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COLORADO REACTIVE AGGREGATE

Dick Hines
Colorado Department of Highways
4340 East Louisiana Avenue
Denver, Colorado 80222

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16. Abstract

Reactive aggregates are a major cause of deterioration of concrete pavements in Colorado. These aggregates react with the alkali in the cement to form a gel. This gel absorbs water and expands, causing cracking and spalling of the concrete.

In this study, tests to identify reactive aggregates were applied to Colorado aggregates. The mortor bar test proved to be the most useful test.

The common remedial measures for reactive aggregate are low alkali cement and class F flyash.

These measures were very effective in reducing expansion. Crushed concrete showing reactive distress from I-70 and I-76 showed low expansion indicating recycle would not be a problem.

Implementation

CDOH specifications now require low alkali cement in all concrete. Class F flyash is required in pavements where reactive aggregate have been a problem.

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I. PROBLEM STATEMENT

A major source of Portland Cement Concrete Pavement deterioration in Colorado is reactive concrete aggregates. A reaction takes place between the cement and concrete aggregates from some sources. This reaction causes expansion within the concrete which can lead to pavement cracking and break-up.

Cracking and deterioration of concrete pavements in Colorado due to reactive aggregates is well documented. I-25, I-76 and I-70 north and east of Denver show extensive distress due to reactive aggregate. Several structures show cracking which may be the result of alkali-silica reactivity.

II. OBJECTIVES OF THE STUDY

There were two primary objectives in this study. The first was to verify the existing methods of detecting whether or not a reactive aggregate problem exists for a given material source. This may result in some modifications of the various tests to accommodate materials and conditions present in Colorado. Secondly, the study was to evaluate readily available fly ashes (pozzlans) and low alkali cements for effectiveness on controlling the reactivity. In view of the present day energy and environmental restrictions on production of low-alkali cement and the governmental push towards using fly ash by-product, this second objective was "in tune" with the desires of all.

A secondary objective was identification of reactive aggregate material sources and low and high alkali content sources of cement. Due to the limited scope of this research only a limited number of aggregates were tested. One high alkali cement and one low alkali cement were used in the testing to simplify comparisons.

Among the aggregates tested were crushed concrete from two existing pavements. For clarity this testing is discussed separately from the testing of virgin aggregates.

III. BACKGROUND

Amorphous silica in some aggregates reacts with the alkali from the cement to form a gel. Over time this gel absorbs water and expands causing cracking of the concrete. Factors affecting the occurrence and severity of this problem include aggregate, the cement, fly ash, and the presence of water.

The most dependable way to identify reactive aggregates is to review performance of concrete made with the aggregate. If sufficient historical data is not available, tests may be conducted on the aggregate to predict reactivity problems. The three common tests used to identify reactive aggregates are listed below:

Mortar Bar Method	ASTM C-277
Chemical Method	ASTM C-289
Petrographic Exam	ASTM C-295

In the "Mortar Bar Method" bars are molded using the aggregate in question. These bars are stored at 100°F and at 100% humidity. Expansion is monitored for one or more years. Excessive expansion indicates that the aggregate-cement combination used in the bars will produce concrete that is subject to deterioration from alkali-silica reactivity. This test is the best predictor of problems if sufficient time is available. It may also be used to evaluate the effectiveness of remedial measures.

For the "Chemical Method" the aggregate is finely crushed and immersed in sodium hydroxide solution. Reduction of alkalinity and dissolved silica are measured. Potential reactivity is estimated using a chart. The chemical method is quick but is not a dependable predictor.

A "Petrograph Exam" is conducted by a professional qualified by education and experience to identify rocks and minerals. The aggregate in question is examined to establish the presence and approximate percentage of minerals known to be reactive with alkalies in cement. Cores from existing concrete may be examined for the presence of cracks and minerals associated with reactivity. This exam is quick and is a good predictor but requires an expert and provides only qualitative results.

The common remedial measures for reactive aggregate are the use of low alkali cement and/or Class F fly ash. Low alkali cement contains less alkali to react with the silica. Class F fly ash provides amorphous silica that reacts with the alkali in a harmless manner.

The "Admixture Effectiveness" test (ASTM C-441) measures the effectiveness of mineral admixtures, such as fly ash, in reducing expansion due to an alkali-silica reaction. In this test mortar bars are molded using pyrex glass as the aggregate. Pyrex glass is very reactive and yields quick and repeatable results. Three bars are molded using straight high alkali cement and three are molded with fly ash replacing 25% of the cement. The bars are stored at 100°F and at 100% humidity for 14 days. Expansion over this period is monitored and expansion for bars with fly ash are compared to that for bars with straight cement. It is required that expansion of fly ash bars not exceed 0.020% and that expansion be reduced by 75% or more when compared to the bars molded from straight cement.

