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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Test Method for Biaxial Flexure Strength (Modulus of Rupture) of Ceramic Substrates[1]

This standard is issued under the fixed designation F 394; 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 biaxial flexure strength (modulus of rupture) of thin ceramic substrates.

1.2 This test method is applicable to specimens in the as-fired condition or to test pieces prepared to have a certain thickness or surface finish.

1.3 This test method may be used with specimens of various thicknesses and having warpage; no limits are placed on the latter, except those mutually imposed by the specifications agreed upon between the manufacturer and the purchaser of the substrates.

1.4 The values stated in inch-pound units are to be regarded as the standard. The metric equivalents of inch-pound units may be approximate.

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:*

C 623 Test Method for Young's Modulus, Shear Modulus, and Poisson's Ratio for Glass and Glass-Ceramics by Resonance[2]

E 1 Specification for ASTM Thermometers[3]

E 4 Practices for Load Verification of Testing Machines[4]

2.2 *Other Standards:*

ACMA Test No. 2: Test Method, Flexural Strength, High Alumina Ceramics, Alumina Ceramic Manufacturers Association[5]

3. Terminology

3.1 *Definitions:*

3.1.1 *biaxial flexure strength, S,* [FL^{-2}]—the maximum stress in a biaxial mode of flexure that a specimen develops at rupture. This stress will normally be the calculated maximum radial tensile stress at the center of the convex surface. This mode of flexure is a cupping of the circular plate caused by central loading and supporting near the rim.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *modulus of rupture (MOR),* [FL^{-2}]—*for this test method*, synonymous with biaxial flexure strength.

4. Summary of Test Method

4.1 The test specimen, a thin circular disk, rests on three symmetrically spaced points near its periphery. It is bent in a cupping fashion by the application of force to the center of the disk through a cylindrical ram. The force is applied to the ram at a prescribed constant rate in a compression test machine until the specimen breaks. The breaking load, the dimensions and elastic constants of the specimen, and the radii of the support and load are used to compute the maximum tensile stress which is at the center of the tension (convex) surface. This is usually the point of origin of the fracture. The computed or center stress then is the breaking stress (MOR). This configuration eliminates premature fracture from an edge defect or anomaly.

5. Significance and Use

5.1 This test method is intended for use by manufacturers and purchasers of brittle substrates for electronic applications. This test method may be used for quality control (by agreement between the manufacturer and the purchaser of ceramic substrates), or for evaluation of new materials or of new processes, by comparison with known or reference materials or products.

5.2 The stress analysis applying to the configuration of this test method has been covered by Kirstein and Woolley.[6] Valid use of the linear elastic equation to determine center stress stipulates that the deflection of the plate at its center shall not exceed one half the specimen thickness (Fig. 1); only bending stresses are considered.

5.3 Ceramic substrate materials are considered to be brittle or perfectly elastic, that is, fracture normally occurs at the

[1] This test method is under the jurisdiction of ASTM Commitee C-21 on Ceramic Whitewares and Related Products and is the direct responsibility of Subcommittee C21.03 on Fundamental Properties.

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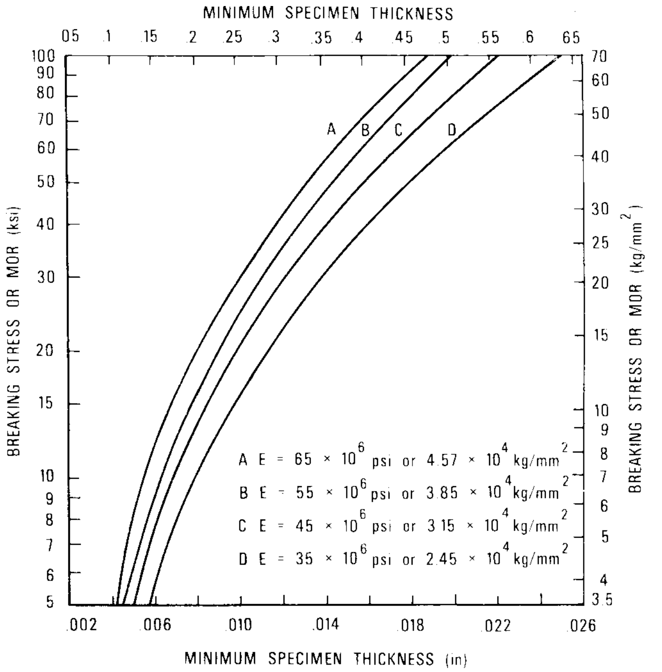
[2] *Annual Book of ASTM Standards*, Vol 15.02.

[3] *Annual Book of ASTM Standards*, Vol 14.03.

[4] *Annual Book of ASTM Standards*, Vol 03.01.

[5] Available from Alumina Ceramic Manufacturers Assn., 331 Madison Ave., New York, NY 10017, Attn: George P. Byrne, Secretary.

[6] Kirsten, A. F., and Woolley, R. M., "Symmetrical Bending of Thin Circular Elastic Plates on Equally Spaced Point Supports," *Journal of Research,* U. S. National Bureau of Standards, JNBAA, Vol 71C, 1967, pp. 1–10.



