# Interpretation of Accelerated Test Method ASTM P214 Test Results

## Daniel P. Johnston

In South Dakota during the last decade, alkali-silica reactivity (ASR) has changed from a localized occurrence to a statewide problem. ASTM P214 was chosen as the preferred test for determining potential reactivity of sands used for concrete in the state. The test was modified to use different NaOH concentrations to explore the feasibility of using two different base strengths to better predict reactivity. Of 30 sands tested, over 40 percent gave results that were inconclusive (expansion values in the 0.1 to 0.2 percent range), and only 10 percent of the sands were nonreactive. A modified interpretation of the test results to include a best fit for expansion at 3, 7, 11, and 14 days, using the general equation $Y = A_2 X^2 + A_1 X + A_0$ ($X$ = Time $^{1/2}$) gave a much clearer pattern of projected reactivity when the $A_1$ coefficients were plotted against the $A_2$ coefficients for all 30 sands. The sands break out into two linear "families" of coefficients: one reactive and one nonreactive. It appears the method also can be used to determine the effectiveness of pozzolans at reducing ASR.

During the past decade in South Dakota, alkali-silica reactivity (ASR) has changed from a localized occurrence to a statewide problem, with a tremendous potential impact on the durability and expected service life of the state's PCC pavements. The first significant manifestation of ASR occurred in the late 1970s on a section of I-90 built in 1972. A local sand used in the concrete mix proved to be highly reactive. Mineralogical analysis of the sand confirmed it contained 44 percent chert. To address this problem, the cement specification for concrete paving mixes was changed to a low alkali cement ($Na_2O$ equivalent $\leq 0.6$ percent) in 1983.

Since 1980, several other concrete pavements have exhibited varying degrees of ASR-related distress involving concrete sands. In addition, the premiere coarse aggregate for concrete in the eastern part of the state, a quartzite, was found to be slow, late-expanding alkali-silica reactive (*1*). Exhaustion of existing sand pits during the past 20 years, coupled with the unknown reactivity of potential new sand sources and concern about the long-term effectiveness of low alkali cement in reducing ASR, prompted an evaluation of all concrete sands being used in South Dakota.

## ASTM P214

The primary test chosen for determining the ASR potential of various sands was ASTM P214 Accelerated Detection of Potentially Deleterious Expansion of Mortar Bars Due to Alkali-Silica Reaction (*2,3*). The test is rapid and reproducible, but interpretation of the test results can be difficult without additional testing. Table 1 lists the test results for 30 sands, and Figure 1 indicates the 95 percent confidence limits (dashed lines). Of the 30 sands, only three can be classified as nonreactive using the 0.1 percent expansion cri-

South Dakota Department of Transportation, 700 East Broadway Ave., Pierre, S.D. 57501–2586.

terion (*4*). Fourteen sands have expansion values that lie in the inconclusive range and thirteen sands are definitely alkali-silica reactive. Using upper values for 95 percent confidence limits adds two more sands (Sands 92 and 120) to the reactive list. Field performance confirms that these sands are indeed reactive; 40 percent of the sands remain in the inconclusive category. ASTM C289 Potential Reactivity of Aggregates (Chemical Method) was also used as a screening method for some of these sands but, unfortunately, a comparison of the two test results with actual field performance complicates interpretation.

In an attempt to determine the effect of base strength on the P214 test, a series of different concentrations of sodium hydroxide (NaOH) was substituted for 1N NaOH. Sand 57, one of the most reactive of the 30 sands, was used in these tests. A control series of mortar bars made with Ottawa sand was run in parallel to determine whether any other factor was involved. Results are listed in Table 2 and presented graphically in Figure 2. Readings were taken up to 30 days after fabrication of the bars to indicate possible long-term trends. Control samples did not undergo expansion at any time regardless of concentration.

