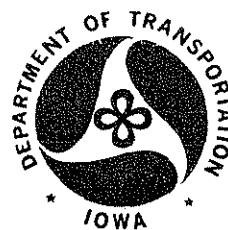


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RESEARCH SECTION  
Office of Materials  
Iowa Dept. of Transportation

SPECIAL REPORT ON  
ALKALI-AGGREGATE REACTIVITY  
IN IOWA



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OFFICE OF MATERIALS  
IOWA DEPARTMENT OF TRANSPORTATION

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The contents of this report reflect the view of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Iowa Department of Transportation.

This report does not constitute a standard, specification or regulation. It reports on the reasons for the study and presents the results of the laboratory investigation and recommendations based on the results of the study.

## GENERAL COMMENTS

There are many urgent state and national needs which the cement industry can help meet. Among those needs are conservation of energy and materials, protection of environmental quality, and preservation of public safety.

The manufacture and use of low alkali portland cement generally entails a greater use of energy and raw materials, in addition to generation of more solid waste materials. However, due to alkali-aggregate reaction, high alkalies in cement may increase the risk to public safety by causing premature pavement or structural failure. The desire to reach a compromise between the use of low-alkali and high-alkali cement comes at a time when high quality aggregates with proven service records are becoming progressively more difficult to obtain.

All available sources of information about trends in the industry suggest a continued drift to higher alkali contents in the future. The Iowa D.O.T.'s specifications currently place a fairly low limit on alkali content in cement. It would be desirable to raise that alkali content limit as quickly as possible only if it can be done without an unreasonable risk.

In this report, remarks will be directed to the most recent limitation of the alkali content of cement in Iowa, the challenges facing the state in the modernization and expansion of cement production facilities, a general view of the outlook for the alkali content limit, and Iowa's position within the cement industry.

## PURPOSE

Most concrete serves its intended function satisfactorily for its design life. Occasionally, however, certain combinations of materials, workmanship and/or environmental conditions arise that hasten concrete deterioration. This seems to be especially true in the varied and often harsh environment of bridges and pavements. Because the final aspect of deterioration is physical, chemical causes, if they occur, are frequently overlooked.

Even if chemical reactions are recognized as contributing factors to the deterioration, their exact nature is usually not completely understood. The alkali-aggregate reaction is one that fits this category and it has been well established that this reaction is potentially detrimental to concrete.

Concrete affected by alkali-aggregate reactivity often has a characteristic appearance such as map-cracking, popouts, gel exudation, and damp spots. Not all of these features are observed on any one particular structure or pavement, but certain similarities do exist wherever the affected concrete is located.

The alkali-silica reactions were the first of the alkali-aggregate reactions to be recognized and they appear to be the most frequent cause of serious problems. While the other types of alkali-aggregate reactions were not ignored, only the alkali-silica reactions were considered in this study.

## INTRODUCTION

During the summer of 1978, Iowa and other states were faced with the problem of inadequate supplies of portland cement. Factors which may have contributed to this problem were too vague and numerous to list. However, several of the major contributing factors were, a significant growth in the demand for cement in the housing and agricultural construction industries, cement plant breakdowns, and changes in the normal time distribution of demand for cement. These factors were coupled with the routine and unexpected required shutdowns of cement kilns for maintenance purposes, or shutdowns required to effect repairs to meet air pollution standards.

All of these factors made it difficult for the cement industry to keep pace with the demand for cement.

At the same time, the Office of Materials received a considerable number of requests from the cement producers to raise the maximum specification limit for the level of allowable alkalies in cement. Iowa had an upper specification limit of 0.75% alkalies calculated as sodium oxide ( $Na_2O$ ), and 0.60% as a specified limit for cement used in concrete with aggregate that may be considered reactive.<sup>1</sup>

Our specification limit of 0.75% alkali for portland cement was arrived at quite arbitrarily with virtually no technical data that can be found to support the limit.

