



# Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)<sup>1</sup>

This standard is issued under the fixed designation C 227; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the Department of Defense.*

## 1. Scope

1.1 This test method covers the determination of the susceptibility of cement-aggregate combinations to expansive reactions involving hydroxyl ions associated with the alkalis (sodium and potassium) by measurement of the increase (or decrease) in length of mortar bars containing the combination during storage under prescribed conditions of test.

1.2 Alkalis participating in the expansive reactions usually are derived from the cement; under some circumstances they may be derived from other constituents of the concrete or from external sources. Two types of alkali reactivity of aggregates are recognized: (1) an alkali-silica reaction involving certain siliceous rocks, minerals, and natural or artificial glasses and (2) an alkali-carbonate reaction involving dolomite in certain calcitic dolomites and dolomitic limestones (see Standard C 294). The method is not recommended as a means to detect the latter reaction because expansions produced in the mortar-bar test by the alkali-carbonate reaction (see Test Method C 586) are generally much less than those produced by the alkali-silica reaction for combinations having equally harmful effects in service.

1.3 The values stated in SI units are to be regarded as standard. The non-SI values, shown in parentheses, are for informational purposes only.

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:

C 33 Specification for Concrete Aggregates<sup>2</sup>

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.26 on Chemical Reactions of Materials.

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<sup>2</sup> *Annual Book of ASTM Standards*, Vol 04.02.

C 109/C 109M Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)<sup>3</sup>

C 289 Test Method for Potential Alkali-Silica Reactivity of Aggregates (Chemical Method)<sup>2</sup>

C 294 Standard Descriptive Nomenclature for Constituents of Concrete Aggregates<sup>2</sup>

C 295 Guide for Petrographic Examination of Aggregates for Concrete<sup>2</sup>

C 305 Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency<sup>3</sup>

C 490 Practice for Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete<sup>2,3</sup>

C 511 Specification for Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in Testing of Hydraulic Cements and Concretes<sup>2,3</sup>

C 586 Test Method for Potential Alkali Reactivity of Carbonate Rocks for Concrete Aggregates (Rock Cylinder Method)<sup>2</sup>

C 856 Practice for Petrographic Examination of Hardened Concrete<sup>2</sup>

C 1437 Test Method for Determining Flow of Hydraulic Cement Mortar<sup>3</sup>

E 11 Specification for Wire Cloth and Sieves for Testing Purposes<sup>4</sup>

## 3. Significance and Use

3.1 Data correlating the results of tests performed using this test method with performance of cement-aggregate combinations in concrete in service, results of petrographic examination of aggregates (Guide C 295), and results of tests for potential reactivity of aggregates by chemical methods have been published in Test Method C 289 and should be consulted in connection with the use of results of tests performed using this

<sup>3</sup> *Annual Book of ASTM Standards*, Vol 04.01.

<sup>4</sup> *Annual Book of ASTM Standards*, Vol 14.02.

test method as the basis for conclusions and recommendations concerning the use of cement-aggregate combinations in concrete.

3.2 The results of tests performed using this method furnish information on the likelihood that a cement-aggregate combination is potentially capable of harmful alkali-silica reactivity with consequent deleterious expansion of concrete. Criteria to determine potential deleterious alkali-silica reactivity of cement-aggregate combinations from the results of this test method have been given in the Appendix of Specification C 33.

3.3 Insignificant expansion may result when potentially deleteriously reactive siliceous rocks are present in comparatively high proportion even when a high-alkali cement is used. This may occur because the alkali-silica reaction products are characterized by an alkali to silica ratio that is so low as to minimize uptake of water and swelling, or because of alkali leaching from the bars (see section on containers). Dolomitic aggregates that are deleteriously affected by the alkali-carbonate reaction when employed as coarse aggregate in concrete may not produce notable expansion in this test method. Also, significant expansion may occur rarely in the test for reasons other than alkali-aggregate reaction, particularly the presence of sulfates in the aggregate that produce a sulfate attack upon the cement paste, ferrous sulfides (pyrite, marcasite, or pyrrhotite) that oxidize and hydrate with the release of sulfate, and materials such as free lime (CaO) or free magnesia (MgO) in the cement or aggregate that progressively hydrate and carbonate.

3.4 When expansions in excess of those given in the Appendix of Specification C 33 are shown in results of tests performed using this test method, it is strongly recommended that supplementary information be developed to confirm that the expansion is actually due to alkali reactivity. Sources of such supplementary information include: (1) petrographic examination of the aggregate to determine if known reactive constituents are present; (2) examination of the specimens after tests to identify the products of alkali reactivity; and (3) tests of the aggregate for potential reactivity by chemical methods (Test Method C 289).

