# Experiments With Alkali-Silica Reactive Constituents of Sand-Gravel Aggregate

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•CONCRETE made with a certain type of natural aggregate, known as sand-gravel aggregate, from the Kansas-Nebraska area and adjoining states is known to undergo a characteristic cement-aggregate reaction resulting in expansion, cracking, and early deterioration. Such aggregates can be recognized by petrographic examination. Investigations by the Bureau of Reclamation and other organizations have shown that satisfactory concrete can be made with sand-gravel aggregates if a low-alkali cement and a suitable crushed limestone coarse aggregate are used.

Although investigators have cited many factors as involved in this cement-aggregate reaction, the cause of the deterioration is still not well understood. Possible explanations ascribe it to (a) an essentially alkali-silica reaction, (b) an alkali-silica reaction aggravated by various other factors, (c) a variety of other causes with a minor, if any, contribution from alkali-silica reaction, and (d) an as yet undefined chemical or physical phenomenon.

The term "cement-aggregate reaction" as used in this paper refers to the processes responsible for the expansive cracking and deterioration of concrete experienced in the use of sand-gravel aggregate in the Kansas-Nebraska area. The term "alkali-silica reaction" is restricted to the alkali-silica reaction process involving the known potentially deleteriously alkali-reactive siliceous aggregate constituents (including opal, chalcedony, certain microcrystalline and cryptocrystalline forms of quartz, tridymite, cristobalite, and acidic to intermediate volcanic glass).

Previous Bureau of Reclamation investigations (1) have concluded in part:

1. Alkali-aggregate reaction is a major cause of expansive cracking and deterioration of concrete made with the generally highly reactive sand-gravel aggregates from the Kansas-Nebraska area.
2. Percent expansion increases sharply with both moderately and highly reactive aggregates when the alkali content of the cement, computed as $Na_2O$ equivalent, reaches about 0.5 percent.
3. Drying shrinkage is another cause of cracking . . . some of the deterioration can be attributed to enlargement of cracks by freezing and thawing action.
4. A coarse-ground cement is less likely to produce deleterious expansion in field concrete than a fine-ground cement.

Literature on this subject (2 through 9) has mentioned a variety of other factors, including the following.

1. Effects of cement brand and type;
2. Expansion considered as a function of alkali content of cement;
3. Expansion considered as not a function of cement alkali content;
4. Release of alkalies from cement;
5. Release of alkalies from aggregate;
6. Quantity and rate of release of calcium hydroxide during hydration of cement;
7. Delayed hydration of free magnesia in cement;
8. Effect of internal fracturing on volume stability of concrete;

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9. Surface texture and bonding characteristics of aggregate;
10. Effects of feldspar in aggregate due to low coefficient of thermal expansion of feldspar, poor bond of smooth surface grains with cement, and high rigidity or low compressibility; and
11. An as yet undefined chemical or physical phenomenon.

Cement-aggregate reaction would, therefore, appear to be due to a combination of factors, rather than to a single causative factor. Alkali-silica reaction is likely to be a major factor in some sand-gravel aggregates; however, not all sand gravels are known to be alkali-silica reactive.

## OBJECTIVE OF PILOT EXPERIMENTS

Since cement-aggregate reaction is associated with a sand-gravel aggregate, the Bureau of Reclamation has undertaken a laboratory test program to study the characteristics of sand-gravel aggregates, and to determine what effect the various rock types and mineral constituents of the aggregate have on the cement-aggregate reaction.

Pilot experiments were conducted to determine the effects of alkali-silica reactive aggregate constituents on cement-aggregate reaction, as measured by mortar bar expansion tests. The sealed moist-storage mortar bar expansion test is used as a measure of alkali-silica reactivity, and the Conrow cycle mortar bar expansion test is used as a measure of cement-aggregate reaction. Both mortar bar expansion tests were made with the natural Republican River aggregate, and with Republican River aggregate processed to remove the alkali-silica reactive constituents. As a control, both mortar bar tests were made with a lithologically somewhat similar nonalkali reactive South Platte River aggregate. Tests were made with the natural aggregate, and with the aggregate blended with the alkali-silica reactive constituents removed from the Republican River aggregate.

