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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Test Method for Flexural Strength (Modulus of Rupture) of Electronic-Grade Ceramics¹

This standard is issued under the fixed designation F 417; 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 procedures for determining the flexural strength (modulus of rupture) of electronic-grade ceramics, including procedures for specimen preparation.

1.2 This test method is applicable to specimens prepared from ceramic blanks at least 0.080 by 0.080 by 1½ in. (2.0 by 28.6 mm).

1.3 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

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

2. Referenced Documents

2.1 ASTM Standards:

C 623 Test Method for Young's Modulus, Shear Modulus, and Poisson's Ratio for Glass and Glass-Ceramics by Resonance²

D 116 Methods of Testing Vitrified Ceramic Materials for Electrical Applications³

E 4 Practices for Load Verification of Testing Machines⁴

F 109 Terminology Relating to Surface Imperfections on Ceramics²

3. Terminology

3.1 Definitions:

3.1.1 *flexural strength, S* [psi(MPa)]—the maximum stress in a mode of flexure that a specimen develops at rupture; normally, the calculated maximum longitudinal tensile stress at mid-point of the specimen test span surface.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *modulus of rupture, MOR* [psi(MPa)]—for purposes of this method, synonymous with flexural strength.

3.3 Definitions relating to surface imperfections may be found in Definitions F 109.

4. Summary of Test Method

4.1 The test specimen, a small bar of square cross section, rests on two cylindrical supports in a compression test machine. It is bent by the application of force, at mid-span, to the opposite face of the bar from that resting on the two supports. The bending force is applied by a third cylinder (identical to the other two) at a prescribed constant rate until the specimen breaks. The breaking load, the dimensions of the specimen, and the test span are used to compute flexural strength.

5. Significance and Use

5.1 Ceramic materials are considered to be brittle or perfectly elastic. Fracture normally occurs at the surface under a tensile stress caused by flexure. The stress is termed the modulus of rupture. The modulus of rupture is influenced by variables associated with the procedure used for its measurement, including the rate of application of stress, test environment, and area of the specimen subject to stress, all of which are specified in this method.

5.2 The modulus of rupture affords a convenient basis for comparing the mechanical properties of ceramic materials. It indicates quality and consistency of quality.

5.3 This test method is intended for use by manufacturers and users of brittle ceramics for electronic applications. It provides for the testing of small specimens (commonly designated "microbars") which may be cut from actual ceramic parts. The test may be used for the purpose of specification acceptance by agreement between manufacturer and user, or for manufacturing control, research, and development.

5.4 The techniques described have been routinely used for similar purposes on larger specimens throughout the ceramics industry for many years.

6. Apparatus

6.1 *Testing Machine* capable of providing a uniform stress rate of 200 ± 30 ksi/min (19.5 to 26.4 MPa/s, or 120 to 162 kgf/mm²·min) as verified in accordance with Practices E 4. The machine shall contain a load- or force-measuring cell with a resolution of 0.2 % of full scale or better on a scale appropriate to the material under test; normally, full scale need not exceed 25 lbf (110 N, or 11 kgf) for typical ceramic materials. The

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² Annual Book of ASTM Standards, Vol 15.02.

³ Annual Book of ASTM Standards, Vol 10.01.

⁴ Annual Book of ASTM Standards, Vol 03.01.

given stress rate corresponds to a load rate of about 50 ± 8 lbf/min (3.7 ± 0.6 N/s) or to a bending strain rate (crosshead speed on some machines) of $(7 \pm 1) \times 10^5/E$ in./min ($(1.98 \pm 0.30) \times 10^3/E$ mm/s), where E is Young's modulus, or modulus of elasticity, of the specimen material expressed in psi (MPa) (Note 1).

6.1.1 The specimen shall be supported in a horizontal plane on two identical steel (preferably hardened) or ceramic cylindrical supports, each having a radius of 0.125 in. (3.18 mm), whose cylindrical axes are nominally parallel and located in a horizontal plane. These axes shall be 1.000 ± 0.003 in. (25.40 ± 0.08 mm) apart; one support shall be mounted to permit rotation of its axis in a vertical plane ($90 \pm 1^\circ$ to the long dimension of the specimen), thus providing alignment with any specimen support surface prepared within the tolerance of 9.3.

6.1.2 The load shall be applied by a third cylindrical support, located in a vertical plane equidistant ± 0.003 in. (± 0.08 mm) from the parallel vertical planes containing the area of the two supporting cylinders.

NOTE 1—Young's modulus may be determined in accordance with the procedures of Test Method C 623.

6.2 *Micrometer Caliper* calibrated to read within ± 0.0001 in. (± 0.003 mm).