3.5 When it has been concluded from the results of tests performed using this test method and supplementary information as outlined that a given cement-aggregate combination should be considered potentially deleteriously reactive, additional studies may be appropriate to develop information on the potential reactivity of other combinations containing the same cement with other aggregates, the same aggregate with other cements, or the same cement-aggregate combination with a mineral admixture.

#### 4. Apparatus

4.1 The apparatus shall conform to Specification C 490, except as follows:

4.2 *Sieves*—Square hole, woven-wire cloth sieves, shall conform to Specification E 11.

4.3 *Mixer, Paddle, and Mixing Bowl*—Mixer, paddle, and mixing bowl shall conform to the requirements of Method C 305, except that the clearance between the lower end of the paddle and the bottom of the bowl shall be 5 to 6 mm (0.20 to 0.24 in.) .

4.4 *Tamper and Trowel*—The tamper and trowel shall conform to Test Method C 109/C 109M.

4.5 *Containers*—Covered containers for storing the test specimens shall be constructed of material that is resistant to corrosion under the test conditions. The wall thickness of the container and cover shall be less than 6 mm ( $\frac{3}{16}$  in.) to reduce the insulating effect and provide a rapid heat transfer for the initial 14-day test period. The cover shall be constructed in a manner to maintain a tight seal between the cover and top of the container wall (Note 1). The container shall be arranged to provide every surface of each specimen with approximately an equal exposure to an absorbent wicking material. The specimens shall not be in direct contact with the wicking material but every surface shall be within 30 mm (1¼ in.) or less of the wicking. A typical arrangement of such a container is shown in Fig. 1 (Note 2). The inner sides and the center core of the containers are to be lined with an absorbent material, such as blotting or filter paper, to act as a wick and to ensure that the atmosphere in the container is quickly saturated with water vapor when it is sealed after the specimens are placed therein (Note 2). The wicking liners will extend into the top of the water in the bottom of the container and above the tops of the specimens. Make provisions to support the bars in a vertical position with the lower end of the bars approximately 25 mm (1 in.) above the surface of the water in the containers. The weight of the specimens shall not be supported on the metal gage studs. A supporting rack shall be provided to ensure that the specimens do not touch the wicking material or each other. The supporting rack shall be constructed of brass wire or other material that is resistant to corrosion under the test conditions and shall not act as a vapor barrier but provide free movement of vapors within the container. Provisions shall be made to prevent water from splashing and dripping onto the specimens (Notes 3-5). If required to prevent the growth of mold on the wicking, add a suitable fungicide to the water in the container. The container size and internal arrangement of the specimens and wicking may be varied at the users discretion, providing expansion data for all specimens can be shown to be equivalent to that developed with the container herein described.

NOTE 1—This seal may be achieved by a double wrap of vinyl tape 88 mm (1½ in.) or greater in width, overlaying the lid and container wall along its full circumference.

NOTE 2—A covered container that has been found acceptable for this purpose is sold by the United States Plastic Corp., 1390 Neubrecht Rd., Lima, OH 45801, as a PVC plating, photo, and chemical tank, stock No. 10062, 6-in. diameter x 17 in. high, with cover.

NOTE 3—The shape and spacing of the center wicking material may be maintained during the test by the use of rubber bands or hardware cloth.

NOTE 4—If concern exists for adequately preventing dripping or splashing, the water should be tested for pH and alkali content.

NOTE 5—The container described in 4.5 and in Fig. 1 has been shown to produce large and reproducible expansions with cement-aggregate combinations such as borosilicate glass: high-alkali cement combination called for by ASTM C 441. However, recent work, at a few laboratories, suggests that the same factors that are responsible for the success with the C 441 mixtures, that is, high, constant, uniform internal relative humidity, will, under certain testing regimes permitted by this test method, promote leaching of alkali from the specimens and result in little or no expansion from some known deleteriously alkali-reactive aggregate: high-alkali cement combinations. Each laboratory should evaluate its containers with a known deleteriously alkali-reactive aggregate (not borosilicate glass