In contrast, both the "American Association of State Highway and Transportation Officials" (AASHTO) and the "American Society

"Standard Practice for Testing and Materials" (ASTM) suggest that a maximum limit of 0.60% on the total alkali content expressed as sodium oxide ( $\text{Na}_2\text{O}$ ) may be specified when the cement is to be used in concrete with aggregates that may be deleteriously reactive.<sup>2,3</sup> The value of 0.60% was arrived at empirically by correlation with field indications of distress, and seems to be a reasonable figure.

The specification does not take into account the proportion of cement to be used in a particular concrete. A mix design with high cement content will have higher potential for chemical attack than a mix with a lower cement content. Further, limiting the alkali content of the cement does not guard against the potential introduction of additional alkalies from other sources such as deicing salt. It may be expected that cement produced so as not to contain more than 0.6% alkalies calculated as sodium oxide will no longer be available from some producers and, if it will be available, will be available only at a premium price.

This alone justified a reexamination of our position for requiring an upper limit on the alkali content in Iowa and began our extensive evaluation of the alkali reactivity of the natural sands that are commonly approved to be used in p. c. concrete throughout the state.

The tests were conducted with the thought being, to eliminate the restriction if we have no alkali-aggregate reaction with our materials.

With the growth of energy constraints dry process kilns, often with suspension preheaters, are now replacing old designs. These

energy efficient kilns provide only limited ability to reduce excess alkali in the raw mix by venting. This development, combined with the increasing tendency to recycle alkali-rich waste cement dust to the raw mix, and the use of coal to fire the kiln, has resulted in a progressive increase in alkali contents of most cements in recent years. Raising of the alkali limits would permit the re-introduction of kiln dust into the cement and facilitate more efficient production of cement.

Kiln dust was not a problem until the Environmental Protection Agency (EPA) imposed regulations prohibiting the release of this dust into the atmosphere. In the interest of clean air, this dust is now collected in large quantities by using special air filtration methods such as electrostatic precipitators.

Reintroduction of the kiln dust into the cement production process will provide the following beneficial results for the cement industry:

1. It will provide a means of disposal of the kiln dust.

This method of disposal will eliminate the possibility of release of the kiln dust into already polluted streams through conventional landfill methods.

2. It will aid in energy savings. Vast amounts of energy have been expended in the production of this kiln dust.

Any method by which this kiln dust may be used would provide an additional cost savings to the cement producers. In addition, with already tight energy supplies in this country, any amount of fuel savings is beneficial to the country as a whole.

In order to allow the introduction of the kiln dust, the Iowa D.O.T. would have to raise its specification limits on alkali content in cement. Raising these limits would have the following beneficial results for Iowa:

1. It would make more cement available. The kiln dust could be processed with the cement producing a larger volume of cement. New sources of raw materials which were previously excluded due to their tendency to increase alkali content of the cement could now be used, increasing the volume of cement. These actions would help stave off any future cement shortages which may occur.
2. It would provide an energy savings to the state as a whole. Higher limits on alkali content in cement allows lower burn temperatures in the kiln.<sup>4</sup> Lower burn temperatures require less fuel, thereby providing an energy savings.\* This is in addition to the energy savings provided by recycling the kiln dust.
3. While it may not reduce the costs of cement, it will probably aid in keeping the costs from rising further by minimizing disposal costs of the kiln dust to the cement producers. Also, the fuel savings the producers

\*For 1978, the cement industry in the U.S. was the sixth largest industrial user of energy, demanding approximately 8.5 million tons of coal, 13.4 million barrels of oil, 217 billion cubic feet of natural gas and 11.1 billion kilowatt hours of electricity.

derive should be reflected in the cost of the cement to the state.

The hesitancy of the Iowa D.O.T. to raise its limit on alkali is due to its concern over possible alkali-aggregate reactions which may occur with Iowa's aggregates. Such reactivity is known to occur in part of the midwestern states but as of yet, there are few, if any known incidences of alkali-aggregate reactions in Iowa. The reaction which Iowa would be concerned with are the alkali-carbonate reaction and the alkali-silica reaction.