## AGGREGATES

### Republican River Aggregate

Republican River aggregate from a source near Indianola, Nebraska, is a typical alkali-silica reactive sand-gravel. This aggregate, used in the past in many Bureau laboratory studies (1), contains alkali-silica reactive particles, has a poor service record, and produces reactive expansion in both the sealed moist-storage and Conrow cycle mortar bar expansion tests.

The aggregate is composed chiefly of individual grains of feldspar and quartz, with some granite, and minor limestones and ferruginous concretions. The fine sand also contains small amounts of hornblende, magnetite, garnet, mica, and, in the pan-size, minor amounts of acidic volcanic glass, chert, and opal. A few particles are partially coated with thin, firmly bonded calcium carbonate, and very few are coated with opal. The alkali-silica reactive constituents—limestones and sandy limestones containing opal, cherts, andesites, and particles of opal and acidic volcanic glass—constitute about 6 percent of the sand. A particle count of the sand retained on the No. 8 sieve showed 35 percent feldspar, 33 percent quartz, 23 percent granite, 7 percent alkali-silica reactive particles, and 2 percent miscellaneous minor constituents.

## SOUTH PLATTE RIVER AGGREGATE

The South Platte River aggregate, from a source near Denver, Colorado, is not considered a sand-gravel aggregate, but bears many similarities to sand-gravels. The chief constituents are similar to those of Republican River aggregates. However, the South Platte River aggregate does not contain opaline particles, is not alkali-reactive, and has a generally satisfactory service record. The aggregate does not produce reactive expansion in either the sealed moist-storage or Conrow cycle mortar bar expansion tests.

The South Platte River aggregate is composed chiefly of granite and coarse-grained quartz and feldspar particles, with minor gneiss, schist, sandstone, devitrified andesite and rhyolite, shale, and ferruginous particles. The coarse sand contains about 75 percent quartz and feldspar particles in approximately equal amounts. The finer sand contains increasing amounts of quartz and lesser feldspar, with minor detrital minerals that include garnet, mica, and magnetite. Glassy rhyolite is the only alkali-reactive constitutent observed, and constitutes only trace amounts, much less than 1 percent in the sand. No opal was detected.

## TEST PROCEDURES

The sealed moist-storage mortar bar expansion test is a routine test employed by the Bureau to test for alkali-reactivity of aggregates. The Bureau's procedure for the test is similar to ASTM Method C-227-61T. Linear expansion of the mortar bars in excess of 0.2 percent in 1 yr indicates a deleteriously alkali-reactive aggregate; expansion of 0.1 to 0.2 percent in 1 yr is potentially deleteriously alkali-reactive; and an expansion of 0.04 to 0.1 percent is regarded with suspicion concerning alkali-reactivity.

The Conrow cycle mortar bar expansion test was devised for the purpose of testing sand-gravel type aggregates in the Kansas-Nebraska area. The Bureau's procedure for the test is similar to ASTM Method C-342-61T. The expansion criteria used by the Bureau are the same as those used for the sealed moist-storage expansion test.

The methods used to remove the alkali-silica reactive particles from the Republican River aggregate included handpicking, hydraulic jigging, heavy liquid separation, and an acid treatment and washing procedure. The alkali-reactive particles are chiefly opaline particles of low specific gravity, and are generally amenable to separation from the denser constitutents of the aggregate, chiefly quartz and feldspar. Opal occurs occasionally in limestones and calcareous sandstones. These particles can be decomposed in dilute hydrochloric acid, and the resultant fines, which will include the opal, can be removed by washing.

