Standard Specification for Slag Cement for Use in Concrete and Mortars

1. Scope

1.1 This specification covers three strength grades of slag cement for use as a cementitious material in concrete and mortar.

NOTE 1—The material described in this specification may be used for blending with portland cement to produce a cement meeting the requirements of Specification C595 or as a separate ingredient in concrete or mortar mixtures. The material may also be useful in a variety of special grouts and mortars, and when used with an appropriate activator, as the principal cementitious material in some applications.

NOTE 2—Information on technical aspects of the use of the material described in this specification is contained in Appendix X1, Appendix X2, and Appendix X3. More detailed information on that subject is contained in ACI 233R-03.

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text, the inch-pound units are shown in brackets. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard. Values are stated in only SI units when inch-pound units are not used in practice.

1.3 The following safety hazards caveat pertains only to the test methods described in this specification. 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.

1.4 The text of this standard references notes and footnotes that provide explanatory information. These notes and footnotes (excluding those in tables) shall not be considered as requirements of this standard.

2. Referenced Documents

2.1 ASTM Standards:

C114 Test Methods for Chemical Analysis of Hydraulic Cement
C125 Terminology Relating to Concrete and Concrete Aggregates
C150 Specification for Portland Cement
C185 Test Method for Air Content of Hydraulic Cement Mortar
C188 Test Method for Density of Hydraulic Cement
C227 Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)
C204 Test Methods for Fineness of Hydraulic Cement by Air-Permeability Apparatus
C430 Test Method for Fineness of Hydraulic Cement by the 45-µm (No. 325) Sieve
C441 Test Method for Effectiveness of Pozzolans or Ground Blast-Furnace Slag in Preventing Excessive Expansion of Concrete Due to the Alkali-Silica Reaction
C452 Test Method for Potential Expansion of Portland-Cement Mortars Exposed to Sulfate
C465 Specification for Processing Additions for Use in the Manufacture of Hydraulic Cements
C595 Specification for Blended Hydraulic Cements
C1012 Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution
C1038 Test Method for Expansion of Hydraulic Cement Mortar Bars Stored in Water
C1260 Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)
C1293 Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction
C1567 Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method)

---

1 This specification is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.27 on Ground Slag. Current edition approved July 15, 2012. Published October 2012. Originally approved in 1982. Last previous edition approved in 2012 as C989/C989M-12. DOI: 10.1520/C989M_2012.1

2 ACI 233R-03 Slag Cement in Concrete and Mortar. Available from American Concrete Institute (ACI), P.O. Box 9094, Farmington Hills, MI 48333.

---

*A Summary of Changes section appears at the end of this standard

Copyright © ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959. United States

Copyright by ASTM Int'l (all rights reserved); Tue Apr 16 04:46:55 EDT 2013

Downloaded/printed by

William Phillips (none) pursuant to License Agreement. No further reproductions authorized.
D3665 Practice for Random Sampling of Construction Materials

3. Terminology

3.1 For definitions of terms used in this test method, refer to Terminology C125.

4. Classification

4.1 Slag cement is classified by performance in the slag activity test in three grades: Grade 80, Grade 100, and Grade 120 (see Table 1).

5. Ordering Information

5.1 The purchaser shall specify the grade of slag cement desired and the optional chemical or physical data to be reported.

6. Additions

6.1 Slag cement covered by this specification shall contain no additions except as follows:

6.1.1 It is permissible to add calcium sulfate to slag cement provided it has been demonstrated by Test Method C1038 that a test mixture will not develop expansion in water exceeding 0.020 % at 14 days. In the test mixture, 50 % of the mass of portland cement shall be replaced by an equal mass of slag cement. The portland cement used in the test mixture shall meet the requirements of Specification C150. The manufacturer supplies cement under this provision, upon request, supporting data shall be supplied to the purchaser.

6.1.2 When processing additions are used in the manufacture of slag cement, the maximum amount used shall comply with the requirements of Specification C465 when tested using a blend that is 50 % slag cement and 50 % portland cement by mass.

