Designation: C 583 – 00

Standard Test Method for Modulus of Rupture of Refractory Materials at Elevated Temperatures[1]

This standard is issued under the fixed designation C 583; 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 high-temperature modulus of rupture of refractory brick or monolithic refractories in an oxidizing atmosphere and under action of a force or stress that is increased at a constant rate.

1.2 *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:*

E 220 Method for Calibration of Thermocouples by Comparison Techniques[2]

3. Significance and Use

3.1 Measuring the modulus of rupture of refractories at elevated temperatures has become a widely accepted means to evaluate materials at service temperatures. Many consumer companies have specifications based on this type of test.

3.2 This test method is limited to furnaces operating under oxidizing conditions. However, with modifications for atmosphere control in other test furnaces, the major criteria of this test procedure may be employed without change.

3.3 This test method is designed for progressive application of a force or stress on a specimen supported as a simple beam with center-point loading. Test apparatus designed for the progressive application of a strain may yield different results, especially since refractory materials will reach a semiplastic state at elevated temperatures where Hooke's law does not apply, that is, stress is then not proportional to strain.

3.4 This test method applies to fired dense refractory brick and shapes, chemically bonded brick and shapes, shapes formed from castables, plastics, or ramming materials, and any other refractory that can be formed to the required specimen dimension.

4. Apparatus

4.1 Use either an electrically heated or gas-fired furnace (Note 1). A typical cross section of the furnace containing the bearing edges is shown in Fig. 1. At least one pair of lower bearing edges, made from volume-stable refractory material (Note 2), shall be installed in the furnace on 5-in. (127-mm) centers. A thrust column, containing the top bearing edge that is made from volume-stable refractory material, shall extend outside the furnace where means are provided for applying a load. The lower bearing edges and the bearing end of the support column shall have rounded bearing surfaces having about a ¼-in. (6-mm) radius (Note 3). The lower bearing surfaces may be made adjustable, but must attain the standard span of 5 ± 3⁄32 in. (127± 2 mm). The length of the lower bearing surfaces shall exceed the specimen width by about ¼ in. The load shall be applied to the upper bearing edge by any suitable means. Instrumentation for measuring the load shall be accurate to 1 lbf (4.45 N). The thrust column shall be maintained in vertical alignment and all bearing surfaces parallel in both horizontal directions.

NOTE 1—The test furnace can be so constructed so that a number of specimens may be heated and tested at the same time. Bearing edges and loading devices may be provided for a number of individual specimens, but a more practical method is to provide means to move individual specimens successively onto a single set of bearing edges for breaking. The use of a separate holding furnace for specimens to be transferred into the test furnace for breaking is also satisfactory.

NOTE 2—A minimum of 90 % alumina content is recommended as a suitable refractory.

NOTE 3—All bearing surfaces should be checked periodically to maintain a round surface.

4.2 It is recommended that the furnace temperature be controlled with calibrated platinum-rhodium/platinum thermocouples connected to a program-controller recorder (see Method E 220). Temperature differential within the furnace shall not be more than ± 20°F (11°C), but the controlling thermocouple shall be placed within ½ in. (13 mm) of the geometric center of a side face of the test specimen when positioned on the bearing edges.

4.3 *Furnace Atmosphere*—Above a furnace temperature of 1470°F (800°C), the furnace atmosphere shall contain a minimum of 0.5 % oxygen with 0 % combustibles. Take the

[1] This test method is under the jurisdiction of ASTM Committee C08 on Refractories and is the direct responsibility of Subcommittee C08.01 on Strength.