The weight loss from processing the samples was recorded. The material removed by processing was collected and blended with the South Platte River aggregate in amounts proportional to the amounts removed from the Republican River aggregate.

The mortar bar tests with the processed Republican River and the blended South Platte River aggregates differed from the routine Bureau procedure in two ways:

1. Only one bar for each mixture was used, instead of the customary three bars.
2. The grading was a straight 19 percent by weight retained on sieves No. 8, 16, 30, 50, and 100 plus 5 percent of material passing the No. 100 sieve.

Only one bar for each mixture could be made because of the time spent in processing the Republican River aggregate to remove the alkali-reactive constituents.

## RESULTS OF MORTAR BAR EXPERIMENTS

### Sealed Moist-Storage Mortar Bar Expansion Test

The natural Republican River aggregate produces deleterious expansion with high- and medium-alkali cements (Table 1). A summary of previous tests, given in Table 2,

TABLE 1

SEALED MOIST-STORAGE MORTAR BAR EXPANSION TEST
Republican River Sand

| Cement | Alkali $Na_2O$ Equiv. (%) | Expansion (%) | | | |
|---|---|---|---|---|---|
| | | Processed Sand[a] | | Natural Sand[b] | |
| | | 1 Yr | 2 Yr | 1 Yr | 2 Yr |
| 7488 | 1.19 | 0.054 | 0.070 | 0.303 | 0.337 |
| M-3100 | 0.50 | 0.045 | 0.071 | 0.152 | — |
| M-3727 | 0.41 | — | — | 0.165 | 0.263 |
| 9406 | 0.16 | 0.013 | 0.013 | — | — |

[a]Alkali-reactive particles removed. [b]Contains alkali-reactive particles.

TABLE 2

SUMMARY OF PREVIOUS SEALED MOIST-STORAGE MORTAR BAR EXPANSION TESTS
Republican River Sand

| Cement | Alkali $Na_2O$ Equiv. (%) | Expansion (%) | |
|---|---|---|---|
| | | 1 Yr | 2 Yr |
| M-3562 | 1.23 | 0.215 | 0.282 |
| M-3562 | 1.23 | 0.183 | 0.248 |
| M-3562 | 1.23 | 0.168 | 0.200 |
| M-3562 | 1.23 | 0.190 | 0.207 |
| 7488 | 1.19 | 0.235 | 0.250 |
| 7488 | 1.19 | 0.254 | — |
| 7488 | 1.19 | 0.303 | 0.337 |
| 7488 | 1.19 | 0.285 | 0.327 |
| 7488 | 1.19 | 0.276 | 0.286 |
| 7488 | 1.19 | 0.264 | — |
| 7488 | 1.19 | 0.264 | 0.278 |
| 7488 | 1.19 | 0.307 | 0.337 |
| 7488 | 1.19 | 0.270 | — |
| 7488 | 1.19 | 0.287 | — |
| 7488 | 1.19 | 0.292 | — |
| 7488 | 1.19 | 0.308 | 0.334 |
| 7488 | 1.19 | 0.228 | 0.260 |
| 7488 | 1.19 | 0.225 | 0.273 |
| 7488 | 1.19 | 0.293 | 0.321 |
| 7488 | 1.19 | 0.342 | 0.365 |
| 7488 | 1.19 | 0.251 | 0.267 |
| 7488 | 1.19 | 0.291 | 0.341 |
| 7488 | 1.19 | 0.176 | 0.219 |
| 7488 | 1.19 | 0.262 | 0.272 |
| M-3527 | 0.92 | 0.222 | — |
| M-3052 | 0.87 | 0.277 | — |
| 2448 | 0.58 | 0.340 | 0.440 |
| 2448 | 0.58 | 0.330 | 0.470 |
| 2448 | 0.58 | 0.303 | 0.406 |
| 2448 | 0.58 | 0.286 | 0.382 |
| M-3100 | 0.50 | 0.173 | — |
| M-3100 | 0.50 | 0.152 | — |
| 8518 | 0.49 | 0.058 | 0.081 |
| M-3727 | 0.41 | 0.165 | 0.263 |
| 2735 | 0.13 | 0.017 | 0.026 |

shows this aggregate to be fairly consistent in producing deleterious expansion with high- and medium-alkali cement (one exception noted).

