), which can be done dynamically within the fabrication machine, to maintain the cutting and dimensional integrity.

8.3 *Handling Precaution*—Exercise care in storage and handling of finished test specimens to avoid the introduction of random and severe flaws. In addition, give attention to pretest storage of test specimens in controlled environments or desiccators to avoid unquantifiable environmental degradation of test specimens prior to testing.

8.4 *Number of Test Specimens*—A minimum of 5 test specimens tested validly is required for the purpose of estimating a mean. A greater number of test specimens may be necessary if estimates regarding the form of the strength distribution are required. If material cost or test specimen availability limit the number of tests to be conducted, fewer tests may be conducted to determine an indication of material properties.

8.5 *Valid Tests*—A valid individual test is one which meets all the following requirements: (*1*) all the testing requirements of this test method, and (*2*) failure occurs in the uniformly stressed gage section. Those tests failing outside the gage section, while not valid, may be interpreted as interrupted tests for the purpose of censored test statistical analyses.

9. Procedure

9.1 *Test Specimen Dimensions*—Determine the diameter of the gage section of each test specimen. Make measurements on at least three different cross-sectional planes in the gage section. To avoid damage in the critical gage section area, it is recommended that these measurements be made either optically (for example, an optical comparator) or mechanically using a flat, anvil-type micrometer. In either case, the resolution of the instrument shall be at least as specified in 6.7. Exercise extreme caution to prevent damage to the test specimen gage section. Ball-tipped or sharp anvil micrometers are not recommended because localized damage (for example, cracking) can be induced. Record and report the measured dimensions and locations of the measurements for use in the calculation of the compressive stress. Use the average of the multiple measurements in the stress calculations.

9.1.1 Conduct periodic, if not 100 %, inspection/measurements of all test specimens and test specimen dimensions to ensure compliance with the drawing specifications. Generally, high-resolution optical methods (for example, an optical comparator) or high-resolution digital point contact methods (for example, coordinate measurement machine) are satisfactory as long at the equipment meets the specifications in 6.7. The frequency of gage section fractures and bending in the gage section are dependent on proper overall test specimen dimensions within the required tolerances.

9.1.2 In some cases it is desirable, but not required, to measure surface finish to quantify the surface condition. Such methods as contacting profilometry can be used to determine surface roughness of the test specimen gage section. When quantified, report surface roughness and direction of the measurement with respect to the test specimen axis.

9.2 *Strain Measurements*—Although strain measurements are not required in this test method, they are highly recommended. In particular, if multiple, axial strain gages are used, they shall conform to Practice E 83 Class B1 and can be used to monitor bending for each test. In addition, appropriate strain measurements can be used to determine elastic constants in the linear region of the stress-strain curves and can serve to indicate underlying fracture mechanisms manifested as nonlinear stress-strain behavior.

9.3 *Test Modes and Rates*:

9.3.1 *General*—Test modes and rates can have distinct and strong influences on fracture behavior of advanced ceramics even at ambient temperatures depending on test environment or condition of the test specimen. Test modes may involve load or displacement control. Recommended rates of testing are intended to be sufficiently rapid to obtain the maximum possible compressive strength at fracture of the material. However, rates other than those recommended here may be used to evaluate rate effects. In all cases the test mode and rate must be reported.

9.3.2 *Displacement Rate*—The size differences of each test specimen geometry require a different testing rate for any given stress rate. Displacement mode is defined as the control of, or free-running displacement of, the test machine actuator or cross head. Thus, the displacement rate can be related to the stress or strain rate in the gage section of the test specimen as follows. Calculate the displacement rate to achieve fracture in 55 to 60 s as follows:

$$\dot{\delta} = \frac{d\delta}{dt} \cong \left(\frac{1}{k_m} + \frac{1}{k_s}\right) \dot{\epsilon} \, EA = \left(\frac{1}{k_m} + \frac{1}{k_s}\right) \dot{\sigma}A \qquad (4)$$

where:
$\dot{\delta}$ = displacement rate of the actuator or cross head, mm/s,
δ = cross-head displacement, mm,
t = time, of s,
k_m = axial stiffness of the test machine and load train (including the test specimen ends and the loading blocks), N/mm,
k_s = stiffness of the uniform gage section of the test specimen, N/mm,
$\dot{\sigma}$ = recommended (or desired) stress rate in the test specimen gage section, MPa/s,
$\dot{\epsilon}$ = strain rate in the test specimen gage section, s⁻¹,
E = elastic modulus of the material, MPa, and
A = cross-sectional area of the gage section.

