



Designation: C1778 – 23

Standard Guide for Reducing the Risk of Deleterious Alkali-Aggregate Reaction in Concrete¹

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1. Scope*

1.1 This guide provides guidance on how to address the potential for deleterious alkali aggregate reaction (AAR) in concrete construction. This guide addresses the process of identifying both potentially alkali-silica reactive (ASR) and alkali-carbonate reactive (ACR) aggregates through standardized testing procedures and the selection of mitigation options to minimize the risk of expansion when ASR aggregates are used in concrete construction. Mitigation methods for ASR aggregates are selected using either prescriptive or performance-based alternatives. Preventive measures for ACR aggregates are limited to avoidance of use. Because the potential for deleterious reactions depends not only on the concrete mixture but also the in-service exposure, guidance is provided on the type of structures and exposure environments where AAR may be of concern.

1.2 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. 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 nonconformance with the standard.

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

¹ This guide is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.50 on Aggregate Reactions in Concrete.

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2. Referenced Documents

2.1 *ASTM Standards*:²

- C33/C33M Specification for Concrete Aggregates
- C114 Test Methods for Chemical Analysis of Hydraulic Cement
- C125 Terminology Relating to Concrete and Concrete Aggregates
- C150/C150M Specification for Portland Cement
- C219 Terminology Relating to Hydraulic and Other Inorganic Cements
- C294 Descriptive Nomenclature for Constituents of Concrete Aggregates
- C295/C295M Guide for Petrographic Examination of Aggregates for Concrete
- C311/C311M Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete
- C586 Test Method for Potential Alkali Reactivity of Carbonate Rocks as Concrete Aggregates (Rock-Cylinder Method)
- C595/C595M Specification for Blended Hydraulic Cements
- C618 Specification for Coal Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
- C823/C823M Practice for Examination and Sampling of Hardened Concrete in Constructions
- C856 Practice for Petrographic Examination of Hardened Concrete
- C989/C989M Specification for Slag Cement for Use in Concrete and Mortars
- C1105 Test Method for Length Change of Concrete Due to Alkali-Carbonate Rock Reaction
- C1157/C1157M Performance Specification for Hydraulic Cement
- C1240 Specification for Silica Fume Used in Cementitious Mixtures
- C1260 Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)

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.

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

C1293/C1293M 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)

C1866 Specification for Ground-Glass Pozzolan for Use in Concrete

2.2 *ACI Standard*:³

ACI 318 Building Code Requirements for Structural Concrete and Commentary

2.3 *AASHTO Standard*:

AASHTO R 80 Standard Practice for Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction⁴

2.4 *CSA Standards*:⁵

A23.2-26A Determination of Potential Alkali-Carbonate Reactivity of Quarried Carbonate Rocks by Chemical Composition

A23.2-27A Standard Practice to Identify Degree of Alkali-Aggregate Reactivity of Aggregates and to Identify Measures to Avoid Deleterious Expansion in Concrete

A23.2-28A Standard Practice for Laboratory Testing to Demonstrate the Effectiveness of Supplementary Cementing Materials and Lithium-Based Admixtures to Prevent Alkali-Silica Reaction in Concrete

3. Terminology

3.1 Definitions:

3.1.1 For definitions of terms used in this Guide, refer to Terminology **C125**, Terminology **C219**, and Descriptive Nomenclature **C294**.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *alkali content*, Na_2O_{eq} , n —value in percent determined by reporting sodium and potassium oxides, determined using procedures for total alkalis in Test Methods **C114**, of cement or supplementary cementitious material, using the following formula:

$$Na_2O_{eq} = \%Na_2O + 0.658 \times \%K_2O$$

3.2.2 *alkali loading*, n —amount of alkalis contributed by the cement in a concrete mixture, expressed in kg/m^3 or lb/yd^3 and calculated by multiplying the cement content of the concrete in kg/m^3 or lb/yd^3 by the alkali content of the portland cement, or the portland cement and limestone portion of a blended cement, divided by 100.