The alkali-carbonate reaction occurs most often in the argillaceous dolomites. Since most of Iowa D.O.T.'s coarse aggregate sources are crushed limestones and gravels, there is not as much concern over this reaction as might be warranted elsewhere. However, the Iowa D.O.T. did perform extensive testing for this reaction in accordance with Test Method ASTM C586, "Potential Alkali Reactivity of Carbonate Aggregates (Rock Cylinder Method)" using Iowa Aggregates.

The conclusions reached show that there appears to be little cause for concern about the alkali-carbonate reaction in Iowa.<sup>5</sup>

The possibility of raising the alkali limit in cement has resulted in a renewed concern over the alkali-silica reaction. Since very little was known about this type of reaction in Iowa aggregates, an investigation was proposed to evaluate the potential alkali-silica reactivity of Iowa's sands that are commonly approved to be used in p.c. concrete.

#### PURPOSE OF INVESTIGATION

The purpose of this investigation was to obtain information relative to the alkali-silica reaction in Iowa aggregates. Of par-

ticular concern were those aggregates in southwestern Iowa thought to be potentially alkali reactive.

Further, should those aggregates have proven to be alkali-reactive, at what cement alkali content could these aggregates be considered to be deleteriously reactive? If the aggregates were proven to be reactive, what types of effects might show up in a structure in which an alkali-silica reaction has occurred? Also, what environmental conditions would cause the reaction?

Finally, based on the information obtained from the investigation, would it be possible to raise the cement alkali content specifications? Would the Iowa D.O.T. eliminate the alkali content limits altogether except for cement used with reactive aggregate in the same manner as AASHTO or ASTM? Also, would there be any other side effects that might occur as the result of using high alkali-cement?

#### THE ALKALI-SILICA REACTION

A high alkali content in cement may be caused by several factors. Raw materials containing sodium or potassium oxides introduce alkalies into the cement. Raw materials which have a higher than acceptable amount of these compounds elevate the alkali content of the finished product.

The type of kiln system also plays a role in the amount of alkali in cement. Each of the major types of kilns has its own peculiarities, but in general the following are true:

1. Kilns which operate at lower burning temperatures increase the alkali content due to failure to evaporate the alkalies.

2. Kilns which introduce hot kiln gasses to the raw materials for preheating raise the alkali level by combining the alkalies in the gasses with the cooler raw materials.
3. Kilns which reintroduce kiln dust into the production process raise alkali content due to the high alkali content of the kiln dust.

The aggregates which will produce an alkali-silica reaction are usually varieties of certain groups or classes of rocks which have similar but not identical properties. The classes of rocks in a group are not necessarily all reactive nor do they react to the same degree. The list of rocks and minerals which will react is fairly extensive and includes commonly found forms such as opal, tridymite, cristobalite, and the acid volcanics.

Also reactive are such minerals as chert, chalcedony, and certain forms of quartz. In addition, certain sedimentary and metamorphic silicate rocks have been described as alkali reactive. These are the siltstones, "some" argillites, greywackes, subgreywackes, arkoses, quartzites, slates, phyllites and quartzmica schists.<sup>6</sup>

Petrographic examination will reveal whether or not these reactive minerals are present in an aggregate source. However, quantities of these substances present in a source probably play a bigger role in determining the rate of concrete deterioration.

The deterioration of concrete through the alkali-silica reaction probably occurs through the following mechanism. As hydration occurs in the

cement the alkali constituents dissolve. The alkalis appear in the solution surrounding the cement paste as alkali hydroxides (i.e., sodium and potassium hydroxide) which are then free to attack the reactive aggregates in the concrete.

The reactive silica aggregates are characterized as having a surface area internally and externally composed of broken silicon to oxygen bonds. The presence of these broken bonds cause an unevenly charged surface which will allow hydration to occur. The water, attached through hydration, consist of hydrogen ions ( $H^+$ ) and hydroxyl ions ( $OH$ ) which are attached to the oxygen and silicon atoms, respectively.

