



Standard Guide for Approximation of Optimum SO₃ in Hydraulic Cement Using Compressive Strength¹

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1. Scope

1.1 This guide describes the determination of approximate optimum SO₃ for maximum compressive strength at 24 h, 3 days, or 7 days by measuring the change in strength produced in hydraulic cement mortar as a result of substituting calcium sulfate for a portion of the cement.

1.2 This guide refers to the sulfur trioxide (SO₃) content of the cement only. Slag cements and occasionally other hydraulic cements can contain sulfide or other forms of sulfur. The determination of SO₃ content by rapid methods may include these other forms, and may therefore produce a significant error. If a significant error occurs, analyze the cement for SO₃ content using the reference test method of Test Methods C114 for sulfur trioxide.

1.3 Values stated as SI units are to be regarded as 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

C109/C109M Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)

C114 Test Methods for Chemical Analysis of Hydraulic Cement

C150 Specification for Portland Cement

C204 Test Methods for Fineness of Hydraulic Cement by Air-Permeability Apparatus

C305 Practice for Mechanical Mixing of Hydraulic Cement

Pastes and Mortars of Plastic Consistency

C471M Test Methods for Chemical Analysis of Gypsum and Gypsum Products (Metric)

C511 Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes

C595 Specification for Blended Hydraulic Cements

C1157 Performance Specification for Hydraulic Cement

C1437 Test Method for Flow of Hydraulic Cement Mortar

3. Significance and Use

3.1 The purpose of this guide is to estimate the SO₃ content for a hydraulic cement that gives maximum compressive strength in mortar made and cured at 23°C. The value obtained is one way to establish an appropriate level of sulfate in the manufacture of cements specified in Specifications C150, C595 and C1157.

3.2 The SO₃ content of a cement giving maximum compressive strength is different at different ages of mortar; typically this SO₃ content is higher at 3 days than the 24-h, and often higher for 7 days than that for 3 days. A manufacturer can choose the age of 24-h, 3 days or 7 days for specimens at which to determine optimum SO₃ content.

3.3 This guide indicates optimum SO₃ content for cement in mortar made and cured at a standard temperature of 23.0 ± 2.0°C (73.5 ± 3.5°F). The optimum SO₃ increases with increasing temperature and may increase when water-reducing admixtures are used.

3.4 It should not be assumed that the optimum SO₃ estimated in this guide is the same SO₃ content for optimum performance of a concrete prepared from the cement.

3.5 The guide is applicable to cements specified in Specifications C150, C595, and C1157.

4. Apparatus

4.1 Use the apparatus as specified in Test Method C109/C109M.

5. Materials

5.1 *Calcium Sulfate*—Use calcium sulfate for addition to the cement that is either a high-grade natural gypsum having an

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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.

SO₃ content of at least 46 %, or the calcium sulfate from the source used for the intended plant production. Grind the calcium sulfate to 100 % passing the 75-μm (No. 200) sieve, and at least 800 m²/kg Blaine fineness (Test Method C204). If the SO₃ content of the calcium sulfate is unknown, analyze it in accordance with Test Methods C471M.

6. Procedure

6.1 *Sulfate Levels to Test*—Test at least five different sulfate levels.

6.1.1 SO₃ contents are to be at least 0.20 % different unless more than five different SO₃ contents are being tested. The maximum and minimum SO₃ content of the blended samples must differ by at least 2.0 % SO₃ content.

NOTE 1—More sulfate levels may be tested to help improve the precision of the interpretation of the results. Extremely high and low sulfate levels can give results that deviate from the typical peak behavior which may need to be treated as outliers when using a mathematical fitting procedure.

6.2 Determine mortar compressive strength at each sulfate level at the age of 24 ± ¼ h, 3 days ± 1 h, or 7 days ± 3 h in accordance with Test Method C109/C109M except as follows:

6.2.1 When mixing in accordance with the “Procedure for Mixing Mortars” section of Practice C305, add the calcium sulfate to the water, unless the calcium sulfate addition has been previously ground and mixed with the cement; then start the mixer and mix at slow speed (140 ± 5 rpm) for 15 s; then stop the mixer and add the cement to the water; then start the mixer and mix at slow speed (140 ± 5 rpm) for 30 s.