The major effect of $OH^-$ concentration is on the rate of expansion. With 0.25N NaOH, the final expansion at 28 days was only 0.008 percent as compared with 0.449 percent for 1N solutions. The 0.5N solution achieved an expansion of 0.228 percent at 28 days, roughly half that of the 1N solution. Both stronger NaOH concentrations had expansion curves that fit the general equation:

$$\text{Expansion (\%)} = A_2 \text{ Time} + A_1 \text{ Time}^{1/2} + A_0 \qquad (1)$$

where $R^2$ values are 0.9992 (1N) and 0.9912(0.5N), even though the 1N curve is convex and the 0.5 curve is concave. The data for the 0.25N curve also fit the equation, but only for expansion values beyond 17 days ($R^2 = 0.9460$). In all cases, the zero value was excluded from the curve-fitting data.

A comparison of response to concentration at 14 and 28 days (Figure 3) shows an almost linear relationship at 14 days but a definite curvilinear one at 28 days. The expansion reaction is subject to a diffusion-controlled delay during the first 2 days and to a significant reduction in reaction rate at later ages owing, no doubt, to get formation and reaction rims interfering with the alkali-silica reactions. A modification of P214 to include expansion testing at more than 1N NaOH concentration, somewhere between 0.5 and 1N, would probably improve the reliability of the test in predicting potential ASR.

The same equation type can be used to analyze the expansion of the 30 sands using the standard 1N concentration. Figures 4, 5, and 6 illustrate three typical curve types obtained from the analyses. Sand 57 is highly reactive and gives a convex curve. The other line in the figure is a regression fit using the same type of equation but

TABLE 1 ASTM P214 Test Results

| SAND | % EXPANSION | s | 95% CONFIDENCE + | 95% CONFIDENCE - | ASTM C289 | FIELD PERFORMANCE |
|------|-------------|-----|------|------|-----------|-------------------|
| 22 | 0.152 | 0.007 | 0.164 | 0.139 | Innocuous | Nonreactive |
| 29 | 0.202 | 0.008 | 0.211 | 0.193 | Innocuous | Reactive |
| 36 | 0.300 | 0.013 | 0.315 | 0.285 | Innocuous | Reactive |
| 43 | 0.125 | 0.016 | 0.144 | 0.106 | Deleterious | Reactive ?? |
| 50 | 0.274 | 0.018 | 0.295 | 0.253 | Pot. Delet. | Reactive |
| 57 | 0.315 | 0.009 | 0.326 | 0.304 | Deleterious | N/A |
| 64 | 0.329 | 0.004 | 0.335 | 0.322 | Deleterious | Reactive |
| 71 | 0.261 | 0.013 | 0.276 | 0.246 | Deleterious | Reactive |
| 78 | 0.261 | 0.026 | 0.291 | 0.231 | Pot. Delet. | Reactive |
| 85 | 0.207 | 0.005 | 0.216 | 0.198 | Deleterious | Reactive |
| 92 | 0.186 | 0.024 | 0.214 | 0.159 | Deleterious | Reactive |
| 99 | 0.161 | 0.010 | 0.172 | 0.149 | Innocuous | Nonreactive |
| 106 | 0.128 | 0.015 | 0.146 | 0.110 | Innocuous | Nonreactive |
| 113 | 0.113 | 0.004 | 0.117 | 0.109 | Innocuous | Nonreactive |
| 120 | 0.192 | 0.020 | 0.215 | 0.169 | Deleterious | Reactive |
| 127 | 0.076 | 0.005 | 0.082 | 0.071 | Pot. Delet. | Nonreactive |
| 134 | 0.128 | 0.008 | 0.137 | 0.118 | N/A | N/A |
| 141 | 0.106 | 0.002 | 0.108 | 0.103 | N/A | N/A |
| 148 | 0.213 | 0.023 | 0.240 | 0.186 | Innocuous | Reactive |
| 155 | 0.044 | 0.001 | 0.045 | 0.043 | Innocuous | Nonreactive |
| 162 | 0.211 | 0.007 | 0.220 | 0.203 | Innocuous | Reactive |
| 169 | 0.164 | 0.003 | 0.168 | 0.160 | Pot. Delet. | Nonreactive |
| 176 | 0.208 | 0.023 | 0.235 | 0.180 | Deleterious | Reactive |
| 183 | 0.124 | 0.007 | 0.132 | 0.115 | Innocuous | Reactive |
| 190 | 0.062 | 0.005 | 0.068 | 0.057 | Innocuous | N/A |
| 197 | 0.140 | 0.017 | 0.160 | 0.120 | N/A | N/A |
| 204 | 0.113 | 0.028 | 0.145 | 0.080 | N/A | N/A |
| 211 | 0.280 | 0.004 | 0.284 | 0.275 | N/A | N/A |
| 218 | 0.367 | 0.019 | 0.389 | 0.345 | N/A | N/A |
| 225 | 0.181 | 0.008 | 0.190 | 0.171 | N/A | N/A |
| Average | 0.1874 | 0.012 | | | | |