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

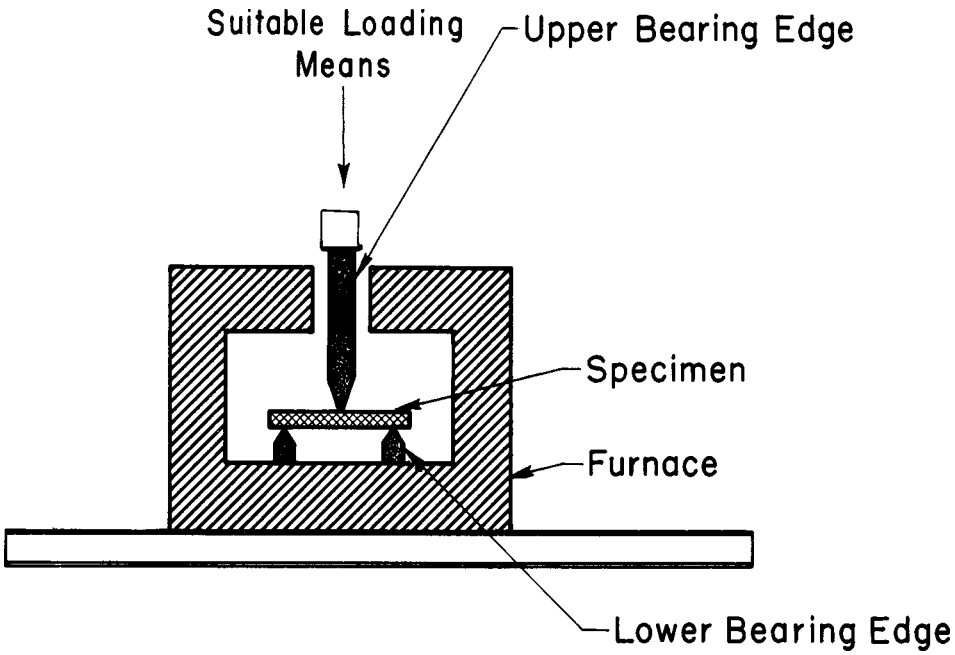

FIG. 1 Cross Section of Typical Apparatus (Heating Means Not Shown)

atmosphere sample from the furnace chamber proper, preferably as near the test specimen as possible.

5. Sampling

5.1 The sample shall consist of five specimens, each taken from five brick or shapes or from test specimens made from monolithic aggregate refractories.

6. Test Specimen

6.1 The standard test specimen shall be 1 ± 1/32 by 1 ± 1/32 by approximately 6 in. (25 ± 0.8 by 25 ± 0.8 by approximately 152 mm). Note in the report if other specimen sizes are used. Specimens cut from brick shall have at least one original brick surface. If cut from shapes, the specimens shall be taken parallel to the longest dimension. For irregular shapes, all four long surfaces of the specimen may be cut faces. Note this in the report.

6.2 Opposite faces of the specimen shall be parallel, and adjacent faces shall be perpendicular.

6.3 Measure the width and depth of the test specimen at mid-span to the nearest 0.01 in. (0.3 mm).

7. Procedure

7.1 Set the specimens in either the test or holding furnace without an applied load, and heat to the test temperature using the following schedule:

7.1.1 *Burned Refractory Products*—The rate of heating from room temperature shall not exceed 600°F (330°C)/h to 1800°F (980°C), and shall not exceed 200°F (110°C)/h from 1800°F to the test temperature (Note 4). Maintain the test temperature for a minimum of 3 h (Note 5).

NOTE 4—Heating at 600°F (330°C)/h can initiate thermal shock in some brick. A maximum heating rate of 150°F (83°C)/h is recommended for materials sensitive to thermal shock.

NOTE 5—Maintaining specimens at test temperature for 3 h before load application is adequate for most compositions and temperatures of interest. However, there may be certain compositions and temperatures requiring additional holding time at temperature in order to obtain consistent results. Experience and use of the test procedure will aid in determining when exploratory testing is required to arrive at the holding time necessary. If departure is made from the specified minimum time, the holding time used will be included in the report of the results.

7.1.2 *Unburned or Chemically Bonded Refractory Products*—The rate of heating from room temperature shall be 600°F (330°C)/h to 1800°F (980°C), and 200°F (110°C)/h from 1800°F to the test temperature. Maintain the test temperature for a minimum of 12 h.

7.2 Following the holding period, move the specimen to the supporting bearing edges. When possible, an original face of the specimen shall be used for the tension face, that is, the face in contact with the two lower bearing edges. Apply the load parallel to the direction (if known) of pressing of the specimen.

7.3 Control test temperature by the thermocouple that is located within ½ in. (13 mm) of the geometric center of a side face of the specimen when it is in position for testing. Hold specimen in testing position 10 min before testing (Note 6). Temperature shall not vary more than minus 0 plus 20°F (11°C) from the specified test temperature.

NOTE 6—This hold period may be shortened for continuously charged furnaces.

7.4 Test temperatures are not specified but must be agreed upon between laboratories and must be included in the report. Test temperatures should be selected in even 100°F (55°C) intervals, but if agreed, other multiples could be used.