IV. WORK PLAN

The work plan was divided into three parts as follows:

A. Aggregate Testing

Mortar bar tests were conducted on aggregate from several sources. For some aggregates three sets of bars were molded to examine the effect of the alkali content of the cement and the effect of fly ash. In these instances one set of bars was molded using high alkali cement, one with low alkali cement, and one with low alkali partially replaced with Class F fly ash.

Petrographic examinations were conducted on aggregates from four sources.

All aggregates included in this study were tested using the Chemical Method.

B. Admixture Testing

Four Class F flayshes were tested using the admixture effectiveness test. The effect of low alkali cement was also examined by molding one set of bars with low alkali cement replacing the high alkali cement used in the control bars.

C. Recycle of Existing Concrete Pavement

Concrete from two existing concrete pavements were tested using the mortar bar test. In each case the existing pavement showed severe reactive aggregate distress. Various remedial measures were applied including low alkali cement, Class F fly ash, and innocuous fine aggregate.

V. DISCUSSION OF TEST RESULTS

A. Aggregate Testing

Aggregate from the Three Bells Pit, on the Cauche la Poudre river near Windsor, was examined using the mortar bar test. Existing concrete pavements constructed using aggregates from this area show moderate to severe reactive aggregate distress. This pit was the aggregate source for two thick concrete overlays recently placed on I-25. Test results are shown in Table 1. With high alkali cement and no fly ash expansion was observed quickly, which would indicate that distress is likely for this combination of materials. Note that low alkali cement reduces expansion substantially. The substitution of Class F fly ash for 20% of the low alkali cement reduces expansion even more.

Four aggregate sources, which supply most of the aggregate in the Denver Metro area, were examined using the mortar bar test. The bars were molded using high alkali cement and no fly ash to see how these aggregates performed with no remedial measures. the results indicate that none of these sources are reactive (see Table 2). A petrographic examination was conducted on aggregate from each of these four sources by Dave Stark of the Portland Cement Association (PCA)(Appendix A). All of the aggregates were determined to be non-reactive. Historically, pavements in the Denver Metro area have not exhibited reactive aggregate distress. Thus, for these four aggregates we have agreement between the mortar bar test, petrographic exams, and historical results.

All five aggregate discussed above were identified as innocuous by testing using the Chemical Method.

B. Admixture Testing

The admixture effectiveness test was conducted on the four Class F fly ashes commonly used in Colorado. In addition, low alkali cement replaced the high alkali cement in one set of bars to determine the effect. The results are shown in Table 3. The fly ashes reduced expansion by 57% to 84%. Two of the four fly ashes meet the test criteria of a 75% reduction of expansion. Use of low alkali cement yielded the most dramatic reduction of expansion of over 96%.

Table 1 - Three Bells Mortar Bar Results

Materials			
Cement Source	Martin-Marietta, Lyons		
Cement Type	I	II	II
Alkali	High	Low	Low
Fly ash	None	None	20% Cherokee-F
Aggregate Source		3 Bells Sterling IR25-3(77)	

% Increase in Mortar Bar Length

Age			
14 days	0.052	0.007	0.005
1 month	0.036	0.002	0.007
2 months	0.039	0.012	0.010
3 months	0.041	0.013	0.011
4 months	0.041	0.014	0.011
6 months	0.041	0.012	0.009
1 year	0.040	0.014	0.011

Table 2 - Denver Aggregates Mortar Bar Results

Materials				
Cement Source	Martin-Marietta, Lyons			
Cement Type	I	I	I	I
Alkali	High	High	High	High
Fly ash	None	None	None	None
Aggregate Source	MPM spec aggregates	Hulcher, Fairplay	Cooley-Morrison	Cooley-Littleton
Size	3/4"	3/4"	3/4"	3/4"

Age	% Increase in Mortar Bar Length			
14 days	0.005	0.006	0.007	0.005
1 month	0.004	0.011	0.008	0.008
2 months	0.010	0.011	0.011	0.012
3 months	0.010	0.011	0.010	0.012
4 months	0.010	0.013	0.010	0.012
6 months	0.010	0.011	0.011	0.013
1 year	0.010	0.011	0.011	0.013

Table 3 - Admixture Effectiveness

Test Results
ASTM C-441

Effectiveness of Mineral Admixtures in Preventing Excessive Expansion of Concrete due to the Alkali-Aggregate Reaction.

