Designation: C1445 – 13

Standard Test Method for Measuring Consistency of Castable Refractory Using a Flow Table[1]

This standard is issued under the fixed designation C1445; 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 procedure for determining the consistency of castable refractory mixes by the flow table method.

1.2 This test method applies to regular weight castable refractories, insulating castable refractories, and castable refractories that require heavy vibration for forming, which are described in Classification C401. They also apply to such castables containing metal fibers.

1.3 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.

1.4 *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]

C71 Terminology Relating to Refractories

C230/C230M Specification for Flow Table for Use in Tests of Hydraulic Cement

C401 Classification of Alumina and Alumina-Silicate Castable Refractories

C860 Test Method for Determining the Consistency of Refractory Castable Using the Ball-In-Hand Test

D346 Practice for Collection and Preparation of Coke Samples for Laboratory Analysis

3. Significance and Use

3.1 The amount of water used in a castable mix for preparing test specimens has a significant influence on subsequent test results. This test method is used primarily to determine and reproduce the consistency required for the optimum casting of refractory castables in the preparation of test specimens and to express that consistency quantitatively. The correct water content is one of the major factors that must be controlled to obtain uniform test specimens. Excess water can reduce strength, increase volume shrinkage, and promote segregation of the castable ingredients. Insufficient water can produce "honeycombs" (air voids) in the castable because of poor consolidation during placement and prevent complete hydration of cement.

3.2 The flow table (see sketches in Specification C230/C230M) has been found to be an excellent tool for measuring the consistency of a castable and should be used in cases where a numerical result is required. Since castables differ somewhat in their "body" or plasticity, it has been found that a good casting range, expressed numerically, might vary from castable to castable. While one material may cast well between 40 and 60 % flow, another material may need to be in the 60 to 80 % flow range to properly flow. Because of this, it has been found that no arbitrary optimum range can be stated for all castables. The flow table then becomes a tool for measuring the flow and not determining it. It can allow the operator to follow the manufacturer's recommendations or to reproduce the consistency of a particular castable between laboratories.

3.3 Total time of wet mixing must be closely controlled to obtain reproducible results.

[1] This test method is under the jurisdiction of ASTM Committee C08 on Refractories and is the direct responsibility of Subcommittee C08.09 on Monolithics.

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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.

Plibrico Ruggedness Test C1445 3/8/2006 23 C Material & Lab Temp

Material used: NIST Calibration Material for C239 Flow Table

		Assigned Flow:
	Sample # AF-4	111
	Plibrico Flow (25 taps): 109, 109	

Ruggendsness Variables

A	Tamper rectangular
a	Tamper round
B	Tamper sealed
b	Tamper unsealed
C	1/2 half fill / 1/2 half tamp - repeat
c	Full mold / full tamp
D	Tamp 44 times
d	Tamp 36 times
E	Table drop 15X in 7 sec
e	Table drop 15X in 11 sec
F	Operator 1 (Len)
f	Operator 2 (Pat)
G	Dummy
g	Dummy

Ruggedness Matrix

1	2	3	4	5	6	7	8
A	A	A	A	a	a	a	a
B	B	b	b	B	B	b	b
C	c	C	c	C	c	C	c
D	D	d	d	d	d	D	D
E	e	E	e	e	E	e	E
F	f	f	F	F	f	f	F
G	g	g	G	g	G	G	g

Results (flow in mm)

Replicate								
1	196	196	195	195	197	197	195	197
	199	196	197	200	197	197	196	198
	199	196	196	201	199	199	199	199
	199	197	195	198	200	199	199	198
avg	**198**	**196**	**196**	**199**	**198**	**198**	**197**	**198**
2	195	199	199	196	198	196	198	197
	198	198	199	198	199	197	198	197
	199	200	198	201	201	197	200	199
	198	198	198	199	201	196	198	198
avg	**198**	**199**	**199**	**199**	**200**	**197**	**199**	**198**
3	196	196	196	198	194	194	199	194
	196	197	197	200	197	196	199	196
	196	197	197	197	201	196	199	197
	197	197	194	197	199	195	199	195
avg	**196**	**197**	**196**	**198**	**198**	**195**	**199**	**196**

Results (flow %)

Replicate								
1	94.1%	92.2%	92.2%	95.1%	94.1%	94.1%	93.1%	94.1%
2	94.1%	95.1%	95.1%	95.1%	96.1%	93.1%	95.1%	94.1%
3	92.2%	93.1%	94.1%	94.1%	94.1%	91.2%	95.1%	92.2%

FIG. 1 Plibrico Ruggedness Test Results

3.4 This test method is not intended to be used to determine the proper water content for gunning applications, although it may provide information of value for interpretation by a skilled operator.

4. Interferences (Factors Known to Affect Results)

4.1 A ruggedness test (Fig. 1) was performed using "C230 Calibration Mixture"[3]. All factors were found not to cause statistically significant effects on measured results. See ASTM Research Report No. RR:C08-1016.

