



Standard Test Method for Cold Bonding Strength of Refractory Mortar¹

This standard is issued under the fixed designation C198; 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 bonding strength of air-setting refractory mortar by determining the flexural strength (modulus of rupture) at room temperature of oven-dried brick-mortar joints.

1.2 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

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:²

C78 Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)

C133 Test Methods for Cold Crushing Strength and Modulus of Rupture of Refractories

C651 Test Method for Flexural Strength of Manufactured Carbon and Graphite Articles Using Four-Point Loading at Room Temperature

E4 Practices for Force Verification of Testing Machines

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Significance and Use

3.1 The data developed by this test method show the bonding strength and intrinsic strength of different qualities of air-setting mortar. The procedures described in this test method

measure the bonding strength and intrinsic strength of air-setting mortars when used with specific brands or lots of refractory brick.

3.2 Note that it is possible to obtain results with these methods for brick and mortar combinations which are incompatible for use at high operating temperatures. The user must determine this compatibility. Only brick and mortar combinations known or intended to be compatible for a particular use should be tested.

3.3 Properties of the brick, including its strength, apparent porosity, and pore size distribution, can affect the measurement of both the bonding strength of the brick-mortar composite and the intrinsic strength of the mortar. The average modulus of rupture of the test brick, as determined by Test Method C133, should exceed that expected for the mortar being tested. The testing of specific brands or lots of brick and mortar is preferred.

3.4 Three modes of failure are available: the break may occur within the brick itself, at the brick-mortar interface, or within the mortar itself. The latter provides a practical measurement of the strength of the mortar itself and is the predominant mode of failure with the four-point flexure test described. The three-point flexure test measures the failure strength of the brick-mortar composite. Failure within the brick itself suggests that either the particular brick contained a serious flaw, or that the mortar joint strength is of the same magnitude or greater than that of the refractory brick. The mode of failure should always be reported in the final report.

3.5 A ruggedness test for this test method³ performed in 1985 found the following variables to be rugged: specimen size (2.5 to 3.0 in.), mortared surface (cut versus uncut), joint thickness ($1/16$ to $1/8$ in.), pulling of rods (fast versus slow), the loading rate (500 to 1000 lbf/min), the method of load application (3- versus 4-point), and the operator.

3.6 The cold bonding strengths of refractory mortars obtained by this test method are suitable for use in research and development, quality control, and for establishing and evaluating compliance with specifications between producers and consumers.

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 For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

³ Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:C08-1008. Contact ASTM Customer Service at service@astm.org.

4. Apparatus

4.1 *Brick*—At least five 9 by 4¼ by 2½-in. (230 by 114 by 65-mm) straight brick having plane surfaces and true rectangular shape and an average modulus of rupture higher than that expected from the mortar under test, when determined in accordance with Test Methods C133, compose a sample.

4.2 *Spacing Rods*—Two joint-thickness spacing rods made of ⅛-in. (2-mm) diameter drill rod cut into 4-in. (102-mm) lengths.

4.3 *Oven*—A drying oven to accommodate at least five 9-in. (230-mm) straight brick standing on end, and for use at 220 to 230°F (105 to 110°C).

4.4 *Testing Machine*—A standard mechanical or hydraulic compression testing machine conforming to the requirements of Practices E4 and having a sensitivity of 20 lbf or less in the range from 0 to 4000 lbf (17.8 kN) may be used.

4.5 *Loading Fixture*—The fixtures shall provide load bearing blocks which ensure that the forces are applied normal to the beam without eccentricity. The directions of loads and reactions may be maintained parallel by judicious use of linkages, roller bearings, and flexure plates. Eccentricity of loading can be avoided by the use of spherical bearings.

4.5.1 Test Methods C133 provide illustrations of three-point loading fixtures which meet the above requirements. One acceptable four-point loading fixture is illustrated in Test Method C78. Another is illustrated in Test Method C651. The span length, L , of the support blocks shall be 7.00 ± 0.05 in. (178 ± 1 mm). The span length, l , of the load-applying blocks for four-point loading shall be 2.33 ± 0.05 in. (59 ± 1 mm) (see Figs. 1 and 2).

5. Sampling

5.1 *Wet Mortars*—The sample of mortar shall be a prepared test sample of about 10 lb (4.5 kg) (approximately ½ gal (1.89