7. Chemical Composition

7.1 Slag cement shall conform to the chemical requirements prescribed in Table 2.

8. Physical Properties

8.1 Slag cement shall conform to the physical requirements of Table 1.

9. Sampling

9.1 The following sampling and testing procedures shall be used by the purchaser to verify compliance with this specification.

NOTE 3—Sulfur in granulated blast-furnace slag is present predominantly as sulfide sulfur. In most cases, instrumental analyses, such as x-ray fluorescence, cannot differentiate sulfide sulfur from sulfate. Determine and report the sulfide sulfur content separately, and do not include it in the SO₃ calculations.

9.2 Take random grab samples either from a delivery unit or at some point in the loading or unloading process so that no sample represents more than 115 Mg [125 tons] (Note 4). If samples are taken from rail cars or trucks, take at least two separate 2-kg [5-lb] portions and thoroughly mix them to obtain a test sample (Note 5). Sample by removing approximately a 300-mm [12-in.] layer of slag cement. Make a hole before obtaining a sample to avoid dust collector material that has discharged into the delivery unit after the predominant slag cement flow has ceased. Sample at a rate of one sample per month or one sample for each 2300 Mg [2500 tons] of shipments, whichever is more frequent.

NOTE 4—Standard statistical procedures are recommended for ensuring that samples are selected by a random procedure; see Practice D3665. These procedures can be used to select the days within a month or within a week that samples will be taken. The delivery unit or time of day then should be chosen randomly.

NOTE 5—The quantity of sample specified is more than adequate for the testing required. A 2-kg [5-lb] portion should be retained in a sealed container for retesting if that is considered necessary to verify compliance.

10. Test Methods

10.1 Slag-Activity Tests with Portland Cement:

10.1.1 Slag activity shall be evaluated by determining the compressive strength of portland-cement mortars and the corresponding mortars made with the same mass of a blend that is 50 % slag cement and 50 % portland cement by mass.

NOTE 6—Appendix X1 discusses the effects of cement, temperature, and amount of slag cement used on performance with portland cement.

10.1.2 Reference Cement—The portland cement used in the slag activity tests shall comply with the standard chemical and physical requirements of Specification C150, Type I or Type II, and with the additional requirements of total alkali content and compressive strength limits as shown in Table 3. Sufficient cement shall be reserved to avoid changing reference cement more often than every two months. After the initial testing to determine compliance with the compressive strength requirement of Table 3, the reference cement shall be re-qualified at least every six months.

---

### Table 1: Physical Requirements

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fineness:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>amount retained when wet screened on a 45-µm (No. 325) sieve, max %</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Specific surface by air permeability, Test Methods C204 shall be determined and reported although no limits are required.</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Air Content of Slag Mortar, max %</td>
<td></td>
<td>12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Slag Activity Index, min %</th>
<th>Last Five Consecutive Samples</th>
<th>Any Individual Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-Day Index</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade 80</td>
<td>75</td>
<td>70</td>
</tr>
<tr>
<td>Grade 100</td>
<td>95</td>
<td>90</td>
</tr>
<tr>
<td>Grade 120</td>
<td>115</td>
<td>110</td>
</tr>
<tr>
<td>28-Day Index</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade 80</td>
<td>75</td>
<td>70</td>
</tr>
<tr>
<td>Grade 100</td>
<td>95</td>
<td>90</td>
</tr>
<tr>
<td>Grade 120</td>
<td>115</td>
<td>110</td>
</tr>
</tbody>
</table>

---

### Table 2: Chemical Requirements

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfide sulfur (S), max, %</td>
<td>2.5</td>
<td></td>
</tr>
</tbody>
</table>


10.1.3 Preparation of Specimens—Prepare mortars in accordance with Test Method C109/C109M, except that sufficient water shall be used in each batch to produce a flow of 110±5%. The proportions of dry ingredients shall be as follows:

- Reference Cement Mortar:
  - 500 g portland cement
  - 1375 g graded standard sand

- Slag Cement-Reference Cement Mortar:
  - 250 g portland cement
  - 250 g slag cement
  - 1375 g graded standard sand

10.1.3.1 Mix a reference cement batch each day that a slag cement-reference cement batch is mixed until at least five batches have been mixed with the reference cement. Thereafter, reference cement batches need not be mixed more often than once a week whenever slag cement is being produced or shipped.