Removal of the alkali-reactive particles from the Republican River aggregate reduced expansion to within safe test limits (Table 1). The maximum expansion recorded in this series of tests was 0.071 percent at 2 yr, indicating only a mild expansion.

The natural South Platte River aggregate does not produce deleterious expansion with high-, medium-, or low-alkali cements (Table 3). Blending the alkali-reactive particles removed from the Republican River aggregate produced less definitive results, but did show some increase in expansion over that obtained with the natural South Platte River aggregate (Table 3). Results were most pronounced with the mixture using a medium-alkali cement, which showed an expansion of 0.110 percent at 1 yr.

## Conrow Cycle Mortar Bar Expansion Test

The natural Republican River aggregate produces deleterious expansion with high-, medium-, and low-alkali cements (Table 4). A summary of previous tests shows that the natural Republican River aggregate consistently produces deleterious expansion with high-, medium-, and low-alkali cements (Table 5).

The processed Republican River aggregate (alkali-reactive constituents removed) showed some anomalous results, although

TABLE 3

SEALED MOIST-STORAGE MORTAR BAR EXPANSION TEST
South Platte River Aggregate

| Cement | Alkali $Na_2O$ Equiv. (%) | Expansion (%) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Blended Sand[a] | | Natural Sand[b] | | Natural Crushed Gravel | |
| | | 1 Yr | 2 Yr | 1 Yr | 2 Yr | 1 Yr | 2 Yr |
| 7488 | 1.19 | 0.067 | 0.081 | 0.031 | 0.037 | 0.028 | 0.029 |
| | | | | 0.032[c] | 0.040 | 0.032[c] | 0.037 |
| | | | | 0.034[d] | 0.044 | 0.030[d] | 0.034 |
| M-3100 | 0.50 | 0.110 | 0.122 | 0.020 | 0.023 | 0.023 | 0.022 |
| M-3727 | 0.41 | — | — | 0.010 | 0.008 | 0.008 | 0.008 |
| 9406 | 0.16 | 0.012 | 0.032 | — | — | — | — |

[a]Contains alkali-reactive particles.
[b]No alkali-reactive particles.
[c]Fifty percent of aggregate replaced with innocuous quartz sand.
[d]Seventy-five percent of aggregate replaced with innocuous quartz sand.

TABLE 4

CONROW CYCLE MORTAR BAR EXPANSION TEST
Republican River Sand

| Cement | Alkali $Na_2O$ Equiv. (%) | Expansion (%) Processed Sand[a] | | Natural Sand[b] | |
|---|---|---|---|---|---|
| | | 1 Yr | 2 Yr | 1 Yr | 2 Yr |
| 7488 | 1.19 | 0.056 | 0.074 | 0.729 | 0.754 |
| M-3100 | 0.50 | 0.307 | 0.336 | 0.753 | 0.770 |
| M-3727 | 0.41 | — | — | 0.206 | — |
| 9406 | 0.16 | 0.215 | 0.248 | 0.328 | 0.371 |

[a]Alkali-reactive particles removed.
[b]Contains alkali-reactive particles. See Table 5 for additional test results with these and other cements.