The cross-sectional area, *A*, is calculated as follows:

$$A = \frac{\pi d^2}{4} \qquad (5)$$

where:
d = diameter of the gage section, mm.

NOTE 3—It is possible to calculate an approximate k_s as $k_s \approx AE/L$ where *L* is the length of the test specimen between the loading blocks. A possible method by which axial stiffness, k_m, can be determined is by measuring the load-displacement curves for various test specimen lengths. The plot of the slope of these load-displacement curves versus test specimen length can then be extrapolated to zero to find the actual machine stiffness, k_m. Alternatively, k_m can be estimated using the manufacturer's value for frame stiffness as a starting point and decreasing this value as necessary to account for various links in the load train.

9.3.3 *Load Rate*—For most advanced ceramics exhibiting linear elastic behavior, compressive fracture is attributed to the coalescence of many microcracks that grow and arrest under compressive loading. When the density of micro cracks reaches a critical point, structural integrity is lost and catastrophic collapse ensues **(5)**. Therefore, a load-controlled test, with load generally related directly to compressive stress in brittle, linear elastic advanced ceramics, can be a preferred test mode. Load rate can be directly related to stress or strain rate thus simplifying data analysis. Stress rates >35–50 MPa/s are recommended. Alternatively, stress or load rates should be selected to produce final fracture in 55 to 60 s to minimize environmental effects when testing in ambient air. Load rate is calculated as follows:

$$\dot{P} = \frac{dP}{dt} = \sigma A = \epsilon E A \qquad (6)$$

where:
$\dot{P}$ = required load rate, N/s,
P = applied force, N, and
 other variables are as defined for Eq 4.

9.4 *Conducting the Compression Test*:

9.4.1 *Mounting the Test Specimen*—The primary concern during testing is that the load train components are parallel and concentric. Prior to each test, remove any nicks in the compression platens (for example, abrade the surfaces with emery cloth) and clean the surfaces with a solvent (for example, acetone). An alignment fixture (Fig. 5) may consist of a precision machinist's V-block (45 mm in length) **(2,5)**. The V-block may be used to align the test specimen ends with the corresponding section of the loading blocks to within 0.005 mm, if possible. The V-block may be supported vertically by two appropriately sized machinists blocks (see Fig. 5). This combination of components may be assembled and placed at the center of the compression platen. The two loading blocks and the test specimen may then be pushed into the V-block. The entire assembly may be visually aligned while firmly holding it together within a 25.4-mm circle (circle center within 0.5 mm of the test machine load line) inscribed on the compression platen. Slowly move the actuator or cross head until a small
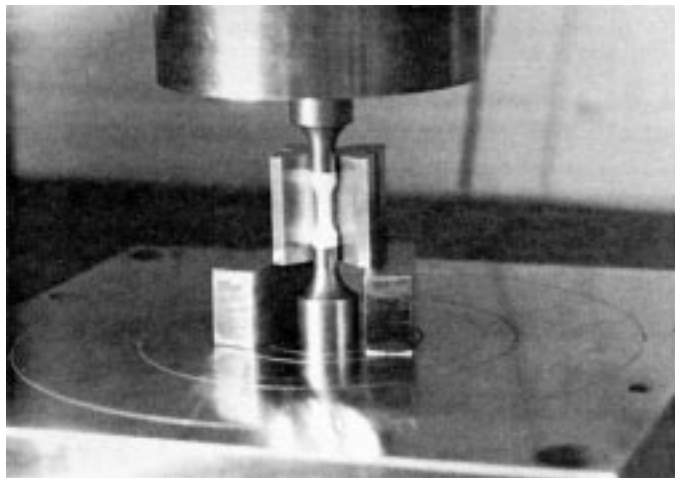

