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Alkali-Silica Reactivity of Fine Aggregates in South Dakota

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16. Abstract

This report presents the results of a study to evaluate the effectiveness of several ASTM test procedures at predicting alkali-silica reactivity (ASR). ASTM C289,P214,C227 and an autoclave expansion test were performed on 31 fine aggregate sources used in PCC concrete in South Dakota. Only ASTM P214 was capable of reliably predicting potential ASR when results were compared to actual field performance. A modified interpretation of the test results to include a best fit for expansion values at 3,7,11 and 14 days using the general equation $\%Expansion = A_0 + A_1 Time^{\frac{1}{2}} + A_2 Time$ gave a much clearer pattern of reactivity when the A_1 coefficients were plotted against the A_2 coefficients. The sands break out into two linear "families" of coefficients-one reactive and one nonreactive. This technique was also applied to four different fly ashes to determine their effectiveness at reducing the potential for ASR expansion at a 15% addition rate. Only one fly ash consistently reduced expansion for all reactive sands tested. The ability of the fly ashes to control expansions at this level appears to be directly related to their SiO_2 content.

The majority of South Dakota concrete sands are alkali-silica reactive and this reactivity is regional. Recommendations were developed for minimizing the risk of premature ASR-related deterioration of concrete including the use of Type II,Low Alkali cement in conjunction with fly ash having an SiO_2 content $\geq$ 40% and an $SiO_2+Al_2O_3+Fe_2O_3 \geq 66\%$. A maximum equivalent alkali content of 0.45% was recommended for cements used with sands containing extremely reactive volcanic minerals, also in conjunction with fly ash.

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Executive Summary

Since 1980 alkali-silica reactivity (ASR) has become an increasingly critical concern with regards to the durability of concrete pavements and structures in South Dakota. The first pavement to exhibit severe ASR was a 38 mile section of I-90 in Lyman County built in 1972. In 1981 cores were taken from the mainline continuously reinforced pavement and from two rest areas built using the same aggregate sources and sent to the Portland Cement Association (PCA) for petrographic analysis. The PCA report on the cores indicated severe ASR occurring in the rest areas but stated the mainline pavement did not have an ASR problem. Time has proven that analysis incorrect as the mainline pavement has continued to deteriorate and become a significant maintenance problem illustrating the difficulties inherent in dealing with ASR in either a predictive or analytical framework.

To combat potential problems with ASR in future construction SDDOT adopted the use of Type II, Low Alkali cement in 1983. Contemporary wisdom contended that the use of portland cement with an equivalent alkali content < 0.6% would eliminate ASR in concrete even if an aggregate source was deleteriously reactive. Unfortunately, confidence in the assumption has been gradually eroded by the discovery of certain aggregates, mostly volcanic in origin, which undergo ASR even in the presence of a low alkali cement and by the growing awareness of deicing salts as an external source of alkali.

Since 1983 numerous pavements statewide have exhibited various degrees of ASR. In addition, Sioux quartzite, the premiere coarse aggregate used in eastern South Dakota, has proven to be slowly reactive. The impact of ASR on concrete durability and pavement life and the need to evaluate aggregate sources and develop strategies to minimize the risk of premature deterioration of PCC pavements prompted this research.

Testing of Fine Aggregate Sources

Four test protocols were chosen for screening sand sources:

1)ASTM C289 "Potential Reactivity of Aggregates (Chemical Method)
2)ASTM P214 "Accelerated Detection of Potentially Deleterious Expansion of Mortar Bars Due to Alkali-Silica Reaction"
3)SD Mortar Bar Autoclave Test
4)ASTM C227 "Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar Bar Method)

The first three tests were conducted by SDDOT in Pierre. The South Dakota School of Mines and Technology (SDSM&T) performed ASTM C227 and ASTM P214 on ten sands for comparative purposes. They also analyzed 17 sands for elemental and mineralogical contents using x-ray fluorescence and X-ray diffraction.

A total of 31 fine aggregate sources were screened for ASR using ASTM C289, ASTM P214 and the autoclave test. The first round of tests examined 21 sands. Subsequent testing encompassed an additional ten sands as well as re-testing the original group.

Test results were compared to actual field performance of fine aggregates, where available. Of the four tests evaluated only ASTM P214 provided a satisfactory correlation with actual alkali-silica

Introduction

Since 1980 alkali-silica reactivity (ASR) has become an increasingly critical concern with regards to the durability of concrete pavements and structures in South Dakota. The first pavement to exhibit severe ASR was a section of I-90 in Lyman County built in 1972 approximately 38 miles long. In 1981 cores were taken from the mainline continuously reinforced pavement and from two rest areas built using the same aggregate sources and sent to the Portland Cement Association (PCA) for petrographic analysis. The PCA report on the cores indicated severe ASR occurring in the rest areas but stated the mainline pavement did not have an ASR problem. Time has proven that analysis incorrect as the mainline pavement has continued to deteriorate and become a significant maintenance problem illustrating the difficulties inherent in dealing with ASR in either a predictive or analytical framework.

Severe ASR is typically associated with the coarse aggregate in a concrete mix but in the case of the I-90 failure the coarse aggregate used was Minnekahta limestone which has an excellent service record in concrete. The sand used for this stretch of Interstate, however, was obtained from a pit on the White River south of I-90. Petrographic analysis revealed a chert content greater then 40% confirming the sand as the source of ASR.

To combat potential problems with ASR in future construction SDDOT adopted the use of Type II, Low Alkali cement in 1983. Contemporary wisdom held that the use of portland cement with an equivalent alkali content < 0.6% would eliminate ASR in concrete even if an aggregate source was deleteriously reactive. Unfortunately, confidence in this assumption has been gradually eroded by the discovery of certain aggregates, mostly volcanic in origin, which undergo ASR even in the presence of a low alkali cement and by the growing awareness of deicing salts as an exterior source of alkali.

Since 1983 numerous pavements statewide have exhibited various degrees of ASR. In addition, Sioux quartzite, the premiere coarse aggregate used in eastern South Dakota, has proven to be slowly reactive. The impact of ASR on concrete durability and pavement life and the need to evaluate aggregate sources and develop strategies to minimize the risk of premature deterioration of PCC pavements prompted this research.

Background

The occurrence of alkali-silica reaction was first reported by Stanton in 1940 (1). A tremendous amount of work has been done on the problem in the half-century since its discovery but there is still a considerable gap between what is known and a comprehensive understanding of the phenomenon. As a result there are no totally reliable tests for predicting the potential of any given aggregate to undergo ASR.

Alkali-silica reaction can best be characterized as a two step process involving attack by strongly alkaline pore water in concrete (pH>13) on silica aggregates that are unstable in such an environment. Susceptible aggregates include amorphous and crystalline silica polymorphs such as opal, chalcedony (chert, flint, agate and jasper), trydimite, crystobalite, volcanic andesites and glasses, microcrystalline and cryptocrystalline quartz and strained quartz minerals. The reactivity of any given silica mineral depends on the amount of order in the crystal structure. Minerals such as opal with a disordered crystal arrangement undergo ASR with extreme rapidity and can cause concrete to deteriorate within five years. Quartz, on the other hand, has an extremely well ordered crystalline form and does not

River valleys in south central and southeastern South Dakota. The greatest difference between the groups lies in lithologic composition with the sand sources west of the Missouri River typically containing more chalcedony and outwash from the Black Hills.

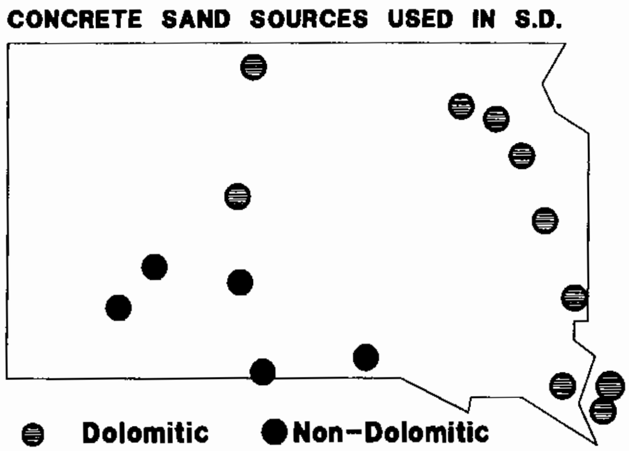

Figure 1 Concrete Sand Sources Used in South Dakota

The glacial outwash sands predominate east and north of the Missouri River with the bulk of the deposits associated with the Big Sioux River and its tributaries. Although most commercial sources are outwash deposits, terrace and valley wall deposits are often associated with them. There is a striking compositional difference between these sands and the "western" sand deposits as shown in Table I. Virtually all of these sands contain a significant portion of carbonate minerals especially dolomite, whereas in the "western" sands dolomite is notably absent and calcite is a minor constituent. The "chert" content in the table is based on polarizing light microscopy and represents amorphous silica minerals generally. Interestingly, the three sand sources from southeastern South Dakota and northwestern Iowa exhibit mineralogical compositions which seem to combine both "western" and glacial sand types consistent with their location near the confluence of the Big Sioux and the Missouri rivers. Ongoing stream deposition and outwash could have caused a mixing of these sand types. These sands contain a significant amount of chalcedony, quartzite and volcanic rocks, all of which can contribute to potential ASR. Figure 1 shows the dolomite distribution for the fifteen sand sources analyzed. Sand sources just to the east of the Missouri also appear to be a mixture of western and glacial sands as they lie in a region of overlap between stream deposition from the abandoned Bad, Grand and Moreau Rivers and glacial outwash and terminal moraines.

Objectives

This research is an outgrowth from two prior research projects SD89-10 "Alkali Reactivity of Concrete Aggregates,"performed by SDSM&T, and SD90-01 "Alkali Reactivity of Concrete Aggregates." The research had the following objectives:

1)To confirm ASTM P214 test results for South Dakota's primary fine aggregate sources.
2)To correlate the P214 test with other predictive tests and observed field performance.
3)To assess the variability of fine aggregate sources in terms of laboratory test results.
4)To explore the feasibility of separating reactive components from fine aggregates.
5)To determine the extent and severity of alkali-carbonate reactivity in South Dakota.
6)To develop recommendations concerning specifications for aggregate acceptance.