TABLE 5

SUMMARY OF PREVIOUS CONROW CYCLE MORTAR BAR EXPANSION TESTS
Republican River Sand

| Cement | Alkali $Na_2O$ Equiv. (%) | Expansion (%) 1 Yr | 2 Yr |
|---|---|---|---|
| 7488 | 1.19 | 0.729 | 0.754 |
| 7488 | 1.19 | 0.550 | — |
| M-2595 | 0.67 | 0.984 | 0.993 |
| M-3100 | 0.50 | 0.753 | 0.770 |
| M-3100 | 0.50 | 0.683 | — |
| M-3100 | 0.50 | 0.500 | — |
| M-3100 | 0.50 | 0.442 | — |
| M-3100 | 0.50 | 0.763 | — |
| M-3727 | 0.41 | 0.206 | — |
| M-2991 | 0.44 | 1.208 | 1.036 |
| 9406 | 0.16 | 0.328 | 0.371 |
| 9406 | 0.16 | 0.194 | — |
| 9406 | 0.16 | 0.172 | — |
| 9406 | 0.16 | 0.191 | — |
| 2735 | 0.13 | 0.874 | 0.884 |
| 2735 | 0.13 | 0.514 | — |
| 2735 | 0.13 | 0.403 | — |

in all cases the expansion was significantly lower than the corresponding expansion obtained with natural Republican River aggregate. The expansions obtained with medium- and low-alkali cements were still sufficient to indicate deleterious expansion according to the test criteria. The high-alkali cement did not produce deleterious expansion.

The natural South Platte River aggregate does not show deleterious expansion in the Conrow cycle test (Table 6). Mortar bar tests with the high-alkali cement were not made, but would not be expected to show significant expansion.

The blended South Platte River aggregate (containing the alkali-reactive particles removed from the Republican River aggregate) showed deleterious expansion in the Conrow cycle test with medium- and high-alkali cement (Table 6). The low-alkali cement did not produce significant expansion.

TABLE 6

CONROW CYCLE MORTAR BAR EXPANSION TEST
South Platte River Aggregate

| Cement | Alkali $Na_2O$ Equiv. (%) | Expansion (%) Blended Sand[a] | | Natural Sand[b] | | Crushed Natural Gravel | |
|---|---|---|---|---|---|---|---|
| | | 1 Yr | 2 Yr | 1 Yr | 2 Yr | 1 Yr | 2 Yr |
| 7488 | 1.19 | 0.478 | 0.540 | — | — | — | — |
| M-3100 | 0.50 | 0.201 | 0.229 | 0.082 | — | 0.022 | — |
| M-3727 | 0.41 | — | — | 0.022 | — | 0.014 | — |
| 9406 | 0.17 | 0.024 | 0.027 | 0.021 | — | 0.016 | — |

[a]Alkali-reactive particles added. [b]Contains no alkali-reactive particles.