The reaction of the hydrated silica with the alkali hydroxide then becomes essentially an acid-base neutralization forming free water and an alkali-silica complex. This complex tends to imbibe water and increase in volume.

The increase in volume creates internal pressures within the cement paste. When the pressures exceed the tensile strength of the surrounding cement paste, cracking and expansion of concrete occur.<sup>7</sup>

Physical evidence that indicates the occurrence of the alkali-silica reaction may be of several types. In mass concrete, the cracks which occur appear in a random pattern. These cracks may

be anywhere from hairline width up to one and one-half inches wide depending upon how massive the structure is. The larger cracks may penetrate as deep as 18 inches (45 cm).

The reaction develops slowly. The surface random cracking may not appear for at least a year, and possibly longer, after the concrete has been placed. The cracking which occurs is a combination of internal expansion of the concrete and external shrinkage due to drying. The expansion which occurs may be so great as to cause construction joints to close up.

Associated with the expansive cracking will normally be the occurrence of surface pop-out of particles undergoing expansion. These pop-outs will be particularly noticeable where the offending particles are large in size.

Adjacent to the particles and appearing in voids in the concrete will be gelatinous exudations and whitish amorphous deposits. These spots and gel exudations generally occur only in those areas which are protected from surface washing or erosive action.

Close examination of the gels will show that they exhibit extreme shrinkage and cracking when exposed to drying conditions. The whitish amorphous deposits which appear are normally a secondary by-product, the results of combination of the gel with soluble free lime which leaches out of the matrix. Rarely is the gel actually seen in conditions which permit drying due to its tendency to desiccate quickly.<sup>8</sup>

There are currently several methods being used to evaluate aggregates for their potential alkali reactivity. The quickest of these methods is the chemical method.

The chemical method of evaluation is designated ASTM C289, "Potential Reactivity of Aggregates (Chemical Method)". This method consists of dissolving the test sample and determining the dissolved silica content photometrically. The amount of dissolved silica will provide an indication of the potential for reaction of the aggregate.

To verify or disprove the results of the chemical method, the mortar-bar expansion test is often used. This method, designated ASTM C227, "Potential Reactivity of Cement-Aggregate Combinations", takes a minimum of three and preferably six months or more to complete. The mortar bar expansion test method is particularly useful in evaluating the effects of differing levels of alkali in cements or aggregates. Levels of reactivity are determined by the percentage of growth of bars made with the cement-aggregate combination in question.

Another method particularly applicable to Iowa according to ASTM is designated ASTM C342, "Potential Volume Change of Cement-Aggregate Combinations". This test is similar in several ways to ASTM C227. The hardware used, the aggregate gradations, and the calculations performed are all similar.

The major differences in the two methods are the methods of bar storage. ASTM C227 requires bar storage in a moist cabinet at  $100 \pm 3^{\circ}\text{F}$  ( $37.8 \pm 1.7^{\circ}\text{C}$ ). ASTM C342 requires bar storage under water at  $73.4 \pm 3.0^{\circ}\text{F}$  ( $23.0 \pm 1.7^{\circ}\text{C}$ ).

Another method of determination of potential alkali reactivity is, "Petrographic Examination of Aggregates for Concrete", designated ASTM C295. Using this method, aggregate particles are classified according to size, distribution, and type of rock or mineral. This type of testing provides a very good indication of the relative quantities of deleterious materials in an aggregate.

More technologically sophisticated methods of identifying potentially reactive aggregates include such methods as X-ray diffraction, differential thermal analysis, and infra-red spectroscopy. These methods are not in widespread use at this time for aggregate identification. However, in the future, as more of the necessary equipment becomes available at an economical price, these methods may prove more useful.

