Designation: C 839 – 82 (Reapproved 2005)

Standard Test Method for Compressive Stress of Porcelain Enamels by Loaded-Beam Method[1]

This standard is issued under the fixed designation C 839; 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.

INTRODUCTION

Many methods and tests have been used in the industry to determine the relative compressive stress of porcelain enamel ground coats and cover coats. Three methods have been most commonly used. They are loaded-beam, warp, and split-ring methods. In the loaded-beam method the measure of stress is the load required to bring a specimen back to a plane after it has been bowed by controlled application of the enamel under test to one side of the specimen. The degree of the deflection of a specimen from a plane caused by controlled application of enamel to one side is the indicating measure of stress in the warp test. The indicating measurement in the split-ring test is the force required to just open a split ring after controlled application of test enamel to the outside surface of a ring.

1. Scope

1.1 This test method covers the measurement of the compressive stresses (Note 1) developed by fired porcelain enamels using the loaded-beam method.

NOTE 1—Although some may interpret the calculations that are used in this test method as indicating compressive load, it is commonly referred to as compressive stress within the porcelain enamel industry.

1.2 This test method is limited to the use of the loaded-beam method. However, this method includes charts (Fig. 1 and Fig. 2) that provide for conversion of loaded-beam test results to warp and ring stress values.

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]

A 424 Specification for Steel, Sheet, for Porcelain Enameling

3. Terminology

3.1 *Description of Term Specific to This Standard*

3.2 *compressive stress or stress*—a term used to designate the degree of compression that exists in a porcelain enamel on steel after processing.

4. Significance and Use

4.1 All porcelain enamel coatings or glass coatings are by necessity under some degree of compression at room temperature. The desired degree of compression or stress depends upon the type of ware and the end use of the item. Some method of determining relative compressive stress of enamels is necessary to establish the suitability of an enamel for a proposed application.

5. Apparatus

5.1 *Furnace*, suitable for simultaneous firing of at least six 1 by 12-in. (25 by 305-mm) specimens in vertical hanging position.

5.2 *Firing Rack*, suitable for furnace.

5.3 *Loaded-Beam Test Apparatus* (see Fig. 3 and Fig. 4).

5.4 *Metric Weights*, slotted, 1 to 500 g.

5.5 *Laboratory Balance*, accurate to 10 mg with necessary weights (1 to 100 g).

5.6 *Brushing Template*, 2¹⁄₁₆ by 10¹⁵⁄₁₆ in. (52 by 278 mm) (see Fig. 5 for one example of achieving the desired end result).

5.7 *Stencil Brush*.

[1] This test method is under the jurisdiction of ASTM Committee B08 on Metallic and Inorganic Coatings and is the direct responsibility of Subcommittee B08.12 on Materials for Porcelain Enamel and Ceramic-Metal Systems.

This test method was developed at the National Bureau of Standards under the sponsorship of the Porcelain Enamel Institute, Inc., and was published as PEI Technical Publication No. T-30 (1973).

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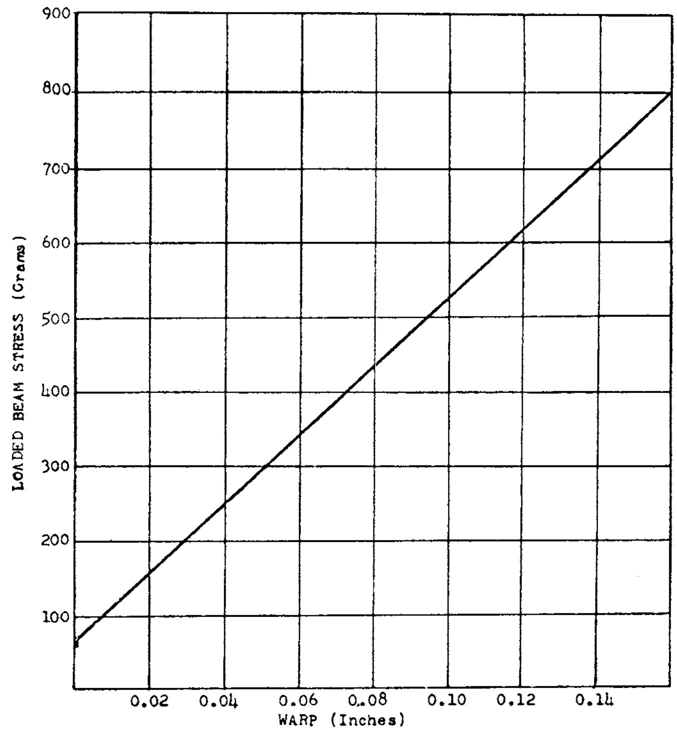
[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.