3.2.2.1 *Discussion*—Alkali loading is abbreviated as KGA [LBA]. In concrete that includes supplementary cementitious materials; only the alkali content of the cement fraction of the cementitious materials is included in the calculation of alkali loading. For example, in a concrete containing $350 kg/m^3$ [590

lb/yd^3] of cementitious materials consisting of 75 % portland cement, 20 % slag, and 5 % silica fume, and where the alkali content of the portland cement is 0.89 % Na_2O_{eq} , the alkali loading of the concrete is calculated as follows:

$$KGA = 350(75/100)(0.89/100) = 2.3 kg/m^3$$

$$[LBA = 590 (75/100)(0.89/100) = 3.9 lb/yd^3]$$

In a concrete containing $355 kg/m^3$ [$600 lb/yd^3$] of Type IS(25) blended cement, with a base portland cement equivalent alkali content of 0.73 %, the alkali loading of the concrete is calculated as follows:

$$KGA = 355(75/100)(0.73/100) = 1.9 kg/m^3$$

$$[LBA = 600 (75/100)(0.73/100) = 3.3 lb/yd^3]$$

In a concrete containing $350 kg/m^3$ [$590 lb/yd^3$] of Type IL(10) portland-limestone cement, with an equivalent alkali content of the finished cement of 0.80 %, the alkali loading of the concrete is calculated as follows:

$$KGA = 350(0.80/100) = 2.8 kg/m^3$$

$$[LBA = 590 (0.80/100) = 4.7 lb/yd^3]$$

In a concrete containing $355 kg/m^3$ [$600 lb/yd^3$] of Type IT(P30)(L10) ternary blended cement, with an equivalent alkali content of the portland cement and limestone fraction of 0.80 %, the alkali loading of the concrete is calculated as follows:

$$KGA = 355(70/100)(0.80/100) = 2.0 kg/m^3$$

$$[LBA = 600 (70/100)(0.80/100) = 3.4 lb/yd^3]$$

The alkali content of the portland cement and limestone fraction of a Type IL or Type IT blended cement as illustrated in the example calculations above can typically be obtained on request from the manufacturer, even when this information is not reported on a mill test report. It can also be determined independently for a Type IL portland-limestone cement through testing a sample obtained by the user according to Test Methods **C114**.

3.2.3 *cement*, n —portland cement, portland-limestone cement, or the portland cement and limestone portion of a blended cement.

3.2.3.1 *Discussion*—This definition does not include slag cement because alkalis present in slag cement are not included in alkali loading calculations as shown in 3.2.2.1.

3.2.4 *deleteriously reactive*, *adj*—used to describe aggregates that undergo chemical reactions that subsequently result in premature deterioration of concrete.

3.2.4.1 *Discussion*—The term used in this standard guide describes aggregates that undergo chemical reactions with hydroxide (OH^-) in the pore solution.

3.2.5 *non-reactive*, *adj*—used to describe materials that do not undergo chemical reactions that subsequently result in premature deterioration of concrete.

3.2.5.1 *Discussion*—Some aggregates with minor amounts of reactive constituents may exhibit the symptoms of alkali-aggregate reaction (AAR) without producing any damage to the concrete; these are termed as non-reactive aggregates.

4. Summary of Guide

4.1 Alkali-aggregate reactions (AAR) occur between the alkali hydroxides in the pore solution of concrete and certain

³ Available from American Concrete Institute (ACI), P.O. Box 9094, Farmington Hills, MI 48333-9094, <http://www.concrete.org>.

⁴ Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001, <http://www.transportation.org>.

⁵ Available from Canadian Standards Association (CSA), 5060 Spectrum Way, Suite 100, Mississauga, ON, L4W 5N4, Canada, <http://www.csa.ca>.

components found in some aggregates. Two types of AAR are recognized depending on the nature of the reactive component: alkali-silica reaction (ASR) involves various types of reactive siliceous (SiO_2 containing) minerals and alkali-carbonate reaction (ACR) involves certain types of rocks that contain dolomite [$\text{CaMg}(\text{CO}_3)_2$]. Both types of reaction can result in expansion and cracking of concrete elements when exposed to moisture, leading to a reduction in the service life of concrete structures.

