

Experience with ASTM P214 in Testing Virginia Aggregates for Alkali-Silica Reactivity

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Recently identified occurrences of concrete deterioration resulting from alkali-silica reactivity (ASR) have prompted an effort to evaluate Virginia aggregates for their susceptibility to this reaction. The aggregates thus far associated with ASR have been metamorphic rocks of varied composition and quartzose sands and gravels in which the reactive constituents are believed to be microcrystalline or strained quartz. These forms of quartz are present in many aggregates from Virginia. A review of the literature suggests that although the traditional tests (ASTM C227 and C289) for identifying aggregates susceptible to ASR are not effective with aggregates containing microcrystalline or strained quartz, ASTM P214, which is a new method, is promising. To evaluate P214's effectiveness, tests have been conducted on aggregates from Virginia, and the results are being compared with field performance and other relevant information. The results thus far indicate that expansions in P214 may be caused by both ASR and alkali-carbonate reactivity and that current P214 criteria are not suitable for aggregates in Virginia. Further experience with the method is necessary to determine whether suitable criteria can be established to discriminate between nonreactive aggregates and reactive aggregates containing microcrystalline or strained quartz.

Virginia was one of the 19 states in a Strategic Highway Research Program (SHRP) survey (1) indicating that it had experienced expansion and cracking of concrete as a result of alkali-silica reactivity (ASR). Although occurrences of ASR in Virginia had been reported in 1941 at a hydroelectric plant (2), in 1968 in a pavement (3), and in 1972 in a bridge deck (4), it was not considered to be of major concern for highway construction. Alkali-carbonate reactivity (ACR), which also causes expansion and cracking of concrete, has received considerable attention in Virginia (5,6). The expansion caused by ASR is the result of the swelling of a gel upon the absorption of water. The gel is produced by the dissolution of silica in the aggregate. The expansion caused by ACR is related to the dedolomitization of certain argillaceous, dolomitic limestones.

In 1979, significant longitudinal cracking was observed in a continuously reinforced concrete pavement (CRCP) that had been constructed near Charlottesville in 1970. The cause of this distress was identified as ASR involving the metabasalt (greenstone) coarse aggregate. In 1986, continuing and mounting maintenance problems with this pavement resulted in the decision to remove and replace approximately 6 mi of it.

The types of distress associated with ASR are well illustrated in the SHRP handbook by Stark (7). These patterns of distress have been observed in CRCP, jointed pavements, bridge decks, substructures, parapets, retaining walls, and median barriers in Virginia. Aggregates associated with alkali-silica gel in such concretes have included metabasalt, granite gneiss, metarhyolite, calc schist, and quartzose natural sands and gravels. These aggregates contain varying amounts of quartz, which occurs in a variety of forms including strained quartz and microcrystalline quartz. Strained quartz has a distorted crystal lattice resulting from postcrystallization deformation evidenced by undulating extinction when viewed with crossed polarized light. Although quartz is apparently less reactive than other forms of silica more traditionally associated with ASR, such as opal, chalcedony, and volcanic glasses, it is sufficiently reactive to cause deterioration (8).

The traditional tests for identifying alkali-silica reactive aggregates [ASTM C289 (Quick Chemical Method) and ASTM C227 (Mortar Bar Method)] have been reported to be unreliable in predicting the reactivity of aggregates containing microcrystalline or strained quartz as the reactive constituent (9–13). In C227 tests of several Virginia aggregates, expansions have not exceeded the traditional 3-month limit of 0.05 percent, much less the 6-month limit of 0.10 percent, even with tests extended for 27 months. Because quartz appears to be the reactive constituent in the Virginia aggregates, a method that can predict its reactivity is needed if the traditional approach of screening aggregates for ASR potential is to be followed. Hooton and Rogers (14) have reported good results using a rapid mortar bar method proposed by Oberholster and Davies (15). For the purpose of evaluation, an adaptation of this test was adopted by ASTM as “P214 Proposed Test Method for Accelerated Detection of Potentially Deleterious Expansion of Mortar Bars Due to Alkali-Silica Reaction” (16).

