Designation: C 1495 – 07

Standard Test Method for Effect of Surface Grinding on Flexure Strength of Advanced Ceramics[1]

This standard is issued under the fixed designation C 1495; 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 the effect of surface grinding on the flexure strength of advanced ceramics. Surface grinding of an advanced ceramic material can introduce microcracks and other changes in the near surface layer, generally referred to as damage (See Fig. 1). Such damage can result in a change—most often a decrease—in flexure strength of the material. The degree of change in flexure strength is determined by both the grinding process and the response characteristics of the specific ceramic material. This method compares the flexure strength of an advanced ceramic material after application of a user-specified surface grinding process with the baseline flexure strength of the same material. The baseline flexure strength is obtained after application of a surface grinding process specified in this standard. The baseline flexure strength is expected to approximate closely the inherent strength of the material. The flexure strength is measured by means of ASTM standard flexure test methods.

1.2 Flexure test methods used to determine the effect of surface grinding are C 1161 Test Method for Flexure Strength of Advanced Ceramics at Ambient Temperatures and C 1211 Test Method for Flexure Strength of Advanced Ceramics at Elevated Temperatures.

1.3 Materials covered in this standard are those advanced ceramics that meet criteria specified in flexure testing standards C 1161 and C 1211.

1.4 The flexure test methods supporting this standard (C 1161 and C 1211) require specimens that have a rectangular cross section, flat surfaces, and that are fabricated with specific dimensions and tolerances. Only grinding processes that are capable of generating the specified flat surfaces, i.e. planar grinding modes, are suitable for evaluation by this method. Among the applicable machine types are horizontal and vertical spindle reciprocating surface grinders, horizontal and vertical spindle rotary surface grinders, double disk grinders, and tool-and-cutter grinders. Incremental cross-feed, plunge, and creep-feed grinding methods may be used.

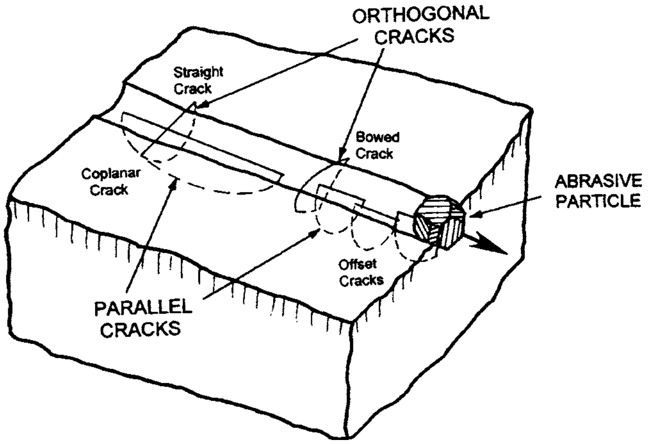


FIG. 1 Microcracks Associated with Grinding (Ref. 1)

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

2. Referenced Documents

2.1 *ASTM Standards:* [2]

C 1145 Terminology of Advanced Ceramics
C 1161 Test Method for Flexural Strength of Advanced Ceramics at Ambient Temperature
C 1211 Test Method for Flexural Strength of Advanced Ceramics at Elevated Temperatures
C 1239 Practice for Reporting Uniaxial Strength Data and Estimating Weibull Distribution Parameters for Advanced Ceramics

---

[1] This test method is under the jurisdiction of ASTM Committee C28 on Advanced Ceramics and is the direct responsibility of Subcommittee C28.01 on Mechanical Properties and Performance.

Current edition approved Feb. 1, 2007. Published February 2007. Originally approved in 2001. Last previous edition approved in 2006 as C 1495 – 06.

[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.

C 1322 Practice for Fractography and Characterization of Fracture Origins in Advanced Ceramics

C 1341 Test Method for Flexural Properties of Continuous Fiber-Reinforced Advanced Ceramic Composites

3. Terminology

3.1 *Materials Related:*

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 *baseline flexure strength*, *n*—in the context of this standard, refers to the flexure strength value obtained after application of a grinding procedure specified in this standard.

3.1.2.1 *Discussion*—For the advanced ceramics to which this this standard is applicable, the baseline flexure strength is expected to be a close approximation to the inherent flexure strength.

3.1.3 *ceramic matrix composite*, *n*—a 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. **C 1341**

3.1.4 *grinding damage*, *n*—any change in a material that is a result of the application of a surface grinding process. Among the types of damage are microcracks (Fig. 1), dislocations, twins, stacking faults, voids, and transformed phases.

3.1.4.1 *Discussion*—Although they do not represent internal changes in microstructure, chips and surface pits, which are a manifestation of microfracture, and abnormally large grinding striations are often referred to as grinding damage. Residual stresses that result from microstructural changes may also be referred to as grinding damage.

3.1.5 *inherent flexure strength*, *n*—the flexure strength of a material in the absence of any effects of surface grinding or other surface finishing process, or of extraneous damage that may be present. The measured inherent flexure strength may depend on the flexure test method, test conditions, and specimen size.

3.1.5.1 *Discussion*—Flaws due to surface finishing or extraneous damage may be present but their effect on flexure strength is negligible compared to that of "inherent" flaws in the material.

3.1.6 *materials lot or batch*, *n*—a single billet or several billets prepared from defined homogeneous quantities of raw materials passing simultaneously through each processing step to the end product is often referred to as belonging to a single lot or batch.

3.1.6.1 *Discussion*—There is no assurance that a single billet is internally homogenous or that billets belonging to the same lot or batch is identical.

3.2 *Grinding Process Related*—Definitions in this section apply to grinding machines and modes that generate planar surfaces. Applicable grinding machines types are identified in (1.4). Some definitions may not be applicable when used in connection with non-planar grinding modes such as centerless and cylindrical modes which are outside of the scope of this standard.

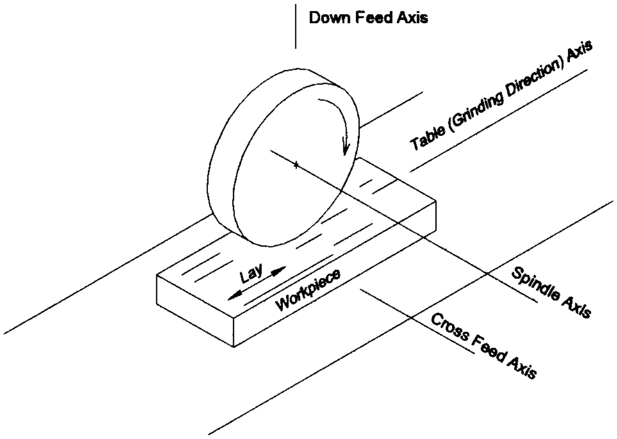


FIG. 2 Machine Axes for Horizontal Spindle Reciprocating Surface Grinder

3.2.1 *blanchard grinding*, *n*—a type of rotary grinding in which the workpiece is held on a rotating table with an axis of rotation that is parallel to the (vertical) spindle axis.