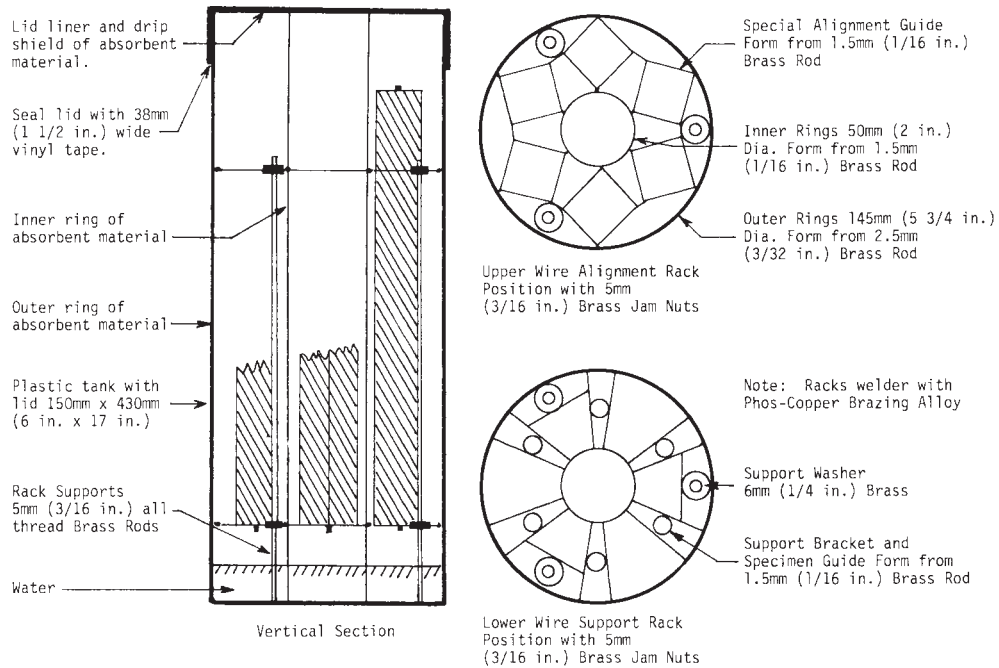


FIG. 1 Diagram of an Acceptable Assembled Container

which releases alkali) and a high-alkali cement, to establish that the expected level of expansion is obtained. If not, try removing the wicking to reduce the condensation and leaching. Minimizing the temperature variation within the storage room and the room in which the bars are read may also reduce condensation on and leaching from the bars.

**5. Temperature and Humidity**

5.1 The temperature of the molding room and dry materials shall be maintained at not less than 20°C (68°F) and not more than 27.5°C (81.5°F). The temperature of the mixing water, of the moist closet or moist room, and of the room in which the measurements are made shall not vary from 23°C (73.4°F) by more than 2.0°C (3°F).

5.2 The relative humidity of the molding room shall be not less than 50 %. The moist closet or room shall conform to Specification C 511.

5.3 The storage room in which the specimens in containers are stored shall be maintained at a temperature that shall not vary from 38.0°C (100°F) by more than 2.0°C (3°F).

**6. Selection and Preparation of Materials**

6.1 *Selection of Aggregate*—Materials proposed for use as fine aggregate in concrete shall be processed as described in 6.2 with a minimum of crushing. Materials proposed for use as coarse aggregate in concrete shall be processed by crushing to produce as nearly as practical a graded product from which a sample can be obtained. The sample shall have the grading as prescribed in 6.2 and be representative of the composition of the coarse aggregate as proposed for use.

6.1.1 When a given quarried material is proposed for use, both as coarse and as fine aggregate, it will be tested only by selection of an appropriate sample crushed to the fine aggregate sizes, unless there is reason to expect that the coarser size fractions have a different composition than the finer sizes and that these differences might significantly affect expansion due

to reaction with the alkalis in cement. In this case the coarser size fractions should be tested in a manner similar to that employed in testing the fine aggregate sizes.

6.1.2 Coarse aggregate crushed to sand size may give increased expansion, owing to the increased surface exposed upon crushing. Therefore, if coarse aggregate tested by this method produces an excessive amount of expansion, the material shall not be classed as objectionably reactive with alkali unless tests of concrete specimens confirm the findings of the tests of the mortar.

6.2 *Preparation of Aggregate*—Fine aggregate shall be tested in a grading meeting the requirements of the specifications for the project except that any material retained on the 4.75-mm (No. 4) sieve shall be removed. Fine aggregates being tested for reasons other than to determine compliance with individual specifications, and all coarse aggregates to which this method is applied shall be graded in accordance with the requirements prescribed in Table 1. Aggregates in which sufficient quantities of the sizes specified in Table 1 do not exist shall be crushed until the required material has been produced. In the case of aggregates containing insufficient amounts of one or more of the larger sizes listed in Table 1, and if no larger material is available for crushing, the first size in which sufficient material is available shall contain the cumulative percentage of material down to that size as determined from the