PURPOSE AND SCOPE

As part of a project investigating the occurrence of alkali-silica reactivity in Virginia, a number of aggregates were tested using P214. The results were compared with other available information pertaining to the potential ASR of the aggregates to evaluate the effectiveness of method P214 for screening or specification purposes.

METHODOLOGY

Samples of aggregates known or suspected to be susceptible to ASR as well as several aggregates believed to be nonreactive were obtained. The aggregates were tested according to method P214. In this method, aggregates are crushed (if necessary) to fine aggregate size (<4.75 mm, $<$ No. 4), washed, and screened to a fixed gradation:

Sieve Size	Mass (%)
4.75–2.36 mm (No. 4–No. 8)	10
2.36–1.18 mm (No. 8–No. 16)	25
1.18 mm–600 μ m (No. 16–No. 30)	25
600–300 μ m (No. 30–No. 50)	25
300–150 μ m (No. 50–No. 100)	15

Mortars are mixed using portland cement and a water-cement ratio of 0.44 if the aggregate is a natural sand or 0.50 if crushed. After mixing, 25- by 25- by 275-mm (1- by 1- by 11-in.) bars are fabricated and stored moist for 24 hr.

When the bars are 1 day old, they are stripped from the molds, measured for length, immersed in room temperature water, and placed in an environment at 80°C. When the bars are 2 days old, they are measured for length (zero reading) and then placed in 1 N sodium hydroxide (NaOH) solution at 80°C. Bars are stored in the NaOH solution at 80°C for 14 days or longer and are periodically measured for changes in length. A large increase in length may be indicative of the potential for ASR.

A low-alkali Type II portland cement from one plant was used in mixing all of the batches. According to P214, expansions in the test are not significantly affected by the alkali content of the cement used. The chemical composition of the cement was as follows:

Component	Percentage
SiO ₂	21.1
Al ₂ O ₃	3.6
Fe ₂ O ₃	2.3
CaO	62.7
MgO	3.8
SO ₃	2.5
Na ₂ O + 0.658 \times K ₂ O	0.43

Duplicate batches for aggregates were mixed on separate days. Three bars from each batch were soaked in the NaOH solution. In most cases, the bars were soaked for at least 28 days.

RESULTS

The results of the P214 tests are given in Table 1. The expansion listed for each batch is the average expansion of three bars. Aggregates classified as alkali-silica reactive in Table 1 have been associated with alkali-silica gel in concretes exhibiting typical ASR crack patterns. The granite gneiss from Shelton, which is classified as suspected ASR, was used in concrete exhibiting typical ASR crack patterns, but field concrete has not yet been examined for the presence of ASR gel. A classification of undetermined indicates that the field performance of the aggregate has not yet been characterized.

The dolomite from Harrisonburg was a sample of the highly expansive alkali-carbonate reactive aggregate "1-8" discussed by Newlon and Sherwood (5). Some particles of the

Augusta limestone exhibit the characteristic texture associated with alkali-carbonate rocks of dolomite rhombs in a matrix of fine-grained calcite and finely disseminated clay.

Collections of alkali-silica gel were visible in polished slabs of tested bars made with all of the aggregates except the Augusta, Harrisonburg, and Blacksburg carbonates. When broken, the surface of an Augusta limestone bar was examined using the UV-gel fluorescence test (7), and gel was indicated on the surfaces of some aggregate particles. The presence of gel was not indicated in the specimens made with the Harrisonburg and Blacksburg aggregates when examined with this method. In a rough, qualitative sense, the amount of gel produced appeared to be related to the amount of expansion for most aggregates. The notable exceptions were the Augusta and Harrisonburg aggregates.

DISCUSSION OF RESULTS

The criteria used in ASTM P214 (14) for evaluating test results are as follows:

- Mean expansion of test specimens exceeding 0.20 percent after 14 days of exposure to NaOH solution is indicative of potentially deleterious expansion with respect to ASR.
- Mean expansion of test specimens of less than 0.10 percent after 14 days is indicative of innocuous behavior with respect to ASR.
- Mean expansion of test specimens of 0.10 to 0.20 percent after 14 days is not yet conclusive with respect to ASR.