10.1.4 Test Ages—Determine the compressive strength of mortar specimens at 7 and 28 days age in accordance with Test Method C109/C109M.

10.1.5 Calculation—Calculate the slag activity index to the nearest percent for both 7 days and 28 days as follows:

\[
\text{Slag activity index, } \% = (SP/P) \times 100
\]  

\[SP = \text{average compressive strength of slag cement-reference cement mortar cubes at designated ages, MPa [psi]}, \text{and} \]
\[P = \text{average compressive strength of reference cement mortar cubes at designated age, MPa [psi]}.\]

The reference cement-mortar strength used to calculate a slag activity index shall, when a reference cement-mortar is mixed until at least five batches have been mixed with the reference cement, be the result for that batch. Otherwise, the average of tests of the five most recent reference cement-mortar batches shall be used.

10.1.6 Report—The report should include the following:

10.1.6.1 Slag activity index, %

10.1.6.2 Compressive strength at 7 and 28 days, of slag cement-reference cement mortar

10.1.6.3 Compressive strength at 7 and 28 days, of portland cement mortar

10.1.6.4 Total alkalies of the reference cement \((\text{Na}_2\text{O} + 0.658 \text{K}_2\text{O})\),

10.1.6.5 Fineness of reference cement, and

10.1.6.6 Potential compound composition of the reference portland cement.

10.1.7 Precision—The following precision statements are applicable when the slag activity index with portland cement is based on properly conducted tests based on single batches of mortar mixed on the same day. They are applicable to the slag activity index determined at 7 or 28 days.

10.1.7.1 The single-laboratory coefficient of variation has been found to be 4.1%. Therefore, the slag activity indices of properly conducted tests based on single batches of mortar mixed on the same day should not differ by more than 11.6% of their average.

10.1.7.2 The multilaboratory coefficient of variation has been found to be 5.7%. Therefore, the slag activity indices of properly conducted tests of single batches by different laboratories should not differ by more than 16.1%.

10.2 Slag Cement Density—Determine in accordance with Test Method C188.

10.3 Amount of Slag Cement Retained on a 45-µm (No. 325) Sieve—Determine in accordance with Test Method C430.

10.4 Slag Cement Fineness by Air Permeability—Determine in accordance with Test Methods C204.

10.5 Sulfate Ion in Slag Cement Reported as SO\(_3\) — Determine as sulfur trioxide in accordance with Test Methods C114, except the sample need not be completely decomposed by acid.

10.6 Sulfide Sulfur in Slag Cement—Determine in accordance with Test Methods C114.

10.7 Chloride Content of Slag—Determine in accordance with Test Methods C114.

10.8 Air Content of Slag Cement Mortar—Determine in accordance with Test Method C185, except use 350 g of slag cement in the standard mortar batch. Calculate using the appropriate density of the slag cement.

11. Rejection and Rehearing

11.1 The purchaser has the right to reject material that fails to conform to the requirements of this specification. Rejection shall be reported to the producer or supplier promptly and in writing. In case of dissatisfaction with the results of the tests, the producer or supplier is not prohibited from making a claim for retesting.

Note 8-In the event of a Slag Activity Index dispute, the purchaser should request a sample of the producer’s reference cement for retest.

12. Certification

12.1 Upon request of the purchaser in the contract or order, a manufacturer’s report shall be furnished at the time of shipment stating the results of tests made on samples of the material taken during production or transfer and certifying that the slag cement conforms to applicable requirements of this specification.