Metric Equivalents

in.	mm	in.	mm
0.02	0.51	0.10	2.54
0.04	1.02	0.12	3.05
0.06	1.52	0.14	3.56
0.08	2.03		

FIG. 1 Conversion Chart for Loaded-Beam Stress to Warp Stress

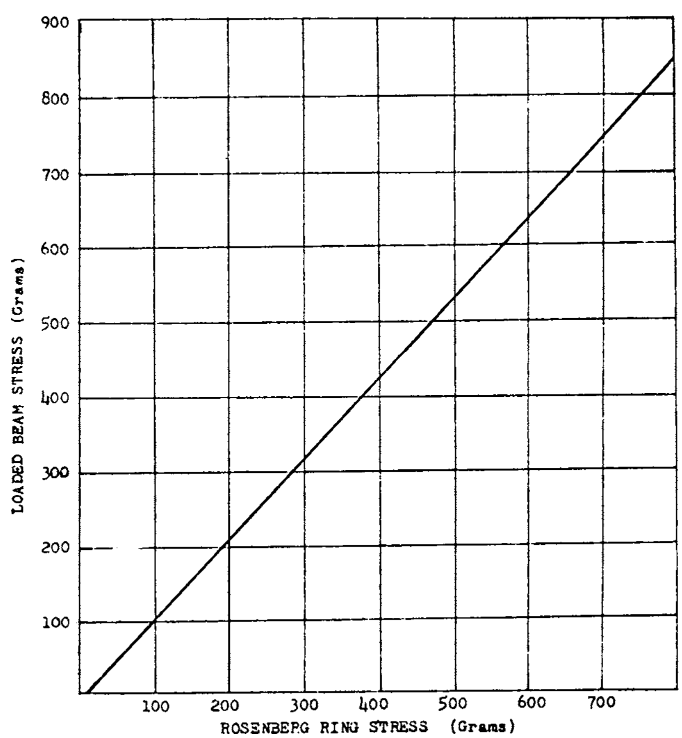
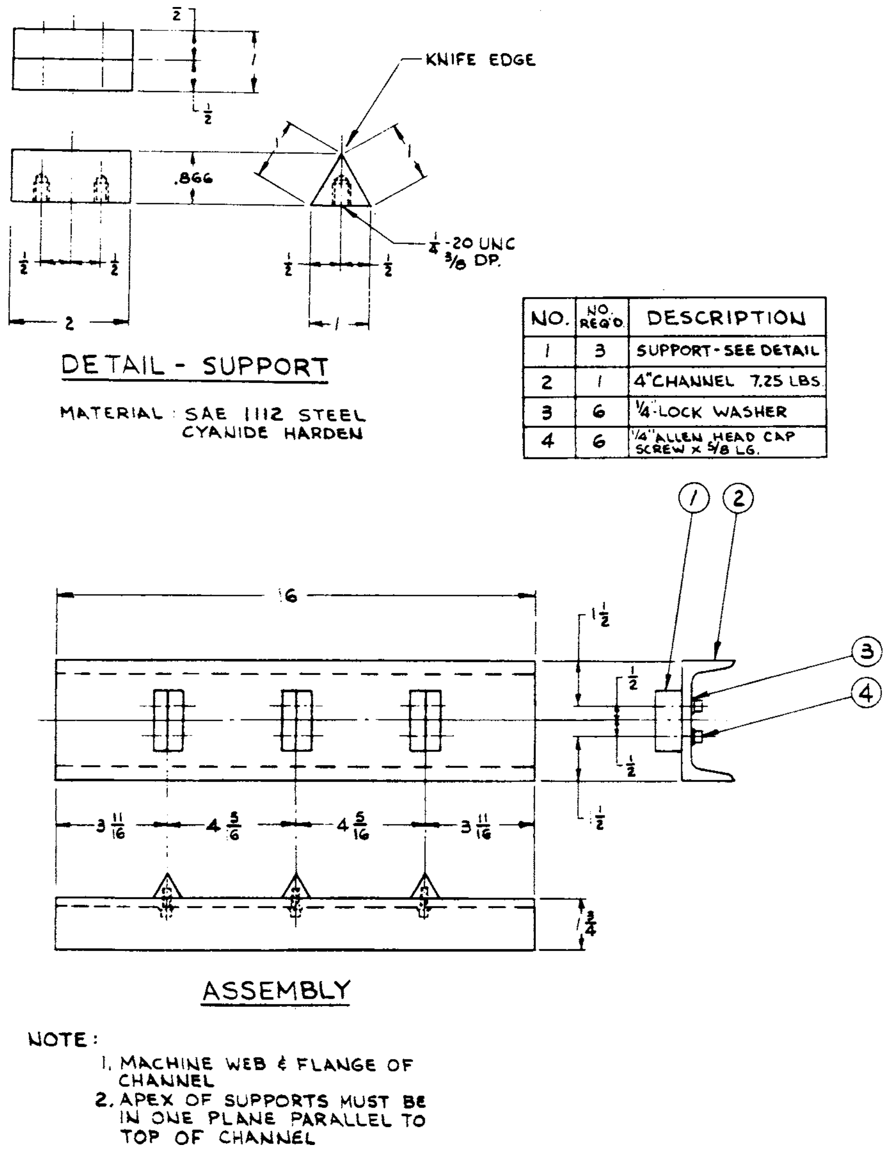