7.5 Bring the top bearing edge to bear at mid-span on the specimen, ensure proper alignment of bearing surfaces, and apply pressure through the loading mechanism until failure of the specimen occurs. The rate of application of the load on the specimen shall be 175 ± 17.5 lbf (778± 77.8 N)/min. The resulting rate of increase in bending stress for the standard 1 by 1 by 6-in. (25 by 25 by 152-mm) specimen is 1312.5 ± 131 psi

(9.05± 0.9 MPa)/min.[3] If nonstandard specimens are used, the proper loading rate should be determined from the foregoing stressing rate and full details disclosed in the report.

7.6 Move the other specimens successfully onto the bearing edges and break them in accordance with the preceding procedure.

8. Calculation

8.1 Calculate the modulus of rupture (MOR) for each rectangular specimen as follows:

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

where:

MOR = modulus of rupture, psi or MPa,
P = concentrated load at rupture, lbf or N,
L = span between supports, in. or mm,
b = breadth or width of specimen, in. or mm, and
d = depth of specimen, in. or mm.

9. Report

9.1 Report the test temperature, the five individual test results, and the average modulus of rupture and standard deviation in pounds-force per square inch (or megapascals) for the five specimens.

9.2 Also, list in the report any deviations from standard test requirements such as specimen size, span, heating rate, soak time, or loading rate.

10. Precision and Bias

10.1 Ruggedness tests conducted in 1977 showed that the most sensitive variables were specimen dimensions, test temperature, and soak time. Of smaller influence were heating rate above 1800°F (980°C) and loading rate. Test results are incorporated in the method.

10.2 *Interlaboratory Test Data*—The results of interlaboratory studies conducted in 1963 and in 1970 were used in 1979 to revise the precision statements in accordance with latest recommendations from ASTM Committee E-11.

10.2.1 In the 1963 study, four types of direct-bonded (fired) magnesite-chrome brick and two types of chemically-bonded magnesite-chrome brick were tested at 1800°F (980°C) and 2300°F (1260°C). Five laboratories tested five specimens of each brick at each test temperature. In the 1970 study, two types of direct-bonded chrome brick, one 95 % MgO fired periclase brick (BOF type), and one 90 % alumina brick were tested at 2700°F (1480°C) by four laboratories using twenty specimens of each type of brick.

10.2.2 The precision was found to vary with the type of brick tested and also with the test temperature. Generally the standard deviation was proportional to the strength level, and relative precision is given in terms of the average coefficients of variation for each brick type and test temperature. However, in the case of fired brick, the relative precision tends to improve with the level of strength.

10.3 *Precision*—For two averages of five specimens tested within one laboratory, their difference is considered significant for a probability of 95 % and $t = 1.96$ if it equals or exceeds the repeatability interval for the applicable brick type in Table 1. Likewise, the difference between two averages obtained by two laboratories is considered significant if it equals or exceeds the applicable reproducibility interval in Table 1.

10.4 *Bias*—No justifiable statement of bias is possible because the true value of hot modulus of rupture cannot be established.

11. Keywords

11.1 compressive load; deformation resistance; flexural strength; high temperature; modulus of rupture; monolithic refractories; refractory brick

[3] This rate is 0.151 MPa/s, which is in agreement with the stress rate in PRE Recommendation R 18, "Determination of the Hot Modulus of Rupture of Shaped and Unshaped Dense and Insulating Refractory Products", 1978. Copies of PRE standards are available from the PRE Secretary, Lowenstrasse 31, P.O. Box 3361, CH-8023 Zurich, Switzerland.

TABLE 1 Relative Precision

Brick Type	Test Temperature °F	Test Temperature °C	Average MOR psi	Average MOR MPa	Coefficient of Variation Within Labs, %	Coefficient of Variation Between Labs, %	Repeatability Interval, % of Average[A]	Reproducibility Interval, % of Average[A]
Chem-bond	1800	980	360	2.48	14.2	13.5	17.6	41.2
Chem-bond	2300	1260	332	2.29	7.7	13.6	9.4	39.1
Direct-bond	1800	980	1530	10.55	15.7	17.4	19.4	52.9
Direct-bond	2300	1260	1208	8.33	17.9	15.3	22.2	47.9
Direct-bond	2700	1480	708	4.88	32.3	29.8	40.0	91.7
Periclase	2700	1480	1302	8.98	21.0	16.2	26.4	52.0
Alumina	2700	1480	1836	12.66	17.6	10.4	21.8	36.1

[A] Based on five specimens.