---

**TABLE 3 Alkali and Strength Limits of Reference Portland Cement for Slag Activity Tests**

| Total Alkalies \((\text{Na}_2\text{O} + 0.658 \text{K}_2\text{O})\) | min % | 0.60 |
| Compressive Strength, MPa, min, 28 days | max % | 0.90 |
| 35 [5000 psi] |

*Note 7—Different reference cements may produce different Slag Activity Index results. Reference portland cement meeting the requirements of 10.1.2 is available from CCRL.*

---

*The sole source of commercially available reference portland cement known to the committee at this time is CCRL, 4441 Buckeystown Pike, Suite C; Frederick, Maryland 21704; www.CCRL.us. 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, which you may attend.
12.2 When specified in the purchase order or contract, test data shall be furnished on the chloride ion content of the slag cement.

Note 9—Guidance on preparing the manufacturer’s report is provided in Appendix X4.

13. Manufacturer’s Statement

13.1 At the request of the purchaser, the manufacturer shall state in writing the nature, amount, and identity of any processing or other additions made to the slag cement.

14. Package Marking and Shipping Information

14.1 When the slag cement is delivered in packages, the classification of the slag cement, the name and brand of the manufacturer, and the mass of the slag cement contained therein shall be plainly marked on each package. Similar information shall be provided in the shipping invoices accompanying the shipment of packaged or bulk slag cement. All packages shall be in good condition at the time of inspection.

15. Storage

15.1 The slag cement shall be stored to permit easy access for proper inspection and identification of each shipment and in a suitable weather-tight building that will protect the slag cement from dampness and minimize quality deterioration.

16. Keywords

16.1 blast furnace slag; granulated blast furnace slag; slag activity index; slag cement

APPENDIXES

(Nonmandatory Information)

X1. CONTRIBUTION OF SLAG CEMENT TO CONCRETE STRENGTH

X1.1 When slag cement is used in concrete with portland cement, the levels and rate of strength development will depend importantly on the properties of the slag cement, the properties of the portland cement, the relative and total amounts of slag cement and portland cement, and the concrete curing temperatures.

X1.2 The reference cement used to test slag activity in this specification must have a minimum 28-day strength of 35 MPa [5000 psi] and an alkali equivalent between 0.6 and 0.9 %. Performance of the slag cement with other portland cements may be significantly different. The slag-activity test also can be used to evaluate relative hydraulic activity of different slag cements with a specific cement or of different shipments of the same slag cement. Such comparisons will be improved if all tests are made with a single sample of cement. To properly classify a slag cement, the reference portland cement must conform to the limits on strength and alkali content. Even within these limits, performance will depend to some extent on the particular cement used. The results of the slag activity test do not provide quantitative predictions of strength performance in concrete. Performance in concrete will depend on a large number of factors including the properties and proportions of the slag cement, the portland cement, and other concrete ingredients, concrete temperatures, and curing conditions; and other conditions.

X1.3 Concrete strengths at 1, 3, and even 7 days may tend to be lower using slag cement-portland cement combinations, particularly at low temperatures or at high slag cement percentages. Concrete proportions will need to be established considering the importance of early strengths, the curing temperatures involved and the properties of the slag cement, the portland cement, and other concrete materials. Generally a higher numerical grade of slag cement can be used in larger amounts and will provide improved early strength performance; however, tests must be made using job materials under job conditions.

X2. SULFATE RESISTANCE

X2.1 General—Concrete manufactured with high percentages of slag cement is generally considered to have greater resistance to attack by sulfates than do portland cements, based largely upon comparisons of these mixtures with similar mixtures containing ordinary (Type I) portlands. These high volume slag cement mixtures (containing 60 % or more slag) are widely used for sulfate and sea-water resistant concretes throughout the world.