FIG. 5 Use of V-blocks for Aligning Load Blocks and Compression Test Specimens (2,5)

preload is developed. Remove the alignment system (that is, V-blocks) and report the preload. It is possible to further verify alignment by either running a dial/digital indicator or pulling a "lead" pencil across the test specimen ends and loading blocks at three places **(2,5)** and noting if the readout on the indicator "jumps" or the lead "catches" on any protruding edges of misaligned parts.

9.4.2 *Preparations for Testing*—Set the test mode and test rate on the test machine. If necessary, attach the lead wires of the strain gages to the signal conditioner and zero the outputs. Ready the autograph and data acquisition systems for data logging. Install the protective shield (see 7.1) for containment of fragments and activate the ventilation systems as required.

NOTE 4—If strain gages are used to monitor bending, the strain gages should be zeroed with the test specimen standing in the V-block on the compression platen but without a preload applied. This will ensure that bending due to the initial loading is factored into the measured bending.

9.4.3 *Conducting the Test*—Initiate the data acquisition. Initiate the test mode. After test specimen fracture, disable the action of the test machine and the data collection of the data acquisition system. The breaking load should be measured with an accuracy of ±1 % of the load range and noted for the report. Carefully collect the test specimen fragments from the compression platen. Place the test specimen fragments into a suitable, nonmetallic container for later analysis.

9.4.4 Determine the ambient temperature and relative humidity in accordance with Test Method E 337.

9.4.5 *Posttest Interpretation*—For a properly conducted compression test, the gage section of test specimen should be pulverized with the ends of the test specimen intact. Improperly conducted compression tests may result in splitting of the test specimen (see Fig. 6). Edge chamfering of the loading ends of test specimens may reduce incidences of splitting and peeling when fracture origins are at these edges.

NOTE 5—Results from test specimens fracturing outside the uniformly stressed gage section cannot be used in the direct calculation of a mean compressive strength at fracture for the entire test set. Such results are considered anomalous and, from a statistical standpoint, can be used as censored tests (that is, test specimens in which a compressive stress at least equal to that calculated by Eq 8 was sustained in the uniform gage section before the test was prematurely terminated by a non-gage section fracture). To complete a required statistical sample (for example, $n = 5$) for purposes of mean strength, test one replacement test specimen for each test specimen that fractures outside the gage section.

9.4.5.1 In addition, although the procedures and recommended compression test specimens of this test method are
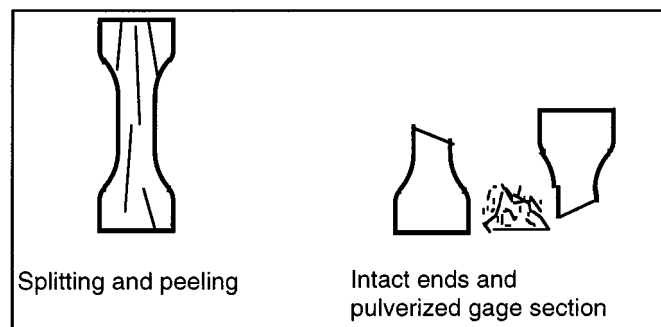

FIG. 6 Illustration of Splitting and Peeling Compared to Intact Ends With a Pulverized Gage Section

intended to minimize incidences of buckling, any test specimens fracturing at stresses greater than or equal to the calculated critical buckling stress are considered to have potentially failed from buckling and may not be representative of actual uniaxial compressive strength (3,6). The following discussion addresses the critical buckling stress that can be calculated from the simple Euler column buckling relation for fixed-end conditions such that:

$$\sigma_{cr} = \frac{P_{cr}}{A} = \frac{[4\pi^2 \, EI \, / \, l^2]}{A} = \frac{\pi^2 \, Er^2}{l^2} \qquad (7)$$

where:
σ_{cr} = Euler critical buckling stress, MPa,
P_{cr} = critical compressive buckling load, N,
A = cross-sectional area of the gage section where $A = \pi r^2$,
r = test specimen radius, mm,
E = longitudinal elastic modulus of the advanced ceramic, MPa
I = moment of inertia where $I = \dfrac{\pi r^4}{4}$, mm^4, and
l = actual, free (unsupported) length of the test specimen gage section, mm.