4.2 Factors which were found to be rugged during the test method evaluation were *(1)* tamper cross section – round versus rectangular, *(2)* tamper surface – polyurethane sealed versus unsealed, *(3)* mold filling procedure, *(4)* number of tamps – 36 versus 44, *(5)* table drop time – 7 s versus 11 s, and *(6)* operator.

5. Apparatus

5.1 *Balance,* 15-lb (6.8-kg) capacity, with sensitivity of 0.002 lb (1 g).

5.2 *Flow Table, Mold, and Calipers,* conforming to the requirements of Specification C230/C230M.

5.3 *Tamper*—A nonabsorbing, nonabrasive, non-brittle material such as a rubber compound having a Shore A durometer hardness of 80 ± 10 or hardwood dowel made nonabsorbing by coating with either solvent or water based polyurethane, and the tamper shall have a cross section of ½ by 1 in. (13 by 25 mm) or an equivalent circular cross sectional area and a convenient length of 5 to 6 in. (127 to 152 mm). The tamping face shall be flat and at right angles to the length of the tamper.

5.4 *Trowel,* having a steel blade 4 to 6 in. (100 to 150 mm) in length, with straight edges.

5.5 *Castable Mixer*—Either a manually or electrically operated (see Fig. 2) mechanical mixer[4] may be used to prepare batches for the consistency determination. Size the mixing bowl to contain 50 to 70 % volume loading with the dry batch.

NOTE 1—Castable-water requirement variation becomes more significant as dry volume loadings drop below 50 % of the capacity of the mixer bowl because the water required to wet the bowl surfaces changes more rapidly with decreasing volume loadings.

5.6 *Thermometer,* dial or digital-type, metal, with a range from 0 to 180°F (−18 to 80°C).

5.7 *Vibrating Table*—An electric vibrating table with 3600 Hz and at least a 1-ft^2 surface.

5.8 *Sample Splitter,* designed to reduce the castable to the desired weight and ensure that the grain size distribution is representative of the original batch.

FIG. 2 Special Mixer for Castable Refractories

NOTE 2—A Jones or riffle-type sample splitter is satisfactory, provided the openings are large enough to accommodate the largest aggregate particle. If a sample splitter is not available, hand reduction by the cone-and-quarter method may be used. Follow the applicable portions of this test method as described in Practice D346.

6. Sampling

6.1 At the time of use, the dry castable mix should be between 68 and 72°F (20 and 22°C). The temperature is measured by inserting the full length of the dial-thermometer stem into the material until the reading is constant.

6.2 Reduce the mass of the castable mix with a sample splitter to obtain the desired batch size in accordance with 6.3. Take precautions to prevent segregation. If additional batches are required, they should also be reduced to the desired batch size with a sample splitter.

6.3 Batch sizes for the flow table test normally consist of 10 lb (4.5 kg) for a regular weight or 5 lb (2.3 kg) for an insulating castable. Mixer size may dictate other sizes. (See 5.5).

7. Procedure

7.1 *Preparation of Castable Sample:*

7.1.1 Weigh the castable sample (see 6.3) to the nearest 0.02 lb (9 g). Place the batch in the mixer described in 5.5 (see Note 1), and dry mix for 1 min. While the mixer is operating at slow speed, add 90 % of the estimated water requirement having a temperature between 68 and 72°F (20 and 22°C), within ½ min. Operate the mixer at 50 to 60 rpm, then add additional water in small amounts from a tared container, and mix until the batch appears to have the desired flow.

7.1.2 The total actual wet mixing time, including water additions, should be 3 min ± 10 s for dense castables, 5 min ± 10 s for insulating castables, and 4 to 6 min for mixes needing heavy vibration, unless specified differently by the manufacturer.

NOTE 3—Mixing times of less than 5 min for insulating castables may influence the results because lightweight aggregates usually soak up water during the initial stages of mixing and affect the consistency of the batch. Depending on the aggregate type, particle breakdown may occur with

[3] Laboratory Flow Table Calibration Mixture available from Cement and Concrete Reference Laboratory; Building Research, 226-Room A365; National Institute of Standards and Technology; Gaithersburg, MD 208989.

[4] The sole source of supply of mechanical mixers known to the committee at this time is Hobart Corporation, 701 S. Ridge Ave., Troy, OH 45374. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

excessive mixing time. This was not observed in subcommittee round-robin tests with a 5-min mixing time using a variety of lightweight castables.

7.2 *Determination of Flow:*

7.2.1 For mixes that do not require heavy vibration for forming, such as regular weight and insulating castable refractories, proceed with flow determination in the following manner:

7.2.1.1 Carefully wipe the flow-table top until clean and dry, and place the flow mold at the center. Place a layer of castable about 1 in. (25 mm) in thickness into the mold, and tamp 20 times with the tamper. The tamping pressure should be just sufficient to ensure uniform filling of the mold. Fill the mold with additional castable, and tamp as specified for the first layer. Cut off the castable to a plane surface flush with the top of the mold by drawing the straightedge of a trowel (held nearly perpendicular to the mold) with a sawing motion, across the top of the mold. Wipe the table top around the mold until clean and dry. Carefully remove any water from around the edge of the flow mold. Lift the mold away from the castable within 1 min after completing the mixing operation described in 7.1.1.