TABLE 1 Grading Requirements

Sieve Size		Mass %
Passing	Retained on	
4.75-mm (No. 4)	2.36-mm (No. 8)	10
2.36-mm (No. 8)	1.18-mm (No. 16)	25
1.18-mm (No. 16)	600-µm (No. 30)	25
600-µm (No. 30)	300-µm (No. 50)	25
300-µm (No. 50)	150-µm (No. 100)	15

grading specified in Table 1. When such procedures are required, special note shall be made thereof in the test report. After the aggregate has been separated into the various sieve sizes, each size shall be washed with a water spray over the sieve to remove adhering dust and fine particles from the aggregate. The portions retained on the various sieves shall then be dried and, unless used immediately, each such portion shall be stored individually in a clean container provided with a tight-fitting cover.

### 6.3 Selection and Preparation of Cement:

6.3.1 *Job Cement*—When it is desired to evaluate a particular cement-aggregate combination for use in particular work, the cement or cements used shall meet the requirements for the work and shall be from the source or sources expected to be used in the work. If several cements may be used in the work, tests desirably should be made using each of these; in any case, the cement or cements whose alkali content exceeds 0.60 %, calculated as  $\text{Na}_2\text{O}$ , should be used.

6.3.2 *Reference Cements*—When it is desired to evaluate aggregates for general use or to compare aggregates for investigational purposes, the cement used shall be of the highest alkali content representative of the general use intended, or available to the laboratory making the tests. The cement or cements selected should comply with applicable specifications. Additional information of value may be obtained by conducting tests in parallel with cements of different alkali content, different  $\text{Na}_2\text{O}:\text{K}_2\text{O}$  ratio, or using pozzolans.

6.3.3 *Preparation of Cement*—Cement for use in this test shall be passed through a 850- $\mu\text{m}$  (No. 20) sieve to remove lumps before use.

## 7. Procedure

### 7.1 Preparation of Test Specimens:

7.1.1 *Number of Specimens*—Make at least four test specimens, two from each of two batches, for each cement-aggregate combination.

7.1.2 *Preparation of Molds*—Prepare the molds in accordance with the requirements of Specification C 490.

7.1.3 *Proportioning of Mortar*—Proportion the dry materials for the test mortar using 1 part of cement to 2.25 parts of graded aggregate by mass. The quantities of dry materials to be mixed at one time in the batch of mortar for making two specimens shall be 300 g of cement and 675 g of aggregate made up by recombining the portions retained on the various sieves (see 6.2) in the grading prescribed in Table 1 or of aggregate in a grading meeting the requirements of the specifications for the project. The amount of mixing water, measured in millimetres, shall be such as to produce a flow of 105 to 120 (as determined in accordance with Test Method C 1437) except that the flow table shall be given 10 drops in approximately 6 s. Express the amount of mixing water used as a percent by mass of the cement.

7.1.4 *Mixing of Mortar*—Mix the mortar in accordance with the requirements of Method C 305.

7.1.5 *Molding of Test Specimens*—Immediately following completion of the flow test return the mortar from the flow table to the mixing bowl. Mix the entire batch for a period of 15 s. Start molding specimens with a total elapsed time of not more than 2 min and 15 s after completion of the original

mixing of the mortar batch. Fill the molds with two approximately equal layers, each layer being compacted with the tamper. Work the mortar into the corners, around the gage studs, and along the surfaces of the mold with the tamper until a homogeneous specimen is obtained. After the top layer has been compacted, cut off the mortar flush with the top of the mold and smooth the surface with a few strokes of the trowel.

7.1.5.1 When a duplicate batch of mortar is to be made immediately for additional specimens, a second flow test is not required, in which case allow the mortar to stand in the mixing bowl for 90 s and then remixed for 15 s before starting the molding of the specimens.

7.1.6 *Sequence of Making Batches of Mortar*—When more than one cement-aggregate combination is to be tested as part of a single investigation, make the total number of batches of mortar (two per cement-aggregate combination) in random order, except that in no case shall the two batches representing a single cement-aggregate combination be made consecutively. When the making of all of the specimens for a single investigation requires that batches be made on 2 working days, each cement-aggregate combination shall be represented by one batch made on each day, and the order in which the combinations are represented by batches shall be different on the 2 days. When more than 2 days are required, one cement-aggregate combination shall be represented by a batch made on each of the working days.

### 7.2 Storage and Measurement of Test Specimens:

7.2.1 *Initial Storage and Measurement*—After each mold has been filled, place the mold immediately in the moist cabinet or room. The specimens shall remain in the molds for  $24 \pm 2$  h. Then remove them from the molds and, while being protected from loss of moisture, properly identify and measure for initial length. The initial and all subsequent measurements shall be made and recorded to the nearest 0.002 mm (0.0001 in.).