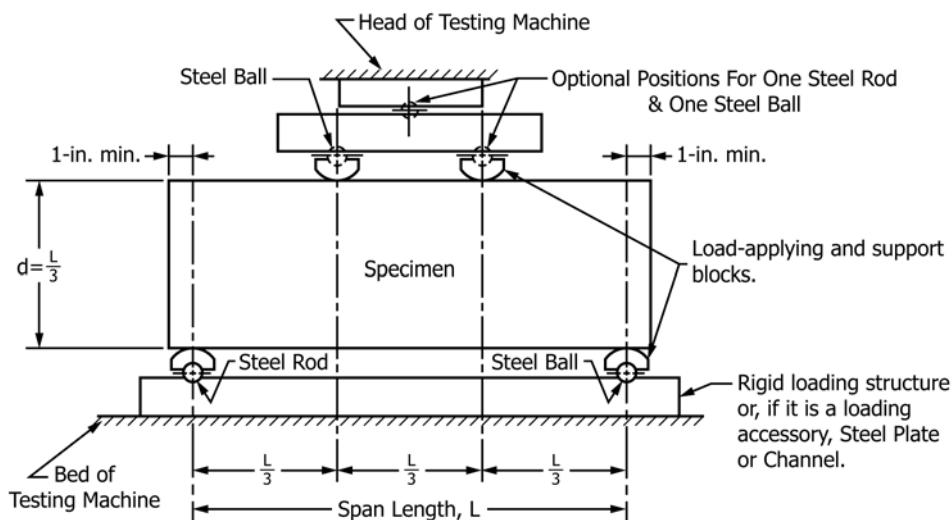
L)). If the weight of the commercial container is appreciably more than 10 lb, the contents of the container shall be thoroughly mixed in the container, or transferred without loss to a clean impervious receptacle of larger size and mixed thoroughly to a uniform consistency. A 10 lb test sample shall then be taken and placed in a suitable covered container resistant to the possible corrosive action of the mortar.

5.2 *Dry Mortars*—The sample of mortar submitted shall be a prepared test sample of 10 lb (4.5 kg) or a larger quantity, such as a 50 or 100-lb (23 or 45-kg) bag from which a 10-lb (4.5 kg) sample may be obtained using acceptable sampling procedures. The 10-lb (4.5 kg) sample should be thoroughly mixed with water to a uniform, troweling consistency and stored in a covered container (resistant to possible corrosive action by the mortar) for at least 16 h prior to the test.

NOTE 1—Reaction of phosphoric acid or aluminum phosphate with metallics may cause the development of hydrogen gas in some mortars. Therefore, the container should be covered only to minimize moisture loss, not tightly sealed.

6. Procedure

6.1 Cut each of the bricks of the sample (see Note 2) into two equal parts on a plane parallel to the 2½ by 4¼-in. (65 by 114-mm) face. Use the uncut 2½ by 4¼ in. face of each dry half-brick to form the mortar joint. The test mortar shall be of troweling consistency; this may require the addition of small amounts of water, followed by thorough mixing. Place approximately double the quantity of mortar required to form a joint ⅛ in. (2 mm) in thickness on the uncut and horizontally placed face of one half-brick. Place two spacing rods in the mortar parallel to the 2½ in. (65 mm) edges of the brick and ¾ in. (19 mm) from each edge. Then place the uncut face of the other half-brick on the mortar. Force out the excess mortar in the joint by pressing on the top half-brick and at the same time



NOTE 1—This apparatus may be used inverted. If the testing machine applies a force through a spherically sealed head, the center pivot may be omitted, provided one load-applying block pivots on a rod and the other on a ball.

NOTE 2—1 in. = 25.4 mm.

FIG. 1 Diagrammatic View of a Suitable Apparatus for Flexure Test of Refractory Mortar Joints, Four-Point Loading Method

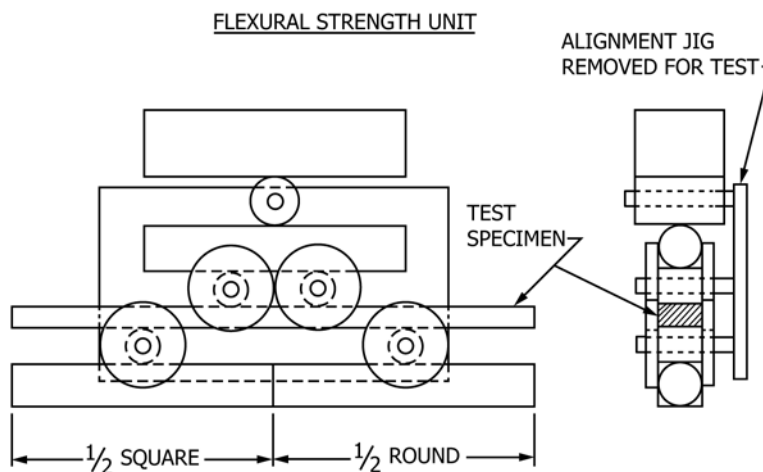


FIG. 2 Beam with Four-Point Loading

moving it with a to-and-fro motion in the direction of the 4½ in. (114 mm) dimension of the brick, using the spacing rods as rollers.

6.1.1 A total of five movements in each direction shall be given, and the distance of travel for the top half-brick should be ¼ in. (6 mm) from center in each direction. Withdraw the rods and clean the excess mortar from the surface of the joint. Allow the joints, prepared in this manner, to air-dry undisturbed at room temperature for 24 h, and then oven-dry at 220 to 230°F (105 to 110°C) for 18 h (overnight). Upon removal from the oven, allow them to cool by radiation until cool to the touch (6 h maximum).

NOTE 2—A thin abrasive cut-off wheel is useful for “sawing” the 9 in. (230 mm) brick in half.