7.2.2 For castables that require heavy vibration for forming, proceed with flow determination in the following manner:

7.2.2.1 Place the mold with large end up on the vibrating table. Place an excess amount of castable into the mold. Turn on the vibrating table while holding the sample mold firmly on the table. Vibrate the sample until all the large air bubbles cease evolving from the castable and the castable fills out the mold. Cease vibration. Scrape off the excess castable above the upper rim of the mold with a straightedge trowel. Vibrate the sample again until its upper surface is smooth and even with the upper rim of the sample mold. The total vibration time should be no more than 30 s. Rotate the sample mold on the vibrating table so that the sample will not adhere to the table. Slide the sample off the vibrating table and place it, inverted, onto the center of a clean, dry flow table. Lift the mold vertically from the table while pressing down upon the castable sample so that minimal deformation of the sample occurs. Lift the mold away from the castable within 1 min after completing the mixing operation described in 7.1.1.

7.2.3 Immediately drop the table 15 times in 9 s a height of ½ in. (13 mm). This distance is automatically controlled by a cam in a properly constructed flow table (see Specification C230/C230M). The flow is the resulting increase in average base diameter of the castable mass, expressed as a percentage of the original base diameter. The special caliper shown in Fig. 1 of Specification C230/C230M is graduated to indicate one fourth of the actual flow so that the readings of four measurements may be added to give the flow value, eliminating calculations of the average of four individual measurements. Using the special caliper, make four measurements of the base diameter of the castable mass at equivalently spaced intervals. Sum the four measurements to obtain the percent flow.

7.2.4 In reproducing a consistency within a specified flow range, it may be necessary to make several trial mixes with varying percentages of water. Make each trial with a fresh batch.

8. Report

8.1 Report the following information:

8.1.1 The type of mixer used to prepare the test batch.

8.1.2 The amount of water used in each batch (% by wt. dry castable).

8.1.3 The total mixing time (minutes).

8.1.4 The dry mix temperature, °F (°C).

8.1.5 The water temperature, °F (°C).

8.1.6 The percent flow directly from the sum of the special calipers, or calculated as follows if using standard calipers:

(average base diameter − original base diameter/original base diameter) × 100 (%)

9. Precision and Bias

9.1 The precision of this test method is based on an interlaboratory study of ASTM C1445, Standard Test Method for Measuring Consistency of Castable Refractory Using a Flow Table, conducted in 2012. Five laboratories participated in this study. Each of the labs reported three replicate consistency results for two different cementitious materials. Every “test result” reported represents an individual determination. Except for the use of only five laboratories, Practice E691 was followed for the design and analysis of the data; the details are given in ASTM Research Report No. RR:C08-1023.[5]

9.1.1 *Repeatability (r)*—The difference between repetitive results obtained by the same operator in a given laboratory applying the same test method with the same apparatus under constant operating conditions on identical test material within short intervals of time would in the long run, in the normal and correct operation of the test method, exceed the following values only in one case in 20.

9.1.1.1 Repeatability can be interpreted as the maximum difference between two results, obtained under repeatability conditions, that is accepted as plausible due to random causes under normal and correct operation of the test method.

9.1.1.2 Repeatability limits are listed in Table 1 below.

TABLE 1 Flow at 5 Minutes

Material	Average[A] $\bar{x}$	Repeatability Standard Deviation S_r	Reproducibility Standard Deviation S_R	Repeatability Limit r	Reproducibility Limit R
Kerneos Standard Cement Mortar	76.89	6.49	11.25	18.17	31.49
Kerneos Standard Refractory Castable	96.14	8.94	10.48	25.03	29.35

[A] The average of the laboratories' calculated averages.

9.1.2 *Reproducibility (R)*—The difference between two single and independent results obtained by different operators applying the same test method in different laboratories using different apparatus on identical test material would, in the long run, in the normal and correct operation of the test method, exceed the following values only in one case in 20.

[5] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:C08-1023. Contact ASTM Customer Service at service@astm.org.

9.1.2.1 Reproducibility can be interpreted as the maximum difference between two results, obtained under reproducibility conditions, that is accepted as plausible due to random causes under normal and correct operation of the test method.

9.1.2.2 Reproducibility limits are listed in Table 1 below.

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

9.1.4 Any judgment in accordance with statements 9.1.1 and 9.1.2 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 which 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. The repeatability limit and the reproducibility limit should be considered as general guides, and the associated probability of 95 % as only a rough indicator of what can be expected.

9.2 *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.

9.3 The precision statement was determined through statistical examination of 30 results, from five laboratories, on two materials.

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

10. Keywords

10.1 castable; concrete; consistency; flow; flow-table; mixing; refractory