3.2.2 *coolant*, *n*—usually a liquid that is applied to the workpiece and/or wheel during grinding for cooling, removal of grinding swarf, and for lubrication.

3.2.3 *coolant flow rate*, *n*—volume of coolant per unit time delivered to the wheel and workpiece during grinding.

3.2.4 *creep-feed grinding*, *n*—a mode of grinding characterized by a relatively large wheel depth-of-cut and correspondingly low rate of feed.

3.2.5 *cross-feed*, *n*—increment of displacement or feed in the cross-feed direction.

3.2.6 *cross-feed direction*, *n*—direction in the plane of grinding which is perpendicular to the principle direction of grinding. (Fig. 2)

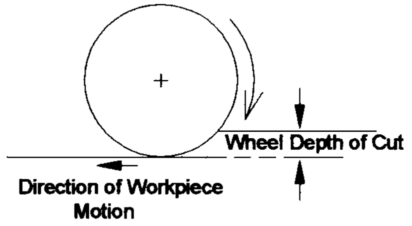
3.2.7 *down-feed*, *n*—increment of displacement or feed in the down feed direction. (Fig. 2)

3.2.8 *down-feed direction*, *n*—direction perpendicular to the plane of grinding for a machine configuration in which the grinding wheel is located above the workpiece. (Fig. 2)

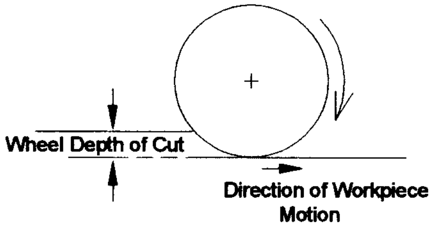
3.2.9 *down-grinding*, *n*—A condition of down-grinding is said to hold when the velocity vector tangent to the surface of the wheel at points of first entry into the grinding zone has a component normal to and directed into the ground surface of the workpiece. (Fig. 3a)

3.2.10 *dressing*, *n*—a conditioning process applied to the abrasive surface of a grinding wheel to improve the efficiency of grinding.

3.2.10.1 *Discussion*—Dressing may accomplish one or more of the following: *1*) removal of bond material from around the grit on the surface of the grinding wheel causing the grit to protrude a greater distance from the surrounding bond, *2*) removal of adhered workpiece material which interferes with the grinding process, removal of worn grit, *3*) removal of bond material thereby exposing underlying unworn grit, and *4*) fracture of worn grit thereby generating sharp edges.

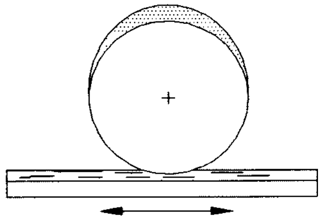


(a) Down Grinding

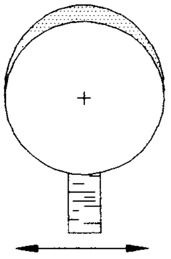


(b) Up Grinding

FIG. 3 Relative Wheel and Workpiece Directions of Motion for Down Grinding and Up Grinding



(a) Longitudinal Direction



(b) Transverse Direction

FIG. 4 Grinding Directions with Respect to Flexure Bar Orientation

3.2.11 *grinding axis*, *n*—any reference line along which the workpiece is translated or about which it is rotated to effect the removal of material during grinding.

3.2.12 *grinding direction*, *n*—when used in reference to flexure test bars, refers to the angle between the long (tensile) axis of the flexure bar and the path followed by grit in the grinding wheel as they move across the ground surface. See longitudinal grinding direction and transverse grinding direction. (Fig. 4)

3.2.13 *grit depth-of-cut*, *n*—nominal maximum depth that individual grit on the grinding wheel penetrate the workpiece surface during grinding. Synonymous with undeformed chip thickness.

3.2.14 *in-feed*, *n*—synonymous with wheel depth-of-cut and down feed.

3.2.15 *longitudinal grinding direction*, *n*—grinding direction parallel to the long axis of the flexure bar. (Fig. 4a)

3.2.16 *machine axes*, *n*—reference line along which translation or about which rotation of a grinding machine component (table, stage, spindle...) takes place. (Fig. 2)

3.2.17 *planar grinding*, *n*—a grinding process which generates a nominally flat (plane) surface.

3.2.18 *reciprocating grinding*, *n*—mode of grinding in which the grinding path consists of a series of linear bidirectional traverses across the workpiece surface.

3.2.19 *rotary grinding*, *n*—modes of planar grinding in which the grinding path in the plane of grinding is an arc, effected either by rotary motion of the workpiece or of the grinding wheel.

3.2.19.1 *Discussion*—Grinding striations left on the workpiece surfaces are arcs.

3.2.20 *surface grinding*, *n*—a grinding process used to generate a flat surface by means of an abrasive tool (grinding wheel) having circular symmetry with respect to an axes about which it is caused to rotate. (Fig. 2)

3.2.21 *table speed*, *n*—speed of the grinding machine table carrying the workpiece usually measured with respect to the machine frame.

3.2.22 *transverse grinding direction*, *n*—grinding direction perpendicular to the long axis of the flexure bar. (Fig. 4b)

3.2.23 *truing*, *n*—process by which the abrasive surface of a grinding wheel is brought to the desired shape and is made concentric with the machine spindle axis of rotation.

3.2.24 *undeformed chip thickness*, *n*—maximum thickness of a chip removed during grinding, assuming that the chip is displaced from the surface without deformation or change in shape.

3.2.24.1 *Discussion*—Equivalent in size to grit depth-of-cut.

3.2.25 *up-grinding*, *n*—a condition of up-grinding is said to hold when the velocity vector tangent to the surface of the wheel at points of first entry into the grinding zone has a component normal to and directed out of the ground surface of the workpiece. (Fig. 3b)

3.2.26 *wheel depth-of-cut*, *n*—depth of penetration of the grinding wheel into the workpiece surface as it moves parallel to the surface to remove a layer of material. (Fig. 3)

3.2.26.1 *Discussion*—Often abbreviated to depth-of-cut.

3.2.27 *wheel specifications*, *n*—description of the grinding wheel dimensions, grit type, grit size, grit concentration, bond type, and any other properties provided by the wheel manufacturer that characterize the grinding wheel.

3.2.28 *wheel surface speed*, *n*—circumferential speed of the grinding wheel surface at points which engage the workpiece during the process of grinding.

3.3 *Surface Finish Related:*

3.3.1 *lay*, *n*—refers to the direction a non-random pattern of surface roughness in the plane of the surface, e.g. the direction of abrasive striations on a surface prepared by grinding. (Fig. 2)

3.3.2 *roughness*, *n*—three-dimensional variations in surface topography characterized by wavelengths in the plane of the surface that are small compared to the design dimensions of the workpiece.

3.3.3 *waviness*, *n*—surface topographic variations characterized by wavelengths in the plane of the surface that are large compared to the roughness but smaller than the design dimensions of the workpiece.

3.4 *Flexure Test Related:*

3.4.1 *break force*, *n*—force at which a test specimen fractures (fails) in a flexure test.

