



Standard Test Method for Dynamic Young's Modulus, Shear Modulus, and Poisson's Ratio for Advanced Ceramics by Impulse Excitation of Vibration¹

This standard is issued under the fixed designation C 1259; 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 determination of the dynamic elastic properties of advanced ceramics at ambient temperatures. Specimens of these materials possess specific mechanical resonant frequencies that are determined by the elastic modulus, mass, and geometry of the test specimen. The dynamic elastic properties of a material can therefore be computed if the geometry, mass, and mechanical resonant frequencies of a suitable (rectangular or cylindrical geometry) test specimen of that material can be measured. Dynamic Young's modulus is determined using the resonant frequency in the flexural mode of vibration. The dynamic shear modulus, or modulus of rigidity, is found using torsional resonant vibrations. Dynamic Young's modulus and dynamic shear modulus are used to compute Poisson's ratio.

1.2 Although not specifically described herein, this test method can also be performed at cryogenic and high temperatures with suitable equipment modifications and appropriate modifications to the calculations to compensate for thermal expansion.

1.3 Where possible, the procedures, sample specifications, and calculations in this test method are consistent with Test Methods C 623, C 747, C 848, and C 1198.

1.4 This test method uses test specimens in bar, rod, and disc geometries. The rod and bar geometries are described in the main body. The disc geometry is addressed in Annex A1.

1.5 The values stated in SI units are to be regarded as the standard.

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

2. Referenced Documents

2.1 ASTM Standards:

C 372 Test Method for Linear Thermal Expansion of Por-

- celain Enamel and Glaze Frits and Fired Ceramic Whiteware Products by the Dilatometer Method²
C 623 Test Method for Young's Modulus, Shear Modulus, and Poisson's Ratio for Glass and Glass-Ceramics by Resonance²
C 747 Test Method for Moduli of Elasticity and Fundamental Frequencies of Carbon and Graphite Materials by Sonic Resonance³
C 848 Test Method for Young's Modulus, Shear Modulus, and Poisson's Ratio for Ceramic Whitewares by Resonance²
C 1145 Terminology of Advanced Ceramics³
C 1161 Test Method for Flexural Strength of Advanced Ceramics at Ambient Temperature³
C 1198 Test Method for Dynamic Young's Modulus, Shear Modulus, and Poisson's Ratio for Advanced Ceramics by Sonic Resonance³
D 4092 Terminology Relating to Dynamic Mechanical Measurements on Plastics⁴
E 6 Terminology Relating to Methods of Mechanical Testing⁵
E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods³
E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method⁶

3. Terminology

3.1 *Definitions*—The definitions of terms relating to mechanical testing appearing in Terminology E 6 should be considered as applying to the terms used in this test method. The definitions of terms relating to advanced ceramics appearing in Terminology C 1145 should be considered as applying to the terms used in this test method. Directly pertinent definitions as listed in Terminologies E 6, C 1145, and D 4092 are shown in the following paragraphs with the appropriate source given in brackets.

3.1.1 *advanced ceramic, n*—a highly engineered, high-performance, predominately nonmetallic, inorganic, ceramic

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² *Annual Book of ASTM Standards*, Vol 15.02.

³ *Annual Book of ASTM Standards*, Vol 15.01.

⁴ *Annual Book of ASTM Standards*, Vol 08.02.

⁵ *Annual Book of ASTM Standards*, Vol 03.01.

⁶ *Annual Book of ASTM Standards*, Vol 14.02.

material having specific functional attributes. (C 1145)

3.1.2 *dynamic mechanical measurement, n*—a technique in which either the modulus or damping, or both, of a substance under oscillatory load or displacement is measured as a function of temperature, frequency, or time, or combination thereof. (D 4092)

3.1.3 *elastic limit* [FL⁻²], *n*—the greatest stress that a material is capable of sustaining without permanent strain remaining upon complete release of the stress. (E 6)

3.1.4 *elastic modulus* [FL⁻²], *n*—the ratio of stress to strain below the proportional limit. (E 6)

3.1.5 *Poisson's ratio* (μ) [nd], *n*—the absolute value of the ratio of transverse strain to the corresponding axial strain resulting from uniformly distributed axial stress below the proportional limit of the material.