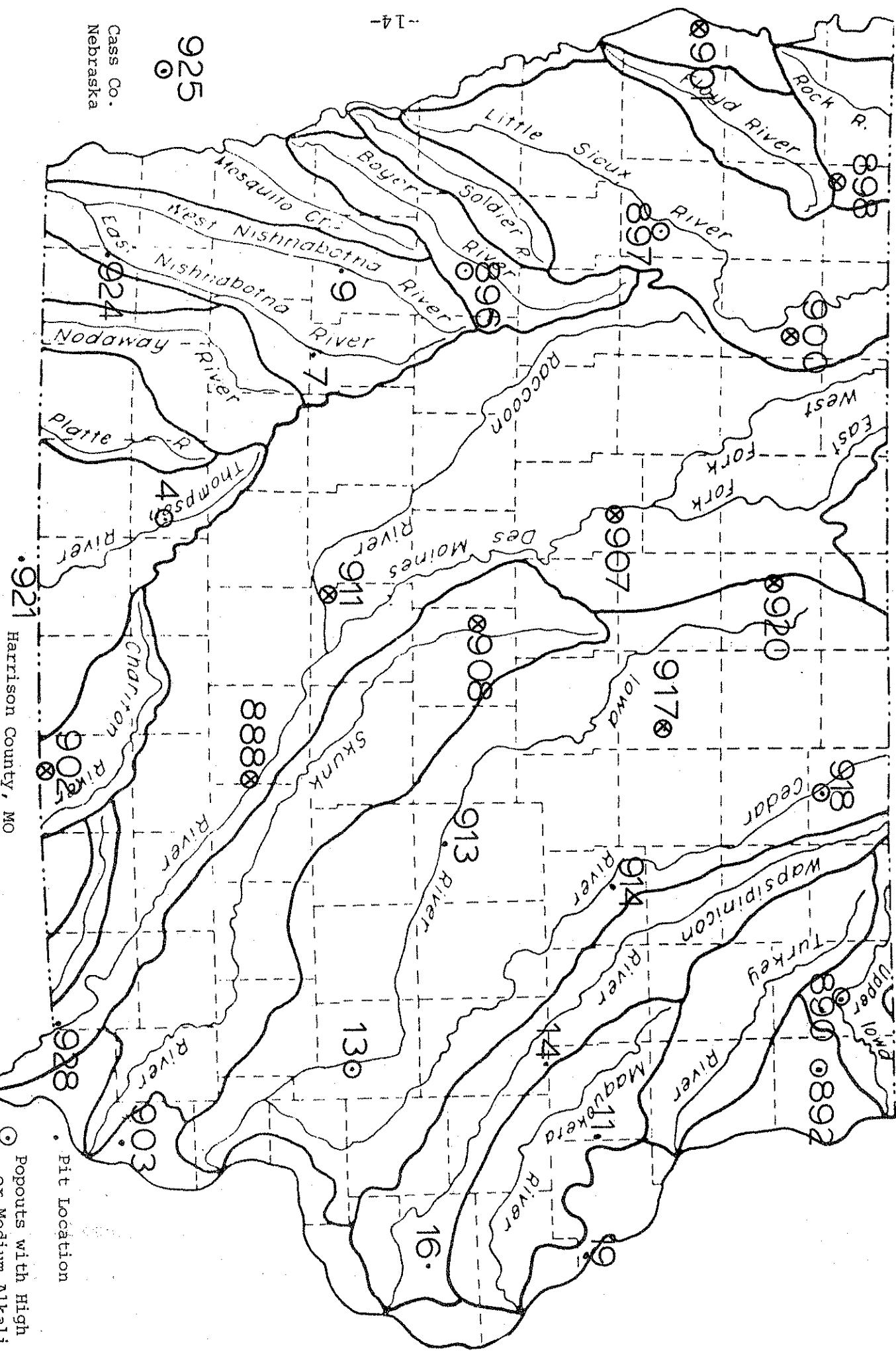
#### LABORATORY TESTING

For Iowa's purpose it was desired that materials similar to those used in the field be tested to indicate potential alkali-aggregate reactivity. The cement sources and the aggregate sources were chosen with this in mind.

The cement sources were selected from Iowa's list of approved sources. These sources are certified based upon their ability to consistently produce a product meeting the physical and chemical requirements of the American Association of State, Highway and Transportation Officials (AASHTO), specification M85 for type I cement.