Tendency to buckle can also be inferred from strain gage information as noted in 6.4.2, if the test specimen is so equipped. In addition, an indication of anomalous behavior (either misalignment or onset of buckling) is if the difference in strain values from the two opposite strain gages is greater than 5 to 10 %. Test specimens fracturing at stresses greater than or equal to σ_{cr} or with strain values indicating anomalies in the test, or both, can be treated as discussed in Note 5 for test specimens fracturing outside the gage section.

NOTE 6—The slenderness ratio (l/r) of the recommended compression test specimen geometries (Specimens A and B in Fig. 4) is approximately 6 to 12 (depending on the assumed effective length). Substituting these values into Eq 7 gives a σ_{cr} of about 0.06E to 0.07E. Given the high values of E for most advanced ceramics, it is highly unlikely that σ_{cr} would be less than the compressive strength of the material when using the recommended compression test specimen geometries. Alternative test specimen geometries with l/r greater than those of the recommended test specimen geometries may give values of σ_{cr} closer to the compressive strength of the material and should be evaluated for buckling.

9.5 *Posttest Validation*—While fractography is not possible due to fragmentation of the test specimen, examination of the test specimen remnants can provide information on the validity of the compression test. In particular, remnants should be examined for evidence of vertical splitting that indicates an invalid test. Pulverization of the gage section and intact end faces are indicative of valid tests (see Fig. 6).

10. Calculation

10.1 *Compressive Strength, General*—The formula for the compressive strength of a uniaxially loaded rod employs the uniaxial breaking load and the original cross-sectional area of the uniform gage section:

$$S_u = \frac{P_{max}}{A} \qquad (8)$$

where:

S_u = compressive strength, MPa,
P_{max} = maximum load, N, and
A = original cross-sectional area, mm^2.

The cross-sectional area A is calculated as follows:

$$A = \frac{\pi \, d^2}{4} \qquad (9)$$

where:
d = average diameter of the gage section, mm, as detailed in 9.1.

10.2 *Modulus of Elasticity*—If strain is measured in the uniform gage section of the test specimen, the modulus of elasticity (that is, ratio of stress to strain at stresses less than the proportional limit) can be calculated as the slope of the least squares regression fit of the linear portion of the engineering stress-engineering strain curve such that:

$$E = \frac{\Delta\sigma}{\Delta\epsilon} \qquad (10)$$

where:
E = modulus of elasticity, and
$\dfrac{\Delta\sigma}{\Delta\epsilon}$ = slope of the $\sigma - \epsilon$ curve within the linear region.

Engineering stress is defined as follows:

$$\sigma = \frac{P}{A} \qquad (11)$$

where:
σ = engineering stress, MPa,
P = applied, uniaxial tensile load, N, and
A = original cross-sectional area, mm^2, as defined in Eq 9.

Engineering strain is defined as follows:

$$\epsilon = \frac{(l - l_o)}{l_o} \qquad (12)$$

where:
ϵ = engineering strain,
l = gage length (test specimen or extensometer gage length) at any time, mm, and
l_o = original gage length in units of mm.

10.3 *Mean, Standard Deviation and Percent Coefficient of Variation*—For each series of tests, the mean, standard deviation, and percent coefficient of variation for each measured value can be calculated as follows:

$$\text{Mean} = \overline{X} = \frac{\sum_{i=1}^{n} X_i}{n} \qquad (13)$$

$$\text{Standard deviation (s.d.)} = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \overline{X})^2}{n - 1}} \qquad (14)$$

$$\text{Percent coefficient of variation} = \% CV = \frac{100 \, (\text{s.d.})}{\overline{X}} \qquad (15)$$

where:
X_i = valid measured value, and
n = number of valid tests.