TABLE 7

SUMMARY OF CHEMICAL COMPOSITION OF CEMENTS

| Chemical Analysis \ Cement No. and Type | 3562 II High Alkali | 7488 II High Alkali | M-3257 I High Alkali | M-3052 II High Alkali | M-2595 II High Alkali | 2448 Medium Alkali | M-3100 II Medium Alkali | 8518 II Medium Alkali | M-2991 II Medium Alkali | M-3727 II Medium Alkali | 9406 II Low Alkali | 2735 II Low Alkali |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total alkalies as $Na_2O$: | 1.23 | 1.19 | 0.918 | 0.87 | 0.67 | 0.58 | 0.50 | 0.49 | 0.439 | 0.41 | 0.16 | 0.13 |
| $Na_2O$ | 1.20 | 1.16 | 0.26 | 0.84 | 0.27 | 0.30 | 0.23 | 0.22 | 0.13 | 0.07 | 0.03 | 0.04 |
| $K_2O$ | 0.04 | 0.04 | 1.00 | 0.04 | 0.61 | 0.42 | 0.41 | 0.39 | 0.47 | 0.51 | 0.20 | 0.14 |
| MgO | 1.51 | 1.58 | 3.77 | 1.95 | 1.50 | 1.36 | 2.69 | 1.11 | 1.64 | 1.0 | 1.68 | 1.30 |
| CaO | 63.42 | 63.85 | 62.05 | 62.91 | 62.86 | 64.46 | 62.86 | 63.88 | 63.46 | — | 62.89 | 64.78 |
| $SiO_2$ | 21.39 | 21.66 | 21.84 | 21.63 | 21.60 | 23.16 | 22.72 | 21.72 | 22.10 | 22.2 | 22.13 | 22.00 |
| $Al_2O_3$ | 4.78 | 5.58 | 5.31 | 5.64 | 5.11 | 4.39 | 4.70 | 5.76 | 5.16 | 4.7 | 5.88 | 4.52 |
| $Fe_2O_3$ | 4.08 | 2.54 | 2.33 | 2.89 | 4.85 | 3.84 | 3.28 | 4.43 | 4.44 | 4.1 | 4.28 | 3.81 |
| $SO_3$ | 1.67 | 2.10 | 2.37 | 2.72 | 1.81 | 1.22 | 1.86 | 1.35 | 1.72 | 1.9 | 2.10 | 1.60 |
| Free lime | 0.33 | — | — | — | — | 0.22 | — | — | — | | — | 0.44 |
| Compound composition (%): | | | | | | | | | | | | |
| $C_3S$ | 52.74 | 48.1 | 40.79 | 41.09 | 45.3 | 46.9 | 41.60 | 45.99 | 44.39 | 46.0 | 36.1 | 54.2 |
| $C_2S$ | 21.56 | 25.9 | 31.93 | 30.51 | 27.9 | 31.1 | 33.84 | 27.65 | 29.96 | 28.0 | 36.2 | 22.3 |
| $C_3A$ | 5.75 | 10.5 | 10.13 | 10.07 | 5.3 | 5.1 | 6.91 | 7.74 | 6.17 | 6.0 | 8.3 | 5.5 |
| $C_4AF$ | 12.40 | 7.7 | 7.08 | 8.79 | 14.7 | 11.7 | 9.97 | 13.47 | 13.50 | 12.0 | 13.0 | 11.6 |
| $CaSO_4$ | 2.84 | 3.6 | 4.03 | 4.63 | 3.1 | 2.1 | 3.16 | 2.30 | 2.92 | — | 3.6 | 2.70 |
| $Mn_2O_3$ | 0.19 | | | | | 0.06 | | 0.27 | | — | — | 0.07 |
| $TiO_2$ | 0.26 | | | | | 0.25 | | | | — | — | 0.32 |
| $P_2O_5$ | 0.10 | | | | | 0.20 | | | | — | — | 0.12 |

## DISCUSSION

Sand-gravel aggregates from various sources in the Kansas-Nebraska area tested by the Bureau range from highly alkali-reactive to essentially nonalkali-reactive, but generally are alkali-reactive. So far as is known, no studies have been made to determine if the degree of distress in field concrete, or in laboratory concrete, or mortar bars, correlates with the alkali-reactivity of the aggregate. The published literature on the sand-gravel problem is of little assistance, as most references give little, if any, attention to the composition and alkali-reactivity of the aggregate.

Petrographic examination of alkali-reactive sand-gravels has shown the alkali-reactive constitutents to consist generally of a very small and variable amount of opaline particles, and also generally small and variable amounts of less reactive chert, volcanic glass, and acidic volcanic rocks.

The various sand-gravels tested by the Bureau usually produce deleterious expansion in the Conrow cycle mortar bar expansion test, but do not always show a deleterious expansion with the sealed moist-storage expansion test. For this reason, the Bureau employs the Conrow cycle test for testing sand-gravel aggregates.

The sealed moist-storage mortar bar expansion tests of Republican River aggregate fairly consistently show deleterious expansion with high- and medium-alkali cements. Deleterious expansions were obtained with two cements having alkali contents as low as 0.41 percent $Na_2O$ equivalent (Tables 1 and 2). Cements with very low alkali contents (0.16 and 0.13 percent $Na_2O$ equivalent) have not produced deleterious expansion. The expansions obtained do not show a linear relationship with alkali content, but do tend to show the sealed moist-storage test as an indicator of alkali-silica reaction. These test results on Republican River aggregate are similar to the experience with tests of other aggregates and mixtures containing small amounts of opal.