3.1.5.1 *Discussion*—In isotropic materials, Young's Modulus (E), shear modulus (G), and Poisson's ratio (μ) are related by the following equation:

$$\mu = (E/2G) - 1 \quad (1)$$

(E 6)

3.1.6 *proportional limit* [FL⁻²], *n*—the greatest stress that a material is capable of sustaining without deviation from proportionality of stress to strain (Hooke's law). (E 6)

3.1.7 *shear modulus* (G) [FL⁻²], *n*—the elastic modulus in shear or torsion. Also called modulus of rigidity or torsional modulus. (E 6)

3.1.8 *Young's modulus* (E) [FL⁻²], *n*—the elastic modulus in tension or compression. (E 6)

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *antinodes, n*—two or more locations that have local maximum displacements, called anti-nodes, in an unconstrained slender rod or bar in resonance. For the fundamental flexure resonance, the anti-nodes are located at the two ends and the center of the specimen.

3.2.2 *elastic, adj*—the property of a material such that an application of stress within the elastic limit of that material making up the body being stressed will cause an instantaneous and uniform deformation, which will be eliminated upon removal of the stress, with the body returning instantly to its original size and shape without energy loss. Most advanced ceramics conform to this definition well enough to make this resonance test valid.

3.2.3 *flexural vibrations, n*—the vibrations that occur when the displacements in a slender rod or bar are in a plane normal to the length dimension.

3.2.4 *homogeneous, adj*—the condition of a specimen such that the composition and density are uniform, so that any smaller specimen taken from the original is representative of the whole. Practically, as long as the geometrical dimensions of the test specimen are large with respect to the size of individual grains, crystals, components, pores, or microcracks, the body can be considered homogeneous.

3.2.5 *in-plane flexure, n*—for rectangular parallelepiped geometries, a flexure mode in which the direction of displacement is in the major plane of the test specimen.

3.2.6 *isotropic, adj*—the condition of a specimen such that the values of the elastic properties are the same in all directions

in the material. Advanced ceramics are considered isotropic on a macroscopic scale, if they are homogeneous and there is a random distribution and orientation of phases, crystallites, components, pores, or microcracks.

3.2.7 *nodes, n*—a slender rod or bar in resonance containing one or more locations having a constant zero displacement. For the fundamental flexural resonance of such a rod or bar, the nodes are located at 0.224 L from each end, where L is the length of the specimen.

3.2.8 *out-of-plane flexure, n*—for rectangular parallelepiped geometries, a flexure mode in which the direction of displacement is perpendicular to the major plane of the test specimen.

3.2.9 *resonant frequency, n*—naturally occurring frequencies of a body driven into flexural, torsional, or longitudinal vibration that are determined by the elastic modulus, mass, and dimensions of the body. The lowest resonant frequency in a given vibrational mode is the fundamental resonant frequency of that mode.

3.2.10 *slender rod or bar, n*—in dynamic elastic property testing, a specimen whose ratio of length to minimum cross-sectional dimension is at least 5 and preferably in the range of 20 to 25.

3.2.11 *torsional vibrations, n*—the vibrations that occur when the oscillations in each cross-sectional plane of a slender rod or bar are such that the plane twists around the length dimension axis.

4. Summary of Test Method

4.1 This test method measures the fundamental resonant frequency of test specimens of suitable geometry by exciting them mechanically by a singular elastic strike with an impulse tool. A transducer (for example, contact accelerometer or non-contacting microphone) senses the resulting mechanical vibrations of the specimen and transforms them into electric signals. Specimen supports, impulse locations, and signal pick-up points are selected to induce and measure specific modes of the transient vibrations. The signals are analyzed, and the fundamental resonant frequency is isolated and measured by the signal analyzer, which provides a numerical reading that is (or is proportional to) either the frequency or the period of the specimen vibration. The appropriate fundamental resonant frequencies, dimensions, and mass of the specimen are used to calculate dynamic Young's modulus, dynamic shear modulus, and Poisson's ratio.

5. Significance and Use

5.1 This test method may be used for material development, characterization, design data generation, and quality control purposes.

5.2 This test method is specifically appropriate for determining the modulus of advanced ceramics that are elastic, homogeneous, and isotropic (1).⁷

5.3 This test method addresses the room temperature determination of dynamic moduli of elasticity of slender bars (rectangular cross-section) and rods (cylindrical). Flat plates

⁷ The boldface numbers in parentheses refer to the list of references at the end of this test method.

and disks may also be measured similarly, but the required equations for determining the moduli are not addressed herein.

5.4 This dynamic test method has several advantages and differences from static loading techniques and from resonant techniques requiring continuous excitation.

5.4.1 The test method is nondestructive in nature and can be used for specimens prepared for other tests. The specimens are subjected to minute strains; hence, the moduli are measured at or near the origin of the stress-strain curve, with the minimum possibility of fracture.