11. Report

11.1 *Test Set*—Report the following information for the test

set. Any significant deviations from the procedures and requirements of this test method should be noted in the report.

11.1.1 Date and location of testing.

11.1.2 Compression test specimen geometry used (that is, either specify Specimen A or B or if neither A or B were used, include an engineering drawing).

11.1.3 Type and configuration of the test machine (include drawing or sketch if necessary). If a commercial test machine was used, the manufacturer and model number are sufficient for describing the test machine.

11.1.4 Type, configuration, and resolution of strain measurement equipment used (include drawing or sketch if necessary). If a commercial extensometer or strain gages were used, the manufacturer and model number are sufficient for describing the strain measurement equipment.

11.1.5 Type and configuration of compression test platen and loading blocks used (include drawing or sketch if necessary). If a commercial platen was used, the manufacturer and model number are sufficient for describing the test setup.

11.1.6 Number (n) of test specimens tested validly (for example, fracture in the gage section). In addition, report total number of test specimens tested (n_T) to provide an indication of the expected success rate of the particular test specimen geometry and test apparatus.

11.1.7 All relevant material data including vintage data or billet identification data. As a minimum, report the date the material was manufactured. For commercial materials, report the commercial designation.

11.1.8 Description of the method of test specimen preparation including all stages of machining.

11.1.9 Heat treatments, coatings, or pretest exposures, if any, applied either to the as-processed material or to the as-fabricated test specimen.

11.1.10 Test environment including relative humidity (Test Method E 337), ambient temperature, and atmosphere (for example, ambient air, dry nitrogen, silicone oil, and so forth).

11.1.11 Test mode (load or displacement control) and actual test rate (load rate or displacement rate). Calculated stress rate should also be reported, if appropriate, MPa/s.

11.1.12 Percent bending and corresponding average strain in the test specimen recorded during the verification as measured at the beginning and end of the test series.

11.1.13 Critical Euler buckling stress for the nominal test geometry, σ_{cr}, MPa.

11.1.14 Mean, standard deviation, and coefficient of variation of the following measured parameters or properties for each test series:

11.1.14.1 Compressive Strength, S_u, MPa.

11.1.14.2 Strain at Compressive Strength, ϵ_u (if applicable).

11.1.14.3 Modulus of elasticity in compression, E, if applicable, MPa.

11.2 *Individual Test Specimens*—Report the following information for each test specimen tested. Note in the report any significant deviations from the procedures and requirements of this test method.

11.2.1 Pertinent overall test specimen dimensions, if measured, such as total length, length of gage section, test specimen end dimensions, and so forth, mm.

11.2.2 Average surface roughness, μm, if measured, of gage section and direction of measurement relative to test specimen axis.

11.2.3 Average cross-sectional dimensions, if measured, or cross-sectional dimensions at the plane of fracture, mm.

11.2.4 Preload applied to the test specimen, N.

11.2.5 Plot of the entire stress-strain curve, if applicable.

11.2.6 Breaking load, P_{max}, N.

11.2.7 Compressive strength, S_u, MPa.

11.2.8 Strain at compressive strength, ϵ_u, if applicable.

11.2.9 Modulus of elasticity in compression, E, if applicable, MPa.

11.2.10 Percent bending and average strain at fracture (if measured).

11.2.11 Type of fracture (for example, gage section pulverization or splitting/non-gage section fracture).

12. Precision and Bias

12.1 Because of the nature of the materials and lack of a wide database on a variety of applicable advanced ceramics, no definitive statement can be made at this time concerning precision and bias of this test method.

12.2 Although no definitive statement can be made regarding the precision and bias, an indication of the precision (that is, percent coefficient of variation) is shown in Table 1 for a range of advanced ceramics tested in the same laboratory (2).