5)Test the fine aggregate using ASTM C289 and the South Dakota Autoclave Test procedures modified to include complete fine aggregate gradations.

6)Test selected reactive aggregates which have been washed or otherwise processed to determine whether reactivity levels are changed.

7)Conduct field surveys to evaluate the field performance of aggregate which have been used in pavements and structures.

8)Analyze field observations and laboratory test results to correlate test methods, to determine the effects of modifying the ASTM C289 and South Dakota autoclave Test procedures, to evaluate the variability of aggregate sources, and to correlate test methods with field performance.

9)Conduct field surveys and tests to determine the extent and severity of alkali-carbonate reactivity in South Dakota.

10)Develop recommendations concerning use of the proposed ASTM P214-based specification and use of alternative test methods.

11)Submit a final report summarizing relevant literature, research methodology, findings, and conclusions.

12)Present a summary of research findings, and recommendations to the Department's Research Review Board.

Testing of Fine Aggregate Sources

Four test protocols were chosen for screening sand sources:

1)ASTM C289 "Potential Reactivity of Aggregate (Chemical Method)

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The first three tests were conducted by SDDOT in Pierre. The South Dakota School of Mines and Technology (SDSM&T) performed ASTM C227 and ASTM P214 on ten sands for comparative purposes as part of research project SD90-01 "Alkali Reactivity of Concrete Aggregates." They also analyzed 17 sands for elemental and mineralogical contents using X-ray fluorescence, X-ray diffraction and petrographic analysis. The results of these analyses are shown in Table I.

A total of 31 fine aggregate sources were screened for ASR using ASTM C289, ASTM P214 and the autoclave test. The first round of tests examined 21 sands with subsequent testing encompassing an additional ten sands as well as re-testing the original group.

generate significant expansion even in aggregates with excellent field performance records. The recommended interpretation guidelines listed in ASTM P214 are:

1) Aggregates causing a mean of expansion < 0.10% at 16 days from casting are innocuous.
2) Aggregates with a mean expansion between 0.10% and 0.20% at 16 days after casting are in the inconclusive range and require supplementary testing.
3) Aggregates with a mean expansion > 0.20% at 16 days after casting are potentially deleteriously expansive.

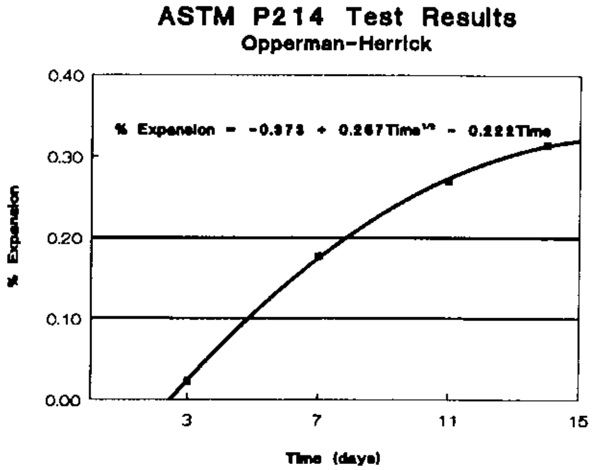

Figure 3 Expansion Curve for a Typical Reactive Sand

P214 results for the South Dakota fine aggregates are shown in Table II along with the standard deviation and 95% confidence intervals. Four mortar bars were fabricated instead of the three normally required to improve the quality of the statistical evaluation of the results. The variation in expansion between a set of four bars is generally quite low and the inclusion of the additional bar allows the exclusion of inappropriate test results without losing accuracy or reliability. The range in variation is acceptable in almost all cases and where there is any remaining question a duplication of the test for that aggregate should clarify the situation.

A paper entitled "Accelerated Test Method ASTM P214 and Interpretation of Test Results" was presented at the 72nd Annual Meeting of the Transportation Research Board (TRB). The paper discusses a new method of interpreting ASTM P214 which was developed as part of this research project. The method is based on curve-fitting the 3, 7, 11 and 14 day expansion values to the general equation :

$$\%Expansion = A_0 + A_1 Time^{\frac{1}{2}} + A_2 Time$$

as shown in Figure 3. The use of this general equation yields a good model of the expansion of almost all the sands tested. Plotting the derived coefficients against each other provides an additional means of analyzing the expansion data beyond

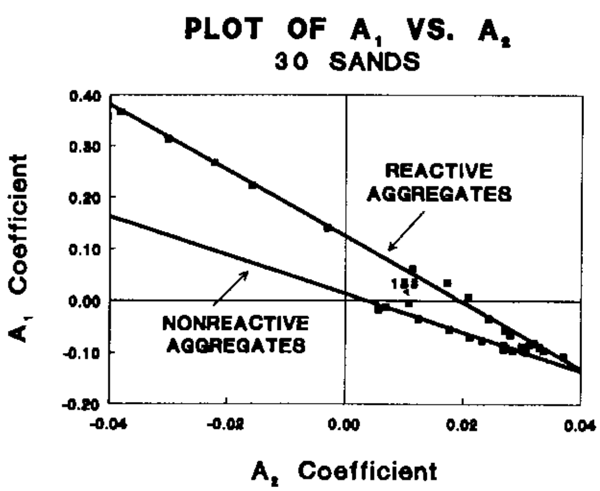

Figure 4 Coefficient Plot for 30 Sands

the limited 14 day expansion criterion. An interesting grouping of sands takes place when coefficient A_1 is plotted against coefficient A_2 as shown in Figure 4. Coefficient A_1 is proportional to the horizontal displacement of the expansion curve from zero and coefficient A_2 is directly proportional to the curvature or rate of expansion. The plot indicates the effect of the NaOH solution on reactive or "nonreactive" aggregate is systematic in both cases and the way a given aggregate causes expansion to occur can be used to characterize its reactivity. The two lines represent least square regressions of the coefficient "families." Of the 31 sands tested 14 gave inconclusive results based on the original criteria. Using this new method only 3 of these sands were interpreted as reactive and the actual breakpoint for innocuous versus reactive expansions occurred at values > 0.165%. Table III shows the coefficient values obtained for each sand and Figures 16 through 45 illustrate the expansion curves. The method appears to improve the predictability of the test by a substantial margin. The test may also be used to determine the relative reactivity of a given aggregate and the optimum methods to be employed to reduce the potential for ASR in PCC where reactive aggregates are used. ASTM P214 is recommended for future screening of concrete aggregates for potential ASR.

SD Autoclave Test

The South Dakota Autoclave Test was an alternative test developed to screen aggregates for ASR. Mortar bars were fabricated using the -#50 +#100 portion of a fine aggregate source and subjected to ASTM C151 "Test Method for Autoclave Expansion of Portland Cement" after enough NaOH was added to the mix water to adjust the equivalent Na_2O content of the cement to 1.25% by weight. A second series of autoclave tests was conducted using the same gradation of sand as that called for in ASTM P214. Neither series of tests correlated well with ASTM P214 nor with each other. Leaching of material out of the bars during autoclaving is probably a key factor contributing to the sporadic results of the test as shown in Table V..

ASTM C227

Professor V. Ramakrishnan of SDSM&T conducted ASTM C227 testing on ten sands as part of research project SD90-01 "Alkali Reactivity of Concrete Aggregates." The test method is very similar to ASTM P214 in that virtually the same mortar bars with the same gradation requirements are used. The mortar bars are conditioned in sealed containers at a temperature of 37.8°C and measurements are made at various ages after allowing the bars to cool for 16 hours. The primary differences between the two tests are the source of alkali and the method of conditioning. ASTM C227 uses a high alkali cement for the test with no external source of alkali and the mortar bars are stood on end in the containers over water without ever being in direct contact with the water. A wick is used to maintain high humidity in the chamber.

The test results obtained by Ramakrishnan (5) are shown below in Table IV. They indicate that the predictive power of the test is extremely poor. ASTM C33 "Concrete Aggregates" recommends a mean % expansion value of 0.10% at six months (180 days) as a threshold value for potential reactivity. Although none of the ten fine aggregates tested achieved a value over 0.10%, seven of those tested are known to be reactive based on field performance.

Table IV : ASTM P227 Test Results-SDSM&T

Pit	% Expansion (180 Days)	Standard Deviation	Coefficient of Variation
Concrete Materials Eagle	0.064	0.020	31.1
Everest Brookings	0.074	0.010	13.5
Opperman Herrick	0.051	0.015	29.4
Mission Hills	0.087	0.023	26.4
Everist Hawarden	0.063	0.009	15.0
Concrete Materials Summit	0.034	0.005	13.5
Birdsall Blunt	0.054	0.018	33.3
Hills Materials Wasta	0.066	0.012	18.7
Birdsall Creston	0.025	0.005	18.8
Harry Perry	0.069	0.020	28.8

Correlation of Test Results

ASTM C289

Correlation of ASTM C289 test results with other test procedures was extremely poor. Figure 5 shows a plot of a retest of all the sands and the graphical criterion for determining reactivity. For comparative purposes, the same sand gradation used in ASTM P214 was employed and virtually all sands tested were either potentially or deleteriously reactive. Table II, on the other hand, lists 11 sands which were rated innocuous using the standard test procedures. Field performance, however, indicates that five of these sands were actually reactive. ASTM C289 does not correlate well with any other test results. This test is not recommended for future screening of fine aggregates.