Materials

Cement Source	Martin-Marietta					
Cement Type	I	II	I	I	I	I
Alkali	high	low	high	high	high	high
Fly ash, Class F	none	none	Jim Bridger	Cherokee	Craig	Nixon
Aggregate Source				CRUSHED PYREX GLASSES		

Age	E_R			E_T		
14 days	0.354	0.012	0.149	0.013	0.055	0.076
4 months	0.568	0.099	0.212	0.143	0.085	0.139
14 months	0.566	0.018	0.215	0.145	0.089	0.147
Re (%)	Control	96.6	57.9	68.1	84.7	78.5

$$Re = \frac{(E_R - E_T) \times 100}{E_R}$$

Where:

Re = Reduction of mortar expansion, %

E_T = Average expansion of mortar bars from the test mixture

E_R = Average expansion of mortar bars from the control mixture

C. Recycle of Existing Concrete Pavement

The first source of crushed concrete examined was the pavement on I-70 between Burlington and Bethune. This pavement exhibits severe reactive aggregate distress. The bars molded using this concrete were 3 inch squares and were stored in a tank with a loose-fitting metal lid. All other mortar bar testing was conducted using 1 inch square bars stored in five gallon plastic paint containers. One set of bars was molded using fine aggregate from the Ready-Mixed pit and two with fine aggregate from the Kuhn pit: one with fly ash and one without. The Kuhn sand is considered to be reactive and the Ready-Mixed sand non-reactive. The results are shown in Table 4. All combinations show either slight contraction or slight expansion which indicates that recycle of this concrete should not be a problem. Contraction observed in some cases may be the result of drying of the bars because the tanks was not adequately sealed. This is why plastic paint containers were used in all subsequent testing. These containers provide a very effective seal which is required to maintain 100% humidity around the bars.

The second source of crushed concrete was I-76 northeast of Sterling. This pavement shows severe reactive aggregate distress. Fine aggregate for all bars was obtained from the McAtee - Willard Pit located southwest of Sterling. Aggregate from this source are considered to be reactive. One set of bars was molded with high alkali cement and three with low alkali cement. For two sets class F fly ash was substituted for the 20% low alkali cement and for one of these sets the concrete was washed. Results are shown in Table 5. All bars indicate that recycle of this concrete should not be a problem. Bars molded using the washed concrete showed the greatest expansion. This is surprising because it was thought that washing the concrete would reduce expansion by removing alkali or gel.

Table 4 - Recycle of I-70 Concrete Mortar Bar Results

Cement	*Portland II	Portland II	Portland II
Fly ash	None	None	None
Sand	Kuhn	Ready-Mixed	Kuhn
Coarse Agg.	Crushed Conc.	Crushed Conc.	Crushed Conc.

% Increase in mortar bar length (3" square bars)

Age			
14 days	0.004	0.009	-0.007
1 month	0.010	0.0005	0.010
2 months	-0.013	-0.013	-0.003
3 months	-0.002	-0.011	0.007
4 months	-0.015	-0.020	-0.001
6 months	0.0005	-0.004	0.011
1 year	-0.013	-0.008	0.001
16 months	-0.009	-0.007	0.005

* low alkali

Table 5 - Recycle of I70 Concrete Mortar Bar Results

Materials

Cement Source	Martin-Marietta, Lyons			
Cement Type	I	II	II	II
Alkali	High	Low	Low	Low
Fly ash	None	None	20% Cherokee Class F	
Sand				McAtee Willard
Coarse Aggregate	Crushed Concrete from I76-Sterling			washed, crushed concrete

% Increase in Mortar Bar Length

Age				
14 days	0.019	0.021	0.016	0.023
1 month	0.026	0.025	0.016	0.027
2 months	0.027	0.026	0.017	0.027
3 months	0.027	0.026	0.017	0.028
4 months	0.027	0.026	0.017	0.032
6 months	0.027	0.027	0.018	0.031
1 year	0.029	0.028	0.020	0.034

VI. Conclusions

These results confirm that the mortar bar test is the most useful approach to evaluate reacting aggregates. This test correctly identified the Three Bells aggregate as reactive and four Denver Metro aggregate sources as innocuous. This agrees with historical results and petrographic exams of Denver Metro aggregates.