FIG. 2 Conversion Chart for Loaded-Beam Stress to Ring Stress



Metric Equivalents

in.	mm	in.	mm
¼	6.35	1¾	44.45
⅜	9.53	2¹⁄₁₆	52.39
⁷⁄₁₆	11.11	3¹¹⁄₁₆	93.68
½	12.7	4	101.6
⅝	15.88	4⁵⁄₁₆	109.54
0.866	22.0	8⅝	219.08
1	25.4	10¹⁵⁄₁₆	277.81
1¼	31.75	12	304.8
1½	38.1	16	406.4
1¹¹⁄₁₆	42.86		

FIG. 3 Loaded-Beam Test Apparatus

5.8 *Fluorescent Light Fixture* with diffusion panel and adjustable support.

6. Test Specimens

6.1 Six specimens are required for each enamel tested.

6.2 Specimens 1 by 12 in. (25 by 305 mm) shall be cut by shearing from flat sheets of 20-gage Commercial Quality Type II enameling iron (see Specification A 424) with thickness 0.036 ± 0.002 in. (0.91 ± 0.05 mm). The 12-in. dimension should be cut perpendicular to the direction of rolling of sheet. Care should be exercised to prevent formation of burrs during shearing. Burrs that are formed may be removed by carefully filing edges or by lightly touching edges to a sanding belt. Since opposing sides of the sheet may produce slightly different results, one side of the sheet should be scribed in such a manner that the scribe mark will appear about 1 in. from one

