



# Standard Test Method for Modulus of Rupture in Bending of Electrode Graphite<sup>1</sup>

This standard is issued under the fixed designation C 1025; 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 approval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This test method covers determination of the modulus of rupture in bending of specimens cut from graphite electrodes using a simple square cross section beam in four-point loading at room temperature.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *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:*<sup>2</sup>

**C 651** Test Method for Flexural Strength of Manufactured Carbon and Graphite Articles Using Four-Point Loading at Room Temperature

**C 709** Terminology Relating to Manufactured Carbon and Graphite

**C 783** Practice for Core Sampling of Graphite Electrodes

**E 4** Practices for Force Verification of Testing Machines

**E 691** Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

## 3. Terminology

3.1 *Definitions:* For definitions of terms relating to manufactured carbon and graphite, see Terminology **C 709**.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *modulus of rupture in bending*— the value of maximum stress in the extreme fiber of a specified beam loaded to failure in bending computed from the calculations in Section 9.

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.F0 on Manufactured Carbon and Graphite Products.

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<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

## 4. Significance and Use

4.1 This test method provides a means for determining the modulus of rupture of a square cross section graphite specimen machined from the electrode core sample obtained according to Practice **C 783**, with a minimum core diameter of 57 mm (2.25 in.) This test method is recommended for quality control or quality assurance purposes, but should not be relied upon to compare materials of radically different particle sizes or orientational characteristics. For these reasons as well as those discussed in 4.2 an absolute value of flexural strength may not be obtained.

4.2 *Specimen Size*— The maximum particle size and maximum pore size vary greatly for manufactured graphite electrodes, generally increasing with electrode diameter. The test is on a rather short stubby beam, therefore the shear stress is not insignificant compared to the flexural stress, and the test results may not agree when a different ratio or specimen size is used.

## 5. Apparatus

5.1 The testing machine shall conform to the requirements of Sections 14 and 17 of Practices **E 4**.

5.2 The four-point loading fixture shall consist of bearing blocks which ensure that forces applied to the beam are normal only and without eccentricity. (See Test Method **C 651**.) The directions of loads and reactions may be maintained parallel by judicious use of linkages, rocker bearings, and flexure plates. Eccentricity of loading can be avoided by the use of spherical bearings. Provision must be made in fixture design for relief of torsional loading to less than 5 % of the nominal specimen strength. Refer to **Fig. 1** for a suggested four-point fixture.

5.3 The bearing block diameter shall be between  $\frac{1}{10}$  and  $\frac{1}{20}$  of the specimen support span, 12 mm (0.50 in.) to 6 mm (0.25 in.). A hardened steel bearing block or its equivalent is necessary to prevent distortion of the loading member.

## 6. Test Specimen

6.1 *Sampling*—A core sample (minimum of 57 mm (2.25 in.) diameter and 165 mm (6.50 in.) long) shall be obtained from the electrode in accordance with Practice **C 783**.

6.2 *Preparation*— A test specimen shall be prepared from the core to yield a parallelepiped of square cross section. The faces shall be parallel and flat within 0.002 mm/mm (0.002 in./