X2.2 Sulfate Resistance of Portland Cements—The sulfate resistance of concrete is dependent upon a number of factors, including mortar permeability and the type and concentration of the sulfate solutions involved. Others, directly related to the cement characteristics, include calcium hydroxide concentration and the tricalcium aluminate (C₃A) content. Specification C150 provides limits on the C₃A for sulfate-resistant cements. Specification C150 Type V requirements provide for a limit on the tetracalcium aluminoferrite (C₄AF) plus twice the C₃A. The C150 table of Optional Physical Requirements includes a maximum limit on expansion of Type V cement in mortar bars when tested by Test Method C452. When this option is selected, the standard limits on tricalcium aluminate and on tetracalcium aluminoferrite plus twice the tricalcium aluminate...
do not apply. Test Method C1012 can be used to measure the effects of exposure to external sulfate environments on mortar or concrete.

X2.3 Effect of Slag Cement on Sulfate Resistance—The use of slag cement will decrease the C₃A content of the cementing materials and decrease the permeability and calcium hydroxide content of the mortar or concrete. Tests have shown that the alumina content of the slag cement also influences sulfate resistance,⁵ ⁶ and that high alumina content can have a detrimental influence at low slag cement-replacement percentages. Data from studies of laboratory exposure of mortars to sodium and magnesium sulfate solutions provide the following general conclusions.

X2.3.1 The combinations of slag cement and portland cement, in which the slag cement content was greater than 60 to 65 %, had high sulfate resistance, always better than the portland cement alone, irrespective of the Al₂O₃ content of the slag cement. The improvement in sulfate resistance was greatest for the portland cements with the higher C₃A contents.

X2.3.2 The low alumina (11 %) slag cement tested increased the sulfate resistance independently of the C₃A content of the portland cement. To obtain adequate sulfate resistance, higher slag cement percentages were necessary with the higher C₃A portland cements.

X2.3.3 The high alumina (18 %) slag cement tested, adversely affected the sulfate resistance of portland cements when blended in low percentages (50 % or less). Some tests indicated rapid decreases in resistance for cements in the 8 and 11 % C₃A ranges with slag cement percentages as low as 20 % or less in the blends.

X2.3.4 Tests on slag cement (7 to 8 % alumina) in Ontario⁷ have shown that a 50:50 combination by mass with Type I portland cement (having up to about 12 % C₃A) is equivalent in sulfate resistance to the Type V cement used in that study.

X2.4 Tests for Sulfate Resistance—When the relative sulfate resistance of a specific portland cement-slag cement combination is desired, tests should be conducted in accordance with Test Method C1012.⁸ Studies by Subcommittee C01.29 on sulfate resistance using Test Method C1012, as reported by Patzias ⁹, recommended the following limits for expansion of portland cement and slag cement combinations at six months of exposure:

Moderate sulfate resistance — 0.10 % max
High sulfate resistance — 0.05 % max

X3. EFFECTIVENESS OF SLAG CEMENT IN PREVENTING EXCESSIVE EXPANSION OF CONCRETE DUE TO ALKALI SILICA REACTION

X3.1 General—When properly proportioned in concrete mixtures, slag cement has been shown to prevent excessive expansion due to alkali-aggregate reaction.

X3.2 ASR in Concrete—Alkali silica reaction occurs in concrete when certain siliceous aggregates are placed in a highly alkaline environment and, in the presence of water, form an expansive gel. When this gel forms, tensile stresses develop in the concrete around the expanding gel which can cause the concrete to crack. The extent of the reaction is directly related to the alkalinity of the solution, the reactivity of the aggregate, and the availability of water, which fuels the reaction.

X3.3 Mitigating AAR with Slag Cement—Slag cement mitigates ASR by reducing the total alkalies in the system and by consuming alkalies in the hydration reaction, making them unavailable for the alkali aggregate reaction. The percentage of slag cement required to mitigate alkali silica reaction is dependent on the reactivity of the aggregate and the alkali loading of the concrete. For concretes containing very reactive aggregates or for concretes with a high alkali loading, higher percentages of slag cement may be required to insure mitigation.