The preceding criteria were used to classify the susceptibility of the tested aggregates to ASR (see Table 1).

Of the aggregates classified as potentially reactive, the Richmond gravel and Rockville metarhyolite have been associated with ASR in the field. The Sylvatus quartzite has only recently been used as a concrete aggregate, and a service history is not available. Given its petrographic character, it should be classified as potentially reactive.

The Augusta limestone, although expanding considerably in the test, did not produce large amounts of gel, which would be expected if the expansion were resulting from ASR. Some particles exhibit the petrographic characteristics of ACR rocks. The Harrisonburg dolomite, which is a known ACR rock, expanded in the test about the same amount. This suggests that the expansion of the Augusta limestone in P214 may be the result of combined ASR and ACR effects or the ACR effects alone. The expansion of the Harrisonburg dolomite indicates that the P214 test may be effective in detecting aggregates susceptible to ACR. It is interesting that the ACR aggregate reduced to the size of sand expands considerably in this test since size reduction is the general explanation given for the ineffectiveness of the ASTM C227 mortar bar test to detect ACR aggregates.

The inconclusive group includes two aggregates associated with ASR in the field (Richmond sand and Mt. Athos calc schist) and a third (Shelton granite gneiss), which is suspected of field reactivity. All three give expansions in excess of 0.15 percent (but less than 0.20 percent) after 14 days in NaOH.

The Warrenton diabase and the Fredericksburg gravel both yield expansions between 0.10 and 0.15 percent. Although

TABLE 1 Aggregate Source, Type, Performance, and P214 Results

Aggregate Source	Rock Type	Field Performance	C 227 Expansion	P214 Expansion (%)			P 214 Classification
				Batch	14 d	28 d	
Augusta	Dolomitic Limestone	Undetermined	—	1	0.24	—	Reactive
				2	0.22	—	
				Avg	0.23	—	
Harrisonburg	Argillaceous Calcitic Dolomite	Alkali-carbonate reactive	—	1	0.24	—	Reactive
				2	0.22	—	
				Avg	0.23	—	
Blacksburg	Argillaceous Dolomite	Good	—	1	0.09	—	Innocuous
				2	0.08	—	
				Avg	0.09	—	
Warrenton	Diabase	Good	—	1	0.15	0.36	Inconclusive
				2	0.11	—	
				Avg	0.13	0.36	
Fredericksburg	Quartzose Sand	Undetermined	—	1	0.10	0.19	Innocuous
				2	0.08	0.21	
				Avg	0.09	0.20	
Fredericksburg	Quartzose Gravel	Undetermined	—	1	0.13	0.28	Inconclusive
				2	0.10	0.28	
				Avg	0.12	0.28	
Richmond	Quartzose Sand	Alkali-silica reactive	0.045% (1) @ 27 months	1	0.18	0.38	Inconclusive
				2	0.19	0.36	
				Avg	0.19	0.37	
Richmond	Quartzose Gravel	Alkali-silica reactive	0.016% (2) @ 6 months	1	0.31	0.50	Reactive
				2	0.32	0.48	
				Avg	0.32	0.49	
Rockville	Metarhyolite	Alkali-silica reactive	0.014% (2) @ 6 months	1	0.40	0.59	Reactive
				2	0.38	—	
				Avg	0.39	0.59	
Sylvatus	Quartzite	Undetermined	0.021% (2) @ 6 months	1	0.27	0.42	Reactive
				2	0.30	0.43	
				Avg	0.29	0.43	
Mt. Athos	Calc schist	Alkali-silica reactive	0.012% (2) @ 6 months	1	0.18	0.32	Inconclusive
				2	0.16	0.28	
				Avg	0.17	0.30	
Shelton	Granite gneiss	Suspected alkali-silica reactive	—	1	0.18	0.30	Inconclusive
				2	0.16	0.26	
				Avg	0.17	0.28	
Red Hill	Granite gneiss	Alkali-silica reactive	0.049% (1) @ 27 months	1	0.07	0.14	Innocuous
				2	0.06	—	
				Avg	0.07	0.14	
Shadwell	Metabasalt	Alkali-silica reactive	0.038% (1) @ 27 months	1	0.08	0.14	Innocuous
				2	0.09	0.16	
				Avg	0.09	0.15	

(1) Personal communication, D. Stark. Tests conducted by CTL, Inc. under SHRP contract using cement with 1% Na₂O equivalent.