3.4.2 *flexural strength*, *n*—a measure of the ultimate strength of a specified beam in bending. **C 1145**

3.4.3 *tensile face*, *n*—side of a flexure test specimen that is stressed in tension in a flexure test.

Other terms related to flexure testing can be found in C 1161.

3.5 *Fractography Related:*

3.5.1 *crack*, *n*—as used in fractography, a plane of fracture without complete separation. **C 1322**

3.5.2 *flaw*, *n*—a structural discontinuity in an advanced ceramic body which acts as a highly localized stress riser. **C 1322**

3.5.3 *fractography*, *n*—means and methods for characterizing a fractured specimen or component. **C 1145**

3.5.4 *fracture origin*, *n*—the source from which brittle fracture commences. **C 1145**

3.5.5 *fracture mirror*, *n—as used in fractography of brittle materials*, a relatively smooth region in the immediate vicinity of and surrounding the fracture origin. **C 1322**

Other terms related to fractography can be found in C 1322.

3.6 *Statistical Analysis Related:*

Terminology related to the reporting of flexural strength data and Weibull distribution parameters can be found in C 1239.

4. Summary of Test Method

4.1 This method compares the flexure strength of an advanced ceramic material that has been subjected to a user-applied surface grinding process with the baseline flexure strength for the same material. The baseline flexure strength is obtained after application of a grinding process specified in this standard and is expected to approximate closely the inherent flexure strength of the material. The user-applied surface grinding process may result in a decrease in flexure strength, no change in flexure strength, or in certain cases an increase in flexure strength. Two procedures, A and B, are available depending on the objective of the measurement. Procedure A is restricted to linear grinding processes obtained, for example, by a horizontal spindle, reciprocating-table surface grinder. In linear grinding processes, the surface finish is usually characterized by straight, parallel striations. Procedure A compares the baseline flexure strength of a material with the flexure strength *1*) after grinding parallel (termed longitudinal) to the long axis of the flexure bar and *2*) after grinding perpendicular (termed transverse) to the long axis of the flexure bar using the same grinding conditions. These two directions are employed because many advanced ceramics exhibit a change in flexure strength that is a minimum when grinding is in the longitudinal direction and a maximum when grinding is in the transverse direction. The grinding processes to be evaluated need only be applied to the tensile face of the test specimen. However, the other faces, especially the adjacent sides, must be prepared in such a way that they do not sustain damage that will influence the fracture process that occurs on the tensile face. (Where a grinding process could result in a substantial loss in flexure strength, it is recommended that this process not be applied to adjacent faces.) Procedure A is useful for obtaining detailed information on the response of a material to surface grinding and for the systematic determination of the influence of different grinding parameters on flexure strength. Three sets of specimens (typically 10 to 30 specimens per set depending on statistical requirements) will be required to evaluate a single grinding condition. Once the baseline strength is determined, only two sets, longitudinal and transverse, will be required for evaluation of additional grinding conditions, provided there is no change in the material from which the specimens are prepared.

4.2 Procedure B is designed mainly for quality control purposes but it may also be used for process development purposes. This procedure is not restricted to linear grinding. As in Procedure A, the flexure strength of specimens ground under user specified conditions is compared with the baseline flexure strength of the same lot of material. Procedure B is applicable to any grinding method that generates a suitably flat surface to meet the geometrical requirements for flexure bars (1.4). The ground surface lay may consist of a straight-line pattern generated by linear grinding, arcs produced by rotary modes of grinding, or any other pattern. However, as in Procedure A, careful consideration must be given to the directionality of the lay with respect to the tensile direction of the flexure bar. When different grinding parameters or different materials are to be compared, care must be taken to maintain the angle between the lay direction and the bar axis for all specimens. Alternatively, similar to Procedure A, tests may be conducted to determine the relationship between lay direction with respect to the bar axis and flexure strength.

5. Significance and Use

5.1 Surface grinding can cause a significant decrease[3] in the flexure strength of advanced ceramics materials. The magnitude of the loss in strength is determined by the grinding conditions and the response of the material. This test method can be used to obtain a detailed characterization of the relationship between grinding conditions and flexure strength for an advanced ceramic material. The effect on flexure strength of varying a single grinding parameter or several grinding parameters can be measured. The method may also be used to compare and rank different materials according to their response to one or more different grinding conditions. Results obtained by this method can be used to develop an optimum grinding process with respect to maximizing material removal rate for a specified flexure strength requirement. The test method can assist in the development of improved grinding-damage-tolerant ceramic materials. It may also be used for

---

[3] In some cases, an increase in flexure strength can be obtained by surface grinding if a highly flawed or lower-strength surface layer is removed by grinding. An increase can also result if a sufficiently large surface residual stress is introduced by grinding or if a favorable phase transformation is induced.

quality control purposes to monitor and assure the consistency of a grinding process in the fabrication of parts from advanced ceramic materials. The test method is applicable to grinding methods that generate a planar surface and is not directly applicable to grinding methods that produce non-planar surfaces such as cylindrical and centerless grinding.

6. Interferences

6.1 The condition and properties of the grinding machine and grinding wheel can have a significant influence on the measured flexure strength. These conditions and properties may not be easily identified, measured or controlled. Machine characteristics such as static and dynamic stiffness can have a substantial effect on damage introduced by grinding. These characteristics are likely to differ for different grinding machines. Grinding wheel specifications give only a qualitative identification and not a detailed or precise measure of properties. Thus despite having common specifications, grinding wheels from different manufacturers may give different results. Wheels from the same manufacturer with the same specifications may also perform differently due to manufacturing process variations. Grinding wheel condition, which is highly sensitive to prior use and the truing and dressing procedure and cycle, can also affect flexure strength. In connection with truing and dressing, the greatest variation is likely to occur when these procedures are performed manually by the operator.

6.2 Property variations in the test material may lead to differences in flexure strength. Such variations may be associated with differences in the population of inherent flaws in the material or to compositional and microstructural variations. When the influence of machining damage on flexure strength competes with the effect of inherent flaws, a material related variation in flaw population could be mistakenly attributed to an effect of machining.

6.3 Specimen surfaces can be scratched or indented during handling, especially during mounting or clamping for grinding. This is most likely to occur when hard abrasive particles are present on the specimen surface or on a surface that contacts the specimen. An extraneous scratch or indentation can act as a source of premature failure during flexure testing. In some cases it may not be possible to distinguish between extraneous and machining induced damage.

6.4 A grinding procedure is specified in this standard for measuring a reference baseline flexure strength. Damage introduced by this grinding procedure is not expected to have a significant effect on the flexure strength of most advanced ceramic materials. For verification, fractographic examination of tested baseline-specimens is used to ascertain the absence of machining damage at the fracture origin. In some instances undetected grinding-induced damage may combine or join with the inherent flaw that acts as the source or origin of fracture. This may impose a negative bias on the measured flexure strength result. Residual stresses introduced by the specified grinding procedure can also influence the baseline flexure strength.