6.2 Place and center the 9 by 4¼ in. (230 by 114 mm) face of the test specimen on the support blocks. Place and center the load-applying block(s) on the opposite face of the specimen ensuring that the applied loads and reactions will remain parallel during testing.

6.3 The load shall be applied in accordance with Test Method C133, except that, when using a hydraulic testing machine, the load shall be applied at the rate of 1000 lbf (4.45 kN)/min.

7. Report

7.1 For three-point loading, calculate the modulus of rupture using Eq 1:

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

where:

MOR = modulus of rupture, lbf/in² (MPa),
 P = maximum applied load at rupture, lbf (N),
 L = span between supports, in. (mm),
 b = breadth or width of specimen, in. (mm), and
 d = depth of specimen, in. (mm).

7.2 For four-point loading, calculate the modulus of rupture using Eq 2 or Eq 3:

7.2.1 If the fracture initiated in the tension surface within the middle third of the span length:

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

7.2.2 If the fracture initiated in the tension surface outside of the middle third of the span length by not more than 5 % of the span:

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

where:

a = average distance between the line of fracture and the nearest support on the tension surface of the beam, in. (mm).

7.2.3 If fracture occurs in the tension surface outside of the middle third of the span length by more than 5 % of the span length, discard the results of the test.

7.3 The report shall include:

7.3.1 The identity (brand, description, lot number, etc.) of the mortar and brick tested;

7.3.2 The type of testing performed, three- or four-point loading;

7.3.3 The number of specimens composing a sample;

7.3.4 Individual dimensions, maximum applied load, calculated modulus of rupture, and the mode of fracture (that is, in brick, at brick-mortar interface or within mortar) observed for each specimen;

7.3.5 The mean modulus of rupture and its standard deviation for the sample.

8. Precision and Bias

8.1 *Precision*—The precision of this test method is based on an interlaboratory study of C198, Standard Test Method for Cold Bonding Strength of Refractory Mortar, conducted in 1989. A total of three laboratories participated in this study, but only two reported 4-point results. Each lab determined five replicate test results for two materials (dry and wet mortar). Every “test result” reported represents an individual determination. Except for the use of only three laboratories, Practice E691 was followed for the design and analysis of the data; the details are given in ASTM Research Report No. RR:C08-1008.

8.1.1 *Repeatability limit (r)*—Two test results obtained within one laboratory shall be judged not equivalent if they

TABLE 1 Modulus of Rupture (MPa), 3-Point Results

	Average, ^A \bar{X}	Repeatability Standard Deviation, S_r	Reproducibility Standard Deviation, S_R	Repeatability Limit, r	Reproducibility Limit, R
3-point Dry, Air-Set, High Alumina Mortar (A-779)	379.5	161.1	240.6	451.2	673.6
3-point Wet Mortar (Franset HT)	445.4	93.7	136.1	262.5	380.9

^A The average of the laboratories' calculated averages.

TABLE 2 Modulus of Rupture (MPa), 4-Point Results

	Average, ^A \bar{X}	Repeatability Standard Deviation, S_r	Reproducibility Standard Deviation, S_R	Repeatability Limit, r	Reproducibility Limit, R
4-point Dry, Air-Set, High Alumina Mortar (A-779)	300.8	170.4	178.7	477.2	500.3
4-point Wet Mortar (Franset HT)	391.3	81.3	119.0	227.6	333.2

^A The average of the laboratories' calculated averages.

differ by more than the “ r ” value for that material; “ r ” is the interval representing the critical difference between two test results for the same material, obtained by the same operator using the same equipment on the same day in the same laboratory.

8.1.1.1 Repeatability limits are listed in **Tables 1 and 2**.

8.1.2 *Reproducibility limit (R)*—Two test results shall be judged not equivalent if they differ by more than the “ R ” value for that material; “ R ” is the interval representing the critical difference between two test results for the same material, obtained by different operators using different equipment in different laboratories.

8.1.2.1 Reproducibility limits are listed in **Tables 1 and 2**.

8.1.3 The above terms (repeatability limit and reproducibility limit) are used as specified in Practice **E177**.

8.1.4 Any judgment in accordance with **8.1.1** and **8.1.2** would normally have an approximate 95 % probability of being correct; however, the precision statistics obtained in this ILS must not be treated as exact mathematical quantities that are applicable to all circumstances and uses. The limited number of materials tested and laboratories reporting results

guarantees that there will be times when differences greater than predicted by the ILS results will arise, sometimes with considerably greater or smaller frequency than the 95 % probability limit would imply. Consider the repeatability limit and the reproducibility limit as general guides, and the associated probability of 95 % as only a rough indicator of what can be expected.

8.2 *Bias*—At the time of the study, there was no accepted reference material suitable for determining the bias for this test method, therefore no statement on bias is being made.

8.3 The precision statement was determined through statistical examination of 50 results, from three laboratories, performing two analyses on two materials.

8.3.1 To judge the equivalency of two test results, it is recommended to choose the material closest in characteristics to the test material.

9. Keywords

9.1 cold bonding strength; flexural strength; high temperature; modulus of rupture; refractory mortar

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