Mortar bar tests substantiate the effectiveness of low alkali cement and class F fly ash as remedial measures for reactive aggregate. For the Three Bells aggregate and the pyrex glass, the remedial measures reduced the expansion substantially.

The Chemical Method identifies all of the aggregates in this study as innocuous. This is wrong in the case of the Three Bells aggregate. In the past, this test has incorrectly identified many reactive aggregates as innocuous.

For the two sources of crushed concrete examined in this study residual reactivity does not appear to be a problem. It is likely that most of the expansion has already taken place.

VII. Implementation

CDOH specifications have recently been modified to require that all portland cement be low alkali. In addition, class F fly ash is required in all concrete pavement constructed in areas where reactive aggregate has been a problem. (see Appendix B)

References

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EXAMINATION OF AGGREGATE FROM COLORADO

by

David Stark*

INTRODUCTION

The Colorado Department of Highways has requested Construction Technology Laboratories (CTL) to examine seven samples of aggregate for potential for deleterious alkali-silica reactivity. Ten to 15 lbs of each sample were received in capped plastic 6 by 12-in. concrete cylinder molds, with the sample designation of each written on the cylinder.

The examination was conducted in accordance with ASTM Designation: C 295-79 Standard Practice for Petrographic Examination of Aggregates for Concrete. Procedures used were those required to identify for potential reactivity the various rock and mineral types present. This included examination of individual aggregate particles under a low power stereomicroscope, and examination of powder mounts in the petrographic microscope. Based on this work, judgment was made on whether those components would be potentially reactive in concrete.

*Principal Research Petrographer, Concrete Materials Research Department, Construction Technology Laboratories, a Division of the Portland Cement Association, 5420 Old Orchard Road, Skokie, Illinois 60077.

RESULTS

Results of the examination are summarized in Table 1. Brief petrographic descriptions are provided in the table for each sample, together with a judgment on whether the aggregates are considered to be potentially reactive.

As indicated in the table, each of the seven samples is not considered to be potentially reactive when used as aggregate in concrete. All were similar in that they were composed primarily of feldspar-rich igneous rock types in the range of granite to diorite, grading into rocks of similar composition with a banded or gneissic texture. The latter textures indicate some degree of metamorphism. Known reactive materials such as opal, chalcedony, and certain volcanic glasses and schistose rocks, were not detected in the examination.

TABLE 1 - SUMMARY OF EXAMINATION OF AGGREGATES

Source	Size Designation	Description	Judgment on Reactivity Potential
Hulcher Fairplay Pit	1-1/2 in.	Sample consisted of estimated 65 to 75% igneous intrusive rock types of granitic to dioritic composition, and 20 to 30% granite to diorite gneiss. Less than 5% of the sample consisted of feldspar-rich particles, probably of igneous origin. A trace of limestone also was present. A few particles carry partial coatings of calcite.	Non-reactive
	3/4 in.	Sample was similar to the 1-1/2 in. size. It was estimated to contain 75 to 85% granitic to dioritic rock types of igneous origin, plus about 15 to 25% of gneissic rocks of similar composition. Less than 5% of the sample consisted entirely of feldspar particles.	Non-reactive
Mobile Pre Mix Spec. Aggr.	1-1/2 in.	Sample consisted entirely of crushed granitic to dioritic rock types of igneous origin, grading into metamorphic rock types, as evidenced by a banded or gneissic texture. A few particles carry partial coatings of calcite.	Non-reactive
	3/4 in.	Sample was similar to the 1-1/2 in. size. None of the particles carried calcite coatings.	Non-reactive
Cooley Morrison Pit	1-1/2 in.	Sample consisted entirely of crushed granitic to dioritic rock types primary of igneous origin, grading into metamorphic rock types of similar composition, but which display a banded or gneissic texture.	Non-reactive
	3/4 in.	Sample was similar to the 1-1/2 in. size.	Non-reactive
Cooley Littleton Pit	Sand	Sample consisted of an estimated 85 to 90% feldspar, and about 5 to 10% fragments of granitic rock types composed primarily of feldspar. Less than 2% of the sample consisted of quartz and hornblende with traces of mica.	Non-reactive

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SPECIFICATION REQUIRING FLY ASH IN COLORADO PAVEMENT

The Contractor shall include Type F Fly Ash in any class of concrete shown in this section. The quantity of Type F Fly Ash shall be equal to 20 percent of the weight of cement and shall be included in addition to the full weight of cement shown in the Concrete Table in subsection 601.02 for any given class.