The Conrow cycle mortar bar expansion test appears to be fairly reliable in testing sand-gravel aggregates for deleterious expansion. The test produces excessive expansion with highly alkali-reactive sand-gravels, such as the Republican River aggregate under investigation here, and also with much less alkali-reactive sand-gravels from other sources. The Conrow cycle test is sensitive to alkali-silica reaction: the removal of the alkali-silica reactive particles from the Republican River aggregate reduced expansion in amounts ranging from 0.1 to 0.7 percent with the various cements. As a rough approximation, the data suggest that the alkali-silica reaction is responsible for up to about one-half of the expansion in the Conrow test. Conversely, the addition of alkali-reactive particles to the essentially inert South Platte River aggregate produced expansion in the Conrow test.

There are some questions regarding the deleterious expansion in the Conrow cycle test with essentially nonalkali-reactive sand-gravel aggregates, such as the processed Republican River aggregate used in this test. Is the expansion due to the presence of opal, occurring in such small amounts as to be either undetected by petrographic examination, or regarded as insignificant and indicated as innocuous by lack of expansion in the sealed moist-storage test? Or is the reaction due to some other reaction which apparently does not involve the alkali-silica reactive constituents, i.e., the hypothetical as yet unknown and undefined process different from alkali-silica reaction? Furthermore, another source of uncertainty is the fact that in situations such as these it is not well known if the degree of distress experienced in field concrete relates to expansion in laboratory tests.

Some differences in the appearance of mortar bar specimens from the sealed moist-storage and Conrow cycle tests have been observed. Bars from the sealed moist-storage test that develop deleterious expansion generally show cracking and some gel exudations. Bars from the Conrow cycle test that develop excessive expansion are generally of good appearance with very little, if any, visible cracking, despite the rather high expansions frequently obtained with the test. This might indicate that the reaction in the Conrow cycle test, even if it is essentially an alkali-silica reaction, may proceed along a different course than it does in the sealed moist-storage test.

## SUMMARY

A pilot series of experiments investigated the effect of alkali-silica reactive constituents in a sand-gravel aggregate in the sealed moist-storage and the Conrow cycle mortar bar expansion tests. A highly alkali-silica reactive sand-gravel from the Republican River was tested. This aggregate produces deleterious expansion in both the sealed moist-storage and the Conrow cycle mortar bar tests. The alkali-silica reactive particles were removed from the aggregate, and the processed aggregate was tested. The removal of the alkali-silica reactive particles reduced expansion in the sealed moist-storage test to within safe test limits. In the Conrow cycle test, expansion was reduced but a significant amount of expansion remained. The remaining expansion appears to be due to the characteristic cement-aggregate reaction of sand-gravel aggregates; however, the possibility of this expansion being due to an exceptionally small amount of alkali-reactive material remaining in the aggregate should not be overlooked.

As a control, the alkali-reactive constituents were blended with an innocuous South Platte River aggregate. The natural South Platte River aggregate does not produce deleterious expansion in either the sealed moist-storage or the Conrow cycle mortar bar expansion tests. The blended South Platte River aggregate produced some expansion in both the sealed moist-storage and the Conrow cycle mortar bar expansion tests.

These tests indicate that alkali-silica reaction is a major factor in the cement-aggregate reaction with alkali-silica reactive sand-gravel aggregates, but does not answer the entire question. The problem of cement-aggregate reaction with nonalkali-reactive sand-gravel aggregates, if such a problem exists, requires further investigation.

These tests also indicate that the Conrow cycle mortar bar expansion test is sensitive to alkali-silica reaction.

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