6.2.2 Use an amount of mixing water to produce a flow of 110 ± 5 using 25 drops of the table as determined in the section on Procedures in Test Method C1437 for all types of cement.

7. Interpretation of Results

7.1 Approximate the SO₃ content which gives the maximum performance by one of the following methods:

7.1.1 *Visual Fit*—Plot the strength versus SO₃ content and interpolate the sulfate level at the peak.

7.1.2 *Least Squares Parabolic Fit*.

7.1.2.1 Determine the equation of a least squares fit according to follow equation:

$$\text{Strength} = a(\text{SO}_3)^2 + b\text{SO}_3 + c$$

where a , b , and c are fitting coefficients.

NOTE 2—Spreadsheet and graphing programs have the capability to calculate the least squares parabolic fit.

7.1.2.2 Approximate the optimum SO₃ by calculating vertex of the parabolic least squares fit from the following equation:

$$\text{Optimum SO}_3 \text{ approximation} = -b/(2a)$$

where a and b are coefficients of the parabolic least squares fit.

7.1.3 *Asymmetric Fit*—In cases where the strength versus SO₃ is skewed to the right or left of the peak a fit using an asymmetric distribution function may provide a better fit than parabolic fit.

NOTE 3—Mathematical and statistics software programs are useful in doing such fits.

NOTE 4—The sulfate level for the maximum performance may or may not be the SO₃ content that one of the tests was conducted at.

8. Retest

8.1 If the approximate optimum sulfate level is greater or lower than all the SO₃ contents tested, then test at additional sulfate levels until at least one SO₃ content is greater than or less than approximate optimum SO₃ content. Repeat the interpretation of results in Section 7 and report on that final set of results.

9. Report

9.1 Report the age of the test specimens.

9.2 Report the method for interpretation of results and the type of equation fit to, if using an asymmetric fit.

9.3 Plot the strength versus SO₃ content, the approximate optimum SO₃ content and any fit used.

9.4 Report of the approximate optimum SO₃ value.

10. Keywords

10.1 blended hydraulic cement; calcium sulfate; cement; compressive strength; gypsum; hydraulic cement; optimum sulfate content (of cement); portland cement; strength (of cement); sulfate content (of cement)

APPENDIX

(Nonmandatory Information)

X1. DISCUSSION OF THE TERM “OPTIMUM”

X1.1 The scope statement notes that this test method determines the optimum SO₃ content in cements in mortar at a particular temperature and age. Usually, but not always, the SO₃ content that produces the highest 24-h strength at 23°C also produces approximately the lowest expansion in water and

the lowest contraction in air at that temperature.

X1.2 The “optimum” determined by this test is approximate. The “optimum” SO_3 content will vary with changes in mortar proportions; between cement paste, mortars and concrete; will vary with the source of SO_3 ; with the age of test; with the use of chemical admixtures; and with the use of supplementary cementitious materials. Thus, the term “optimum SO_3 ” refers to an approximate value.

X1.3 The age for determining the optimum is typically chosen by the manufacturer based on experience with local concrete materials.

X1.4 For convenience, the method uses the compressive strength of specimens at three different SO_3 contents for the

cement. If the strength results are plotted against SO_3 content, the three points are assumed to give a curve in the shape of a parabola, and the calculation used assumes this shape. If more points are used with smaller SO_3 content increments, the shape of the curve is seen to be that of a “sawtooth,” with a decreasing slope up to the apex at maximum strength, followed by a precipitous fall in strength immediately after the apex. The apex represents the actual optimum SO_3 content, and is typically higher than that calculated using three points. Therefore, this affords a small “cushion” when targeting the calculated optimum SO_3 (determined using three points) during manufacture to allow for variation in the process.

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