6.5 A number of flexure test related factors can influence the value of the measured flexure strength. Among the most important for susceptible materials is slow crack growth due to environmental moisture. This and other interferences are discussed in C 1161 and C 1211.

TABLE 1 Flexure Specimen Configurations, Dimensions, and Tolerances[A]

Configuration	Width (b), mm	Depth (d), mm	Length (L_T) min, mm
A	2.0 (±0.05)	1.5 (±0.05)	25
B	4.0 (±0.13)	3.0 (±0.13)	45
C	8.0 (±0.13)	6.0 (±0.13)	90

[A] C 1161 and C 1211 give complete details and graphics on parallelism, perpendicularity, chamfers, and radii.

7. Materials

7.1 This standard covers materials that are suitable for testing by C 1161 Test Method for Flexure Strength of Advanced Ceramics at Ambient Temperatures and C 1211 Test Method for Flexure Strength of Advanced Ceramics at Elevated Temperatures. ASTM Standards C 1161 and C 1211 require that the material be isotropic and homogeneous, that the moduli of elasticity in tension and compression be identical, and that the material be linearly elastic. It is also required that the grain size be no greater than one fiftieth of the flexure test specimen thickness.

8. Specimen Dimensions

8.1 The required specimen dimensions and tolerances are specified in the flexure test standards (C 1161 and C 1211) and are given in Table 1. In preparing test specimens, allowance must be made for a thickness ≥0.4 mm to be removed from the surface by the grinding process being tested. For most materials this thickness will eliminate damage associated with prior machining operations and allow a steady state condition to be achieved for the grinding process under investigation. A thickness smaller than 0.4 mm may be used, but tests must be carried out to determine that prior damage has been removed and steady state is achieved in the grinding process under investigation. These tests will require comparison of flexure strength values obtained using the smaller thickness with values obtained for a thickness ≥0.4 mm.

9. Grinding Dimensions

9.1 A comprehensive discussion of grinding conditions is beyond the scope of this standard. More complete treatments can be found in the open literature and in textbooks on grinding (**2**).The following description is included mainly to assist in the identification and categorization of important factors. In principle, grinding conditions comprise all grinding related factors that influence the measured flexure strength of the specimen. Some factors may be inherent to the design of the grinding machine and not easily or directly subject to control, for example, the static and dynamic stiffness characteristics of the machine, and vibrations inherent to the machine. Other factors such as the feed rates and wheel grit size are subject to direct control. This standard is primarily concerned with the evaluation of the influence of the latter factors. Grinding variables typically available for direct control are identified in the sections below.

9.2 *Directly Controlled Machining Variables*—Machining variables that are subject to direct control can be placed in three

TABLE 2 Adjustable Machining Parameters

Wheel Speed
Down Feed
Table Speed
Cross-Feed
Grinding Direction (with respect to specimen geometry)

TABLE 3 Grinding Wheel Characteristics

Diameter (size range determined by machine)
Width
Bond type
Grit Size
Grit Size distribution
Grit Concentration
Grit Characteristics (type, shape, friability, etc.)

categories: *1*) machine control parameters such as down-feed and table speed (Table 2), *2*) grinding wheel characteristics (Table 3), and *3*) coolant variables. As with any test, there are limits in the precision to which a given parameter can be controlled. These limits can vary substantially for different machines. For example, a conventional grinding machine with hydraulically operated table feeds probably will not offer as precise control over table speed and cross-feed as a CNC (computer numerically control) type machine with precision lead screw drives and encoder feed back. The importance of a given parameter or variable will of course depend on its influence on the flexure strength of the material being tested. Low precision with respect to a parameter or variable does not necessarily adversely affect the application of this standard. The standard can in fact be employed to assess the sensitivity of flexure strength to a given parameter or variable. For example, for a certain machine, wheel speed is reduced by 10 % under load during grinding due to limitations in motor speed control and power. The question may be asked, "Will this reduction in speed influence flexure strength?" One or more tests can be conducted at 20 % higher and lower speeds to evaluate sensitivity to wheel speed. The outcome will help determine whether, indeed, a 10 % reduction in wheel speed has a significant effect on flexure strength of the material under study.

9.2.1 Guidance in the choice of an appropriate set of grinding variables is obtained by considering the two relationships used to determine removal rate, Eq 1 and grit depth-of-cut, Eq 2. For linear reciprocating surface grinding the removal rate, Q_w, is given by:

$$Q_w = v_w a c_w \tag{1}$$

where:
v_w = table speed,
a = down-feed, and
c_w = cross-feed.

Increasing any or all of the independent variables will result in an increase in removal rate. Limits on the magnitudes of these parameters are imposed by the capacity of the machine in terms of range of operation, available power, and operating speed of the grinding wheel. The capacity of the workpiece to sustain the imposed grinding forces without failure and wheel grit size are also limiting factors. Seeking a higher removal rate by increasing v_w and/or a can adversely effect surface finish, flexure strength, and wheel wear.

9.2.2 The grit depth-of-cut, h_m, for linear reciprocating surface grinding can be approximated by (**2**):

$$h_m = (1/Cr)^{\frac{1}{2}} (v_w/v_s)^{\frac{1}{2}} (a/d)^{\frac{1}{4}} \tag{2}$$

where:
C = concentration per unit area of grit that are active during grinding,
r = is a factor describing the shape of the grit,
v_s = the wheel speed, and
d = the wheel diameter.

Because of variations in height and location of grit on the surface of the wheel, not all exposed grit will be engaged in cutting under a given set of grinding conditions. Those grit actually engaged in cutting are referred to as active grit. Grinding parameters should be chosen so that h_m is much less than approximately 1/3 the nominal grit size. If h_m is too large, excessive wheel wear may occur and the grinding forces may reach a level that results in complete failure of the wheel or damage to the machine and/or workpiece. The grit depth-of-cut also plays an important role in determining grinding induced damage. It is reasoned that the greater the depth of penetration of the grit into the surface of the specimen during material removal, the larger the cracks introduced, and consequently the greater the reduction in flexure strength. Supporting this argument is the well-known fact that cracks introduced by hardness indentation increase in size with increasing indentation load.

9.2.3 Experiments have shown that flexure strength does indeed decrease with increasing grit depth-of-cut. However, the actual relationship between flexure strength and grit depth-of-cut is quite complex and must account for the introduction of residual stresses and thermal effects, as well as dynamic material response factors and other aspects of the grit workpiece interaction process. From Eq 2, it is seen that increasing the grit concentration, wheel speed or wheel diameter decreases the grit depth-of-cut, while increasing the table speed or down-feed increases the grit depth-of-cut. The effects of down-feed and wheel diameter appear as the one-fourth root and consequently are expected to have a smaller effect relative to changes in the other parameters which exhibit a square root dependence. Although grit size does not explicitly appear in Eq 2, experiment shows that grit size is the factor that is most consistent in its influence on flexure strength. Namely, there is nearly always an inverse relationship between grit size and flexure strength. This is caused primarily by the fact the Eq 2 does not explicitly account for the non-uniform height distribution of exposed grit that exists on most grinding wheels. Thus, larger heights and correspondingly greater grit depths of penetration are almost certain to occur for larger grit sizes at a given down-feed setting.