7.2.2 *Subsequent Storage and Measurement*—Stand the specimens on end over, but not in contact with, water in the storage container. Seal and place the container for 12 days in a cabinet or room maintained at a temperature of  $38.0 \pm 2.0^\circ\text{C}$  ( $100 \pm 3^\circ\text{F}$ ). When the specimens are 14 days old measure their length after removal of the container and contents from the storage room or cabinet, and after the container and contents have been stored at  $23.0 \pm 2.0^\circ\text{C}$  ( $73.4 \pm 3^\circ\text{F}$ ) for at least 16 h before opening the container and making the 14-day measurement. Additional measurements shall be made at later ages as required.

7.2.3 Additional information of value may often be obtained by returning the specimens to the  $38.0^\circ\text{C}$  ( $100^\circ\text{F}$ ) storage after the 14-day test and making additional measurements at later ages. Measurements at ages of 1, 2, 3, 4, 6, 9, and 12 months and, if necessary, at least every 6 months thereafter are suggested.

7.2.4 After each length measurement specimens may be examined, in the same manner described in Section 9, to provide supplemental information on their condition.

7.2.5 All specimens placed in a given container after the initial length measurement at  $24 \pm 2$  h shall have been made on the same day and shall be placed in the container at the same

time so that all specimens in a given container shall be due for measurement at the same time. Each time length measurements are made, clean the container and change the water.

7.2.6 Always place the specimens in the comparator with the same end uppermost and after measurement replace the specimens in the container in inverted position as compared with the previous period.

## 8. Calculation

8.1 Calculate the difference between the initial length of the specimen and the length at each period of measurement to the nearest 0.001 % of the effective gage length and record as the expansion of the specimen for that period. Report the average of the expansion of the four specimens of a given cement-aggregate combination to the nearest 0.01 % as the expansion for the combination for a given period.

## 9. Examination at End of Test

9.1 After the final length change measurements have been made, each specimen shall be tested for warping and shall be examined (see Note 6).

9.1.1 *Warping*—The warping, if any, that each specimen has manifested during the test period, shall be determined by placing the specimen on a plane surface and measuring the maximum separation between the specimen and the surface. The specimen shall be placed so that its ends curve down to the reference surface and the measurement made to the nearest 0.3 mm (0.01 in.).

9.1.2 *Examination*—Items to be noted in the examination include:

- 9.1.2.1 Presence, location, and type of pattern of cracking,
- 9.1.2.2 Appearance of surfaces, surface mottling, and
- 9.1.2.3 Surficial deposits or exudations, their nature, thickness and continuity.

NOTE 6—When it is believed that additional features of noteworthy importance are likely to be revealed thereby, a further examination of the interior of the specimen may be made, following Practice C 856. In such cases, the presence of gel-filled pores and fissures, evidence of reaction with aggregate particles of specific types and the nature of such evidence

and the properties of the reaction products are among the items to be noted.

## 10. Report

10.1 Report the following information:

- 10.1.1 Type and source of aggregate,
- 10.1.2 Type and source of portland cement,
- 10.1.3 Alkali content of cement as percent potassium oxide ( $K_2O$ ), sodium oxide ( $Na_2O$ ), and calculated sodium oxide ( $Na_2O$ ) equivalent,
- 10.1.4 Average length change in percent at each reading of the specimens,
- 10.1.5 Any relevant information concerning the preparation of aggregates, including the grading of the aggregate when it differs from that given in 6.2,
- 10.1.6 Any significant features revealed by examination of the specimens during and after test,
- 10.1.7 Amount of mixing water expressed as percent by mass of cement, and
- 10.1.8 Type, source, proportions, and chemical analyses, including  $Na_2O$  and  $K_2O$ , of any pozzolans employed in the tests.

## 11. Precision and Bias

11.1 Precision shall be considered satisfactory if the differences in the value for percentage expansion of any given specimen in a group from the average value for percentage expansion of the group does not exceed 0.003, except that, if the average expansion exceeds 0.020 %, the repeatability shall be considered satisfactory if the percentage expansion of each specimen molded from the same cement-aggregate combination is within 15 % of the average.

11.2 Interlaboratory test data for the determination of revisions to this section in accordance with Practice C 670 are being evaluated by Subcommittee C09.02.02 and will be included in a later revision of this test method.

## 12. Keywords

12.1 aggregate; alkali-silica reaction; cement; length change; mortar

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