NOTE 1—The minimum specimen thickness is required to keep the center deflection less than one half of the thickness. A value of 0.23 was assumed for Poisson's ratio, and *E* is Young's modulus of elasticity of the test specimen.

FIG. 1 Estimated Minimum Specimen Thickness

surface under a tensile stress caused by flexure. The stress is termed the modulus of rupture. The modulus of rupture (MOR) is influenced by variables associated with the procedure, including the rate of stressing, test environment, and area of the specimen subject to stress, all of which are specified in this test method.

6. Apparatus

6.1 *Testing Machine*—Any compression-type testing machine capable of providing a uniform stress rate of 200 ± 30 ksi/min (19.5 to 26.4 MPa/s) as verified by Practices E 4, and containing a load- or force-measuring cell having a resolution of 0.2 % of full scale or better on a scale appropriate to the material under test.

6.2 *Test Fixture for Supporting and Loading Specimens*—A recommended fixture is shown in Fig. 2.[7] The support points are provided by three ball bearings 0.125 in. (3.18 mm) in diameter, positioned 120° apart on a 1.00 ± 0.01-in. (25.2 to 25.6-mm) diameter circle. The load is applied to the specimen center by a right circular cylinder of hardened steel having a diameter of 0.063 ± 0.001 in. (1.58 to 1.63 mm), with the end flat and perpendicular to the axis. The cylinder must apply the load perpendicularly (90 ± 1°) to the plane containing the tops of the support balls, and the cylinder axis must be within 0.03 in. (0.8 mm) of the center of the support circle.

6.3 *A Pad of Nonrigid Material* to be used between the cylinder and specimen to distribute the load uniformly over the

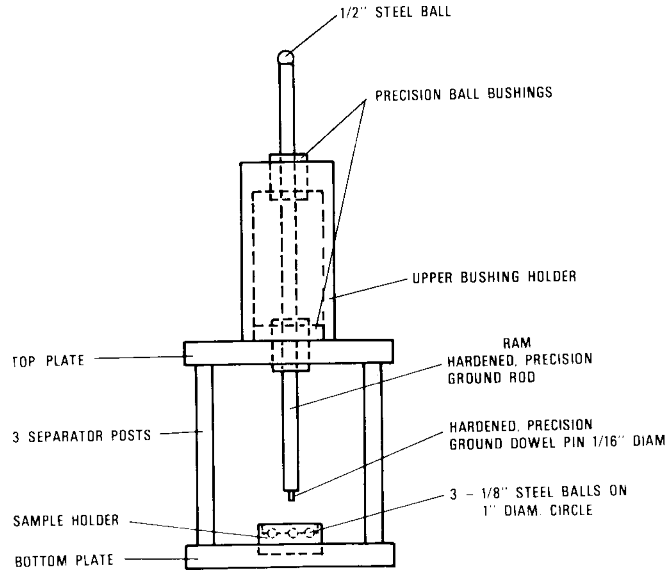


FIG. 2 Biaxial-Flexure Strength-Test Fixture

0.063-in. (1.60-mm) diameter cylinder end; this pad material may be 0.002-in. (0.05-mm) thick polyethylene sheet.

6.4 *Measuring Devices* for measuring the specimen thickness to the nearest 0.0001 in. or 0.002 mm, and the specimen diameter to the nearest 0.001 in. or 0.02 mm.

6.5 *Surface Grinder* for specimen preparation as specified in 7.2 and 7.3.

6.6 *Desiccator* for specimen storage prior to testing.

6.7 *Hygrometer* for measuring ambient-test relative humidity to an accuracy of ±5 % of the reading.

6.8 *Thermometer* for measuring ambient-test room temperature. A thermometer conforming to Thermometer 63°C as prescribed in Specification E 1 is suitable.

6.9 *Drying Oven* for drying specimens after preparation at a temperature of 150 to 200°C.

6.10 *Timer* to time the loading period to the nearest 1 s in order to verify the stress rate.

6.11 *Detergent*, appropriate to the substrate material and to the contamination to be removed (see 7.4).

7. Test Specimens

7.1 Specimens shall be formed or cut to size by suitable methods (see 7.2) with care being taken that as-fired test surfaces shall be protected during processing. Specimens shall be 1.250 ± 0.062 in. (30.18 to 33.32 mm) in diameter. Thickness of as-fired specimens shall not be specified except as to the minimum thickness required to limit the deflection of the specimen center to one half the specimen thickness at fracture as given in Fig. 1. Edge finish also is not specified.

7.2 *Specimen Grinding*—If ground, rather than as-fired, surfaces are desired, the specimens shall be ground to thickness using a 180 mesh or finer diamond grit surface grinding wheel with a wheel-surface to specimen-surface relative feed rate not exceeding 6000 ft/min or 30 m/s. The stock removal rate shall not exceed 0.001 in. or 0.02 mm downfeed and 0.010 in. or 0.2 mm crossfeed per pass to the last 0.001 in. The final 0.001 in. shall be removed with a maximum downfeed of 0.0002 in. or 0.005 mm and with a maximum crossfeed of 0.005 in. or 0.12

[7] Wachtman, J. B., Jr., Capps, W., and Mandel, J., "Biaxial Flexure Tests of Ceramic Substrates," *Journal of Materials*, JMLSA, Vol 7, No. 2, June 1972, pp. 188–194.