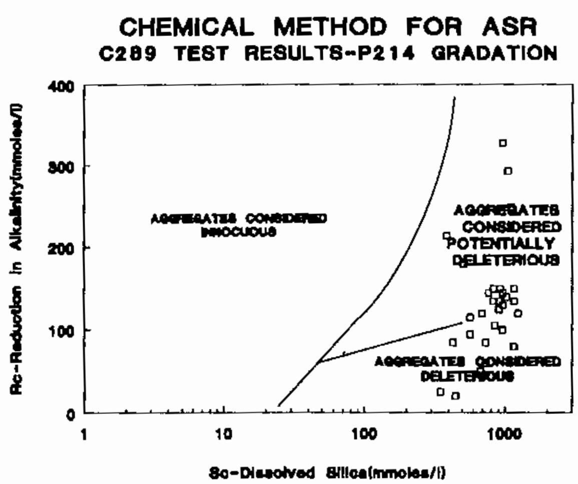

Figure 5 ASTM C289 Test Results P214 Gradation

ASTM P214

The first round screening of 21 sands using ASTM P214 employed only two mortar bars per sand source as there was a need to obtain results as quickly as possible. In addition, the initial testing series with the DOT series 2. Although the two sets of DOT data show a high degree of correlation the SDSM&T data does not although general trends are somewhat the same. The time-temperature history of the sets of test specimens must have been different enough to generate discrepancies in the final expansions. ASTM P214 results presented by outside laboratories should not be considered directly comparable to our results unless a strong correlation exists for a number of aggregate indicating a direct correspondence in the conditioning of specimens. ASTM P214 is suitable for evaluating new or untested coarse and fine aggregate sources for potential alkali-silica reactivity.

SD Autoclave Test

Figures 48 and 49 illustrate the correlations between the two series of South Dakota Autoclave tests and the corresponding P214 tests. Series 1 used #50 to #10 material whereas series 2 incorporated the standard P214 gradation.

Unfortunately, the SD Autoclave test does not seem capable of differentiating reactive aggregate from "nonreactive." Many of the nonreactive sands had expansion values greater than sands known to be reactive. The greatest weakness of the test is the relatively minor and narrow range of expansion with the error inherent in the length measurement representing a significant portion of final expansion value. Neither graph provides any evidence that the autoclave test is worth pursuing. This test is not recommended for future screening of fine aggregates for ASR.

ASTM C227

Currently, ASTM C227 is the accepted means of screening aggregate for ASR. Unfortunately, the test has three major drawbacks:

1)It takes from 3-18 months to obtain potentially unreliable results.

2)The expansion of the mortar bars is extremely sensitive to the configuration of the containment vessel.

3)There is a tremendous controversy concerning interpretation of test results. In fact there is an effort underway to remove C227 from ASTM.

The results of the work by Ramakrishnan on the ten sands he tested confirm these problems. ASTM C33 states a % expansion value greater than 0.1% at 6 months indicates a reactive aggregate. Although 7 of the 10 sands were definitely reactive based on field performance none of the test results indicated reactivity using this criterion. Figure 50 shows how well the C227 results correlated with the P214 test results for the SDSM&T testing. The correlation does not support the use of ASTM C227 as a screening method unless the criteria for reactivity are lowered and the problems with sample conditioning resolved. This test is not recommended for screening fine aggregates for ASR.

Correlation of Test Results with Field Performance

The final arbiter of whether a test for ASR-susceptible aggregates is worthwhile must be the actual field performance of the aggregate. No matter what a test result may suggest about the potential reactivity of

Table V : Comparison of ASTM P214 and SD Autoclave Test Results

Pit	% Expansion (SDSM&T)	% Expanion (Series 1)	% Expansion (Series 2)	% Expansion (Pit Run)	Autoclave(Gradation)	
					(P214)	(+50-100)
Conc. Matls. Eagle	0.145		0.151		0.073	0.046
Conc. Matls. Brandon		0.223	0.202	0.204	0.073	
Heib Delmont		0.295	0.300	0.328	0.097	0.061
Everist Brookings	0.163	0.142	0.125	0.165	0.072	0.052
Jensen Herreid		0.269	0.274		0.073	0.055
Opperman Herrick	0.217	0.357	0.315		0.093	0.063
Opperman Burke			0.329		0.098	
Fisher Ft. Yates		0.268	0.261		0.066	
Mission Hills	0.268	0.172	0.261		0.074	0.042
Higman Akron		0.265	0.207	0.214	0.068	0.050
Everist Hawarden	0.177	0.220	0.187	0.192	0.069	0.052
Conc. Matls. Summit	0.113	0.136	0.161	0.171	0.066	0.051
McLiaughlin Watertown		0.116	0.128		0.078	0.046
Northern Conc. Agg		0.122	0.113	0.110	0.073	0.052
Birdsall Blunt	0.149	0.146	0.192		0.068	0.044
Hills Matls. Centennial		0.125	0.076		0.046	0.040
Thorpe Pit Britton			0.128		0.070	
Sisseton Ready Mix			0.106		0.076	
Hills Matls. Wasta	0.172	0.261	0.213		0.063	0.053
Fisher Spearfish		0.099	0.044		0.069	0.054
Birdsall Wasta		0.226	0.211		0.067	0.042
Birdsall Oral		0.170	0.164		0.066	
Birdsall Creston	0.140	0.210	0.208		0.068	0.036
Fisher Mitchell (Manu)		0.134	0.124		0.038	0.013
Fisher Mitchell (Natural)		0.061	0.063		0.037	0.011
Henrick & Son Bigstone			0.140		0.069	
B&B Concrete			0.113		0.080	
Wagner Bldg. Supplies			0.280		0.099	
Bachman Winner			0.367		0.110	
Myrl & Roy's Nelson			0.181	0.167	0.072	

Table I does not offer any clues as to other sources of reactivity but microscopic examination suggests that the reactivity of the "western" sands, especially, is largely due to what may be quartzites and volcanic rocks. Opperman Herrick, Heib Delmont, Mission Hills and Higman Akron fine aggregates all contain a large proportion of these materials and all exhibit P214 expansions in excess of 0.2%. Further evidence of volcanics being involved is provided by two PCC pavements on US18. Both projects exhibit early stage cracking typical of ASR even though the concrete contains a low alkali cement. The projects both used Opperman Herrick sand as fine aggregate. The presence of reactive volcanic rocks is further supported by the appearance of reactivity within 5-10 years after construction.

Use of ASTM P214 to Evaluate Pozzolan Effectiveness

Oberholster and Davies (6) reported that ASTM P214 is an effective means of reliably determining whether a pozzolan or other mineral admixture can reduce the potential for deleterious ASR occurring in concrete containing a reactive aggregate. A series of tests using 4 fly ashes were conducted with the original group of 21 sands to determine whether the ASTM P214 procedure could be used to evaluate their ability to reduce potential ASR expansion. Mortar bars were fabricated as before with 10% of the cement removed and 15% of fly ash added as replacement then subjected to the standard test procedure.

Table VI shows the chemical and physical properties of the various fly ashes. Although all four ashes tested are Class C ($SiO_2+Al_2O_3+Fe_2O_3<70\%$) the Coal Creek Ash is very close to an F fly ash at 68.4%. Table VII is a comparison of ASTM P214 expansion values with and without fly ash addition, illustrated graphically in Figure 10 for Coal Creek ash and in Figures 51-53 for the other ashes. The high degree of linearity in the response of the sands to each fly ash strongly supports the applicability of ASTM P214 in evaluating the effectiveness of fly ash and other pozzolans at reducing ASR. Coal Creek Ash was extremely effective at expansion reduction. Only three out of ten highly reactive sands (P214 > 0.2%) had values in excess of

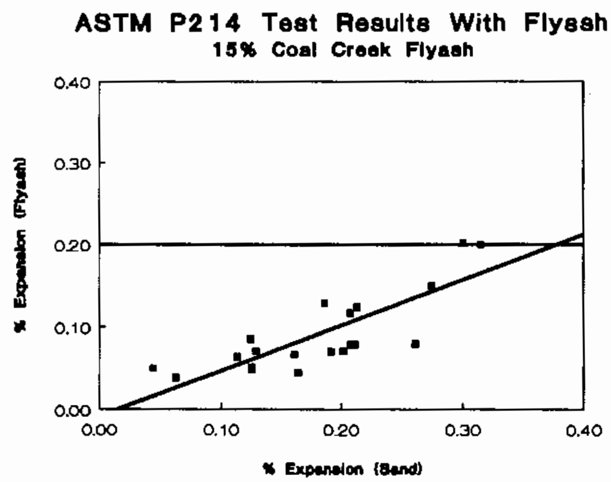

Figure 10 Coal Creek Fly Ash Expansion Reduction

0.2% after addition of this fly ash. None of the other fly ashes performed nearly as well. Whereas Coal Creek significantly reduced the expansion of all sands tested, Neal #3 actually increased expansion values with 7 of the 21 sands. Neal #4 and Rock Mountain Ashes increased expansion for 10 and 7 sands, respectively. Undoubtedly, the high SiO_2 content (46%) and low available alkalies (0.7%) in Coal Creek Ash are responsible for its superior performance. This is supported by the SiO_2 Regression coefficient values in the last column of Table VII. These are based on linear least square fits of the reduction in expansion data for each sand plotted against the SiO_2 content of the fly ashes. A coefficient of 1.0 represents an exact correspondence. An average regression coefficient of determination value (R^2) of 0.745 is obtained for the 21 sands when the difference in expansion between a given sand and the expansion achieved with each of the four fly ashes is correlated with the SiO_2 content of each ash. Figure 11 shows this relationship for the Harry Perry sand, the most expansive of all the sands tested. Requiring a minimum $SiO_2+Al_2O_3+Fe_2O_3 \geq 66\%$ and a minimum SiO_2 content $\geq 40\%$ should insure that the fly ashes added to reduce ASR potential will be effective.