including zero. Sand 169 is inconclusive and fits a concave curve. Sand 183 is *Slear* quartzite and does not correspond in its behavior to any other sand tested. All of the sands fit the general equation well except for the three sands with expansion values below 0.10 percent Table 3 lists second degree polynomial coefficients for the various sands.
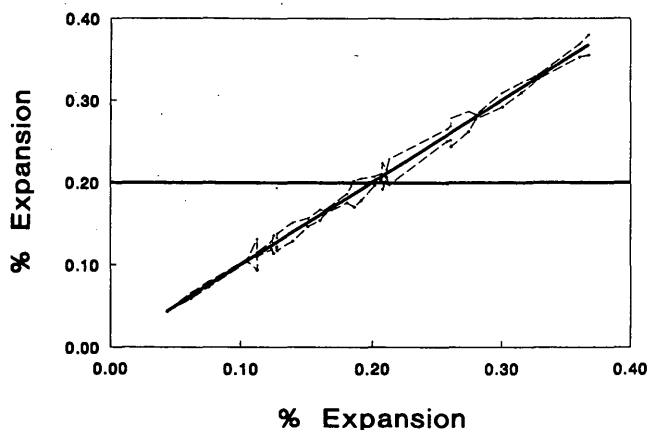


FIGURE 1 95 percent confidence intervals for 30 sands.

The major problem with using the 14-day expansion value as a primary indicator of reactivity is that it is an isolated point and does not reflect the way a certain sand or coarse aggregate expands during the test. ASTM P214 is a very severe test and causes expansion to occur even when the aggregate tested is nonreactive in its field performance. By examining the coefficients for the general expansion curve and combining these with the 14-day test results, it may be possible to clarify the "inconclusive" range. The manner in which a sand expands can be considered an index of the sand's reactivity, regardless of the final expansion value achieved. Coefficients for each sand represent how the expansion develops, as they

TABLE 2 Percentage Expansion at Different NaOH Concentrations

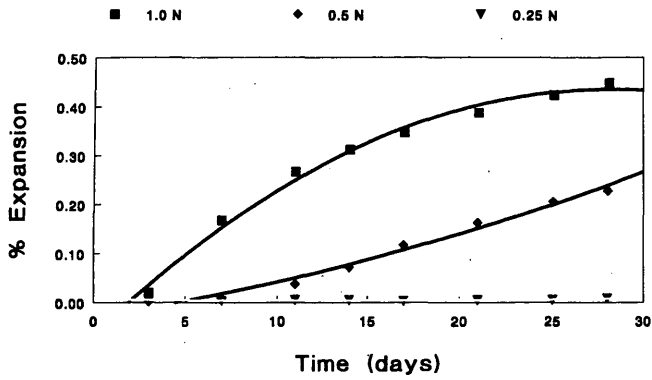| DAY | % EXPANSION | | |
|-----|------|------|------|
| | 0.25 N | 0.5 N | 1.0 N |
| 3 | 0.004 | 0.002 | 0.02 |
| 7 | 0.002 | 0.008 | 0.168 |
| 11 | 0.003 | 0.038 | 0.267 |
| 14 | 0.004 | 0.072 | 0.312 |
| 17 | 0.002 | 0.117 | 0.347 |
| 21 | 0.004 | 0.163 | 0.387 |
| 25 | 0.005 | 0.206 | 0.424 |
| 28 | 0.008 | 0.228 | 0.449 |