12.3 It is difficult to design one-piece compressive strength test specimens without some stress concentration in the gage section. Finite element analyses indicate stress raisers at the transition radius of the gage section of both Test Specimen Geometries A and B (2). Depending on the relative maximum stresses caused by these stress raisers, a systematic bias of measured compressive strength could occur and be interpreted as a conservative estimate of the actual compressive strength (2).

12.4 Test results for the aluminum oxide (Al_2O_3) reported in Table 1 were generated from test specimens fabricated from the same billet, although the tests on each type of test specimen geometry were conducted by different investigators several years apart (2). The difference in the mean strengths for Test

TABLE 1 Compression Test Results from a Single Laboratory (2)

NOTE 1—Although conducted with fewer test specimens than the other materials in this table as well as fewer than the minimum required in this test method, the three tests of a cobalt-sintered WC (Kennametal, Grade 3406, hot-pressed, 1987 vintage) using Geometry B gave a mean compressive strength of 4,290 MPa and a standard deviation of 10 MPa.

Material	Compression Test Specimen Geometry	Mean Compressive Strength, MPa	Number of Tests	Percent Coefficient of Variation, %
Al_2O_3[A]	A	3490	10	2.4
Al_2O_3[A]	B	3590	10	3.2
SiC-sintered #	B	4550	10	9.5
SiC-hot pressed ##	B	6290	10	4.3
B_4C[+]	B	4830	10	10.1
TiB_2[++]	B	5670	10	3.3
SiC_w/Al_2O_3[+++]	B	6400	10	5.5

[A]Coors, AD94, sintered, 1984 vintage; # Carborundum, Hexoloy SA, sintered, 1985 vintage; ## Norton, NC203, hot pressed, 1985 vintage;[+] Ceradyne, hot pressed, 1983 vintage;[++] Ceradyne, Ceralloy #225, hot pressed, 1983 vintage;[+++] ARCO, SA25, hot pressed, 1986 vintage

Specimen Geometries A and B is only 100 MPa. However, this difference is statistically significant at the 95 % confidence level (two-sided t-statistic = 2.32 for 18 degrees of freedom because of the greater scatter (that is, greater coefficient of variation) for Test Specimen Geometry B. This significance suggests that there may be slight influences of geometry (for example, volume, surface area, stress raiser, and so forth)

between the two configurations which have not been quantified at this time.

13. Keywords

13.1 advanced ceramic; compression test; compressive strength

APPENDIXES

(Nonmandatory Information)

X1. VERIFICATION OF LOAD TRAIN BENDING

X1.1 *Purpose of Verification*—The purpose of this verification procedure is to demonstrate that the compression test setup can be used by the test operator to consistently meet the limit on percent bending as specified in 6.5. Thus, this verification procedure should involve no more care in setup than will be used in the routine testing of the actual compressive test specimen. The bending under compressive load should be measured using verification (or actual) test specimens of exactly the same design as that to be used for the compressive tests. For the verification purposes, apply strain gages as shown in Fig. X1.1 Conduct Verification measurements (*1*) at the beginning and end of a series of tests with a measurement at the midpoint of the series recommended, (*2*) whenever the grip interfaces and load train couplers are installed on a different test machine, (*3*) whenever a different operator is conducting a series of tests, (*4*) whenever damage or misalignment is suspected.

X1.2 *Verification Test Specimen*—The test specimen used for verification must be machined very carefully with attention to all tolerances and concentricity requirements. Ideally, the material of the verification test specimen should be identical to that being tested. An alternative material (isotropic, homogeneous, or continuous) with similar elastic modulus, elastic strain capability, and hardness to the test material may be used. Inspect the test specimen carefully with an optical comparator before strain gages are attached to ensure that these requirements are met. After the strain gages are applied it will no longer be possible to meaningfully inspect the test specimen, so care should be exercised in handling and using it.