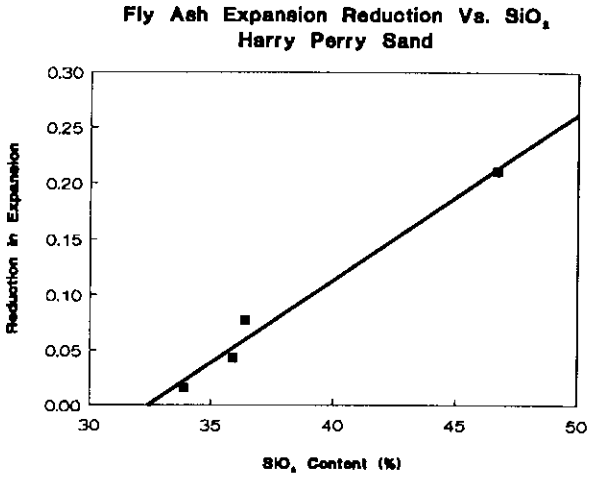

Figure 11 Expansion Reduction Vs. SiO_2 Content

To guage the effectiveness of the four ashes on an individual sand basis coefficient plots were created for each of the sands tested. A typical plot for an aggressively reactive sand is shown in Figure 12 and the plots for the other sands tested with fly ash are shown in Figures 54-72. The most interesting aspect of these plots is the change in position of the plotted coefficients with the addition of fly ash. Coal Creek Ash (1) shifts the plot from the reactive to the unreactive lines for 8 of the 12 reactive sands in the group. The other four sands, all aggressively reactive (Heib Delmont, Opperman Herrick,

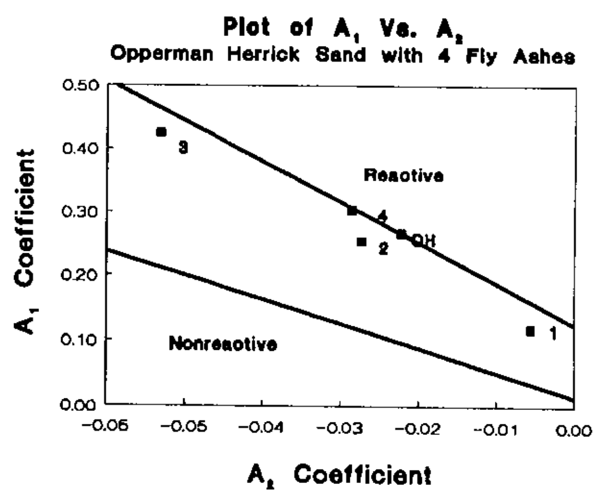

Figure 12 Typical Reactive Sand with 4 Fly Ashes

Table VII : ASTM P214 Test Results With Fly Ashes

Pit	ASTM P214 Test Results					SiO_2
	Sand	Coal Creek (15 %)	Neal #3 (15 %)	Neal #4 (15 %)	Rocky Mtn. (15 %)	Regression R^2
Conc. Matls. Brandon	0.202	0.071	0.187	0.264	0.205	0.790
Heib Delmont	0.300	0.202	0.259	0.291	0.232	0.452
Everist Brookings	0.125	0.051	0.128	0.191	0.137	0.709
Jensen Herreid	0.274	0.150	0.290	0.285	0.270	0.903
Opperman Herrick	0.315	0.200	0.286	0.340	0.331	0.902
Mission Hills	0.261	0.080	0.237	0.312	0.236	0.794
Higman Akron	0.207	0.117	0.210	0.220	0.194	0.847
Everist Hawarden	0.186	0.129	0.163	0.177	0.188	0.940
Conc. Matls.Summit	0.161	0.067	0.162	0.176	0.131	0.708
McLlaughlin Watertown	0.128	0.071	0.087	0.118	0.119	0.714
Northern Conc. Agg.	0.113	0.064	0.094	0.142	0.128	0.719
Birdsall Blunt	0.192	0.070	0.208	0.254	0.235	0.939
Hills Centennial	0.125	0.049	0.069	0.055	0.058	0.382
Hills Wasta	0.213	0.124	0.197	0.185	0.172	0.764
Fisher Spearfish	0.044	0.050	0.079	0.110	0.090	0.715
Birdsall Wasta	0.211	0.079	0.213	0.200	0.178	0.828
Birdsall Oral	0.164	0.045	0.128	0.165	0.151	0.920
Birdsall Creston	0.208	0.079	0.177	0.221	0.170	0.770
Fisher Mitchell (Man.)	0.124	0.085	0.063	0.095	0.076	0.057
Fisher Mitchell (Nat.)	0.063	0.039	0.052	0.064	0.060	0.823
Harry Perry	0.467	0.256	0.390	0.424	0.451	0.981

Investigation of Alkali-Carbonate Reactivity

The final task of this research project was to investigate alkali-carbonate reactivity. This portion of the research was not pursued as the testing procedures used were insensitive to ACR and the extent of ASR research made this topic of secondary importance. This task was expanded into a separate research problem and work on ACR is scheduled to begin in the spring of 1994.

generally high summertime humidities in eastern South Dakota and the combination has greatly increased maintenance costs on these pavements while shortening pavement life. The continual use of appropriate fly ashes or other pozzolans in concrete mixes with quartzite should greatly reduce these problems in the future.

Several questions concerning ASR and concrete aggregate durability in general still remain. The deterioration of concrete pavement on SD37 south of Huron has not been explained satisfactorily as the Everist Brookings sand used in its construction is not verified by ASTM P214 test results. A reference by Mather (8) to a highly dolomitic aggregate near Watertown which undergoes alkali-carbonate reactivity and dedolomization is intriguing and may explain this discrepancy as alkali carbonate reactive aggregates do not necessarily yield high expansion values when subjected to ASTM P214. Although alkali carbonate reactivity was originally part of this research it was not investigated due to the already extensive nature of the research. A separate research project on this problem is scheduled to begin in the spring of 1994.

Conclusions

1.Of all screening methods for detecting potential alkali silica reactivity ASTM P214 emerges as the only one which projects an aggregate's reactivity reliably and reproducibly. ASTM C227, ASTM C289 and the SD Autoclave test all give conflicting results which tend to defy proper interpretation.

2.The use of coefficient plots for interpreting ASTM P214 improves the reliability and accuracy of the test with the elimination of the potentially deleterious classification for almost all fine aggregate tested. Reactive aggregate can be classified as mild, moderate and aggressively reactive based on the expansion of an aggregate with and without pozzolan addition.

3.All sands tested which have an expansion of 0.165% or below were nonreactive based on field performance except for Sioux quartzite which is slow, late-expanding alkali reactive.

4.Type II low alkali cement is insufficient to insure that no alkali silica reactivity will occur when reactive aggregate are used in concrete.

5.ASTM P214 can be used to screen fly ashes and other pozzolans for the ability to reduce the potential for alkali silica reactivity. A reduction in expansion, however, does not necessarily mean that no reaction will occur. Coefficient plots give a better picture of how effective a given fly ash or pozzolan may be.

6.Class C fly ashes with low SiO_2 contents are inherently unpredictable when added to concrete containing reactive aggregates unless the rate of addition is 30% or greater.

7.Alkali silica reactivity can be managed using Type II low alkali and super-low alkali cements and fly ash or pozzolan admixtures but such solutions must be considered "potentially" effective especially for aggressively reactive aggregates. The problem of ASR should not be considered solved and the jury is still out on whether there will ever be a final answer.

problems. A good case in point is the Platte-Winner bridge where an aggressively reactive sand was used and severe ASR cracking is developing in the substructure. The addition of NaCl deicing salts to bridge decks at increasing rates to satisfy the public demand for safe winter driving conditions is also accelerating the onset of ASR-related structural problems. Fly ash should help to mitigate these problems in most situations while providing three other benefits:

1)Greater concrete workability at lower w/c ratios.

2)Lower concrete permeability which will slow the rate of chloride penetration.

3)Reduction in cracking due to lower w/c and cement factor.

5.The proposed research project on alkali carbonate reactivity should also address the potential alkali silica reactivity of coarse aggregate sources which have been used or continue to be used in concrete. The work plan for SD94-01 "Identification and Elimination of Alkali-Carbonate and Alkali-Silica Reactivity" includes ASTM P214 testing of coarse aggregate sources as part of the research.