FIGURE 2    Percentage expansion versus time for Sand 57.
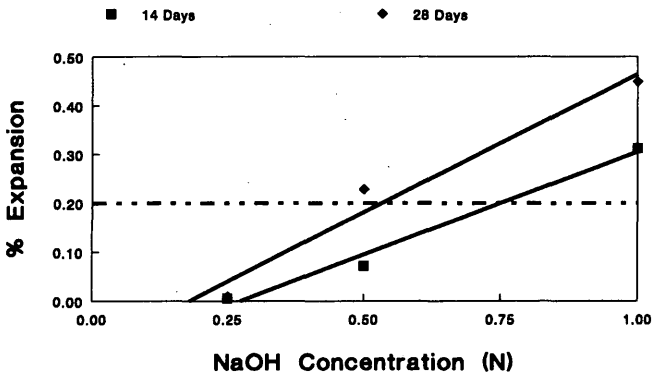


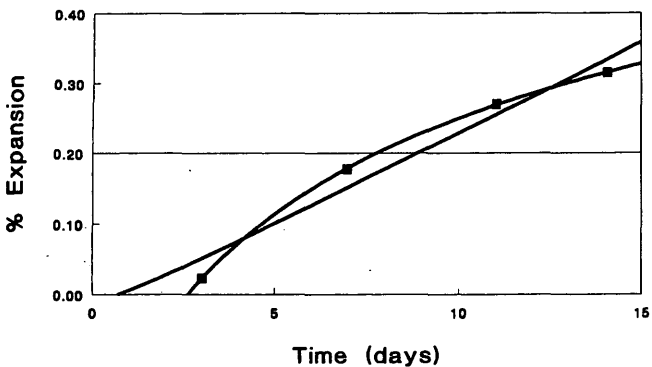FIGURE 3    Percentage expansion versus NaOH concentration.



FIGURE 4    Typical ASTM P214 test result (Sand 57).



FIGURE 5    Typical ASTM P214 test result (Sand 169).
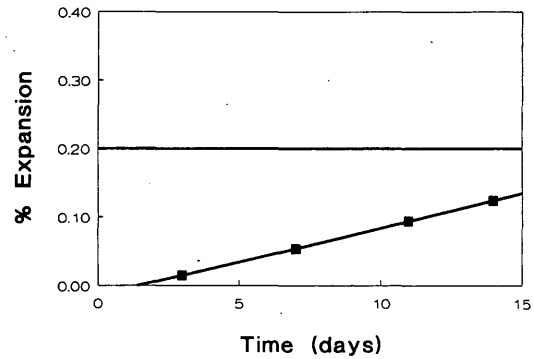


FIGURE 6    ASTM P214 test results (Sand 183, quartzite).

are proportional to the intrinsic properties of each individual curve, such as curvature and displacement from the vertical and horizontal axes.