The cements were chosen to have three alkali contents. These were 0.65, 0.89, and 1.20 percent expressed as sodium oxide ( $\text{Na}_2\text{O}$ ) equivalents.

Aggregate selections were from evenly distributed sources throughout the state. An attempt was made to select the natural



sands that are commonly approved to be used in p.c. concrete throughout the state. The aggregates selected were also chosen for their location along various major waterways in Iowa (Figure 1).

It was thought that these locations would provide an indication of the types of reactive materials in the drainage basins. The sand pits would contain particles washed down from upstream locations. Should testing produce any peculiar reactions, then further examination of the basins would be warranted.

In all, there were 31 sands tested. The sands were tested for gradation, shale content, and specific gravity. These are the tests performed on a routine basis on all sands.

The first testing for alkali-reactivity was performed according to ASTM C289, "Potential Reactivity of Aggregates" (Chemical Method) and was meant primarily as a means with which to compare the results of the mortar bar expansion test. The proper gradations were established, aggregates were dissolved, and the titrations were performed.

After the chemical testing was completed, work commenced on the physical testing according to ASTM C227 "Potential Alkali Reactivity of Cement-Aggregate Combinations" (Mortar Bar Method). The mortar bars were made and schedules established for the bars subsequent to removal and measurements. The specimens were placed in moisture cabinets with tight fitting covers and were stored in a 100°F (37.8°C) oven controlled within  $\pm 3^{\circ}\text{F}$  (1.7°C) for the proper time intervals until measurements were made. At the end of testing for length changes, the bars were physically examined for signs of deterioration.

## TEST RESULTS

Results of chemical testing according to ASTM C289 showed that of the thirty-one aggregates tested, none could be conclusively shown to be reactive. Three of the aggregates tested, the sands from the Denison, the Oreapolis, and the Farmington pits were initially determined to be borderline suspects to alkali-aggregate reaction. When corrected for carbonates, these aggregates also proved to be innocuous.

Results of the mortar-bar expansion test (ASTM C227) confirmed the results of the chemical tests since there were no expansive cement aggregate combinations at three months or six months.

At three months, several bars recovered from shrinkage by growing to their original length. Two sets of bars actually recorded a 0.01 and 0.03 percent growth at three months, those being the high-alkali cement with aggregate from the Oreapolis pit in Cass County, Nebraska, and the Yates pit in Webster County, Iowa. However, at the six months reading these bars all shrank or returned to their original length.

In general, all the bars continued to shrink until approximately four months of age, at which time the amount of continued shrinkage became negligible. At six months of age, none of the cement-aggregate combinations showed any significant growth (Table 1).

While growth was not observed, several other indications of at least minor alkali-aggregate reaction were displayed. Many of the bars had white spots on their surfaces. Often, these spots were associated with minor popouts which occurred on the surfaces of the bars (Figure 2). Occasionally these white spots were found in the vicinity of a minute quantity of clear to opaque gel formation exuded from within the bars.

Table 1. Test results of fine aggregates combined with cements of differing alkali contents. Negative values indicate shrinkage. Values underlined represent single maximum high and low values of growth and shrinkage respectively.