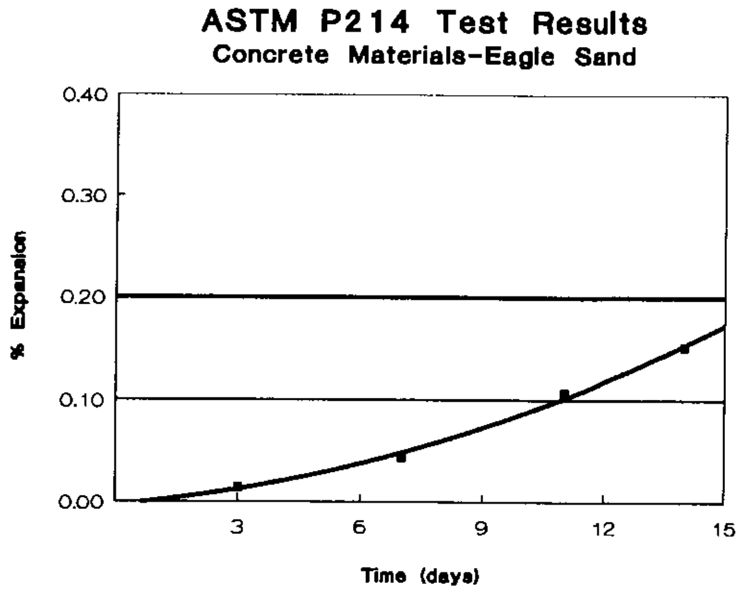

Figure 16 Concrete Materials Eagle Sand

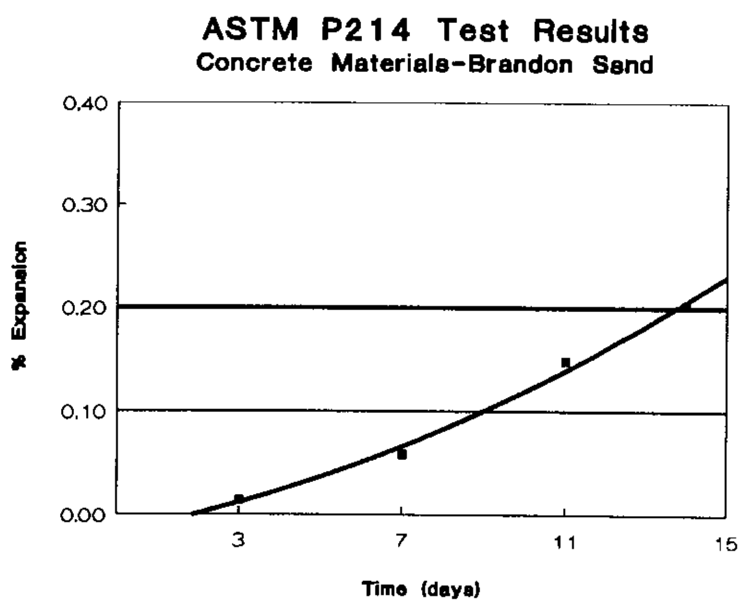

Figure 17 Concrete Materials Brandon Sand

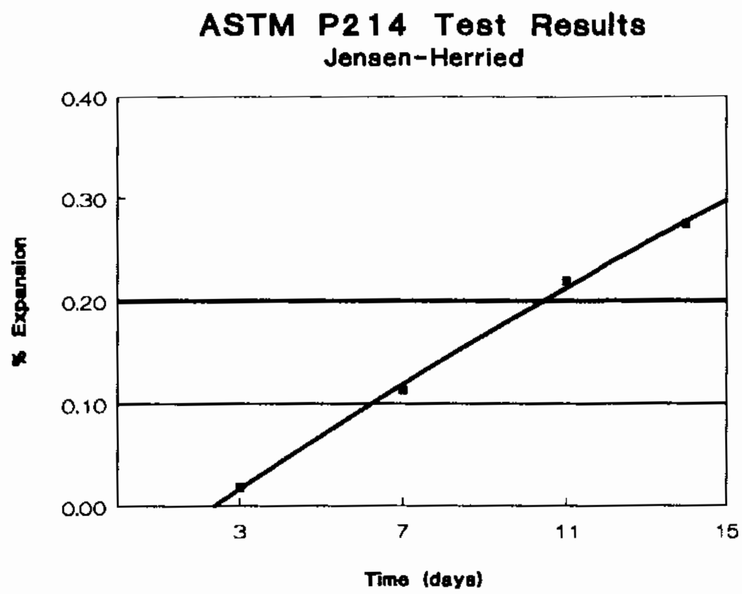

Figure 20 Jensen Herreid Sand

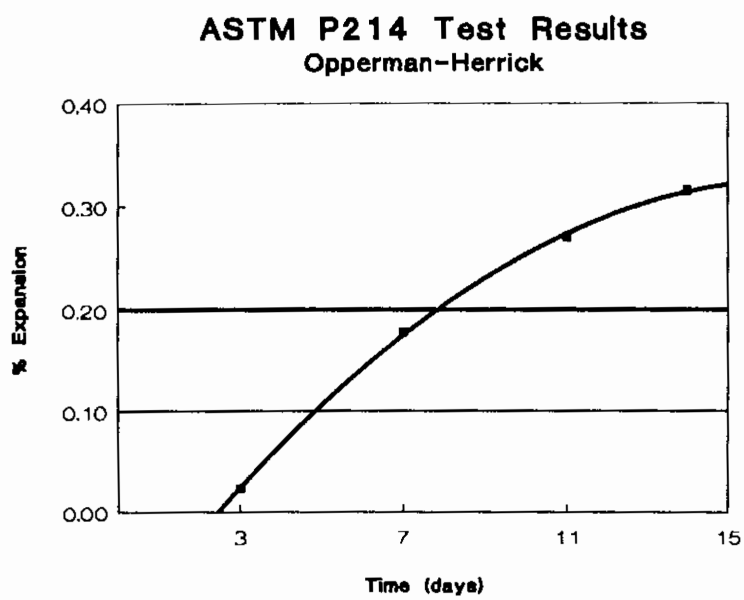

Figure 21 Opperman Herrick Sand

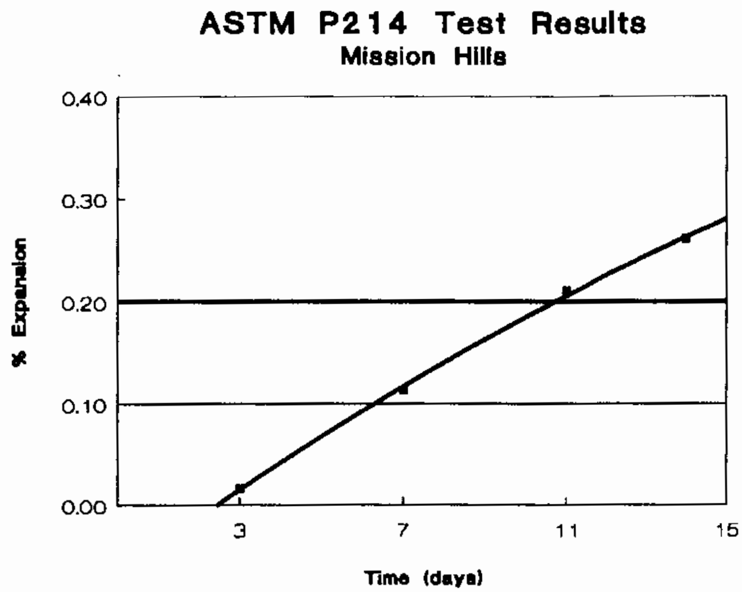

Figure 24 Mission Hills Sand

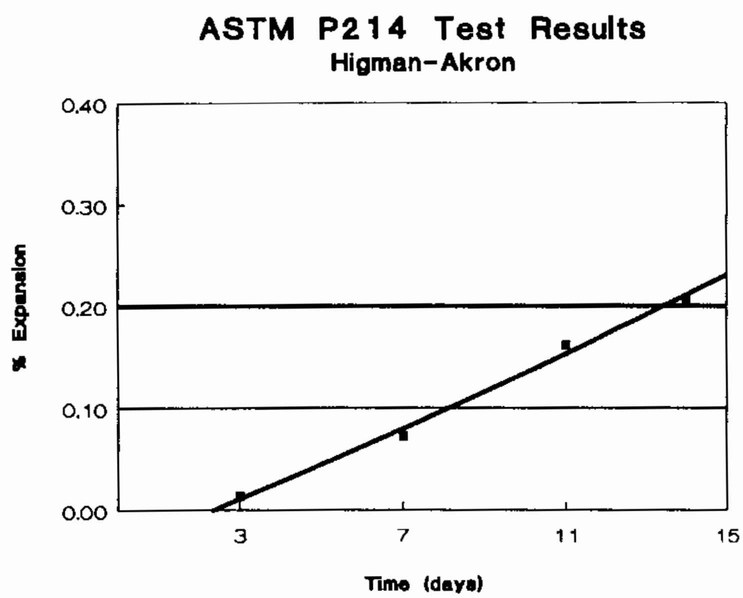

Figure 25 Higman Akron Sand