At first glance, these coefficients do not appear to contain any more information than the 14-day expansion values. When the coefficients are plotted against each other, however, they separate into two distinct groups, one reactive and the other nonreactive. Figure 7 is a plot of $A_1$ (the first order coefficient) versus $A_2$ (the second order coefficient) for the general equation for all 30 sands. Both groups form a linear relationship with respect to the coefficients to a high degree of significance. A comparison of the 14-day expansion
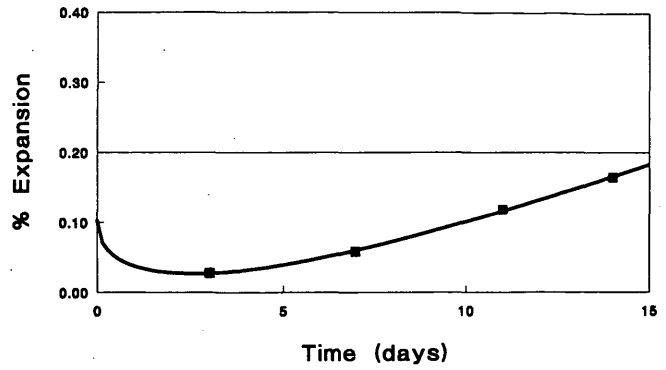
criteria with the linear classes of sands indicates an upward trend along the bottom unreactive line until Sand 169 is reached at a 0.164 percent expansion. All sands more expansive than this lie on the reactive line with the degree of expansion generally trending upward from right to left. Figure 8 is an expansion of Figure 7 in the region where most sands are plotted. It shows a clear differentiation between reactive and unreactive sands. Only three sands are somewhat "inconclusive" (Sands 99, 183, and 225). Sand 183 is quartzite and lies between the reactive and unreactive zones, presumably in a region where a slow, late expanding ASR aggregate belongs. Sand 99 is not quite on the nonreactive line but is considerably closer to the nonreactive sands than to the reactive ones. Sand 225 is much closer to the reactive sands and probably could be classified as reactive.

A comparison of projected reactivity with known field performance indicates striking accuracy of the coefficient plots at predicting potential reactivity. Of the sands with 20 or more years of use in South Dakota concrete pavements, the projected reactivity matched the known field performance in all but two cases. Sand 43 was used in a pavement that showed signs of severe ASR approximately 15 years after construction. Unfortunately, the coarse aggregate use in the pavement came from the same supplier and may be the actual source of the deterioration reaction. The mineralogical composition of Sand 43 is primarily dolomitic, and the estimated chert content by polarized light microscopy is under 5 percent; both facts argue in favor of its not being alkali-silica reactive. Sand 99 is also a dolomitic sand and comes from the same region of the state as Sand 43. There is a possibility that both aggregate are alkali-carbonate reactive, as discussed by Mather et al. (*5*).