Dist.	Sand/ID	Cement Alkali Content	3 Months			6 Months		
			H	M	L	H	M	L
1	Yates	907	.03 G	-.02	-.02	-.03	-.02	-.01
1	Ames	908	.00	-.01	-.02	.00	-.01	-.02
1	Army Post Road	911	.00	-.01	-.02	.00	-.01	-.02
1	Tama	913	-.03	-.06 S	-.03	-.03	-.06	-.06
2	Decorah	890	-.03	-.02	-.02	-.02	-.01	-.02
2	Bente	892	.00	-.01	-.02	.00	-.01	-.03
2	Cedar Bend	914	-.02	-.02	-.01	-.02	-.01	-.03
2	Geneva	917	.00	-.01	-.02	.00	-.01	-.02
2	Osage	918	-.02	-.02	-.02	-.02	-.02	-.03
2	Sankey	920	-.02	-.05	-.04 S	-.02	-.05	-.06
3	Cherokee	897	-.03	-.03	-.03	-.03	-.02	-.02
3	Akron	901	.00	-.01	-.02	-.01	-.02	-.03
3	Denison	896	-.02	-.02	-.02	-.03	-.03	-.05
3	Ashton	898	-.02	-.01	-.01	-.02	-.01	-.02
3	Spencer	900	-.02	-.02	-.02	-.02	-.02	-.02
3	* Sioux Falls Quartzite Sp		-.02	-.02	-.02	-.08 S	-.08 S	-.06
4	Thayer	4	-.02	-.03	-.03	-.03	-.06	-.05
4	Brayton	7	-.01	-.02	-.02	-.01	-.02	-.02
4	Shenandoah	924	-.02	-.03	-.01	-.02	-.02	-.01
4	Oreapolis	925	.01	-.01	-.02	.00	-.02	-.03
4	Harlan	9	-.02	-.02	-.02	-.02	-.04	-.03
5	Tracy	888	-.02	-.02	-.01	-.02	-.04	-.03
5	Cincinnati	902	-.03	-.03	-.02	-.03	-.06	-.05
5	Spring Gravel	903	-.03	-.02	-.02	-.02	-.02	-.02
5	Mt. Mariah	921	.00	-.01	-.01	.00	-.02	-.02
5	Farmington	928	.00	-.01	-.01	-.01	-.02	-.02
6	Tegler	11	-.04 S	-.03	-.01	-.03	-.02	-.01
6	Stevens	13	.00	-.02	-.01	-.01	-.03	-.02
6	Coggan	14	-.03	-.03	-.01	-.03	-.06	-.03
6	Behr	16	-.02	-.01	-.02	-.02	-.02	-.02
6	9 Mile Bend	19	-.02	-.02	-.01	-.03	-.03	-.02

\*Excessive drying is suspected for the six month readings.

All the sands tested except the metamorphic quartzite required 132 cc of water to provide a flow between 105-120% on the Humboldt flow table. This is the required consistency according to specification 5.3 of ASTM C227. The metamorphic quartzite required 138 cc of water to meet the same criteria.

Based on the batch weights for making two specimens of 300 g of cement and 675 g of aggregate, the computed w/c for the sands excluding the metamorphic quartzite was 0.44. The computed w/c for the metamorphic quartzite was 0.46.

The popouts occurring with the white spots were normally four to five millimeters in diameter at the surface of the bar. The popouts normally left a cone-shaped depression in the bar one to two millimeters deep (Figure 3). The offending particle could usually be found at the apex of the cone. Close examination of the particle generally revealed a fractured particle exterior. Many of the popouts appeared to be caused by particles of shale which had undergone expansion.

Those cement-aggregate combinations which did show signs of shale popouts would occasionally have associated discolorations. These discolorations were thought to be iron oxides which would leach out of the shale in the high moisture environment of the moisture cabinet. Occasionally a brownish-black tarry substance would appear that was thought to be particles of organic matter or coal undergoing chemical breakdown in the high moisture environment.

Comparisons of test results with records of the physical testing of the fine aggregates show that those aggregates with a shale content greater than 0.4 percent always reacted with a high and medium alkali content cement to produce popouts. However, the sample of aggregates with shale contents this high was fairly small, only six samples. For this reason, we cannot say conclusively that a shale content of 0.4 percent or more will definitely produce popouts.