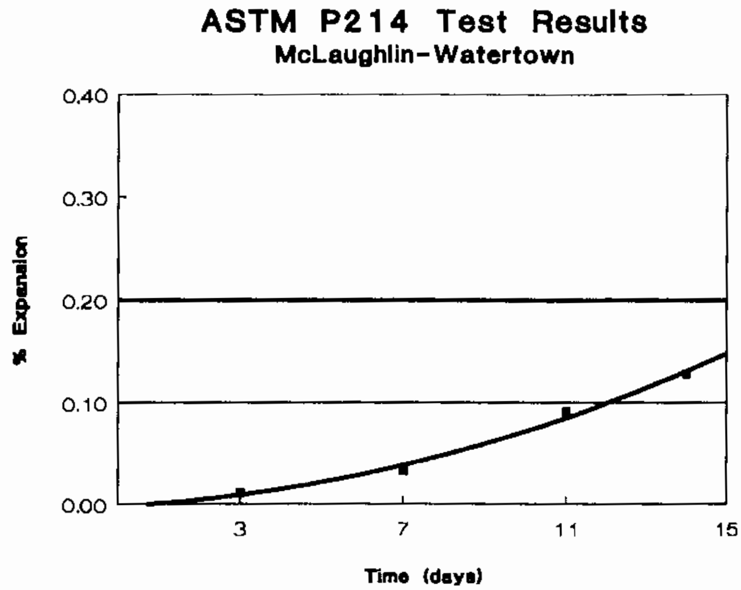

Figure 28 McLaughlin Watertown Sand

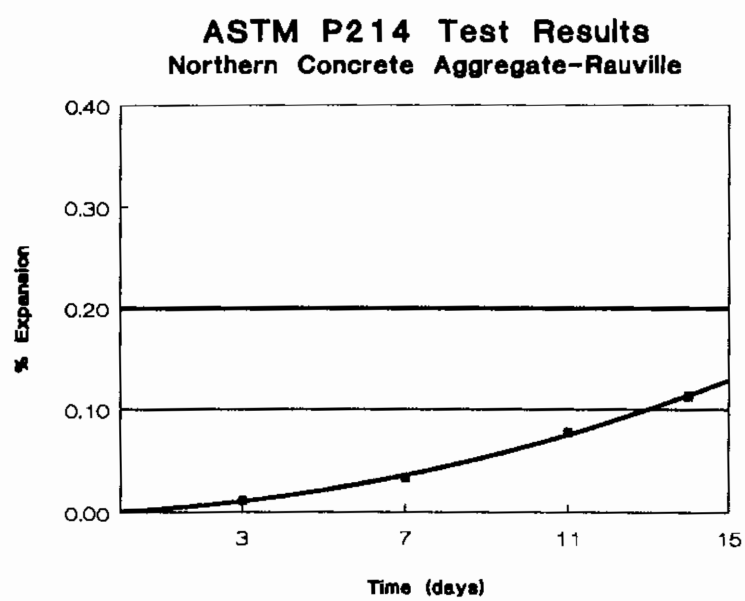

Figure 29 Northern Concrete Aggregate Sand

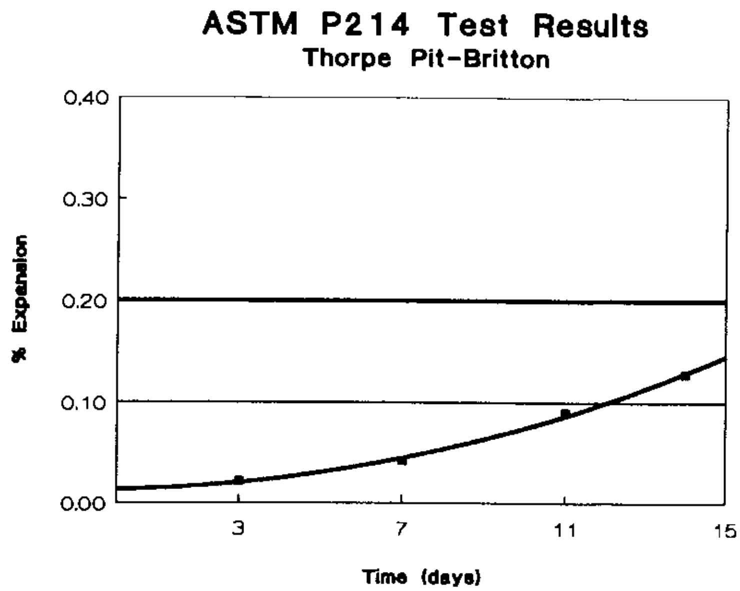

Figure 32 Thorpe Sand

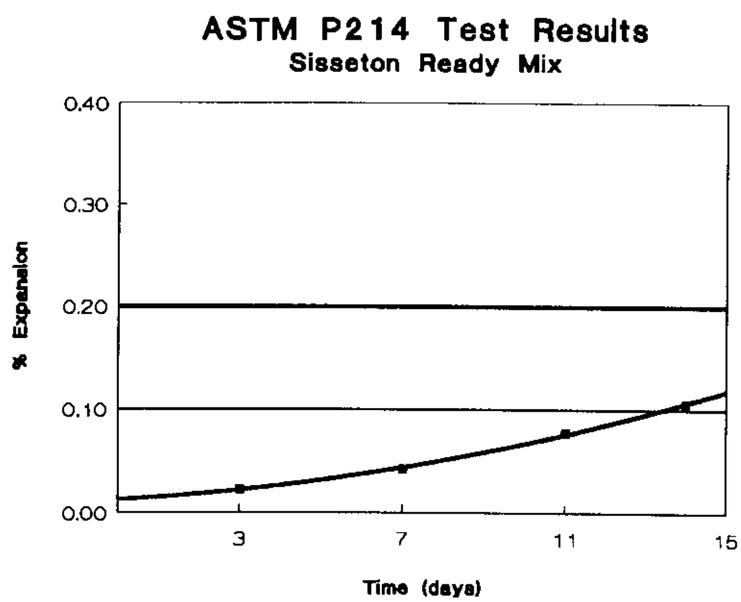

Figure 33 Sisseton Ready Mix Sand

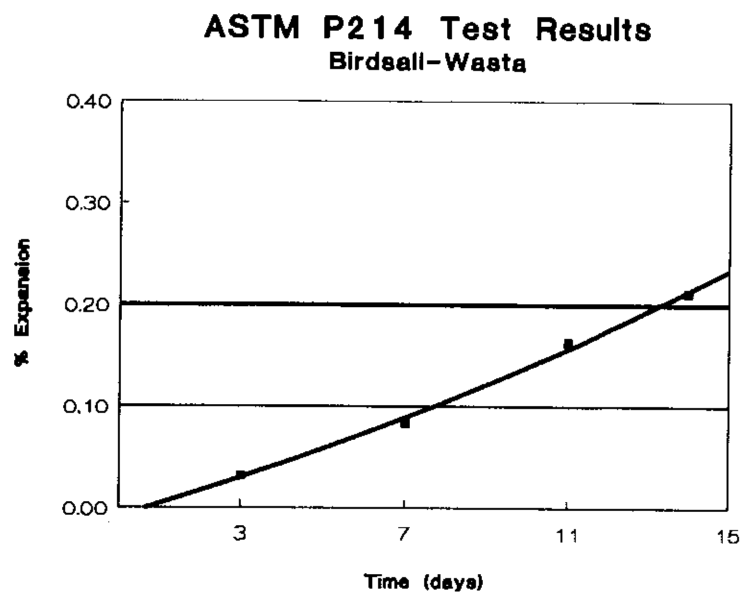

Figure 36 Birdsall Wasta Sand

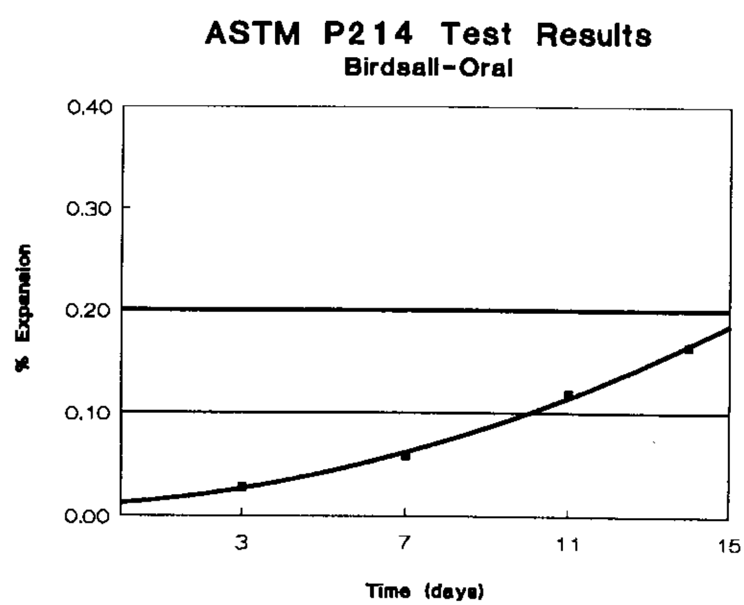

Figure 37 Birdsall Oral Sand

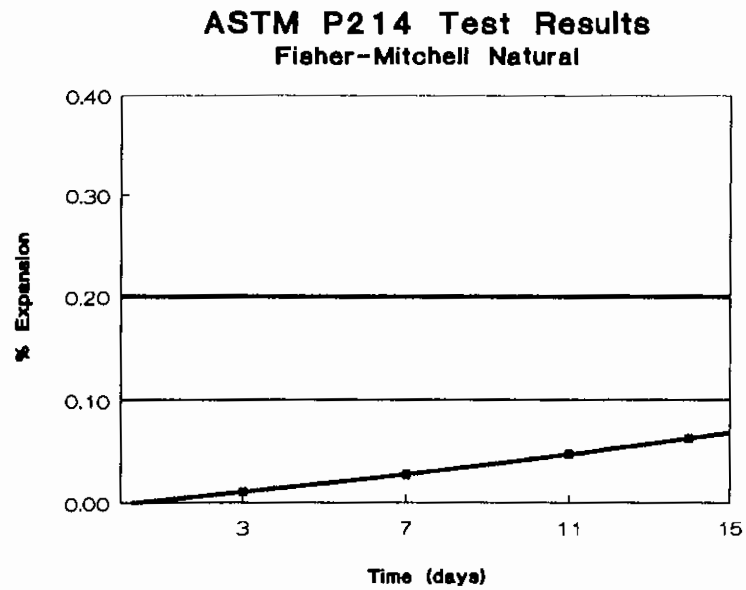