X3.4 Test Methods for AAR—There are several test methods that have been used to determine the effectiveness of slag cement in preventing deleterious expansion in concrete mixtures containing potentially reactive aggregates. However, there is no general agreement on the relation between the results of these tests and the amount of expansion to be expected or tolerated in service. Therefore, evaluation of the suitability of slag replacement level for successful mitigation of ASR should be based upon judgment, interpretation of test data, and results of examinations of concrete structures containing the same aggregates and similar cementitious materials having similar levels of alkalies. Results of the tests referred to in this appendix may assist in making the evaluation.

Test Method C441—This test method evaluates cementitious materials in mortar bars as in Test Method C227 using highly-reactive borosilicate glass as the aggregate. In evaluating the results of this test, it should be recognized that borosilicate glass is more reactive than most construction aggregates; therefore, the amount of a given pozzolan or ground slag necessary to control expansion with a portland cement of given alkali content may be higher than needed to avoid deleterious expansion with a particular construction aggregate. Those who specify Test Method C441 commonly

---

require testing in accordance with the job mixture requirements of this test method and limit the average expansion of mortar bars at 14 days to 0.020 % or less.

Test Method C1293—The test method evaluates combinations of aggregate with slag for potential alkali-silica reaction expansion using concrete prisms. The test method is accelerated by using an elevated alkali content and Test Method C227 exposure conditions. The appendix to Test Method C1293 provides guidance on interpretation of the results. When evaluating the effectiveness of various slag cement replacement levels in mitigating ASR, those mixtures with expansions equal to or greater than 0.04 % at two years are considered potentially deleteriously reactive. This test method is considered to be the most reliable procedure among ASTM Test Methods for the evaluation of aggregates for alkali-silica reaction.

Test Method C1567—This test method can be used to evaluate specific combinations of aggregate and cementitious materials composed of hydraulic cement and slag cement under storage conditions described in Test Method C1260. Since the mortar specimens are stored in 1N NaOH solution, the test may underestimate the effectiveness of cementitious materials that rely to a significant degree on low alkali content for mitigation. In general, expansions less than 0.10 % at 16 days are considered to indicate effective control of potential ASR related expansion of the aggregate by the specific combination of cementitious materials.

X4. MANUFACTURER’S CERTIFICATION (MILL TEST REPORT)

X4.1 To provide uniformity for reporting the results of tests performed on slag cements under this specification, as required by Section 12 of Specification C989/C989M entitled “Certification,” an example Mill Test Report is shown in Fig. X4.1.

X4.2 The identity information given should unambiguously identify the cement production represented by the Mill Test Report and may vary depending upon the manufacturer’s designation and purchaser’s requirements.

X4.3 The Manufacturer’s Certification statement may vary depending upon the manufacturer’s procurement order, or legal requirements, but should certify that the slag cement shipped is represented by the certificate and that the cement conforms to applicable requirements of the specification at the time it was tested (or retested) or shipped.

X4.4 The sample Mill Test Report has been developed to reflect the chemical and physical requirements of this specification and recommends reporting all analyses and tests normally performed on slag cements meeting Specification C989/C989M. Purchaser reporting requirements should govern if different from normal reporting by the manufacturer or from those recommended here.

X4.5 Slag cements may be shipped prior to later-age test data being available. In such cases, the test value may be left blank. Alternatively, the manufacturer can generally provide estimates based on historical production data. The report should indicate if such estimates are provided.
SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this specification since the last issue, C989/C989M–12, that may impact the use of this specification. (Approved July 15, 2012)

(1) Rewrote Appendix X3.

(2) Added new Appendix X4, including new Fig. X4.1.

Committee C09 has identified the location of selected changes to this specification since the last issue, C989/C989M–11, that may impact the use of this specification. (Approved July 1, 2012)

(1) Revisions were made to Note 7 to identify a source of reference portland cement for slag activity testing.
Committee C09 has identified the location of selected changes to this specification since the last issue, C989–10, that may impact the use of this specification. (Approved December 15, 2011)

(1) Revised the standard as a dual units specification.  
(2) Revised 12.1.

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org). Permission rights to photocopy the standard may also be secured from the ASTM website (www.astm.org/COPYRIGHT/).