X1.2.1 For simplicity, mount a minimum of four foil resistance strain gages on the verification test specimen as shown in Fig. X1.1. Note that the strain gage plane should be within 0.5 mm of the longitudinal center of the reduced or designated gage section. Avoid placing the strain gages closer than one strain gage length from geometrical features such as the transition radius from the gage section which can cause strain concentrations and inaccurate measures of the strain in the uniform gage section. Strain gages on dummy test specimens composed of isotropic homogeneous materials should be as narrow as possible to minimize strain averaging. Equally space the four strain gages (90° apart) around the circumference of the gage section.

X1.3 *Verification Procedure*—Procedures for verifying alignment are described in detail in Practice E 1012. However, salient points for circular cross sections are described here for emphasis. The following discussion is not intended to replace Practice E 1012, but rather is intended to elucidate those aspects which are directly applicable to this particular test method.

X1.3.1 Place the test specimen and alignment device (V-block) in the compression platen.

X1.3.2 Connect the lead wires of the strain gages to the conditioning equipment and allow the strain gages to equilibrate under power for at least 30 min prior to conducting the verification tests. This will minimize drift during actual conduct of the verifications.

X1.3.3 Zero the strain gages before applying any preload to the test specimen. This will allow any bending due to the compression fixture to be recorded.
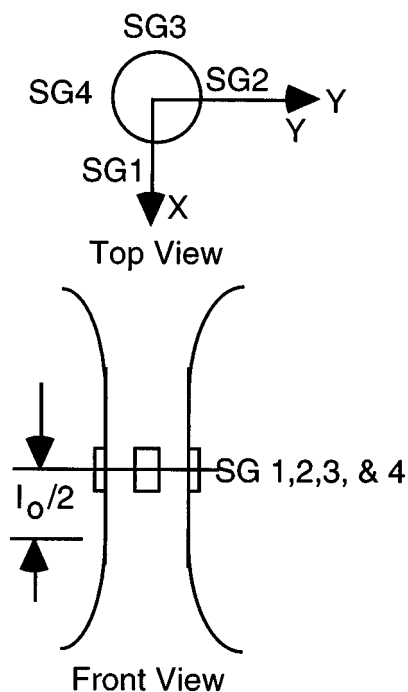
FIG. X1.1 Illustration of Strain Gage Placement on Gage Section Planes and Strain Gage Numbering (I_o = Gage Section Length, SG = Strain Gage)

X1.3.4 Apply a small preload to the test specimen to stabilize it within the compression fixture and remove the alignment device (V-block).

X1.3.5 Apply a sufficient load to the test specimen to achieve a mean strain equal to either one half the anticipated strain at fracture in the test material or a strain of –0.0005 (that is, –500 microstrain) whichever is greater. It is desirable to record the strain (and hence percent bending) as a function of the applied load to monitor any self-alignment of the load train.

X1.3.6 Calculate percent bending as follows referring to Fig. X1.1 for the strain gage numbers. Percent bending is calculated as follows:

$$PB = \frac{\epsilon_b}{\epsilon_o} 100 \qquad (X1.1)$$

$$\epsilon_b = \left[\left(\frac{\epsilon_1 - \epsilon_3}{2} \right)^2 + \left(\frac{\epsilon_2 - \epsilon_4}{2} \right)^2 \right]^{\frac{1}{2}} \qquad (X1.2)$$

$$\epsilon_o = \frac{\epsilon_1 + \epsilon_2 + \epsilon_3 + \epsilon_4}{4} \qquad (X1.3)$$

where:
ϵ_1, ϵ_2, ϵ_3, and ϵ_4 = strain readings for the individual strain gages. Strain gage readings are in units of strain and compressive strains are negative.

X1.3.7 The direction of the maximum bending strain is determined as follows:

$$\theta = \arctan \left[\frac{\epsilon_{(next\ greatest\ of\ 1,2,3,4)} - \epsilon_o}{\epsilon_{(greatest\ of\ 1,2,3,4)} - \epsilon_o} \right] \qquad (X1.4)$$

where θ is measured from the strain gage with the greatest reading in the direction of the strain gage with the next greatest reading where counter clockwise is positive as viewed from the top of the test specimen.