4.2 This guide describes approaches for identifying potentially deleteriously reactive aggregates and selecting appropriate preventive measures to minimize the risk of expansion when such aggregates are used in concrete in exposure environments where AAR may be of concern. Preventive measures include avoiding use of the reactive aggregate, limiting the alkali loading of the concrete, using supplementary cementitious materials, using lithium-based admixtures, or a combination of these strategies.

5. Significance and Use

5.1 This guide provides recommendations for identifying the potential for deleterious AAR and selecting appropriate preventive measures, based on a prescriptive-based or performance approach, to minimize the risk of deleterious reaction. In regions where occurrences of AAR are rare or the aggregate sources in use have a satisfactory field performance record verified by following the guidance in this standard, it is reasonable to continue to rely on the previous field history without subjecting the aggregates to laboratory tests for AAR. In regions where AAR problems have occurred or the reactivity of aggregates is known to vary from source to source, it may be necessary to follow a testing program to determine potential reactivity and evaluate preventive measures. In this guide, the level of prevention required is a function of the reactivity of the aggregate, the nature of the exposure conditions (especially availability of moisture), the criticality of the structure, and the availability of alkali in the concrete.

5.2 *Risk Evaluation*—To use this guide effectively, it is necessary to define the level of risk that is acceptable, as this will determine the type and complexity of testing (Note 1). The risk of deleterious expansion occurring as a result of a failure to detect deleteriously reactive aggregates can be reduced by routine testing using petrography, or laboratory expansion tests, or both.

NOTE 1—The level of risk of alkali-silica reaction will depend upon the nature of the project (criticality of the structure and anticipated exposure). The determination of the level of risk is the responsibility of the individual in charge of the design, commonly a representative of the owner, and for structures designed in accordance with ACI 318, the level of acceptable risk would be determined by the licensed design professional.

5.3 For conventional structures, preventive measures determined by either performance testing or the prescriptive approach described in this guide can be expected to generally reduce the risk of expansion as a result of ASR to an acceptable level. For certain critical structures, such as those exposed to continuous moisture (for example, hydraulic dams or power plants), in which ASR-related expansion cannot be tolerated, more conservative mitigation measures may be warranted.

5.4 There are no proven measures for effectively preventing damaging expansion with alkali carbonate reactive rocks in concrete and such materials need to be avoided.

5.5 If an aggregate is identified as potentially deleteriously reactive as a result of ASR, and the structure size, class, and exposure condition requires preventive measures, the aggregate may be accepted for use together with appropriate preventive measures following the prescriptive or performance methods outlined in this guide.

6. Procedure

6.1 The flow chart in Fig. 1 shows the general sequence of testing and decisions that should be made when evaluating a source of aggregate for potential AAR. Solid lines show the approach recommended for a lower risk of AAR. The amount and time of testing can be reduced with acceptance of a higher level of risk following the flow chart along the dashed lines. Prior documented satisfactory field performance of the aggregate in concrete is generally considered to be sufficient for its acceptance in new concrete. However, reliance on prior field performance without following the guidance and recommended testing in 7.1 may not be sufficient to safeguard against damage as a result of AAR in new construction. This is due to the difficulties in assuring that the materials and mixture proportions used in existing structures built 10 to 20 years ago (the time frame needed to ensure that a deleterious reaction as a result of AAR has not occurred) are similar to those being proposed for use today. In most cases, it will be necessary to perform laboratory tests to determine whether the aggregate is potentially deleteriously reactive for the specific concrete mixture to be used.

6.1.1 It is recommended that the potential AAR of a new or not previously tested source be established following the solid lines from beginning to end of the flow chart. There are several test methods available for evaluating potential AAR. Petrographic examination, determination of chemical constituents, and mortar bar and concrete prism expansion tests are recommended in this guide. If there are no changes in the geologic uniformity of the deposit or mineralogical composition, then the aggregate could be subsequently monitored using a revised approach based on interpretation of the initial test results (see 7.7). A revised approach would allow for the omission of tests based on suitable existing data, or for omission of less reliable tests if more reliable tests are being performed.

6.2 If the aggregate is deemed to be non-reactive, it can be accepted for use in concrete with no further consideration of mitigation provided that the other physical properties of the aggregate render it suitable for use (refer to Specification C33/C33M). If the aggregate is a quarried carbonate, tests are required to determine whether the potential reaction is of the alkali-carbonate or alkali-silica type. Aggregate deemed alkali carbonate reactive should be avoided. Aggregate deemed alkali silica reactive can be tested for efficacy of preventive measures. Steps for selecting appropriate preventive measures for ASR follow either a performance-based (Section 8) or prescriptive-based (Section 9) approach. In the performance-based approach, a potential preventive measure is tested to determine if the measure provides a reduction in expansion

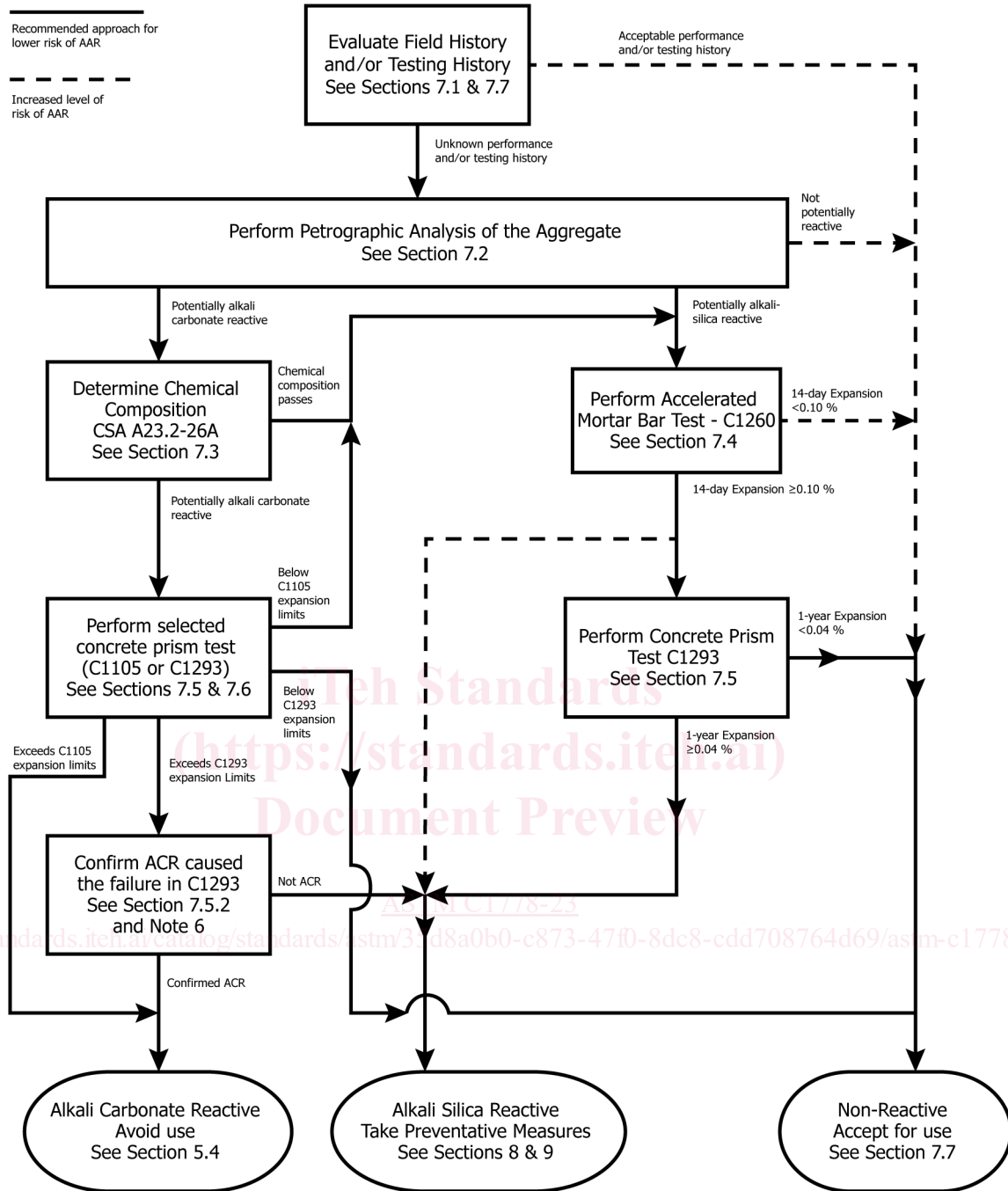


FIG. 1 Sequence of Laboratory Tests for Evaluating Aggregate Reactivity

below the limits outlined in this guide. Both approaches are intended to minimize the potential for deleterious expansion in field concrete.

7. Determining Aggregate Reactivity

7.1 Use of Field Performance History:

7.1.1 The long-term field performance history of an aggregate can be established by surveying existing structures that were constructed using the same aggregate source. As many structures as practical should be included in the survey and these structures should, if possible, represent different types of

construction (for example, foundations, walls, bridges, pavements, sidewalks, and structural elements). Practice C823/C823M provides useful guidance when surveying structures to establish field performance history. The following information should be documented for each structure:

7.1.1.1 Age—Structures should be at least 15 years old as visible damage from AAR can take more than ten years to develop.

7.1.1.2 Alkali loading of the concrete.

7.1.1.3 Use and content of pozzolans or slag cement or blended cements during construction.

7.1.1.4 *Exposure Condition*—Availability of moisture and use of deicing chemicals.

7.1.1.5 Symptoms of distress observed.

7.1.2 Cores should be taken from a representative number of these structures and a petrographic examination conducted using Practice C856 to establish the following (Note 2):

7.1.2.1 The aggregate used in the structure surveyed is of similar mineralogical composition, as determined by Guide C295/C295M, to that of the aggregate to be used.

7.1.2.2 Any evidence of damage as a result of AAR; and

7.1.2.3 The presence, quantity, and composition (if known) of fly ash, slag cement, or other supplementary cementitious materials.

NOTE 2—Even if signs of deterioration are not observed, cores should be taken to establish uniformity of materials.

7.1.3 If the results of the field survey indicate that the aggregate is non-reactive, the aggregate may be used in new construction provided that the new concrete is not produced with a higher concrete alkali content, a lower replacement level of supplementary cementitious material (SCM), or placed in a more aggressive exposure condition than the structures included in the survey.

7.1.4 There is a certain level of uncertainty associated with accepting aggregates solely on the basis of field performance because of difficulties in establishing unequivocally that the materials and proportions used more than 10 to 15 years ago are sufficiently similar to those to be used in new construction. If field performance indicates that an aggregate source is potentially deleteriously reactive, laboratory testing can be conducted to determine the level of aggregate reactivity and evaluate preventive measures. The use of long-term performance is considered to be a reliable method in determining the

suitability of an aggregate; however, it is often very difficult to acquire the necessary information and background for existing structures.

7.2 *Petrographic Assessment:*

7.2.1 Petrographic examination of aggregates should be conducted in accordance with Guide C295/C295M. Petrography can reveal useful information about the composition of an aggregate, including the identification and approximate amount of potentially reactive minerals. Petrography can be used to classify an aggregate as potentially reactive, but expansion testing is required to determine the extent of the reactivity and appropriate mitigation measures. Aggregates may be accepted as non-reactive solely on the basis of petrography, but there is a certain level of uncertainty associated with such a decision. For example, some reactive phases may not be detected by optical microscopy. If a petrographer is examining aggregates from well-known and tested sources, it is reasonable to use petrography to classify the aggregate reactivity on a routine basis.

7.2.2 Petrographers should look for alkali-reactive silica components such as opal, chert, chalcedony, cristobalite, tridymite, strained and micro-crystalline quartz, and volcanic glass. Petrographers should also ascertain the presence of mineralogical and textural features characteristic of alkali-carbonate reactive aggregates. Deleteriously reactive alkali-carbonate aggregates often exhibit a characteristic microscopic texture consisting of dolomite rhombs within a fine-grained matrix of calcite, quartz, and clay (2)⁶. However, there have

⁶ The boldface numbers in parentheses refer to the list of references at the end of this standard.

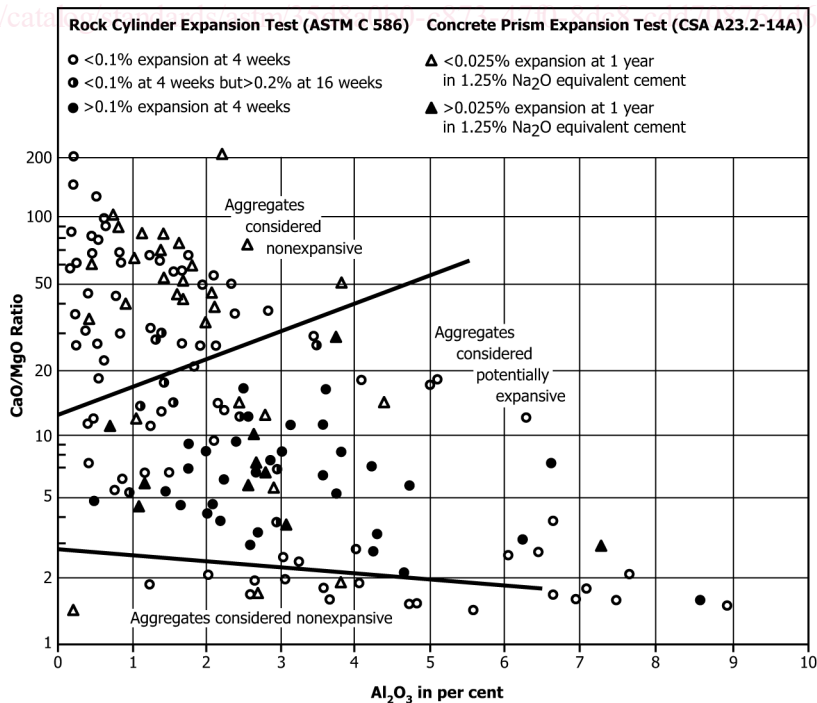


FIG. 2 Plot of CaO/MgO Ratio Versus the Al₂O₃ Content of Quarried Carbonite Rocks (1)

been reports of deleterious ACR with aggregates that do not exhibit this “classic” texture (3).

7.3 *Determination of Potential Alkali-Carbonate Reactive Rocks by Chemical Composition, CSA A23.2-26A*—If the aggregate being assessed is a quarried carbonate rock, the potential for ACR may be assessed on the basis of its chemical composition (1). This test involves the determination of lime (CaO), magnesia (MgO), and alumina (Al₂O₃) contents of the rock and determining where the composition of the rock falls on a plot of CaO/MgO ratio versus the Al₂O₃ content, as shown in Fig. 2.

7.3.1 If the composition does not fall in the range of “aggregates considered to be potentially expansive” in Fig. 2, the aggregate is considered to be not potentially alkali-carbonate reactive and should be tested using the options for evaluation of potential alkali-silica reactivity outlined in this guide.

7.3.2 If the composition falls in the range of “aggregates considered to be potentially expansive” in Fig. 2, the aggregate is considered to be potentially alkali-carbonate reactive. Such aggregates may be tested using either of the following concrete prism tests: Test Method C1293/C1293M or C1105 using a low-alkali content (see 7.5 and 7.6).

7.4 *Accelerated Mortar Bar Test, Test Method C1260*—This test method is suitable for assessing potentially alkali-silica reactive aggregates (Note 3).

NOTE 3—Test Method C1260 (accelerated mortar bar test) is not suitable for detecting ACR as aggregates that are alkali-carbonate reactive may not expand when crushed to the gradations used in Test Method C1260.

7.4.1 If mortar bars in this test expand by less than 0.10 % after 14 days immersion, the aggregate is considered to be innocuous according to this test. (Note 4) (4-6).

NOTE 4—Coarse aggregate for Test Method C1260 is crushed to sand size (<5 mm [0.2 in.]) and then washed and graded to meet the grading requirements of the test method. Sands are washed and graded to meet the same grading requirements. The test is intended to evaluate coarse and fine aggregate separately and should not be used to evaluate job combinations of coarse and fine aggregates

7.4.2 If the mortar bars expand 0.10 % or greater after 14 days immersion, the aggregate is considered to be potentially deleteriously reactive (Note 5) (4, 7, 8), and it is recommended to confirm reactivity in concrete using Test Method C1293/C1293M (concrete prism test) (Note 5 and Note 6).

NOTE 5—If expansion by 0.10 % or greater occurs, it is recommended to confirm that the expansion is actually due to alkali-silica reaction using supplementary information. Sources of supplementary information include: (1) petrographic examination of the aggregate in accordance with Guide C295/C295M to determine if known reactive constituents are present; (2) examination of the specimens after test in accordance with Practice C856 to identify the products of alkali-silica reaction; and (3) if available, field service or previous test records to assess performance.

NOTE 6—Test Method C1260 may give a false-negative result for some slowly reactive aggregate, aggregates with pessimum effect, and/or aggregates containing deleterious strained quartz when microcrystalline quartz is also present (9). Some granitic gneisses, orthoquartzite and metabasalts have been found to be deleteriously expansive in field performance even though their expansion in this test was less than 0.10 % (7, 10). For this aggregate type, it is recommended that prior field performance be investigated. In the absence of field performance data, the aggregate reactivity should be further evaluated using Test Method C1293/C1293M or mitigative measures should be taken following the prescriptive approach outlined in Section 9.

NOTE 7—The potential reactivity of various varieties of quartz may not be accurately determined by Test Method C1260 since the test method may produce a false-positive result with a number of aggregates that have shown mixed results in field performance (8). For aggregates producing false positives with Test Method C1260, Test Method C1567 may also provide overly conservative estimates of the amount of SCM to control ASR. These aggregates are those plotting in Zone 1 of Fig. 3 if Test Method C1260 and Test Method C1293/C1293M results for the same aggregate are compared.

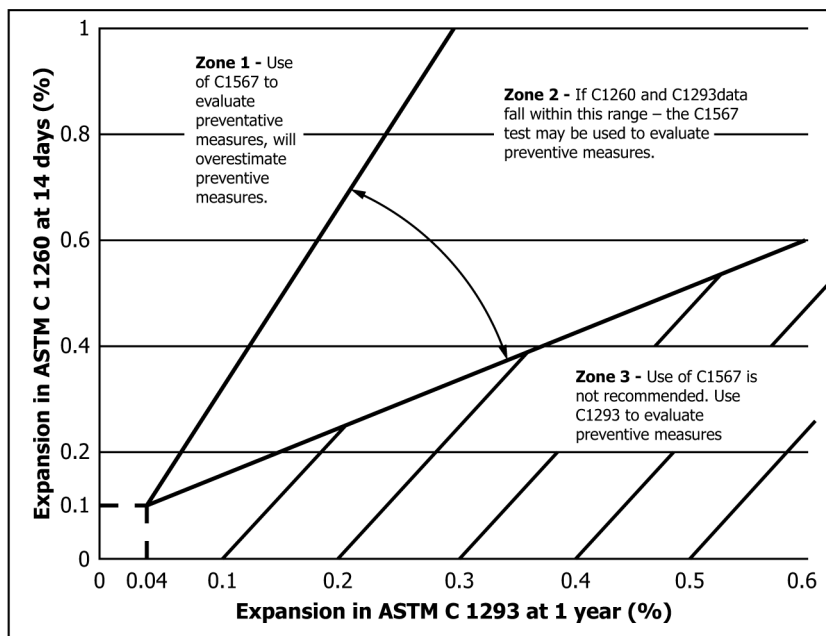


FIG. 3 Comparison of Test Method C1260, Accelerated Mortar Bar, and Test Method C1293/C1293M, Concrete Prism Test, Data for Purpose of Determining Whether Test Method C1567 is Suitable for Evaluating Preventative Measures with a Specific Aggregate