9.2.4 *Grinding Wheel Condition (Balancing, Truing, Dressing, and Wear)*—In addition to the design characteristics of the grinding wheel (Table 3), the condition of the grinding wheel can exercise a significant influence on the damage introduced during grinding and consequently on flexure strength. The condition of the grinding wheel can be described in terms of its balance, trueness, grit exposure, and state of wear.

9.2.5 Balancing may be carried out manually by the operator, or automatically if the machine is so equipped. An out-of-balance wheel will result in vibration or oscillation of the wheel with respect to the workpiece causing the depth-of-cut to vary as the wheel rotates against the workpiece surface. The extent of these depth variations will depend on the degree of imbalance and stiffness characteristics of the machine and on grinding conditions. Out-of-balance can be detected by means of an accelerometer mounted on the grinding machine. Periodic depth waves in the surface finish topography of the workpiece may also be used to identify out-of-balance, however similar variations in surface finish may be produced by a wheel that is not true. Balancing of the wheel may be done statically and/or dynamically, on or off the machine. Various devices and methods are available for accomplishing this.

9.2.6 A wheel that runs true is one that, when mounted on the machine, presents a grinding surface that exhibits circular symmetry with respect to the axis of rotation of the spindle. As noted above (9.2.5), a periodic variation in height (referred to as waviness) of the workpiece surface along the direction of grinding will result if the wheel does not possess circular symmetry. In reciprocating surface grinding, the wheel is generally trued to obtain a cylindrical form for generation of flat workpiece surfaces.

9.2.7 Since the waviness in the surface finish whether caused by wheel imbalance, by lack of concentricity, or by both, reflects a corresponding variation in the depth-of-cut, the potential exists for an associated adverse effect on flexure strength. Instead of a constant depth-of-cut, the actual depth-of-cut oscillates about an average value. The maximum depth-of-cut value is the relevant quantity with respect to assessing the influence of down-feed on flexure strength.

9.2.8 Because of the elastic compliance of the machine, grinding wheel, and workpiece, it should be noted that the actual depth-of-cut will be less than the set down-feed value. Only after several successive advances in down-feed will the depth-of-cut approach the set value of down-feed. In addition to elastic compliance, wheel wear also will result in a depth-of-cut that is less than the set down-feed value. Accurate determination of the depth-of-cut will require direct measurement of the thickness of material removed from the specimen. Finally, it should be pointed out that the above influences on depth-of-cut might have only a minor effect on flexure strength because of the fourth root dependence of depth-of-cut in Eq 2.

9.2.9 Truing is normally done with the wheel mounted on the grinding machine. For diamond grit wheels, a brake truer or powered rotary truing device is commonly used. Truing with one of these devices is a grinding operation itself in which the truing device is equipped with a grinding wheel of the correct grade for the wheel being trued. Truing wheels are usually operated at a surface speed that is different from that of the wheel being trued. The ratio of grinding wheel surface speed to truing wheel surface speed is chosen to optimize the truing process, i.e. to maximize the rate of volume removal from the grinding wheel and minimize the volume lost from the truing wheel. The run-out of an effectively trued wheel is typically less than 2 μm. Truing is rarely, if ever, applied to single-layer plated or brazed diamond wheels.

9.2.10 The form of the grinding wheel is also determined by truing. For planar surface grinding where the wheel periphery is the operational surface as in Fig. 2, truing is performed to make this surface cylindrical and concentric with the spindle axis of rotation. Any departure in shape from a true cylinder will cause a variation in the depth-of-cut as the wheel engages the workpiece surface. For rotary grinding modes, the face of the wheel is the primarily operational surface and truing is performed to make this surface flat and perpendicular to the spindle axis. With continued use, wheel wear will eventually determine the steady-state form of the grinding wheel. The steady state form is specific to the wheel width, grinding conditions, and workpiece dimensions.

9.2.11 Efficient cutting requires the presence of sharp grit that protrude fractionally above the surface of the surrounding bond material. Dressing refers primarily to the removal of bond material from the surface of the grinding wheel thereby increasing the height at which the grit stand above the surface, removing worn grit, and/or allowing the exposure fresh grit. Several methods for dressing are available. Most often dressing is accomplished by grinding a specially formulated block of material (dressing stick) composed of weakly bonded abrasive grit, commonly aluminum oxide or silicon carbide. The type and size of the grit and nature of the bond characterizing the dressing stick is chosen for the grinding wheel. Dressing is carried out at a relatively large grit depth-of-cut to enhance the abrasion of the bond material surrounding the diamond grit.

9.2.12 *Coolant (Grinding Fluid)*—Three principle effects are provided by the coolant or grinding fluid. These are extraction of heat generated during grinding from the workpiece and wheel, removal of chips from the grinding zone, and lubrication of the cutting zone. Any or all of these may have direct and indirect influences on damage introduced by grinding and consequently on flexure strength. Perhaps the most critical function of the coolant is chip removal. Without effective removal, chips may accumulate on the wheel interfering with the contact between the grit and workpiece. Under extreme conditions rubbing of accumulated chips may cause excessive forces resulting in stalling or catastrophic damage to the workpiece, wheel or grinding machine. The direct effects of cooling and lubrication on damage are not fully understood. However, both cooling and lubrication can reduce wheel wear and in that way reduce damage, at least to the extent that wheel wear itself affects damage. Some grinding fluids may perform better than others. Thus, care must be exercised in selecting a grinding fluid that is appropriate to the grinding conditions and the workpiece material. If a concentrate that must be mixed with water is used, an appropriate concentration, usually recommended by the supplier, must be chosen.

9.2.13 In general, coolant is delivered by a nozzle that is directed at the junction between the wheel and workpiece and carried into the contact by the rotation of the wheel. Flow rate and nozzle direction may be adjustable. Some machine designs may utilize more than one nozzle. For example, a second nozzle may be directed normal to the wheel surface using the force of the coolant flow to flush accumulated chips from the surface of the wheel. Alternatively, or in addition to delivery by nozzles, coolant may be supplied radially through holes in the wheel surface.

9.2.14 The coolant supply facility should be equipped with a filtration system typically capable of removing particles greater than 5 μm in size. Large hard particles, especially diamond grit lost from the wheel, entrained in the coolant and delivered to the wheel/workpiece contact zone may scratch the workpiece introducing damage that degrades flexure strength.

10. Grinding Test Procedures

10.1 *Grinding Test Procedure A*—This procedure compares the flexure strength of a material after application of a user-specified grinding condition with the baseline flexure strength of the same material. The baseline flexure strength is determined using grinding conditions specified in 10.1.4. Only planar grinding modes that generate a surface finish consisting of nominally parallel striations are evaluated by this procedure. Initially, three sets of specimens are required to evaluate a given grinding condition. One set of specimens is used to determine the baseline strength of the material. The second and third sets are used to measure flexure strength after longitudinal grinding and transverse grinding. If additional grinding conditions are to be evaluated for the same lot of material, then only two sets of specimens, one for longitudinal and one for transverse grinding, will be required for each condition.