TABLE 3    Coefficients for Equation 1

| SAND | % EXPANSION | A2 | A1 | A0 | PROJECTED REACTIVITY |
|------|-------------|-----|-----|-----|----------------------|
| 22 | 0.152 | 0.0306 | -0.0979 | 0.0914 | Nonreactive |
| 29 | 0.202 | 0.0370 | -0.1069 | 0.0874 | Reactive |
| 36 | 0.300 | -0.0158 | 0.2228 | -0.3108 | Reactive |
| 43 | 0.125 | 0.0271 | -0.0910 | 0.0867 | Nonreactive |
| 50 | 0.274 | 0.0173 | 0.0351 | -0.0952 | Reactive |
| 57 | 0.315 | -0.0222 | 0.2673 | -0.3731 | Reactive |
| 64 | 0.328 | -0.0301 | 0.3136 | -0.4246 | Reactive |
| 71 | 0.261 | 0.0208 | 0.0077 | -0.0577 | Reactive |
| 78 | 0.261 | 0.0113 | 0.0618 | -0.1252 | Reactive |
| 85 | 0.207 | 0.0244 | -0.0341 | -0.0020 | Reactive |
| 92 | 0.186 | 0.0336 | -0.0952 | 0.0754 | Reactive |
| 99 | 0.161 | 0.0299 | -0.0875 | 0.0723 | Nonreactive |
| 106 | 0.128 | 0.0284 | -0.0953 | 0.0901 | Nonreactive |
| 113 | 0.113 | 0.0232 | -0.0759 | 0.0729 | Nonreactive |
| 120 | 0.192 | 0.0279 | -0.0651 | 0.0479 | Reactive |
| 127 | 0.076 | 0.0124 | -0.0345 | 0.0316 | Nonreactive |
| 134 | 0.128 | 0.0268 | -0.0930 | 0.1014 | Nonreactive |
| 141 | 0.106 | 0.0176 | -0.0548 | 0.0645 | Nonreactive |
| 148 | 0.213 | 0.0321 | -0.0815 | 0.0710 | Reactive |
| 155 | 0.044 | 0.0056 | -0.0172 | 0.0297 | Nonreactive |
| 162 | 0.211 | 0.0270 | -0.0567 | 0.0481 | Reactive |
| 169 | 0.164 | 0.0301 | -0.0961 | 0.1038 | Nonreactive |
| 176 | 0.208 | 0.0329 | -0.0898 | 0.0861 | Reactive |
| 183 | 0.124 | 0.0107 | -0.0043 | -0.0099 | Reactive |
| 190 | 0.062 | 0.0067 | -0.0111 | 0.0097 | Nonreactive |
| 197 | 0.140 | 0.0268 | -0.0860 | 0.0884 | Nonreactive |
| 204 | 0.113 | 0.0211 | -0.0705 | 0.0810 | Nonreactive |
| 211 | 0.280 | -0.0030 | 0.1413 | -0.2049 | Reactive |
| 218 | 0.367 | -0.0382 | 0.3663 | -0.4693 | Reactive |
| 225 | 0.181 | 0.0312 | -0.0847 | 0.0633 | Reactive |
|  |  |  |  |  |  |
| Gabbro | 0.015 | -0.0029 | 0.0194 | -0.0175 | Nonreactive |
| G+4.5% Opal | 0.271 | -0.0323 | 0.3119 | -0.4163 | Reactive |
| Harzburgite | 0.051 | 0.0049 | -0.0047 | 0.0087 | Nonreactive |
| H+4.5% Opal | 0.276 | -0.0378 | 0.3399 | -0.4438 | Reactive |

Further confirmation of the status of an aggregate can be obtained by plotting the zero order coefficient, $A_0$, against $A_2$, as shown in Figure 9. Again, two straight lines are obtained with the points on one representing reactive sands and those on the other nonreactive. The relationship is not quite as clear as the previous one, but using the combination of the two plots allows some refinement of the projected reactivity. For instance, if $A_0$ is negative, then the sand is reactive. The quartzite sample is off by itself, but it does have a negative $A_0$. Sand 225 is reactive, and whether Sand 99 is remains inconclusive.
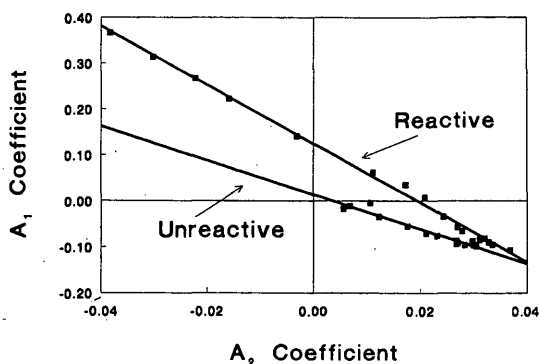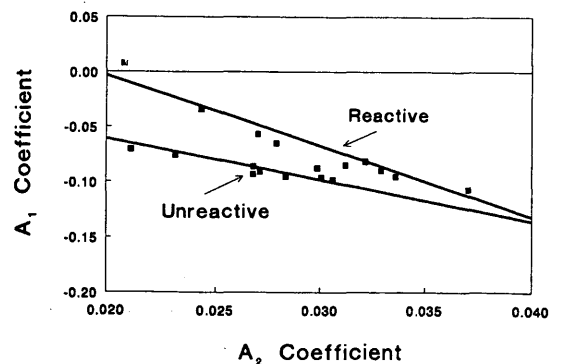