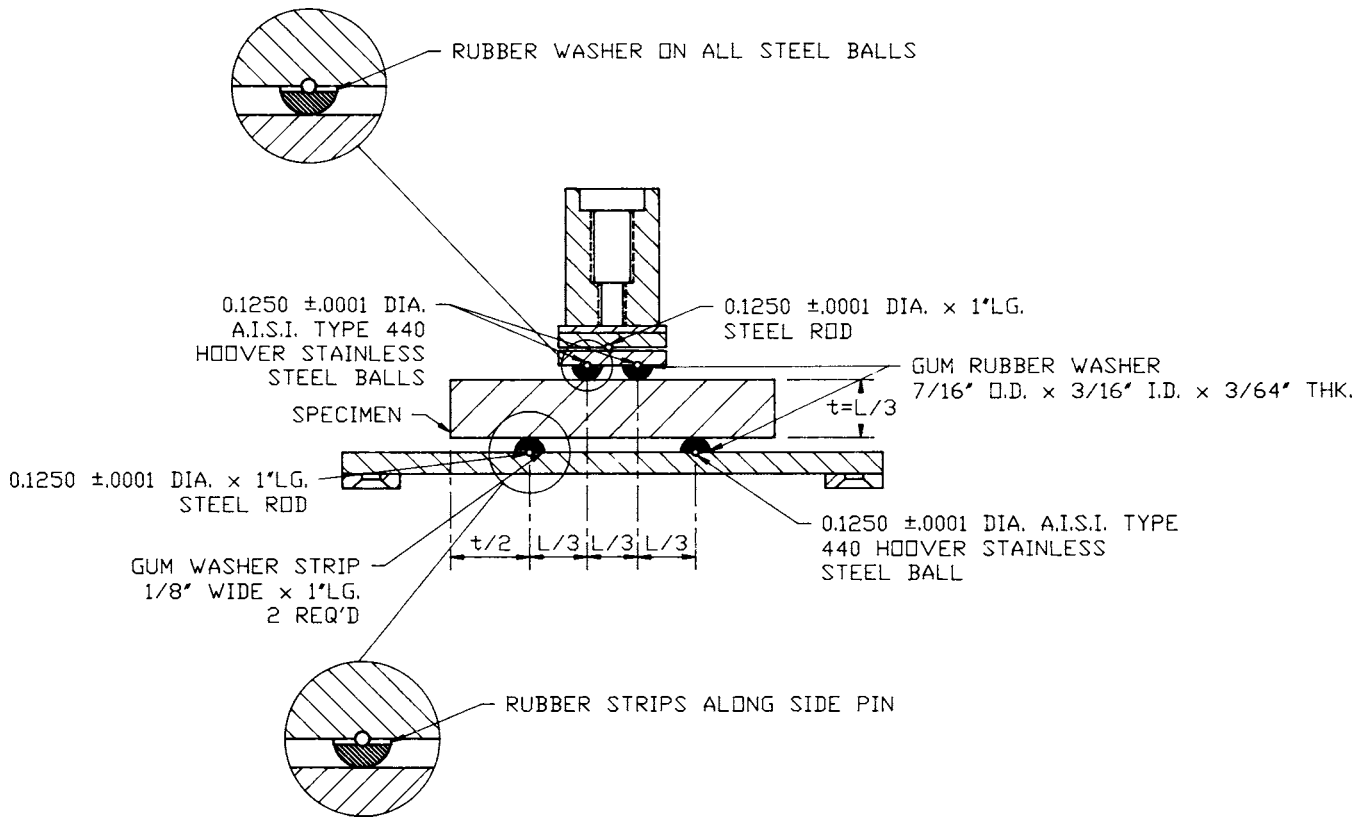


FIG. 1 Beam with Four-Point Loading (Not to Scale)

in.) of length. Specimen edges shall be free from visible flaws and chips. All surfaces shall be smooth with a surface texture equivalent to that obtained from a precision band saw or better.

6.3 The square cross section specimen shall be 38 by 38 mm (1.50 by 1.50 in.) and at least 153 mm (6.0 in.) long.

6.4 *Measurements*—All dimensions shall be measured to at least 0.03 mm (0.001 in.).

6.5 *Drying*—Each specimen must be dried in an oven at greater than 110°C for 2 h. The specimen must then be cooled to room temperature in a desiccator and held there prior to testing.

## 7. Procedure

7.1 Center the specimen in the test fixture. Make sure that no extraneous torsional loads are being introduced to the specimen.

7.2 The support span shall be equal to three times the specimen thickness, 114 mm (4.5 in.). The load span shall be one third the support span, 38 mm (1.50 in.). Refer to Fig. 1.

7.3 Apply the breaking load at a maximum rate of 0.02 mm/s (0.05 in./min).

## 8. Test Data Record

8.1 Measurements to 0.03 mm (0.001 in.) shall be made to determine the average width and thickness of the specimen at the section of failure.