10.1.1 *Initial Specimen Preparation*—A minimum of 10 specimens per set is recommended in order to provide a sufficiently large sample size for statistical analysis. For rigorous statistical analyses employing Weibull probability distribution (Section 13), a minimum of 30 specimens per set is recommended (see C 1239). When testing is performed for design or size scaling purposes, a minimum of 30 specimens per set is recommended. Increasing the number of specimens in each set will in general reduce scatter associated with statistical sampling effects. Ultimately, variability in the material, in the grinding process, and in the flexure test will determine the measurement uncertainty.

10.1.2 *Flexure Test Specimen Size*—Test specimens of three different sizes A, B, and C are specified in flexure test Standards C 1161 and C 1211. Unless constraints are imposed by the amount and dimensions of the available material, the larger B or C size specimen should be chosen to take advantage of the potential reduction in statistical variation resulting from the larger volume under tension during flexure testing with these larger specimens.

10.1.3 *Specimen Orientation, Identification and Distribution*—Depending on dimensions, one or more specimens may be prepared from each piece of stock material. In the flexure test, typically only a small region adjacent to the tensile surface of the specimen influences the flexure strength. Therefore, consideration must be given to the existence of property variations within each piece of the stock material and to variations among different pieces of stock material. Each specimen should be marked for identification and its location and orientation with respect to the stock material geometry should be recorded. If the stock piece or billet exhibits identifiable manufacturing features then location and orientation should also be referenced with respect to such features. Preferably, all specimens should belong to the same lot of material. The distribution of specimens among the test sets should be balanced. For example, if some specimens are derived from the center of a billet and others were located near the outer surface, approximately equal numbers of specimens from each source should be assigned to each set. Similarly, if specimens were prepared from five billets, each set should contain approximately the same number of specimens from each of the five billets. Furthermore, specimens should be chosen randomly from each source for assignment to each set. The baseline strength of each new lot of material shall be measured to establish that a materials-related change in flexure strength is not attributed to or mistaken for the effects of grinding damage.

TABLE 4 Rough Grinding

Wheel: 320 grit (270/325 mesh; FEPA 54) diamond, 75 - 100 concentration, ≥ 150 mm diameter, > 6 mm width
Wheel Surface Speed: 25 - 30 m/s
Table Speed: 125 - 200 mm/s
Down Feed: 0.025 mm
Cross-Feed: 0.5 - 1.0 mm
Coolant: Flood application

10.1.4 *Preparation of Specimens for Measurement of Baseline Flexure Strength*—A thickness of ≥0.4 mm must be removed from each side of the specimen by surface grinding to obtain the dimensions and tolerances specified by the applicable flexure test standard (C 1161 and C 1211). Two stages of grinding are defined—rough grinding (Table 4) and finish grinding (Table 5). Only the tensile face requires finish grinding. One face of each specimen will be selected and identified as the tensile face in the flexure test. Rough grinding will be applied to the remaining faces, removing the requisite ≥0.4 mm from each face. For the tensile face, rough grinding is applied until the final 0.1 mm is reached. Finish grinding is then employed to remove the final 0.1 mm of thickness. All grinding is done in the longitudinal direction, i.e. parallel to the long axis of the flexure bar.

10.1.5 *Preparation Scheme*—Depending on the available stock material, preparation of each specimen will require several separate grinding operations. Unless the stock material is of such a size that cutting is not required, it will be necessary at some point to perform one or more cutting operations with a thin grinding blade to separate the specimen(s) from a larger billet. To gain overall efficiency, grinding to complete one or more specimen sides may be carried out prior to cutting individual specimens from the billet. However, to minimize the possible introduction of extraneous damage during handling and mounting, it is recommended that the tensile surface be the last surface to be ground before chamfering. To gain additional efficiency, several billets or individual specimens may be mounted together and ground as a unit. The ends of the specimens do not require grinding.

10.1.6 General specifications of grinding wheels to be used in preparation of baseline strength specimens are given in Tables 4 and 5. Friable types of diamond and non-metallic bonds (usually identified as resin or polymer) have been found

TABLE 5 Finish Grinding

Wheel: 600 grit (10/20 µm; FEPA M16) diamond, 50 - 75 concentration, ≥ 150 mm diameter, > 6 mm width
Wheel Surface Speed: 25 - 30 m/s
Table Speed: 125 - 200 mm/s
Down Feed: 0.0025 mm
Cross-Feed: 0.5 - 1.0 mm
Coolant: Flood application

suitable for grinding advanced ceramics. The wheel should be balanced, trued and dressed (9.2.4-9.2.10) prior to the initiation of grinding.

10.1.7 Chamfering of the two edges at the tensile face of the specimen is to be done using the finish grinding procedure. The rough grinding procedure may be used to chamfer the two edges not bounding the tensile face. Chamfer sizes must adhere to limits given in C 1161 and C 1211.

10.1.8 Mounting of stock material and of partly completed specimens during the various stages of grinding may be done mechanically or by the use of wax or cement. Care must be taken during handling and mounting not to scratch, chip, or damage the specimen surfaces and edges.

10.1.9 *Preparation of User-Specified Grinding Condition Evaluation Specimens*—The tensile face of the specimens selected for user-specified grinding condition evaluation will be identified in advance (10.1.4). The grinding evaluation conditions will be applied only to that surface. Unless otherwise required by the grinding conditions being evaluated, a minimum thickness of 0.4 mm shall be allowed for depths of cut ≥0.080 mm. For depths of cut larger than 0.080 mm allowance should be made for the removal of a thickness at least 5 times the depth-of-cut. For creep feed grinding, a thickness equal to the creep feed depth should be allowed. The rough grinding condition specified in Table 4 shall be used to grind the remaining faces of the specimens. The tensile faces of the entire set of longitudinal specimens are to be ground as a unit using the grinding condition under evaluation. Similarly, the tensile faces of the transverse set of specimens shall be ground as a unit. Where possible it is recommended that both the longitudinal and transverse sets be mounted and ground as a unit. In any case, the sequence and grouping of specimens during grinding is to be recorded.

10.1.10 The rough grinding condition (Table 4) shall be used for applying chamfers unless the grinding condition evaluated utilizes a wheel with a grit size smaller than 320 grit. Where this is the case the smaller grit size wheel shall be used for grinding chamfers bounding the tensile face utilizing conditions given in Table 5, replacing the designated 600 grit wheel with the condition evaluation wheel. Alternatively, chamfers may be applied with a 600 grit wheel. Chamfer diemnsions must adhere to limits and tolerances given in C 1161.

10.1.11 All grinding evaluation conditions should be recorded and reported (14). The report will include specimen material type and lot identification information, and specimen tensile face location with respect to stock material boundaries. Grinding condition evaluation parameters shall be reported (9 and 14).