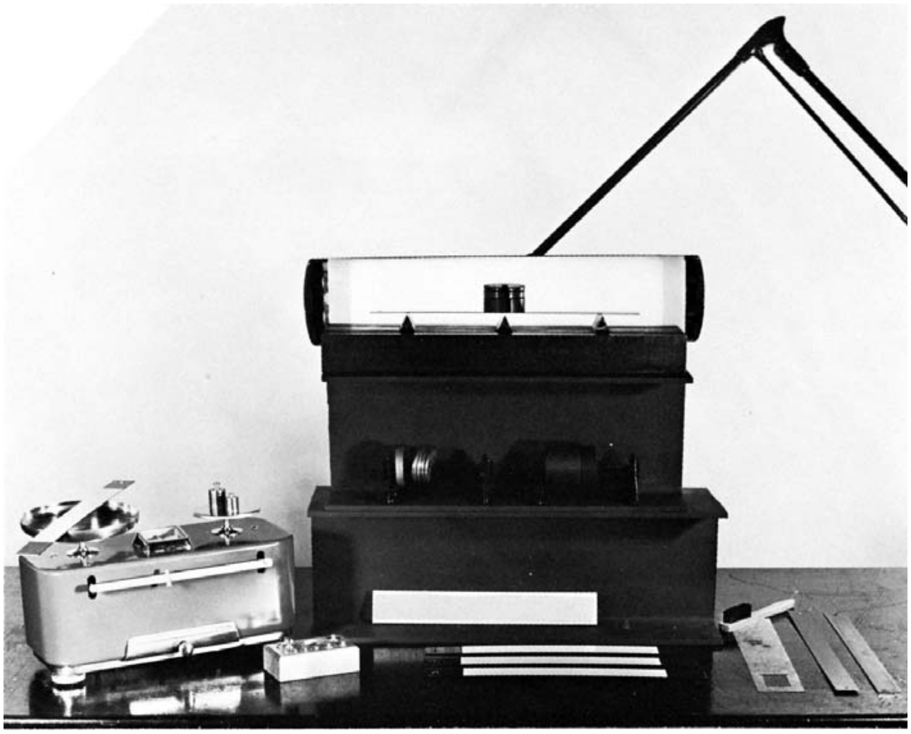
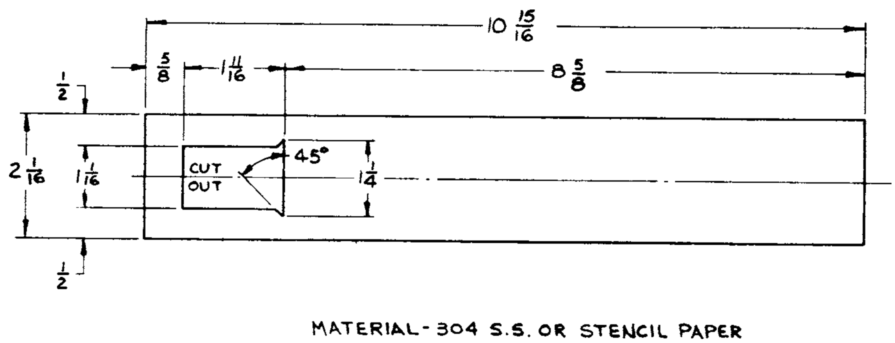


FIG. 4 Loaded-Beam Test Apparatus



NOTE 1—See Fig. 3 for metric equivalents.

FIG. 5 Brushing Template

end of the resulting strips after shearing. A ¼ -in. (6.35-mm) diameter hole should be punched in one end of the specimen for hanging purposes during drying and firing. The center of the hole should be on the center line 7⁄16 in. (11 mm) from the end of the specimen. Specimens should be numbered for identification during the testing procedure. They may be permanently identified by metal stamping on the scribed side while being supported on an anvil (see Fig. 6).

7. Procedure

7.1 *Application of Ground Coat to Test Strips*:

7.1.1 Subject the specimens to a pickle procedure normal for ground coat application. Pickle in a suspended vertical position to prevent distortion.