8.2 The load at failure shall be recorded to ±1 %.

## 9. Calculation

9.1 If the fracture occurs within the load span, calculate the modulus of rupture, the maximum bending moment, the

distance from the neutral axis to the location where the fiber failed, and the moment of inertia of the original cross section as follows:

9.1.1 Modulus of rupture:

$$MOR = Mc/I$$

$$MOR = (PL/bt^2)(1000)$$

9.1.2 Maximum bending moment:

$$M = (P/2)(L/3)$$

9.1.3 Distance from the neutral axis to the location where the fiber failed:

$$c = (t/2)$$

9.1.4 Moment of inertia of the original cross-section:

$$I = (bt^3/12)$$

where:

MOR = modulus of rupture, kPa (psi · 10<sup>-3</sup>),

M = maximum bending moment, N · mm (lbf · in),

c = distance from the neutral axis to the location where the fiber failed, mm (in.),

I = moment of inertia of the original cross-section, mm<sup>4</sup> (in.<sup>4</sup>),

P = maximum applied load indicated by the testing machine, N (lbf),

L = support span length, mm (in.),

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

t = average thickness of the specimen, mm (in.).

9.2 If the fracture occurs outside of the load span, this observation shall be reported.

9.3 A multiplying factor of 0.145 may be used to convert kPa to psi.

## 10. Report

10.1 The report of each test shall include the following:

- 10.1.1 Sample identification,
- 10.1.2 Average width to the nearest 0.03 mm (0.001 in.),
- 10.1.3 Average thickness to nearest 0.03 mm (0.001 in.),
- 10.1.4 Support span length, mm (in.),
- 10.1.5 Rate of loading, mm (in.)/min. or N (lb)/min.
- 10.1.6 Maximum applied load, N (lb),
- 10.1.7 Modulus of rupture calculated to the nearest 70 kPa (10 psi),
- 10.1.8 Defects in specimen,
- 10.1.9 Orientation and location of specimen within the parent electrode, and
- 10.1.10 Failure mode and location.

## 11. Precision and Bias <sup>3</sup>

11.1 The precision of this test method (see Practice E 691) was determined from an ASTM round robin test on 38-mm (1.50-in.) square cross section specimens which were cut from a 153-mm (6.0-in.) thick slab from a 610 mm (24.0 in.) diameter premium grade electrode having a maximum particle size less than 6 mm (0.25 in.). Since this round robin was a destructive test, each participating laboratory tested only their samples. The samples sent to each laboratory were selected so as to represent the slab of graphite; that is, samples from different radial locations within the 610-mm (24.0-in.) diameter slab. Hence the stated precision not only represents the variations within the test itself but also the variations within the sampled electrode.

11.2 The referenced ASTM round robin test was a multi-purpose test and only that portion of the test data accumulated on four-point bending tests on square cross section specimens was analyzed to arrive at the stated precision. Six laboratories participated in the test to the extent that their methodology and

test fixtures conform to, but may not be identical to, this method and the fixture shown in Fig. 1.

11.3 The six sets of data contained all of the specimens of the stated test geometry, and form a homogeneous population. The data also exhibited a correlation between strength and density. Their mean strength, corrected by regression to the mean density, was 225.4 kPa (1550 psi) with a standard deviation of 4.3 kPa (110 psi). Plotted on probability paper, their distribution appeared normal with no significant skewness or kurtosis. Tested by analysis of variation with degrees of freedom 5 (between groups) and 24 (within groups against the null hypothesis and the random effects hypothesis), a difference between labs was barely discernible. The null hypothesis was satisfied at 90 % confidence level. The confidence band on the ratio of variances (between labs to within labs) included zero at the two-sided 80 % confidence level. Best estimates for the standard deviations are:

11.3.1 *Between Laboratories:*

$$s_b = 6.76 \text{ kPa (47 psi)}$$

with 5 df.

11.3.2 *Within Laboratories:*

$$s_w = 14.6 \text{ kPa (100 psi)}$$

with 24 df.

11.3.3 *Mean Value:*

$$\bar{x} = 225.4 \text{ kPa (1550 psi)}$$

11.3.4 It can also be safely concluded that the within-lab variability is largely due to materials variability for which no data was available for correlation. Known effects include orientation and disparate flaws.

11.4 The stated precision of this test will probably worsen if electrodes having a maximum particle size larger than 6 mm (0.25 in.) are tested using this test method.

11.5 *Bias*—Bias cannot be determined as this is a destructive test and no standard specimens are available.

## 12. Keywords

12.1 carbon; electrode graphite; flexural strength; graphite; modulus of rupture

<sup>3</sup> Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:C05-1009.

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