10.2 *Grinding Test Procedure B*—No requirements are imposed on the grinding process except that it must be capable of generating a flat surface meeting the dimensional requirements of C 1161 or C 1211. Two or more sets of specimens are required depending on the number of conditions to be evaluated. Requirements for specimen identification, selection and orientation with respect to stock material, and assignment among sets are given in 10.1.3. One set of specimens will be used to determine the baseline flexure strength characteristic of all sets of specimens. The procedure for preparing specimens for measurement of baseline strength is given in sections 10.1.4-10.1.8. The remaining set or sets will be used to measure the flexure strength for the grinding condition(s) to be evaluated. The evaluation may consist of comparing a given grinding process over time as a quality control measure, or it may determine the influence on flexure strength of one or more grinding variables for the purpose of process development.

10.2.1 In evaluating a grinding condition or process, care must be taken to insure that the grinding lay is the same for all specimens. Flexure strength is highly sensitive to the angle between grinding striations and the tensile direction in the flexure test. Specimens with different lays can exhibit different flexure strengths. Rotary grinding methods in particular can result in a lay that differs among specimens located at different positions in the path traversed by the grinding wheel.

10.2.2 Lay may also differ over the surface of a single specimen resulting in non-random local differences in flexure strength. Such differences can be revealed by fractographic examination whereby a bias may be found in the location of fracture origins. For example, most or all fracture origins may be located near one edge of the specimens where the lay orientation is closest to the transverse direction. When lay varies locally over the specimen surface, the standard Weibull statistical analysis (C 1239) will not be applicable. That analysis assumes a random distribution of flaws.

10.2.3 Procedure B may be used to evaluate the effect of lay on flexure strength but will require sets of specimens with identical lay patterns.

10.2.4 Chamfers applied to edges bounding the grinding evaluation face are ground in the longitudinal direction; that is, the grinding lay on the chamfers must be parallel to the long axis of the specimen. The procedure given in 10.1.10 is to be used.

10.2.5 Results of Procedure B can only be considered valid when tests are carried out on sets of specimens derived from the same pool of material (10.1.3). Specimen sets derived from a different pool of material require re-measurement of the baseline strength for that lot.

10.2.6 All grinding conditions, e.g. Tables 2 and 3, shall be recorded and reported (14). The report will include specimen material type and lot identification information, and specimen tensile face location with respect to stock material boundaries.

11. Flexure Test

11.1 The detailed procedures for conducting flexure tests are given in C 1161 Test Method for Flexure Strength of Advanced Ceramics at Ambient Temperatures and C 1211 Test Method for Flexure Strength of Advanced Ceramics at Elevated Temperatures. C 1161 and C 1211 cite procedures for conducting tests in both three-point and four-point flexure. Only the four-point flexure test applies to this standard.

12. Fractography

12.1 Examination of the fracture surfaces to locate and assess the nature of the fracture origin is an important requirement of this standard. This examination carries special significance for baseline strength evaluation specimens, since the results can indicate whether failure of a given specimen was due to an inherent flaw, necessary for the baseline measurement, or was associated with machining or extraneous damage. In addition, the fractography results indicate the validity of the flexure test. An inordinate number of failures at or outside of the inner beating contact region suggest incorrect specimen/fixture alignment or damage caused by the bearing. Similarly, a preference for failures at the chamfer edges suggests improper application of chamfers.

12.2 Fractographic examination can require a considerable expenditure of time, especially when the number of specimens is large or when optical microscope observation does not suffice and SEM is necessary to establish the nature of the origin. When it is not feasible to examine all specimens, a minimum often specimens from each set shall be examined. When each set consists of 10 specimens, this would require examination of all specimens. For larger sets, the specimens from each set shall be chosen as follows: *1*) the three lowest strength specimens, *2*) the three highest strength specimens, and *3*) four specimens randomly selected from the remainder. Preference is given to the highest and lowest strength specimens because of the general expectation that machining damage will cause a reduction in flexure strength. For example, if it is found that the three highest strength specimens all failed from machining damage, there is an increased likelihood that this was the source of failure for most specimens in the set. In contrast, if none of the low strength specimens failed from machining damage, then it is likely that most of the specimens did not fail from machining damage.

12.3 Procedures and techniques for conducting fractography are given in C 1322 Practice for Fractography and Characterization of Fracture Origins in Advanced Ceramics. Record the following information for each specimen examined:

12.3.1 *Location of the Fracture Origin*—Determine and record the location of fracture origin with respect to the inner span bearing contacts, the specimen edges, and depth below the surface.

12.3.2 *Nature of the Fracture Origin*—Determine whether fracture originated at an inherent flaw in the material (inclusion, pore(s), large grain, or other heterogeneity) or at a machining flaw or non-machining-related scratch or other extraneous damage.

12.3.3 *Optional*—Measure length and depth of fracture origin and mirror. These measurements can be used to ascertain that the fracture origin identified is consistent in size with the measured flexure strength (C 1322).

12.4 The small width and close proximity to the surface of machining induced cracks (Fig. 1) can make them difficult to detect. However, when it can be concluded that the origin of failure is not an inherent flaw and fractography indicates that the origin lies at the surface, there is a possibility that machining damage is the source of failure. Under these circumstances, it is clear that attention should be focused on a search for the tell-tail signs (C 1322) of machining damage. One example of the appearance of machining damage at a fracture origin is shown schematically in Fig. 5. Additional examples can be found in C 1322 and Ref. (**1**).

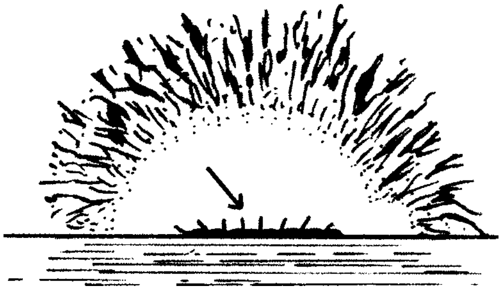


FIG. 5 Schematic Drawing of Machining Crack (Arrow) at Fracture Origin(C 1322 and Ref. 1)

13. Analysis of Data

13.1 Flexure strength values for each test specimen are determined from break force, specimen width and thickness, and flexure span as described in C 1161 and C 1211. In general, flexure strength data for advanced ceramic materials are found to be adequately described by the Weibull distribution. Procedures and recommendations for conducting Weibull statistical analyses are given in C 1239 Practice for Reporting Uniaxial Strength Data and Estimating Weibull Distribution Parameters for Advanced Ceramics. Results for each set of specimens should be evaluated with respect to scatter and uniformity of fit to the Weibull distribution curve. Special note should be taken of the presence of outliers and non-uniformity in the distribution of values.