7.1.2 Measure and record metal thickness of the test specimens.

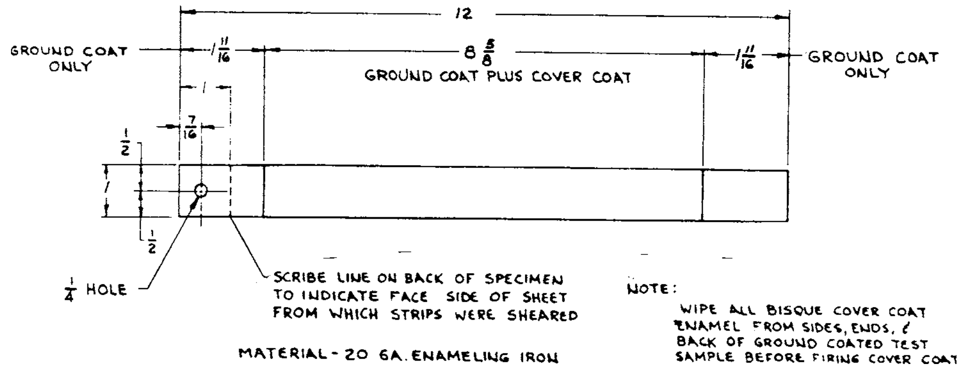
7.1.3 Apply a medium high-temperature ground coat (1520 to 1540°F (825 to 840°C)) by spraying. With scribed sides up, first spray the back sides of strips to give 1.5 g dry weight per strip. Dry and cool. Reverse the strips and spray a like amount on the face side. Dry and cool. Use a relatively dry spray to avoid formation of beads on the edges of the strips (Note 2).

7.1.4 Fire the strips in a vertical hanging position at the optimum time and temperature for the ground coat. The preferred procedure is to fire multiples of six simultaneously. Cool in a suspended position, avoiding drafts or forced cooling.

7.1.5 Weigh and record the weight of each strip to the nearest 0.01 g.

7.1.6 Place each strip on the test apparatus with the scribed side down.

7.1.7 Measure and record the ground coat residual load, which is the weight in grams required to cause the strip to just rest on the three knife edges of the fixture. Discard any strips having zero or negative stress (reverse bow) or having positive load of more than 50 g.



NOTE 1—Wipe all bisque cover coat enamel from sides, ends, and back of ground coated test sample before firing cover coat.
NOTE 2—See Fig. 3 for metric equivalents.

FIG. 6 Detail of Test Specimen

NOTE 2—More consistently uniform and usable specimens will result if a spraying technique is developed whereby a few hundredths of a gram less enamel is applied to the back than to the face. This practice reduces the possibility of developing a concavity in the strip as viewed from the face side.

7.2 *Application of Test Enamel*:

7.2.1 Apply test enamel to the face side of six ground-coated specimens by spraying. Apply the enamel to yield a dry weight of 30 g/ft ^{2} (323 g/m^2, or 2½ g per strip). Use a relatively dry spray to avoid formation of beads along edges. After drying and cooling, use a template to brush back 1^{11}⁄16 in. (43 mm) from each end of strip, leaving 8⅝ in. (179 mm) of cover coat on the strip. Wipe the edges and back of strips with a felt pad and dust with a soft-bristled brush or wool duster.

7.2.2 Fire panels, again in a vertical hanging position, at optimum temperature and time for the test enamel as cover coat. Cool in a vertical position, avoiding forced cooling. Rapid cooling produces greater residual compressive stresses.

7.2.3 Weigh each strip to the nearest 0.01 g and record.

7.3 *Measurement of Load*:

7.3.1 Center each coated strip individually over the three knife edges of the fixture with face side upward and punched hole to left. Stops or blocks may be of aid in centering the strips on knife edges.

7.3.2 Centrally load the strip with slotted weights over the center knife edge until the strip just touches the central knife edge. A strong diffuse light source behind the test fixture facilitates observation of the end point.

7.3.3 Measure and record the uncorrected compressive load of each of the cover-coated test strips. The load, in grams, required to cause the strip to just touch the central knife edge is the uncorrected compressive load.

7.3.4 Corrected load is uncorrected compressive load minus residual ground coat load (see 7.1.7).

8. Calculation

8.1 Calculate the corrected load, *L*, by subtracting the residual ground coat load from the uncorrected compressive load.