(2) Tests conducted by Virginia Transportation Research Council using cement with 1% Na₂O equivalent.

the field performance of the Warrenton aggregate is reported to be good, that of the Fredericksburg gravel has yet to be determined. However, gravel from Fredericksburg was used by Buck and Mather (10) in their work on the reactivity of quartz because its composition was similar to that of sands and gravels associated with ASR in Charleston, South Carolina. The Fredericksburg gravels are composed primarily of quartz and quartzite and differ from those of the Richmond area in being relatively chert-free. The relative abundance of chert composed of microcrystalline quartz is at least a partial explanation of the higher expansions of the Richmond gravels and sands. Although Buck and Mather (10) conclude that the reactive constituent in these aggregates is strained quartz, Grattan-Bellew (17) suggests that strained quartz per se is not reactive; rather, microcrystalline quartz associated with the strained quartz in such aggregates is the reactive element.

In any case, it appears that the Fredericksburg gravel, the Richmond sand, the Mt. Athos calc schist, and Shelton granite

gneiss should be considered potentially reactive. The results with the Warrenton diabase, which would seem an unlikely candidate for ASR, are still unclear. Because of the expansions and the gel produced, a closer look at field structures, particularly older ones, should be taken.

The Blacksburg dolomite, the Fredericksburg sand, the Red Hill granite gneiss, and the Shadwell metabasalt were classified as innocuous with respect to ASR. The Blacksburg dolomite showed no evidence of reactivity in the tested mortar bars; undoubtedly, it is innocuous with respect to ASR. However, both the Red Hill granite gneiss and Shadwell metabasalt have been associated with field occurrences of ASR. The low expansions of these aggregates in the P214 test present a drawback to its widespread use until the relationship between deleterious reactivity in the field and expansion in the test is more clearly understood. The Fredericksburg sand (like the Fredericksburg gravel discussed above) is compositionally similar to aggregates in a reported case of ASR.

The Red Hill granite gneiss, Shadwell metabasalt, and probably the Fredericksburg sand should be considered potentially reactive.

CONCLUSIONS

The P214 method for testing an aggregate's potential for deleterious ASR appears to be capable of causing both the alkali-silica reaction and the alkali-carbonate reaction to occur in mortar bars in approximately 2 weeks. In this respect, it is a significant improvement over the C227 method.

However, the criteria listed in P214 for evaluating expansion results do not appear to be reliable in classifying the ASR potential of all the aggregates tested. Lowering the expansion limit for potentially deleterious reactivity to 0.10 percent would improve the situation but would not totally solve the problem because there are at least two reactive aggregates with expansions less than 0.10 percent. One of these, the Red Hill granite gneiss, has many petrographically similar counterparts in the Piedmont of Virginia, and establishing a limit that excludes it may result in the misclassification of other reactive aggregates. Clearly, more experience with the test is needed to develop a better understanding of the relationship between an aggregate's expansion in the test and its reactivity in the field.

Although P214 is capable of identifying many reactive aggregates not so identified by C289 or C227, the results reported here are supportive of Hooton's suggestion (18) that because some reactive gneisses and quartzites from the eastern seaboard of the United States do not expand in the method, it may not be suitable for evaluating those aggregates.

To establish appropriate criteria, a wide range of aggregates with known performance histories should be tested to determine whether expansions in P214 can be used to discriminate between deleteriously and nondeleteriously reactive aggregates. At the present time, appropriate limits cannot be established that would allow the use of P214 as a specification tool for Virginia aggregates.

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