13.2 Typically, machining evaluation specimen sets that are ground in the transverse direction show the greatest reduction in strength compared to the baseline strength. However, when grinding is in the longitudinal direction, many, if not most, advanced ceramics exhibit little reduction in strength, even under relatively severe grinding conditions. This is because the damage introduced by grinding is highly anisotropic and the weakest tensile direction is perpendicular to the grinding direction. Even for the transverse direction, machining damage does not always cause a reduction in strength. To be the preferred source of failure, machining induced flaws must in effect be larger than inherent flaws in the material. Also, machining induced residual stresses, which are compressive in nature, may act to compensate for the strength reduction caused by machining flaws (**3**).

13.3 Fractography results are especially important with respect to indicating whether failure of a given specimen was a consequence of machining induced damage or was due to the presence of an inherent flaw in the material. For specimens in the set used for inherent flexure strength determination, failure should not have occurred at machining induced flaws or at extraneous surface damage. Any such specimens should be excluded from the evaluation of baseline strength. If all or a majority of specimens in the baseline strength set are found to have failed from machining or extraneous damage, then it will be necessary to repeat the baseline strength determination taking care to apply the specified conditions. One easily overlooked source of unexpected machining damage is the grinding wheel. The presence of even a single grit larger than is specified for the wheel could result in excessive damage. The wheel supplier should be consulted concerning the diamond particle size distribution employed. If after repeating the baseline strength determination, the majority of failures are still found to originate at machining damage, then this test method is not applicable to the material under investigation. As an additional step, polishing might be applied after final grinding to reduce or eliminate grinding damage, but specification of polishing procedures is outside the scope of this standard.

13.4 Fracture origins of baseline flexure strength specimens should be randomly distributed within the area bounded by the inner span bearing contacts, although an occasional origin outside the inner span does occur. A nonrandom grouping of origins, for example a high concentration in the region below one of the inner beating contacts or near a chamfer edge could result from misalignment during flexure testing. The alignment should be corrected and the test repeated. A non-random distribution of failure origins could also occur if the material itself is inhomogeneous. In this case, the standard is not applicable. Caution should be exercised in drawing conclusions solely based on an apparently non-random distribution of failure origins. For small numbers of specimens, the distribution may only appear nonrandom for lack of a large enough sample.

13.5 The distribution of fracture origins for grinding-condition-evaluation specimens should be inspected as a means to assess the validity of each test. If the fracture origins are not randomly distributed within the inner span region, the flexure test should be checked for proper alignment as noted in 13.4. A large concentrations of origins at one or both of the chamfers edges could result if edge damage was not removed by chamfering or if the chamfering process itself introduced excess damage. The chamfering process should be reviewed to be certain that it complies with 10.1.10. For grinding evaluation specimens, a nonrandom distribution of origins associated with grinding damage not necessarily indicate a deficiency in the test procedure. A preponderance of origins at a certain location could result from transient exposure to a large grit on the grinding wheel as it passed over several specimens in transverse grinding. The presence of an unusually large striation at the origins could be evidence of such an event. Additional tests will be required to determine whether this is representative of the grinding process under evaluation or is in effect an infrequent occurrence.

13.6 A failure origin associated with machining or extraneous damage that is located on the side of the specimen requires that the observation be discarded. Failures originating at the side of the specimen due to machining damage are only likely to occur when the procedure used to grind the tensile face causes less damage than the procedure specified in 10.1.9 for the sides. In the event that a large number of failures from machining damage occur on the sides, the procedure used to grind the tensile face should also be used to grind the sides of the specimen.

14. Reporting

14.1 Report for Procedure A (10.1) shall contain the following:

14.1.1 Material specifications (Source, Type, Lot Number, Billet Dimensions).

14.1.2 Specimen size.

14.1.3 Layout of Specimens in each billet and Associated Billet and Specimen Number.

14.1.4 Number of Specimens per Set.

14.1.5 Set designation and list of specimens in each set. Sets are identified as follows:

Baseline Strength Set
Grinding Evaluation Set x_i—Longitudinal
Grinding Evaluation Set x_i—Transverse

Here x_i represents a number assigned by the user. If more than one grinding condition is evaluated then sets for each condition must be assigned a unique number.

14.1.6 The grinding parameters that must be specified for Grinding Evaluation Set x_i—Longitudinal and Set x_i—Transverse are listed below. If complete specification requires additional parameters, then these should be added.

Grinding machine Type, Manufacturer and Model
Grinding wheel specifications
Wheel Truing and Dressing Procedure
Wheel speed
Table speed (workpiece feed rate) in grinding direction
Cross-Feed increment
Wheel depth-of-cut
Coolant manufacturer, type, and concentration
Coolant flow rate

14.1.7 A report on flexure test results shall be prepared for each test set. The contents of the report are prescribed by C 1161 or C 1211, which ever test method was used. Specifications on specimen preparation and machining included in these standards are not required since that information will be reported in 14.1.

14.1.8 A report on fractography results shall be prepared for each test set. The contents of the reports are prescribed by C 1322.

14.1.9 *Final Analysis of Results and Determination of Statistical Significance*—C 1239 should be consulted with respect to conducting a Weibull statistical analysis on each test set. Alternatively, or in addition, commercially available software may be used to conduct the statistical analysis. Such software can be especially valuable in connection with establishing the extent to which statistically significant differences exist between different data sets.

14.2 *Report for Procedure B (10.2)*—The report for Procedure B differs from the report for Procedure A (14.1) only with respect to the grinding evaluation conditions, 14.1.3. Procedure B does not require grinding in the longitudinal and transverse directions for evaluation of a given grinding condition. Indeed, longitudinal and transverse will not be relevant designations for rotary modes of grinding allowed under Procedure B. Section 14.1.3 should be modified to include the relevant parameters. Otherwise, the report contents should duplicate 14.1.

15. Precision and Bias

15.1 *Precision*—Round robin tests have not been conducted, therefore no statement can be made regarding the precision of this test method. Procedures for the calculation of confidence bounds on Weibull statistical parameters, which are important for the assessment of the statistical significance of differences between different test sets, can be found in C 1239.

15.2 *Bias*—No statement can be made about bias for this method since no standard reference materials (SRM's) are available for determination of bias.

16. Keywords

16.1 surface grinding; machining; advanced ceramic; flexure strength; baseline flexure strength; damage tolerance

REFERENCES

(1) Quinn, G. D., Ives, L. K., and Jahanmir, S., "On the Nature of Machining Cracks in Ground Ceramics: Part I: SRBSN Strengths and Fractographic Analysis," *Machining Science and Technology*, Vol. 9, 2005, pp. 169 – 210.

(2) Malkin, Stephen, Grinding Technology: Theory & Applications of Machining with Abrasives, Society of Manufacturing Engineers, Dearborn MI, 1996.

(3) Pfeiffer, W. and Hollstein, T., "Damage Determination and Strength Prediction of Machined Ceramics by X-Ray Diffraction Techniques," in *Machining of Advanced Ceramics*, Said Jahanmir, Ed., NIST Special Publication 847, Gaithersburg, MD, 1993, pp. 235-245.

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org).

Copyright by ASTM Int'l (all rights reserved); Thu Apr 16 09:22:41 EDT 2009
Downloaded/printed by
Laurentian University pursuant to License Agreement. No further reproductions authorized.