8.2 Calculate the compressive stress, S_c, for each test specimen as follows:

$$S_c = L \times \frac{1.80}{W} \times \frac{0.036}{T_i} \quad (1)$$

or

$$S_c = L \times \frac{1.80}{W} \times \frac{0.914}{T_m} \quad (2)$$

where:

S_c = compressive stress of the specimen, gf/in. (or gf/mm),
L = corrected load for cover-coated strip, gf,
1.80 = calculated fired weight of enamel on 8⅝ -in. (219-mm) length of strip equivalent to 30 g/ft^2 (323 g/m^2) (dry),
W = actual fired weight of test enamel on strip to the nearest 0.01 g,
T_i = actual metal thickness, in., and
T_m = actual metal thickness, mm.

8.3 Determine the average of the six compressive stress values and report as the compressive stress of the tested enamel.

8.4 If the end use of the test data requires a statistical comparison of samples, the standard deviation and statistical error of the six specimens comprising one lot may be calculated by the root-mean-square method. The compressive stress of the enamel may then be reported as the numerical average of the test values together with their statistical error (see Appendix X1 for an example of data treatment).

9. Conversion of Test Results

9.1 Conversion charts may be used to make approximate conversions of results of the loaded-beam test method in terms of other test methods (or vice versa if necessary). Fig. 1 provides for conversion of loaded-beam test results to warp values. Fig. 2 may be used to convert loaded-beam results to ring-stress values.

10. Precision and Accuracy

10.1 The precision and accuracy of this test method are being developed.

APPENDIX

(Nonmandatory Information)

X1. EXAMPLE OF DATA TREATMENT

X1.1 Table X1.1 provides sample values for six specimens to illustrate the application of formulas necessary for the measurement of compressive stress.

X1.2 The following compressive stress values for individual specimens are calculated by applying the formula: $S_c = L \times (1.80/W) \times (0.036/T_i)$ (see Section 8):

Specimen No.	Compressive Stress (S_c)
1	525
2	524
3	496
4	510
5	488
6	481
	Mean 504

X1.3 Calculate the statistical error of the determination as follows:

$$e = 1.05\,s \tag{X1.1}$$

where:
e = statistical error of the mean value for the samples at the 95 % confidence level, and
s = standard deviation of the six individual values from the average of all six.

NOTE X1.1—The factor 1.05 applies only when the number of specimens is six and the confidence level is 95 %. For larger or smaller numbers of specimens, use the "a" values for that number shown in Table 2, Part 2, of STP 15 D.[3]

X1.4 Calculate the standard deviation, s, as follows:

$$s = \sqrt{\frac{\Sigma S_c^{\,2} - \frac{(\Sigma S_c)^2}{n}}{n-1}} \tag{X1.2}$$

where:
n = number of specimens,
$\Sigma S_c^{\,2}$ = sum of the squares of the stress values of the six individual specimens, and
$(\Sigma S_c)^2$ = square of the sum of the six stress values.

X1.5 The following calculations are involved in applying Eq X1.2:

Specimen	S_c	S_c^2	
1	525	275 625	
2	524	274 576	
3	496	246 016	
4	510	260 100	
5	488	238 144	
6	481	231 361	
$\Sigma S_c =$	3 024	1 525 822	$= \Sigma S_c^2$
Mean $S_c =$	504		

$$s = \sqrt{\frac{1\,525\,822 - \frac{9\,144\,576}{6}}{5}} \tag{X1.3}$$

$$= \sqrt{\frac{1\,525\,822 - 1\,524\,096}{5}}$$

$$= \sqrt{\frac{1\,726}{5}} = \sqrt{345.2}$$

$$s = 18.6$$

X1.6 Applying Eq X1.1, $e = 1.05 \times 18.6 = 19.5$.

X1.7 Compressive stress value for example Enamel A thus becomes 504 ± 19.5.

[3] *Special Technical Publication 15 D,* available from American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103.

TABLE X1.1 Sample Values

Enamel	Specimen No.	Application (g), W	Residual Load	Final Load	Corrected Load, L	Metal Thickness, T_i
A	1	1.76	1	486	485	0.034
	2	1.71	12	482	470	
	3	1.80	7	475	468	
	4	1.82	30	517	487	
	5	1.77	5	458	453	
	6	1.75	5	447	442	

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