Figure 40 Fisher Mitchell Natural Sand

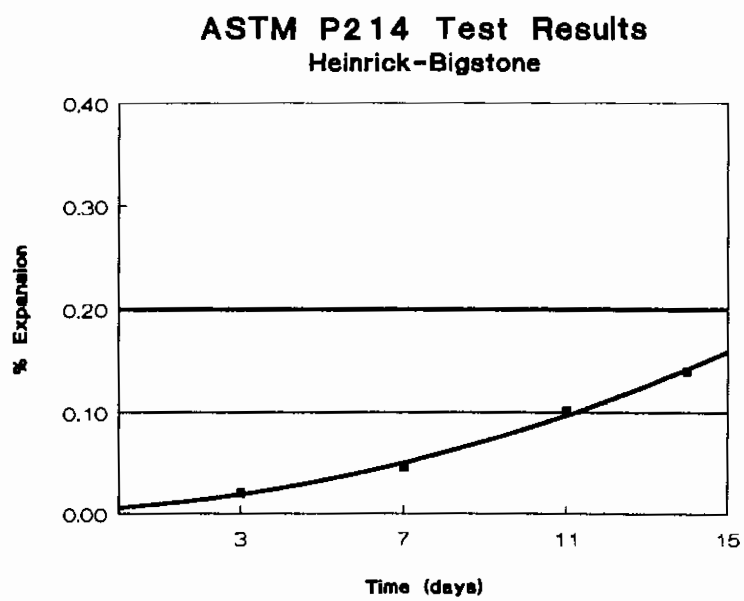

Figure 41 Heinrich Bigstone Sand

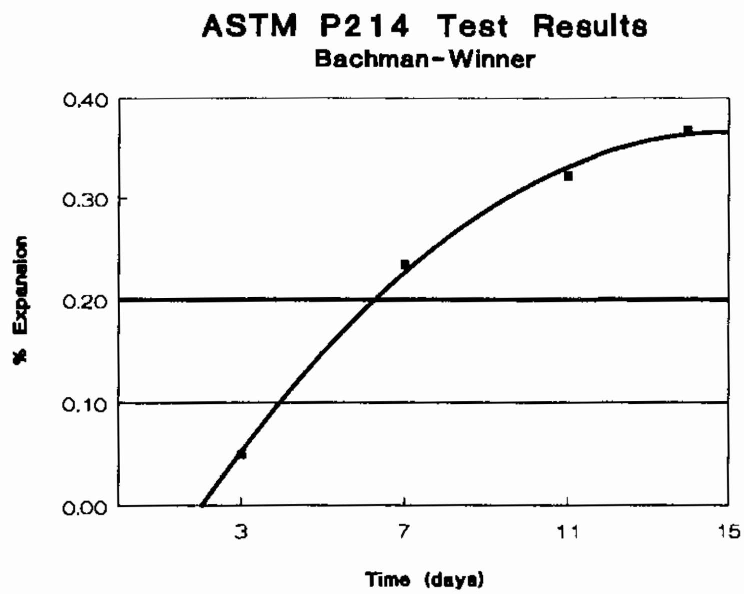

Figure 44 Bachman-Winner Sand

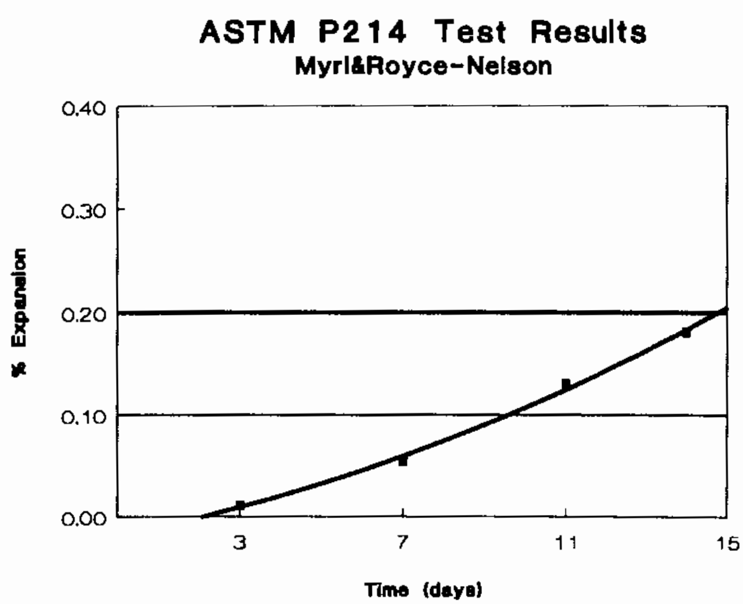

Figure 45 Myrl & Royce Nelson Sand

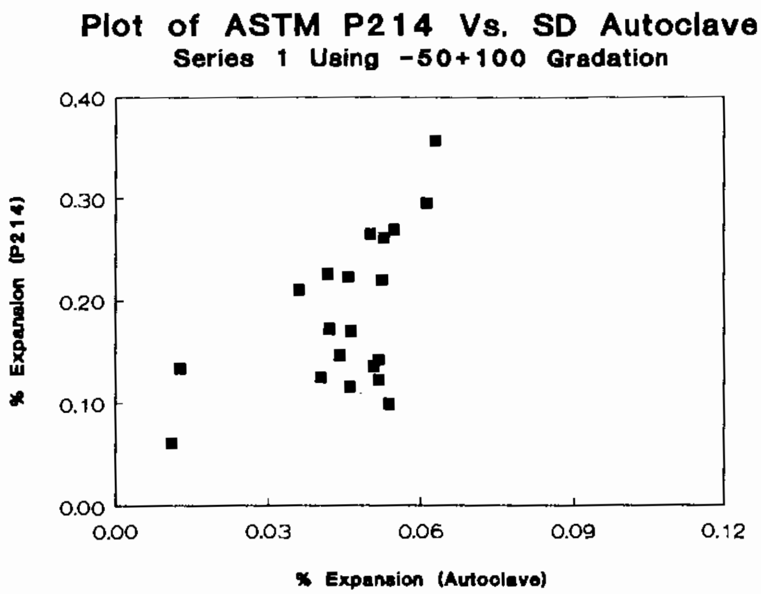

Figure 48 ASTM P214 Vs. SD Autoclave (Seriesl)

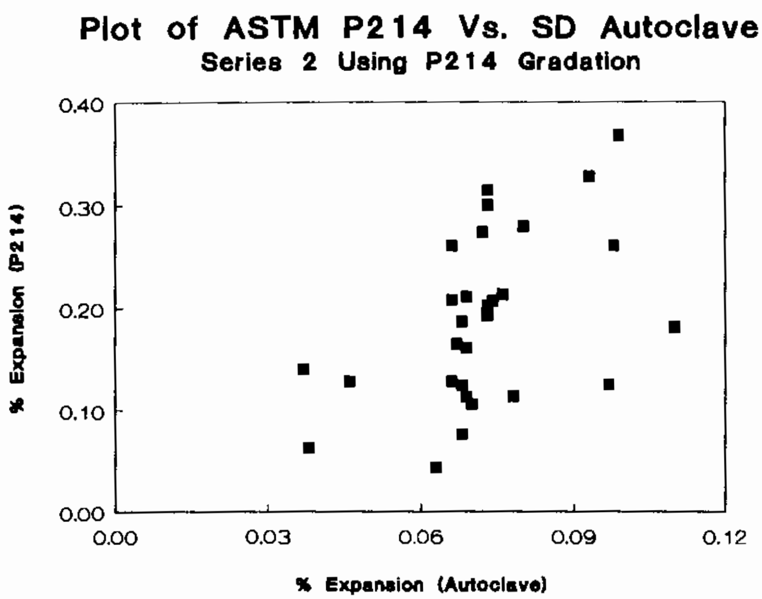

Figure 49 ASTM P214 Vs. SD Autoclave (Series 2)