6.3 *Diamond Saw*, if specimen blanks are to be cut from fired ware.

6.4 *Grinder* with diamond-grit wheel, 180 mesh or finer.

6.5 *Drying Oven*, with temperature range from 300 to 400°F (or 150 to 200°C).

6.6 *Desiccator*.

7. Reagents and Materials

7.1 *Detergent Solution*—An aqueous, nonionic, surfactant solution.

7.2 *Fuchsine Solution*, as specified in Methods D 116.

8. Sampling

8.1 Since the method is destructive, a representative sample must be selected from each lot to be tested. Unless otherwise agreed upon by parties to the test, the sample shall consist of 10 specimens per test lot.

9. Preparation of Test Specimens

9.1 Cut specimen blanks from fired ware with a diamond saw, or form and fire to size by suitable methods. Minimum blank dimensions shall be 0.080 by 0.080 by $1\frac{1}{8}$ in. (2.0 by 2.0 by 28.6 mm).

9.2 Grind the blanks to final specimen size with a diamond-grit surface grinding wheel (see 6.4). The relative feed rate between wheel surface and specimen surface shall not exceed 6000 ft/min (30.5 m/s). The stock removal rate per pass shall not exceed 0.001 in. (0.03 mm) downfeed and 0.010 in. (0.3 mm) crossfeed to the last 0.001 in. of material to be removed. Remove the final 0.001 in. with a maximum downfeed of 0.0002 in. (0.005 mm) per pass and with a maximum 0.005-in. (0.13-mm) crossfeed per pass. Do all grinding in a direction parallel with the length of the bar. Remove approximately equal stock from opposite faces.

9.3 Finished dimensions of the specimen shall be 0.070 ± 0.003 by 0.070 ± 0.003 by 1.125 in. (1.78 ± 0.078 by $1.78 \pm$

0.078 by 28.58 mm) minimum. The angle between adjacent faces shall be $90 \pm 1^\circ$.

9.4 Test the specimens for porosity in accordance with Method D of Methods D 116. Reject a specimen if one or more cracks, porous areas, or closed chips are observed or if there are any open chips greater than 0.005 in. (0.13 mm) in the portion of the specimen that will lie between the supporting cylinders.

9.5 Clean the specimens in detergent and hot water, followed by a hot-water rinse. During cleaning, the specimens may be ultrasonically agitated for up to 5 min. Dry the specimens in an oven at 300 to 400°F (or 150 to 200°C) for at least 1 h. Place the specimens in a desiccator and cool to room temperature. Remove the specimens from the desiccator and test immediately.

10. Procedure

10.1 Place the test specimen on the two supporting cylinders with approximately equal amounts of overlap at each end. Apply the stress uniformly and normal to the upper surface of the specimen, midway ± 0.003 in. (± 0.08 mm) between the supporting cylinders at a rate of 200 ± 30 ksi/min (19.5 to 26.4 MPa/s, or 120 to 162 kgf/mm²·min) (see 6.1) until fracture occurs.

10.2 Note and record the load at fracture to the nearest 0.05 lbf (or 0.25 N, or 0.025 kgf); measure and record the specimen thickness and width to the nearest 0.0001 in. (0.003 mm) at the break using the micrometer caliper.

11. Calculations

11.1 Calculate the flexural strength for each specimen as follows:

$$S = 3PL/2bd^2 \quad (1)$$

where:

S = flexural strength, psi (or MPa),

P = load at fracture, lbf (or N),

L = distance between supporting knife edges, in. (or mm),

b = width of specimen, in. (or mm), and

d = thickness of specimen, in. (or mm).

NOTE 2—If P is read in kgf, S will be calculated in kgf/mm². To obtain S in MPa with P in kgf, multiply the right-hand side of Eq 1 by 9.807. If S is desired in ksi and P is recorded in lbf, divide the right-hand side of Eq 1 by 1000.

11.2 Calculate the mean value of S for the test lot as follows:

$$\bar{S} = (S_1 + S_2 + S_3 + \dots S_n)/n \quad (2)$$

where:

$\bar{S}$ = mean value of flexural strength for the lot,

$S_1, S_2 \dots S_n$ = individual specimen flexural strengths, and

n = number of specimens.

11.3 Calculate the sample standard deviation of S for the test lot as follows:

$$s = \{[(S_1 - \bar{S})^2 + (S_2 - \bar{S})^2 + (S_3 - \bar{S})^2 + \dots (S_n - \bar{S})^2]/(n-1)]^{1/2} \quad (3)$$

where s = sample standard deviation, psi (or MPa).

11.4 Calculate the coefficient of variation of S for the test lot as follows:

