



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

This standard is issued under the fixed designation C1778; 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 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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:²

C33/C33M Specification for Concrete Aggregates

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 Risk Management for Alkali Aggregate Reactions.

Current edition approved Oct. 1, 2014. Published November 2014. DOI: 10.1520/C1778-14.

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.

C125 Terminology Relating to Concrete and Concrete Aggregates

C150/C150M Specification for Portland Cement

C294 Descriptive Nomenclature for Constituents of Concrete Aggregates

C295 Guide for Petrographic Examination of Aggregates for Concrete

C311 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 Specification for Blended Hydraulic Cements

C618 Specification for Coal Fly 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 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 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)

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)

2.2 ACI Standard:³

ACI 318 Building Code Requirements for Structural Concrete and Commentary

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

2.3 AASHTO Standard:

AASHTO PP 65 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** and Descriptive Nomenclature **C294**.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *alkali content, n*—the alkali content of the cement expressed as % Na₂O_{eq} and calculated as Na₂O + (0.658 K₂O).

3.2.2 *alkali loading, n*—the total amount of alkalis in the concrete mixture expressed in kg/m³ or lb/yd³; this is calculated by multiplying the portland cement content of the concrete in kg/m³ or lb/yd³ by the alkali content of the cement divided by 100.

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

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

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

3.2.4.1 *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 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 (SiO₂ containing) minerals and alkali-carbonate reaction (ACR) involves certain types of rocks that contain dolomite [CaMg(CO₃)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 generally associated with the responsible 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 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 conventional structures. 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 by selective quarrying.

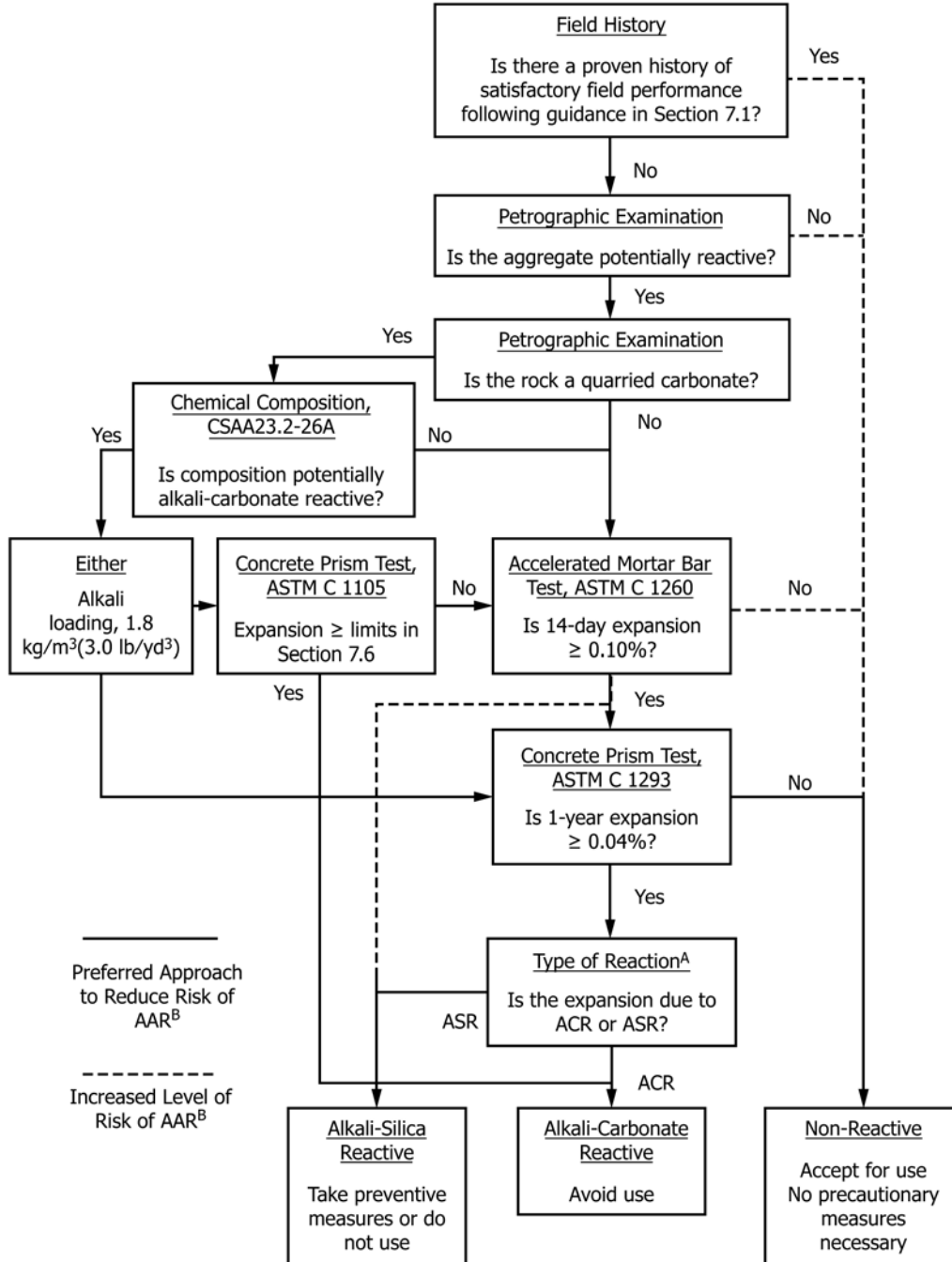
⁴ Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001, <http://www.transportation.org>.

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

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. Prior documented satisfactory field performance of the aggregate in concrete is



^A The type of reaction only needs to be determined after the concrete prism test if the aggregate being tested is a quarried carbonate that has been identified as being potentially alkali-carbonate reactive by chemical composition in accordance with test method CSA A23.2-26A.

^B The solid lines show the preferred approach. However, some agencies may want to reduce the amount of testing and accept a higher level of risk and this can be achieved by following the direction of the hashed lines.

FIG. 1 Sequence of Laboratory Tests for Evaluating Aggregate Reactivity

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. 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 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, additional tests are required to determine whether the potential reaction is of the alkali-carbonate or alkali-silica type.

6.2 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 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 Cement content and alkali content of the cement used during construction.

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 as a result of AAR or other causes.

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, 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 SCM replacement level, 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. 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 (1). However, there have

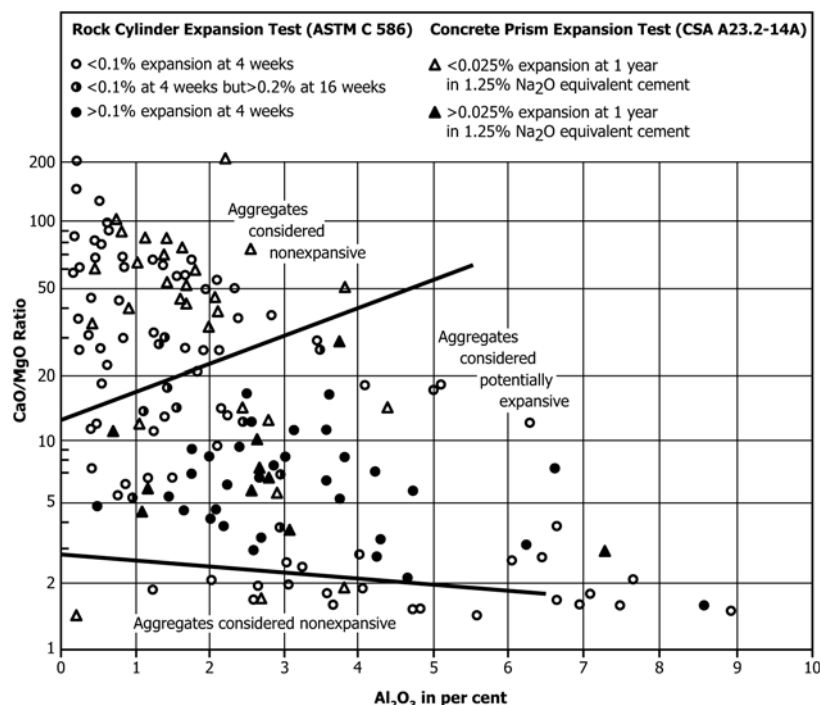


FIG. 2 Plot of CaO/MgO Ratio Versus the Al₂O₃ Content of Quarried Carbonite Rocks (2)

been reports of deleterious ACR with aggregates that do not exhibit this “classic” texture (2).⁶

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 (3). 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 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.

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

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 in most cases. If the mortar bars expand by 0.10 % or greater after 14 days immersion it is considered to be potentially deleteriously reactive (Note 4). If the mortar bars expand by 0.10 % or greater after 14 days immersion it is recommended to confirm reactivity using Test Method C1293 (concrete prism test) (Note 5).

NOTE 4—Test Method C1260—Coarse aggregate for Test Method C1260 are 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 aggregates separately and should not be used to evaluate job combinations of coarse and fine aggregates.

NOTE 5—In regions where Test Method C1260 is known to produce false-positive results, that is, expansion is by 0.10 % or greater yet the aggregate has a record of good field performance, it may be desired to rely on Test Method C1293. In 8.3 and Fig. 3 this would be Zone 1 where relying solely on Test Method C1567 to evaluate preventive measures would result in overly conservative estimates of the amount of SCM to control ASR.

7.5 Concrete Prism Test, Test Method C1293—This concrete prism test is suitable for evaluating potentially alkali-silica reactive aggregates and alkali-carbonate reactive aggregates. Despite the 1-year duration of the test, it is considered by many researchers to be the most reliable laboratory test for predicting field performance of aggregates (4). If the potentially reactive aggregate being tested is a coarse aggregate, use a non-reactive fine aggregate and vice versa. The coarse-fine aggregate combination should be used to make concrete prisms with a specified high-alkali loading. The test is intended to evaluate coarse and fine aggregates separately and should not be used to evaluate job combinations of coarse and fine aggregates.

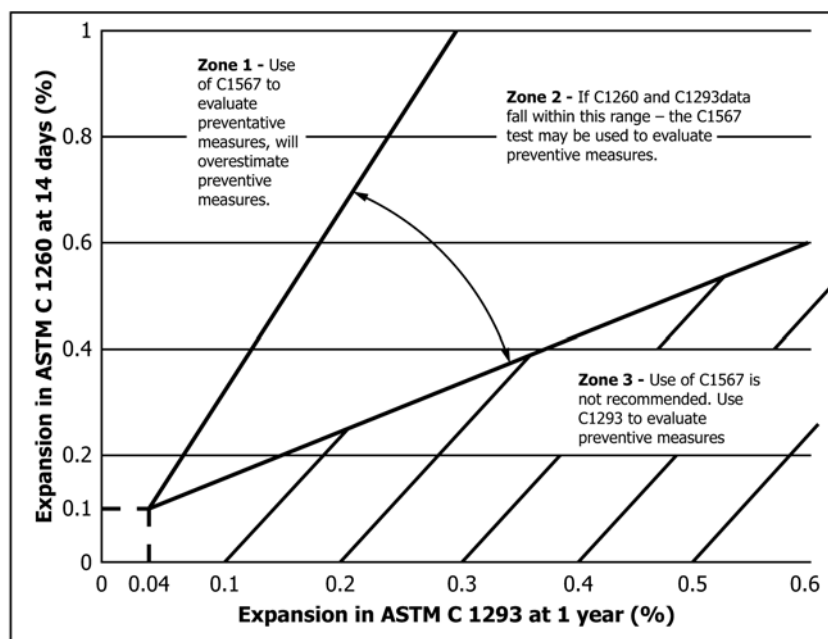


FIG. 3 Comparison of Test Method C1260, Accelerated Mortar Bar, and Test Method C1293, Concrete Prism Test, Data for Purpose of Determining Whether Test Method C1567 is Suitable for Evaluating Preventative Measures with a Specific Aggregate

7.5.1 If concrete prisms in this test expand by less than 0.04 % after one year, the aggregate is considered non-reactive and may be used in concrete with no further testing for AAR. If the prisms expand by 0.04 % or greater at one year, the aggregate is considered to be reactive and preventive measures, as outlined in Section 8 or 9, are required if the aggregate is to be used in concrete construction for structures and exposure conditions requiring preventive measures.

7.5.2 If the aggregate tested is a quarried carbonate rock with a chemical composition that falls within the region in (Fig. 2), labeled as “aggregates considered to be potentially reactive,” and exhibited concrete prism expansion of 0.04 % or greater at one year, and was not tested using Test Method C1105 (see 7.6), the concrete prisms should be examined to determine whether ACR contributed to the expansion or additional testing may be warranted (Note 6). If damaging ACR is detected, either in isolation or in combination with ASR, the aggregate should not be used in concrete without selective quarrying or aggregate processing to limit the alkali-reactive carbonate components to acceptable levels.

NOTE 6—The determination of the extent to which the ACR contributed to the expansion of the concrete should be conducted by an expert having experience with ACR. Methods may include one or more of the following: a petrographic examination of the concrete (Practice C856), accelerated microbar testing of the aggregate (5), or rock cylinder expansion tests (Test Method C586) conducted on samples of rock from the quarry.

7.5.3 If an aggregate is reactive according to Test Method C1293, and is to be used in construction, appropriate preventive measures need to be taken following the procedures outlined in 8 or 9.

7.6 Concrete Prism Test for Alkali-Carbonate Reaction, Test Method C1105—For quarried carbonate rocks with compositions falling within the region of “aggregates considered to be potentially reactive” in Fig. 2, this concrete prism test for

alkali-carbonate reaction may also be used, but the alkali loading of the concrete should be kept below 1.8 kg/m³ [3.0 lb/yd³] Na₂O_{eq} to ensure that potential expansion as a result of ASR is eliminated during the test.

7.6.1 If the expansion results from Test Method C1105 are 0.025 % or greater at six months or are 0.030 % or greater at twelve months, the aggregate is considered to be alkali-carbonate reactive and its use in concrete is to be avoided (Note 7). If the expansion results do not exceed these values, the aggregate is considered to be not alkali-carbonate reactive but should be tested for alkali-silica reactivity as outlined in this guide.

NOTE 7—It is recommended that the test be conducted for a period of twelve months, but expansion values at six months can be used if needed.

7.7 Interpretation of Results from Laboratory Tests—Use Fig. 1 to interpret the results from laboratory and field testing and to make decisions regarding the risk of alkali-silica or alkali-carbonate reaction occurring in concrete.

7.7.1 Fig. 1 shows dotted lines from the boxes marked “Field History,” “Petrographic Examination,” and “Accelerated Mortar Bar Test” to the box marked “Non-Reactive” as there is an element of uncertainty associated with accepting aggregates solely on the basis of these tests. With some aggregates, it may not be possible to identify reactive constituents by petrographic examination.

7.7.2 Test Method C1260 is generally recognized as a relatively severe test that identifies as potentially deleteriously reactive many aggregate sources that have a history of satisfactory field performance and that Test Method C1293 identifies as non-reactive. For this reason, results from Test Method C1260 should not be used to reject an aggregate. If an aggregate is potentially reactive based on the results of Test Method C1260 (expansion ≥ 0.10 % after 14 days immersion),

its reactivity should be confirmed by testing using Test Method C1293 or the potentially reactive aggregate should be used with appropriate mitigation measures (Section 8 or 9). If the results of Test Methods C1260 and C1293 are in disagreement, the results of Test Method C1293 should be considered the more reliable.

Although there were exceptions, in the past, it was often assumed that aggregates that passed Test Method C1260 (expansion < 0.10 % after 14 days immersion) were most likely to pass Test Method C1293 (expansion < 0.04 % at 1 year), and such aggregates could be accepted for use in concrete without the need for confirmatory testing using Test Method C1293. However, there have been an increasing number of coarse aggregates that have been found to pass Test Method C1260 and fail Test Method C1293 and this is somewhat disconcerting for specifications that permit the use of aggregates passing Test Method C1260 with no further testing (that is, no requirements for Test Method C1293) (Note 8) (6) (7). Consequently, there is a risk associated with accepting an aggregate solely on the basis of the results from Test Method C1260.

NOTE 8—Several agencies have extended the duration of Test Method C1260 and use an expansion limit of 0.10 % or even 0.08 % after 28 days immersion in 1N NaOH at 80°C [176°F]. This more onerous requirement should not be adopted unless it can be demonstrated that extension of the test period is required to capture aggregates that are believed to be similar to those that have been identified as being deleteriously reactive either by concrete prism testing or field performance. Applying the extended test duration to all aggregates may result in an unacceptable number of cases in which the accelerated mortar bar test results in false positives. Note that extending the test duration does not capture all of the aggregates that have been found to pass Test Method C1260 but fail Test Method C1293.

7.7.3 In Fig. 1, Test Method C1260 is shown with a broken line, as there is the possibility of incorrectly identifying a deleteriously reactive aggregate as being non-reactive using this method. The most reliable approach for determining aggregate reactivity is to use Test Method C1293 for all cases (that is, to exclude Test Method C1260 from the evaluation process). However, it is recognized that the long duration of Test Method C1293 makes it impractical for use in many circumstances and there is a need for a more rapid test.

8. Performance-based Approach for Selecting Appropriate Preventive Measures

8.1 In the performance-based approach, the efficacy of the preventive measure is tested in combination with the reactive aggregate using either Test Method C1293 or C1567 (Note 9). This approach is suitable for selecting the appropriate level of supplementary cementitious materials (SCMs). Test Methods C1567 and C1293 are not able to consider the effects of low-alkali cement on the performance of a concrete mixture made with reactive aggregates (see Note 10). The effects of low-alkali cement on mitigation measures should be evaluated using Section 9.

NOTE 9—Currently, there is no ASTM standard analogous to Test Method C1567 for testing the efficacy of lithium. Research is underway to establish a standardized method as well as precision and bias statements. However, several agencies [American Association of State Highway and Transportation Officials (AASHTO), Federal Highway Administration (FHWA), and Canadian Standards Association (CSA)] specify testing procedures to evaluate the efficacy of lithium nitrate to control alkali-silica

reaction in concrete specimens. Guidance on these testing procedures can be found in: AASHTO PP-65, CSA A23.2-28A, and an FHWA Report (8).

8.2 *Performance Testing Using Test Method C1293*—The ability of SCMs such as fly ash, slag cement, silica fume, and natural pozzolans, to control deleterious expansion with a reactive aggregate can be evaluated using Test Method C1293. When testing SCMs, the total cementitious materials content is maintained at 420 kg/m³ (708 lb/yd³), but the portland cement is replaced partially with the desired amount of the SCM (or combination of SCMs) under investigation. The alkali content of the portland cement component of the mixture only is raised to 1.25 % Na₂O_{eq} (Note 10). A number of tests should be conducted using varying levels of SCM(s) to optimize the proportions that will meet the expansion criteria. The test duration for evaluating preventive measures is two years. If expansions are <0.04 % at two years, the combination of SCM and reactive aggregate is considered suitable for use in concrete construction.

NOTE 10—The expansion of concrete prisms produced with cement (Specification C150/C150M Type I) alkalies raised to 1.25 % Na₂O_{eq} provides a reliable prediction of the field expansion of concrete produced with cement with alkalies up to 1.0 % Na₂O_{eq}. If the cement to be used in the field has an alkali content above 1.00 % Na₂O_{eq}, this same cement should be used for the concrete prism test and the alkalies should be raised by 0.25 % Na₂O_{eq} by the addition of NaOH to the mix water (9). Due to the potential for alkali leaching from the concrete prisms during storage, there is no simple way to modify Test Method C1293 to provide a reliable evaluation of the beneficial effects of using low-alkali cements or a concrete with low-alkali loading.

8.3 *Performance Testing Using Test Method C1567*—Before Test Method C1567 can be used to determine the performance of a specific SCM-aggregate combination, it is recommended that it first be demonstrated that the reactivity of the aggregate being evaluated is properly identified. It is recommended that the results of Test Methods C1260 and C1293 for the aggregate being used (without preventive measures) be performed. After subjecting the aggregate to both tests, the results are plotted on Fig. 3. Provided data do not fall within Zone 3 indicated in Fig. 3, Test Method C1567 can then be used to determine the efficacy of SCMs. Neglecting to perform this type of comparison may result in either: (1) an overly conservative estimate of aggregate reactivity using Test Method C1260 resulting in overestimation of required SCM amounts or (2) a less conservative estimate of aggregate reactivity using Test Method C1260 resulting in underestimation of required SCM amounts. This represents an inherent risk in relying solely on the results of Test Method C1260 or Test Method C1567. It is recommended that Test Methods C1260 and C1293 be compared regularly (every two years would be a conservative recommendation) unless the results of petrography or other tests indicate a significant change in the composition of the material in the quarry; in which case, new tests should be initiated (8).

8.3.1 Test Method C1567 was developed specifically for “determining the potential alkali-silica reactivity of combinations of cementitious materials and aggregates.” Combinations of cementitious materials and aggregates will be deemed acceptable for use if the resulting expansion is <0.10 % after 14 days immersion in 1M NaOH (Note 11).

NOTE 11—This test method is not suitable for evaluating SCMs with

high levels of alkalis (fly ash with >4.0 % $\text{Na}_2\text{O}_{\text{eq}}$ and slag cement and silica fume with >1.0 % $\text{Na}_2\text{O}_{\text{eq}}$). Such materials should be evaluated using the concrete prism test. Also, since mortar bars are immersed in 1.0 N NaOH solution (equivalent to a portland cement with approximately 1.4 % $\text{Na}_2\text{O}_{\text{eq}}$), Test Method C1567 is not suitable for evaluating the beneficial effect of low-alkali cement.

9. Prescriptive Approach for Selecting Appropriate Preventive Measures

9.1 Using the prescriptive approach, the level of prevention is determined by considering the class (criticality of structure), size, and exposure condition of the structure; the degree of aggregate reactivity; and the level of alkalis from the portland cement (when low-alkali cement alone is used or when SCMs are used as preventive measures). The approach follows the prescriptive requirement in Tables 1-8. This approach is similar to that originally developed in Canada (CSA A23.2-27A) and being developed in Europe (10). It is also similar to the current guidance in AASHTO PP 65.

9.1.1 The prescriptive approach is suitable for selecting the appropriate level of SCM, the maximum alkali loading, or both of the concrete. It can be used as an option if complete performance test data are not available.

9.1.2 *Degree of Alkali-silica Reactivity*—The degree of alkali-silica reactivity of an aggregate is determined by testing the aggregate in accordance with Test Method C1293 and using the expansion value at one year. Aggregate-reactivity classes are given in Table 1. If data from Test Method C1293 are not available, data from Test Method C1260 may be used to classify aggregate reactivity as shown in Table 1. If the coarse and fine aggregates are of different reactivity, the level of prevention should be selected on the basis of the more reactive aggregate.

9.1.3 *Level of ASR Risk*—The risk of ASR occurring in a structure can be determined by considering the aggregate reactivity and the exposure conditions using Table 2. The guidance provided in Table 2 can be used in the absence of other information regarding exposure conditions of a particular structure and is meant as an aid to choosing the proper prescriptive approach to minimize the potential for deleterious ASR.

9.1.4 *Determining the Level of Prevention*—By considering the risk of ASR from Table 2 combined with the class of structure from Table 3, the level of prevention required is determined from Table 4.

9.1.5 Identification of Preventive Measures:

9.1.5.1 *Option 1: Limiting the Alkali Loading of the Concrete*—The potential for damaging ASR can be minimized by limiting the alkali loading of the concrete. Maximum permissible alkali loadings are given in Table 5. The alkali

TABLE 2 Determining the Level of ASR Risk

Size and Exposure Conditions	Aggregate-Reactivity Class			
	R0	R1	R2	R3
Non-massive ^A concrete in a dry ^B environment	Level 1	Level 1	Level 2	Level 3
Massive ^A elements in a dry ^B environment	Level 1	Level 2	Level 3	Level 4
All concrete exposed to humid air, buried or immersed	Level 1	Level 3	Level 4	Level 5
All concrete exposed to alkalis in service ^C	Level 1	Level 4	Level 5	Level 6

^A A massive element has a least dimension of greater than 0.9 m [3 ft].

^B A dry environment corresponds to an average ambient relative humidity lower than 60 %, normally only found in the interior of buildings.

^C Examples of structures exposed to alkalis in service include marine structures exposed to seawater and highway structures exposed to deicing salts (for example, NaCl) or anti-icing salts (for example, potassium acetate, sodium formate, and so forth).

loading of concrete is calculated on the basis of the alkali contributed by the portland cement alone (alkali content).

9.1.5.2 *Option 2: Using SCM*—The potential for damaging ASR can be minimized by using a sufficient quantity of a suitable SCM such as fly ash, slag cement, silica fume, or natural pozzolan (Note 12). Table 6 provides minimum replacement levels for fly ash with less than 18 % CaO determined in accordance with Specification C311 and meeting the requirements of Specification C618, silica fume with more than 85 % SiO_2 and meeting the requirements of Specification C1240, and slag cement meeting the requirements of Specification C989. Fly ashes with more than 18 % CaO can be used to mitigate ASR; however, their effectiveness should be evaluated following the performance-based approach outlined in 8.2 and 8.3. When two or more SCMs are used together to control ASR, the minimum replacement levels given in Table 6 for the individual SCMs may be reduced provided that the sum of proportions of both SCM is greater than or equal to one. For example, when silica fume and slag are used together, the silica fume level may be reduced to one third of the minimum silica fume level given in Table 6 provided that the slag level is at least two thirds of the minimum slag level.

NOTE 12—Many natural pozzolans, such as metakaolin, calcined clays, shales, and volcanic ash have been shown to be effective in controlling expansion as a result of ASR. However, no prescriptive measures are provided for natural pozzolans in Table 6 as this class of materials covers a wide variety of pozzolan types with a broad range of properties. When natural pozzolans are to be used to control ASR, the efficacy of the particular aggregate-pozzolan combination should be determined by performance testing.

The minimum replacement levels in Table 6 are appropriate for use with portland cements of moderate-to-high alkali contents (0.7 to 1.0 % $\text{Na}_2\text{O}_{\text{eq}}$). Table 7 provides recommendations for adjusting the level of SCM when the alkali content of the portland cement is above or below this range (9). When SCMs are combined with lower alkali cements (<0.7 % $\text{Na}_2\text{O}_{\text{eq}}$), the risk is sufficiently low to adopt the value of the minimum replacement level for the next prevention level down. For example, if slag cement is to be used in Prevention Level Y with low-alkali cement, the level of slag cement can be reduced to the level specified for Prevention Level X (35 %). The replacement levels used should not be below those given in Table 6 for Prevention Level W, regardless of the alkali

TABLE 1 Classification of Aggregate Reactivity

Aggregate-Reactivity Class	Description of Aggregate Reactivity	1-Year Expansion in Test Method C1293, %	14-Day Expansion in Test Method C1260, %
R0	Non-reactive	<0.04	<0.10
R1	Moderately reactive	≥0.04, <0.12	≥0.10, <0.30
R2	Highly reactive	≥0.12, <0.24	≥0.30, <0.45
R3	Very highly reactive	≥0.24	≥0.45

**TABLE 3 Structures Classified on Basis of the Severity of Consequences Should ASR^A Occur
(Modified for Highway Structures from RILEM TC 191-ARP)**

Class	Consequence of ASR	Acceptability of ASR	Examples ^B
Class SC1	Safety, economic, or environmental consequences small or negligible	Some deterioration from ASR may be tolerated	Non-load-bearing elements inside buildings Concrete elements not exposed to moisture Temporary structures (service life < 5 years)
Class SC2	Some safety, economic, or environmental consequences if major deterioration	Moderate risk of ASR is acceptable	Sidewalks, curbs, and gutters Elements with service life < 40 years
Class SC3	Significant safety, economic, or environmental consequences if minor damage	Minor risk of ASR may be acceptable	Pavements Foundations elements Retaining walls Culverts Highway barriers Rural, low-volume roads Precast elements in which economic costs of replacement are severe Service life normally 40 to 74 years
Class SC4	Serious safety, economic, or environmental consequences if minor damage	ASR cannot be tolerated	Major bridges Power plants Dams Nuclear facilities Water treatment facilities Waste water treatment facilities Tunnels Critical elements that are very difficult to inspect or repair Service life normally ≥ 75 years

^A This table does not consider the consequences of damage as a result of ACR. This protocol does not permit the use of alkali-carbonate aggregates.

^B The types of structures listed under each class are meant to serve as examples. Some owners may decide to use their own classification system. For example, sidewalks, curbs, and gutters may be placed in the SC3 class in some jurisdictions.

TABLE 4 Determining Level of Prevention

Level of ASR Risk (Table 2)	Classification of Structure (Table 3)			
	Class SC1	Class SC2	Class SC3	Class SC4
Risk Level 1	V	V	V	V
Risk Level 2	V	V	W	X
Risk Level 3	V	W	X	Y
Risk Level 4	W	X	Y	Z
Risk Level 5	X	Y	Z	ZZ
Risk Level 6	Y	Z	ZZ	^A

^A It may not be permitted to construct a Class SC4 structure (see Table 3) if the risk of ASR is Level 6. Measures should be taken to reduce the level of risk in these circumstances (9).

TABLE 5 Maximum Alkali Loadings to Provide Various Levels of Prevention

Prevention Level	Maximum alkali loading of concrete (Na ₂ O _{eq})	
	kg/m ³	lb/yd ³
V	No Limit	
W	3.0	5.0
X	2.4	4.0
Y	1.8	3.0
Z ^A	Table 8	
ZZ ^A		

^A SCMs may be used in Prevention Levels Z and ZZ.

content of the portland cement. Similarly, if higher alkali cements ($>1.0\%$ Na₂O_{eq}) are used together with SCMs, the replacement level of SCM should be increased to that required for the next prevention level up. For example, if slag cement is to be used in Prevention Level Y with high-alkali cement, the level of slag cement should be increased to the level specified for Prevention Level Z (65 %).

The prescriptive option in this guide should not be used when the alkali content of the portland cement exceeds 1.25 % Na₂O_{eq}.

9.1.5.3 Option 3: Controlling the Alkali Level of Concrete and Using SCMs when Highest Levels of Prevention Are

Required (Levels Z and ZZ)—If highest levels of prevention are needed, a combination of Options 1 and 2 may be required. This approach requires that a minimum level of SCM be used and that a maximum limit be placed on the alkali content of the concrete contributed by the portland cement. Options for Prevention Levels Z and ZZ are given in Table 8.

10. Keywords

10.1 AAR; ACR; alkali-aggregate reaction; alkali-carbonate reaction; alkali-silica reaction; ASR; concrete; concrete durability; laboratory testing; pozzolans; reactive aggregates; risk evaluation; supplementary cementitious materials

TABLE 6 Minimum Levels of SCM to Provide Appropriate Level of Prevention

Type of SCM ^A	Alkali Content of SCM (% Na ₂ O _e)	Minimum Replacement Level ^D (% by mass)				
		Level W	Level X	Level Y	Level Z	Level ZZ
Fly ash ^B	<3.0	15	20	25	35	
(CaO ≤ 18 %)	3.0 – 4.0	20	25	30	40	
Slag Cement	<1.0	25	35	50	65	
Silica Fume ^C	<1.0	2.0 × KGA	2.5 × KGA	3.0 × KGA	4.0 × KGA	Table 8
(SiO ₂ > 85 %)		or	or	or	or	
		1.2 × LBA	1.5 × LBA	1.8 × LBA	2.5 × LBA	

^A The SCM may be added directly to the concrete mixer or it may be a component of a blended cement. Fly ash should meet the requirements of Specification C618, slag cement should meet the specifications of C989, and silica fume should meet the requirements of Specification C1240. Blended cements should meet the requirements of Specification C595 or C1157.

^B Fly ashes with greater than 18 % CaO can mitigate ASR. The efficacy of these higher calcium fly ashes should be evaluated using the performance-based testing outlined in 8.2 and 8.3.

^C The minimum level of silica fume (as a percentage of cementing material) is calculated on the basis of the alkali (Na₂O_e) loading of the concrete contributed by the portland cement and expressed in either units of kg/m³ (KGA in Table 6) or lb/yd³ (LBA in Table 6). KGA is calculated by multiplying the cement content of the concrete in kg/m³ by the alkali content of the cement divided by 100. For example, for a concrete containing 300 kg/m³ of cement with an alkali content of 0.91 % Na₂O_e, the value of KGA = 300 × 0.91/100 = 2.73 kg/m³. For this concrete, the minimum replacement level of silica fume for Protection Level X is 2.5 × 2.73 = 6.8 %. LBA is calculated by multiplying the cement content of the concrete in lb/yd³ by the alkali content of the cement divided by 100. For example, for a concrete containing 500 lb/yd³ of cement with an alkali content of 0.81 % Na₂O_e, the value of LBA = 500 × 0.81/100 = 4.05 lb/yd³. For this concrete, the minimum replacement level of silica fume for Level Y is 1.8 × 4.05 = 8.1 %. Regardless of the calculated value, the minimum level of silica fume may not be less than 7 % when it is the only method of prevention.

^D Note—the use of high levels of SCM in concrete may increase the risk of problems as a result of deicer salt scaling if the concrete is not properly proportioned, finished, and cured.

TABLE 7 Adjusting Minimum Level of SCM Based on Alkali Content of Portland Cement

Cement Alkali Content (% Na ₂ O _e)	Level of SCM
<0.70	Reduce the minimum amount of SCM given in Table 6 by one prevention level ^A
0.70 to 1.00	Use the minimum levels of SCM given in Table 6
>1.00 to 1.25	Increase the minimum amount of SCM given in Table 6 by one prevention level
>1.25	No guidance is given

^A The replacement levels should not be below those given in Table 6 for prevention level, W, regardless of the alkali content of the portland cement.

TABLE 8 Using SCM and Limiting Alkali Loading of Concrete to Provide Highest Levels of Prevention

Prevention Level	SCM as Sole Prevention	Limiting concrete alkali loading plus SCM	
	Minimum SCM level	Maximum alkali loading, kg/m ³ [lb/yd ³]	Minimum SCM level
Z	SCM level shown for Level Z in Table 6	1.8 [3.0]	SCM level shown for Level Y in Table 6
ZZ	Not permitted	1.8 [3.0]	SCM level shown for Level Z in Table 6

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