FIGURE 7    Plot of $A_1$ versus $A_2$ for 30 sands.
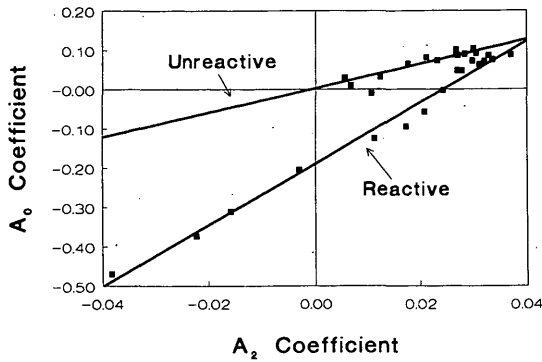


FIGURE 8    Plot of $A_1$ versus $A_2$ for 30 sands.

FIGURE 9   Plot of $A_0$ versus $A_2$ for 30 sands.



FIGURE 10   Expansion results for gabbro and 4.5 percent opal (*6*).

The use of coefficients to clarify potential ASR is possibly of great benefit. The unusual linearity in the coefficient plots can be attributed to the existence of two separate mechanisms for expansion. Coefficient $A_2$ is directly proportional to the curvature of the expansion curve. $A_1$ is directly proportional to the horizontal displacement of the curve from zero, and $A_0$ is related to the vertical displacement. The existence of "families" of curves indicates systematic reactions. The preliminary least square fits for reactive sands are

$$A_1 = -6.409\,A_2 + 0.125$$

$$A_0 = 7.802\,A_2 - 0.190$$

and for the nonreactive sands are

$$A_1 = 3.733\,A_2 + 0.014$$

$$A_0 = 3.119\,A_2 + 0.002$$

The true applicability of the method for determining potential reactivity cannot be determined without using data on other aggregates obtained by other laboratories. An initial attempt to do so involved data on two coarse aggregates, a gabbro and an harzburgite, tested by Daoud (*6*). Both aggregates are nonreactive, so Daoud added the pessimum amount of opal to each and retested them. He also took daily readings of expansion up to 12 days after the zero reading. Figure 10 presents a plot of his data for the gabbro + 4.5 percent opal. The general equation was fitted to his Daoud's data in two ways. The first relatively poor fit included the zero reading and readings at days 1 and 2, whereas the much more exact fit used only data from days 3 to 12. Figure 11 is a plot of $A_1$ versus $A_2$ for the gabbro, and for the gabbro + 4.5 percent opal. Results support the wide application of the method.

## Determining Pozzolans Effectiveness for Reducing ASR

A promising application of the proposed method of interpreting ASTM P214 test results would be as an accelerated replacement for ASTM C441 Effectiveness of Mineral Admixtures or Ground Blast-Furnace Slag in Preventing Excessive Expansion of Concrete Due to the Alkali-Silica Reaction. Figure 12 illustrates the effect of
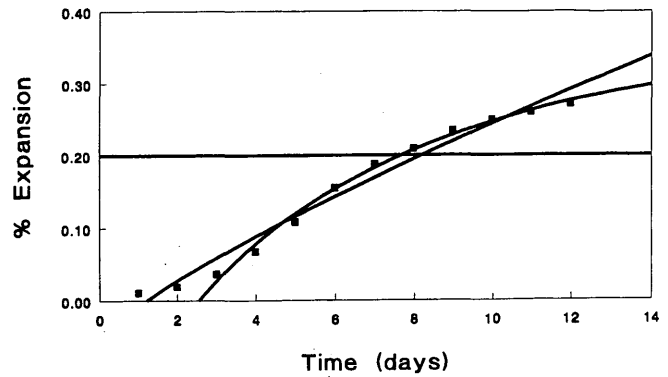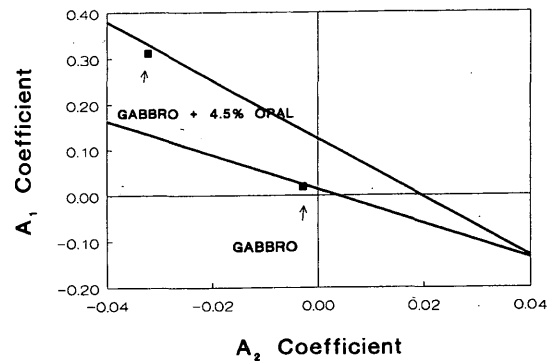