5.4.2 The impulse excitation test uses an impact tool and simple supports for the test specimen. There is no requirement for complex support systems that require elaborate setup or alignment.

5.5 This technique can be used to measure resonant frequencies alone for the purposes of quality control and acceptance of test specimens of both regular and complex shapes. A range of acceptable resonant frequencies is determined for a specimen with a particular geometry and mass. The technique is particularly suitable for testing specimens with complex geometries (other than parallelepipeds, cylinders/rods, or discs) that would not be suitable for testing by other procedures. Any specimen with a frequency response falling outside the prescribed frequency range is rejected. The actual modulus of each specimen need not be determined as long as the limits of the selected frequency range are known to include the resonant frequency that the specimen must possess if its geometry and mass are within specified tolerances.

5.6 If a thermal treatment or an environmental exposure affects the elastic response of the test specimen, this test method may be suitable for the determination of specific effects of thermal history, environment exposure, etc. Specimen descriptions should include any specific thermal treatments or environmental exposures that the specimens have received.

6. Interferences

6.1 The relationships between resonant frequency and dynamic modulus presented herein are specifically applicable to homogeneous, elastic, isotropic materials.

6.1.1 This method of determining the moduli is applicable to composite ceramics and inhomogeneous materials only with careful consideration of the effect of inhomogeneities and anisotropy. The character (volume fraction, size, morphology, distribution, orientation, elastic properties, and interfacial bonding) of the reinforcement and inhomogeneities in the specimens will have a direct effect on the elastic properties of the specimen as a whole. These effects must be considered in interpreting the test results for composites and inhomogeneous materials.

6.1.2 The procedure involves measuring transient elastic vibrations. Materials with very high damping capacity may be difficult to measure with this technique if the vibration damps out before the frequency counter can measure the signal (commonly within three to five cycles).

6.1.3 If specific surface treatments (coatings, machining, grinding, etching, etc.) change the elastic properties of the near-surface material, there will be accentuated effects on the properties measured by this flexural method, as compared to static/bulk measurements by tensile or compression testing.

6.1.4 The test method is not satisfactory for specimens that have major discontinuities, such as large cracks (internal or surface) or voids.

6.2 This test method for determining moduli is limited to specimens with regular geometries (rectangular parallelepiped, cylinders, and discs) for which analytical equations are available to relate geometry, mass, and modulus to the resonant vibration frequencies. The test method is not appropriate for determining the elastic properties of materials that cannot be fabricated into such geometries.

6.2.1 The analytical equations assume parallel and concentric dimensions for the regular geometries of the specimen. Deviations from the specified tolerances for the dimensions of the specimens will change the resonant frequencies and introduce error into the calculations.

6.2.2 Edge treatments such as chamfers or radii are not considered in the analytical equations. Edge chamfers on flexure bars prepared according to Test Method C 1161 will change the resonant frequency of the test bars and introduce error into the calculations of the dynamic modulus. It is recommended that specimens for this test method not have chamfered or rounded edges. Alternately, if narrow rectangular specimens with chamfers or edge radii are tested, then the procedures in Annex A2 should be used to correct the calculated Young's modulus, E .

6.2.3 For specimens with as-fabricated and rough or uneven surfaces, variations in dimensions can have a significant effect in the calculations. For example, in the calculation of dynamic modulus, the modulus value is inversely proportional to the cube of the thickness. Uniform specimen dimensions and precise measurements are essential for accurate results.

6.3 The test method assumes that the specimen is vibrating freely, with no significant restraint or impediment. Specimen supports should be designed and located properly in accordance with 9.3.1, 9.4.1, and 9.5.1 so the specimen can vibrate freely in the desired mode. In using direct contact transducers, the transducer should be positioned away from anti-nodes and with minimal force to avoid interference with free vibration. With noncontacting transducers, the maximum sensitivity is accomplished by placing the transducer at an antinode.

6.4 Proper location of the impulse point and transducer is important in introducing and measuring the desired vibration mode. The locations of the impulse point and transducer should not be changed in multiple readings; changes in position may develop and detect alternate vibration modes. In the same manner, the force used in impacting should be consistent in multiple readings.

6.5 If the frequency readings are not repeatable for a specific set of impulse and transducer locations on a specimen, it may be because several different modes of vibration are being developed and detected in the test. The geometry of the test bar and desired vibration mode should be evaluated and used to identify the nodes and antinodes of the desired vibrations. More consistent measurements may be obtained if the impulse point and transducer locations are shifted to induce and measure the single desired mode of vibration.

7. Apparatus

7.1 Apparatus suitable for accurately detecting, analyzing,