X1.3.8 The effect of the test specimen warpage can be checked by rotating the test specimen 180° about its longitudinal axis and performing the bending checks again. If similar results are obtained at each rotation, then the degree of alignment can be considered representative of the load train and not indicative of the test specimen. If load train alignment is within the specifications of 6.5, the maximum percent bending should be recorded and the compression tests may be conducted. If the load train alignment is outside the specifications of 6.5, then the load train must be aligned or adjusted according to the specific procedures unique to the individual testing setup. This verification procedure must then be repeated to confirm the achieved alignment.

X2. Alternative Compression Test Specimen Geometry:

X2.1 Localized contact and constraint stresses at the loading block/test specimen interface can lead to crack initiation and subsequent fracture in compression test specimens at longitudinal stresses much less than the "true" compressive strength of the material. The reduced gage section compression test specimens shown in Fig. 4 tested in combination with loading blocks shown in Fig. 3 of a compatible material (6.2.1.2) are intended to eliminate non-gage section failures thereby achieving the measurement of the maximum compressive strength potential of the test material. However, circumstances may arise where material size limitations, fabrication costs, or nonmechanical performance considerations (for example, electrical performance during mechanical testing), or

combination thereof, may preclude the use of reduced gage section compression test specimens.

X2.2 The simplest alternative compression test specimen geometry is a right circular cylinder as discussed in Test Method C 773. A previous investigative comparison of measured compressive strengths using right circular cylinder (columnar) and reduced gage section (dumbbell) compression test specimens showed fractures initiating from the edges of the loading block/test specimen interface in the columnar test specimens but not in the dumbbell test specimens (6). Nonetheless, the right circular cylinder is an efficient use of material, is simple and cost-effective to fabricate, and presents a uniform
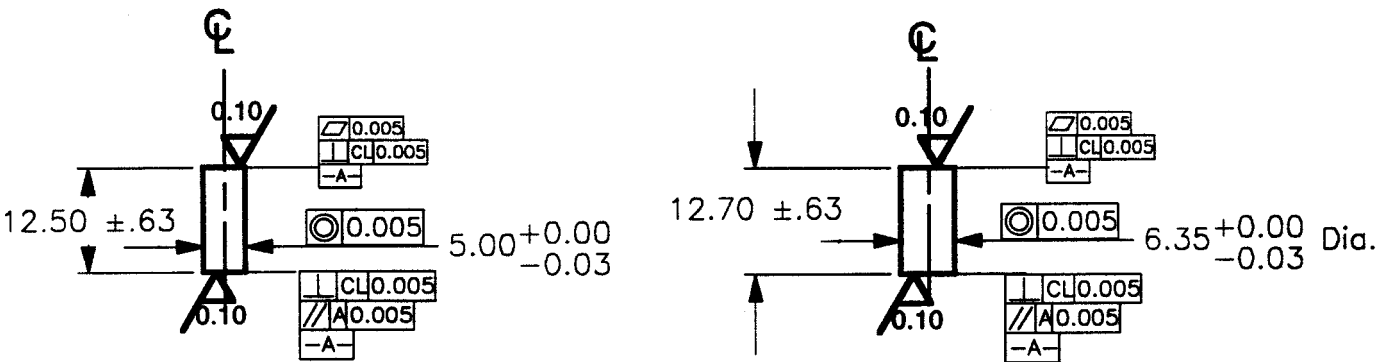
NOTE 1—Dimensions in millimetres, surface finish in micrometres.
FIG. X2.1 Alternative Compression Test Specimens in Accordance with Ref (6) and Test Method C 773, Respectively

cross section which may have nonmechanical performance advantages (for example, electrical properties during mechanical loading).

X2.3 Two possible right circular cylinder compression test specimens are shown in Fig. X2.1. Note that while these geometries are taken from Ref (**6**) and Test Method C 773, the

requirements of 6.2.1.2 and 8.1-8.5 are not obviated. As discussed in 8.1.2, test specimen dimensions and geometries other than those shown in Figs. 4 and X2.1 may be used, however, the effect of any stress concentrations must be considered when developing a compression test specimen geometry.

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