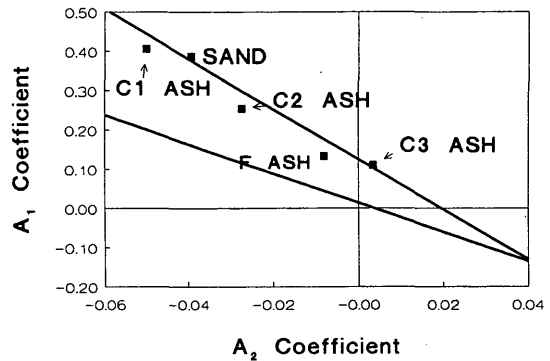FIGURE 11   Plot of $A_1$ versus $A_2$ for gabbro and 4.5 percent opal (6).



FIGURE 12   Plot of $A_1$ versus $A_2$ for Sand 57 with four fly ashes (10 percent).

10 percent addition of three Class C fly ashes and one Class F fly ash on the expansion behavior of Sand 57. Figure 13 is based on data from Ramakrishnan and Ramachandran (*7*) and demonstrates the effect of increasing addition of a Class F fly ash on the reactivity of Sand 57. Several items of note from the graphs follow:

• At a 10 percent addition rate, the fly ashes do not mitigate the potential reactivity of Sand 57, although they decrease the rate of reactivity.
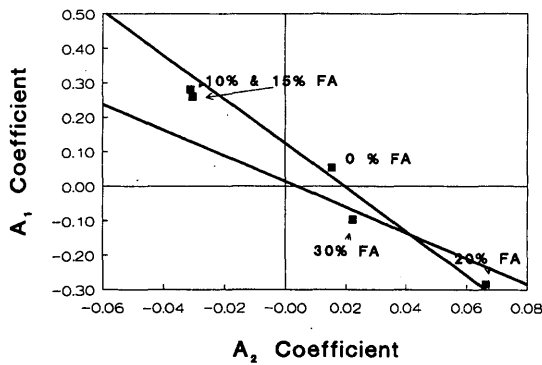
**FIGURE 13   Plot of $A_1$ versus $A_2$ for Sand 57 with various percentages of Class F fly ash (FA).**

• Ramakrishnan (7) and Ramachandran obtained a somewhat lower 14-day expansion for Sand 57 (0.2755 percent versus 0.315 percent), but the coefficient plot still indicates reactivity.

• A 20 percent addition of the fly ash reduces the 14-day expansion below 0.20 percent, but the coefficient plot still indicates reactivity.

• A 30 percent addition eliminates potential ASR, and the coefficient plot confirms this.

## CONCLUSIONS

• ASTM P214 is a good test for determining potential ASR.

• Using two different NaOH concentrations for the test, one at 1N and the other somewhere between 0.5 and 1N, may help minimize inconclusive results.

• Using a curve-fitting equation of the form $Y = A_2 X^2 + A_1 X + A_0$ ($X = $ Time$^{1/2}$) and plotting the polynomial coefficients against

each other appears to increase the predictive value of test results in the 0.1 to 0.2 percent expansion range.

• ASTM P214 can also be used to determine the effectiveness of various pozzolans at reducing potential ASR.

• Further work in analyzing data for different aggregates subjected to ASTM P214 by various laboratories is needed before the validity and limitations of the proposed method of interpreting ASTM P214 can be properly evaluated. It may be necessary for each laboratory to develop its own correlations to ensure proper interpretation.

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