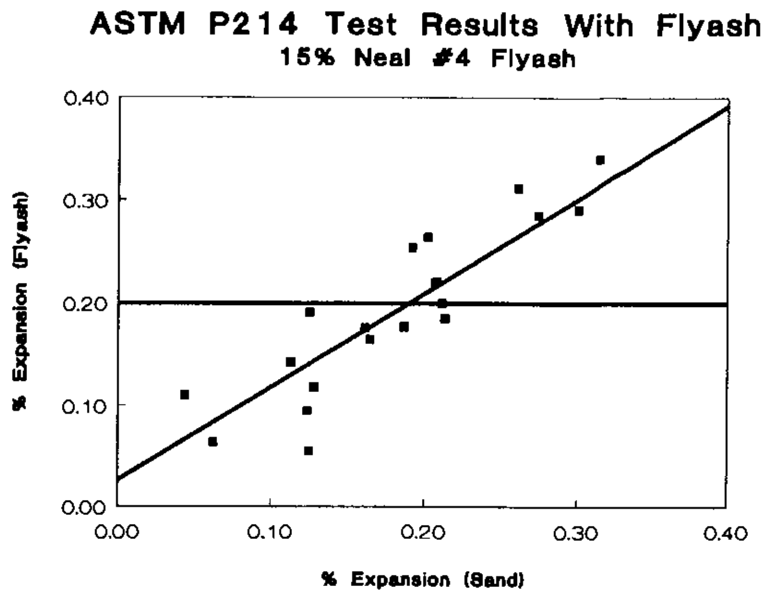

Figure 52 15 % Neal #4 Fly Ash

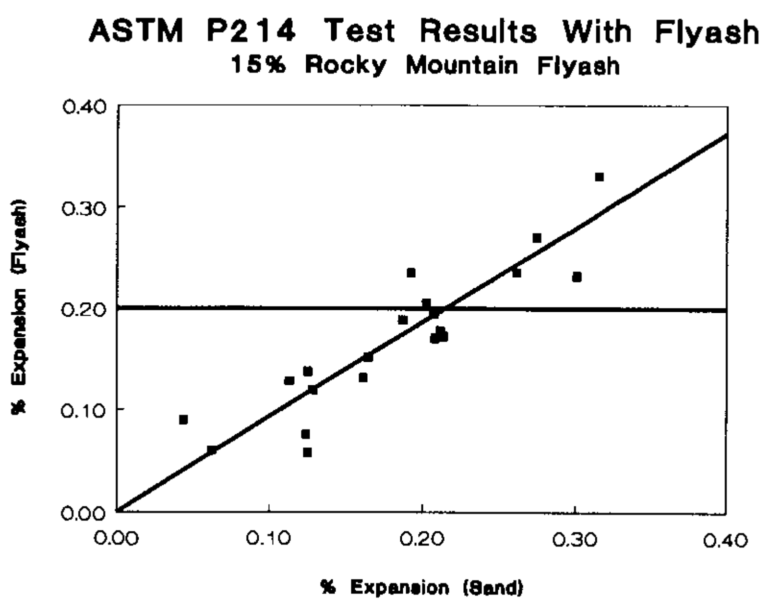

Figure 53 15% Rocky Mountain Fly Ash

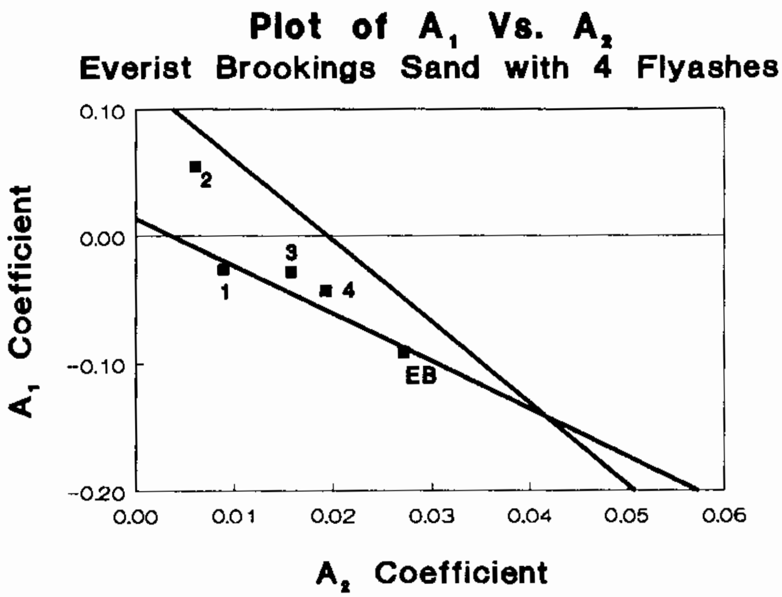

Figure 56 Everist Brookings Sand

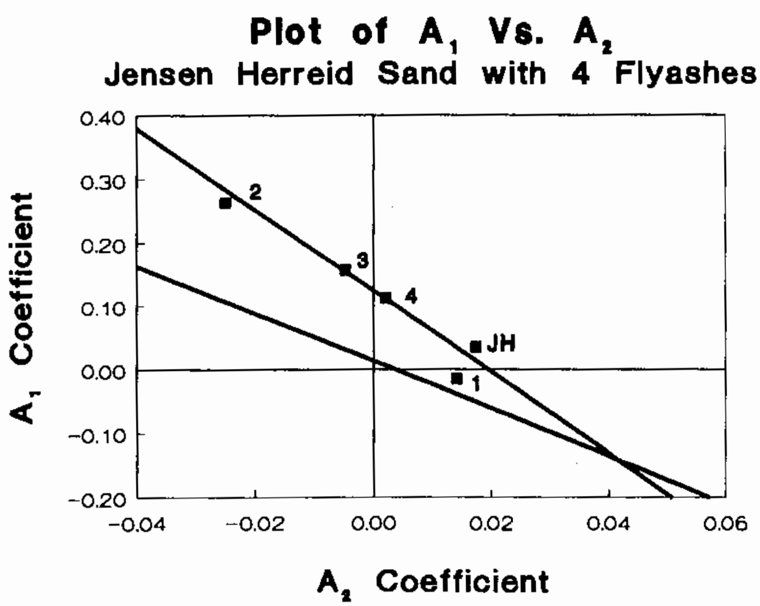

Figure 57 Jensen Herreid Sand

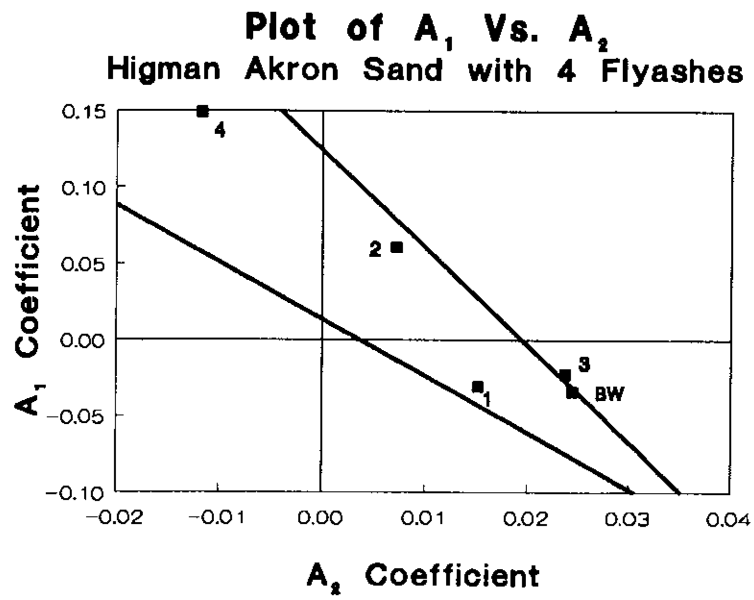

Figure 60 Higman Akron Sand

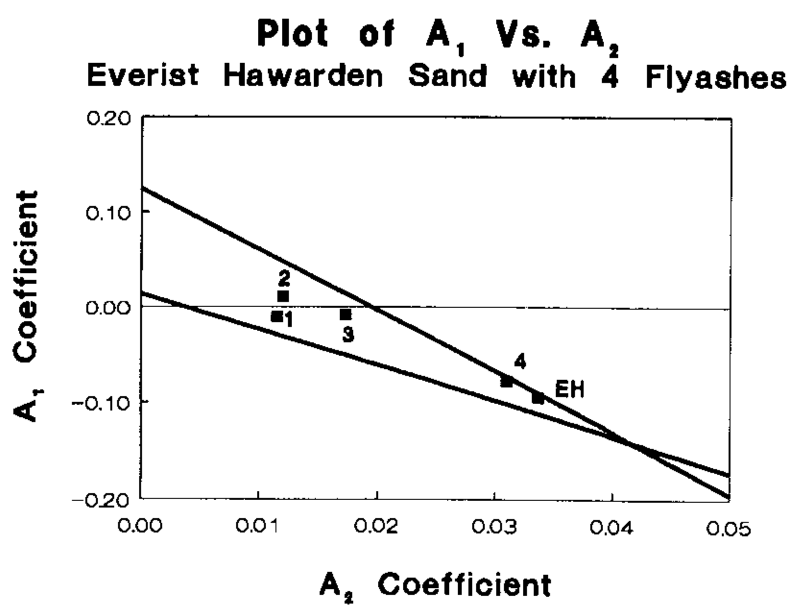

Figure 61 Everist Hawarden Sand

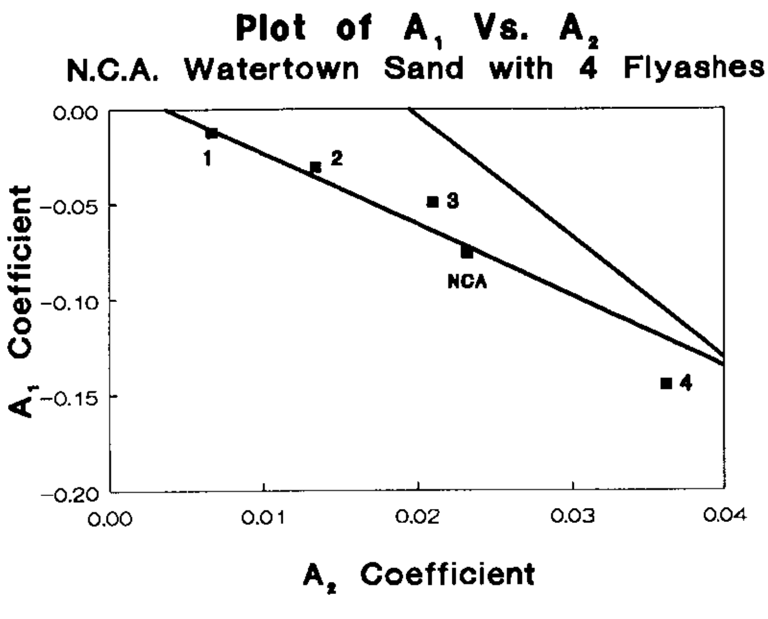

Figure 64 Northern Concrete Aggregate Sand

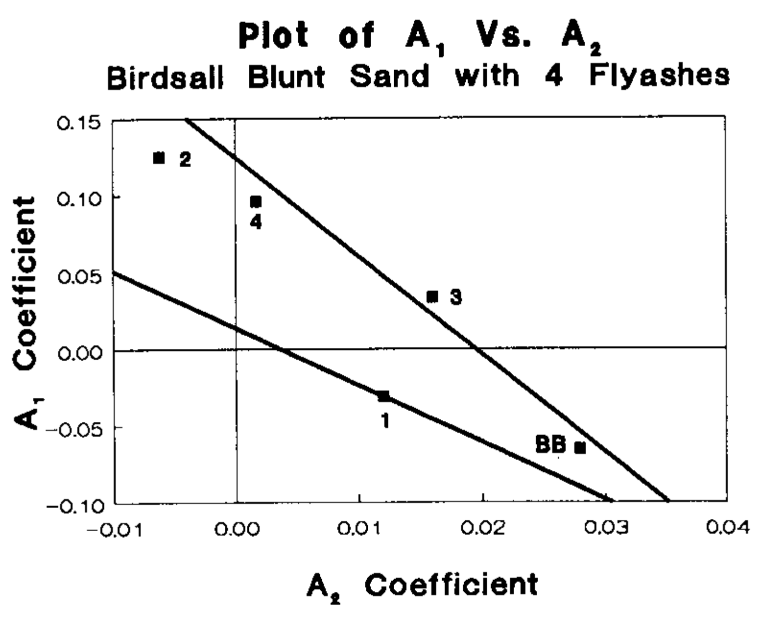

Figure 65 Birdsall Blunt Sand

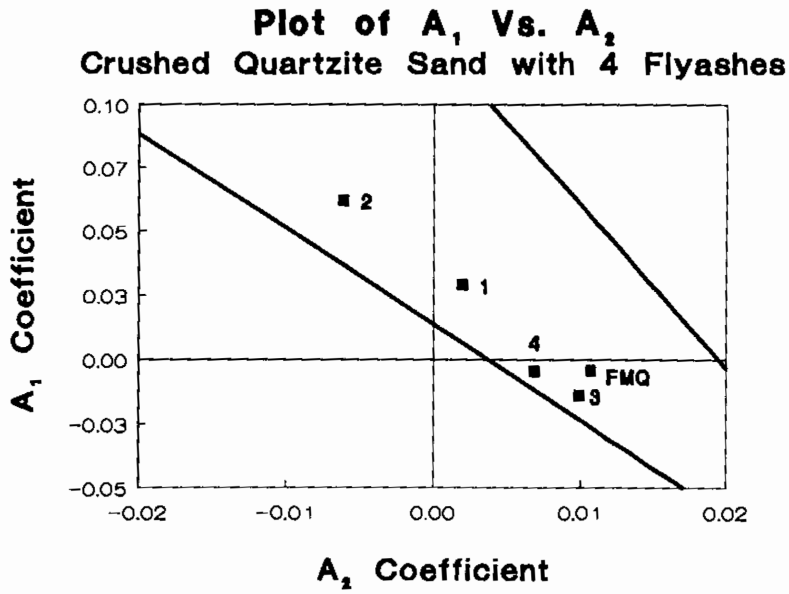

Figure 72 Crushed Quartzite