Minor popouts occurred with even trace amounts of shale. This would seem to indicate that while shale content may relate to the

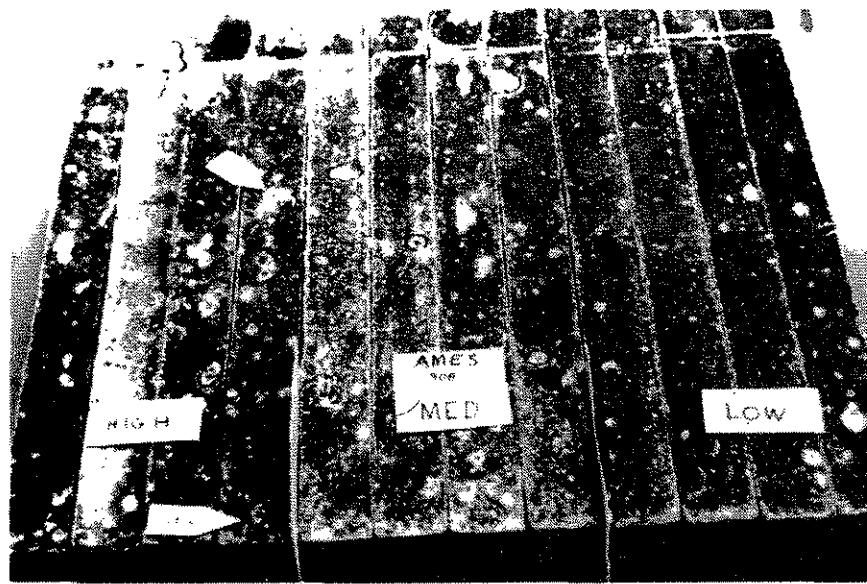


Figure 2. Bars showing evidence of some alkali-aggregate reaction.  
Locations of small popouts are circled.



Figure 3. A gel exudation, scraped from the bar may be found on the knife edge.

frequency of surface popouts, shale content is not the only factor involved (Table 2).

Of the 31 aggregate samples tested, 18 produced popouts when combined with the high or medium alkali content cement. Of these 18, 10 produced popouts with both the high and medium alkali content cements, 3 of the samples produced popouts with the high alkali content cement, and 5 of the samples produced popouts with the medium alkali-content cement only.

In addition, there is one instance of popouts occurring with the low-alkali-content cement only. This case appeared to be an isolated case in which some particles of iron were oxidized causing minor popouts to occur in one bar of the set of four. The alkali level of the cement was not a factor.

Detailed examination at the completion of the test showed that none of the bars show any detectable warpage. One bar did show a visible crack. Examination of the particle which caused the crack showed the particle to be a fairly large shale particle (Figure 4).

#### CONCLUSIONS

The general observations that have been made while performing the day-to-day measurements and examinations of the mortar bars suggest the following. Iowa's fine aggregates do not have reactive particles available in sufficient quantities to cause serious concern for the structural integrity of the concrete.

It is assumed that cement-aggregate combinations which expand more than 0.10% in 6 months or 0.05% in 3 months are capable of harmful reactivity. No cement-aggregate combination used exceeded

Table 2. Summary of Physical Characteristics of the  
Aggregates Used for Evaluation of Alkali Reactivity

<u>Sand</u>	<u>Sp.G.</u>	<u>% Shale</u>	<u>% Coal</u>	Popouts		
				H	M	L
907	2.649	0.6	trace	X	X	
908	2.688	0.5	trace	X	X	
913	2.667	0.2	0			
911	2.681	0.2	trace	X	X	
890	2.665	trace	0			
892	2.677	trace	0	X		
920	2.710	1.0	0	X	X	
917	2.714	1.0	0	X	X	
914	2.649	trace	0			
918	2.671	trace	trace			X
897	2.706	0.2	0	X		
901	2.677	0.2	0	X	X	
896	2.671	0.1	0			X
898	2.688	0.4	0	X	X	
900	2.672	0.4	0	X	X	
Quartzite	2.640	0	0			X
924	2.656	0.3	0			
925	2.653	trace	trace			
4	2.688	0.2	0			X
7	2.670	0.3	0			
9	2.677	trace	0			
903	2.677	0.2	0			
928	2.723	trace	0			
902	2.692	0.2	0	X	X	
921	2.649	trace	0			
888	2.681	trace	0	X	X	
11	2.649	0.2	0			
13	2.649	trace	0	X	X	
14	2.670	0.2	trace			
16	2.695	0.2	0			
19	2.663	trace	trace			

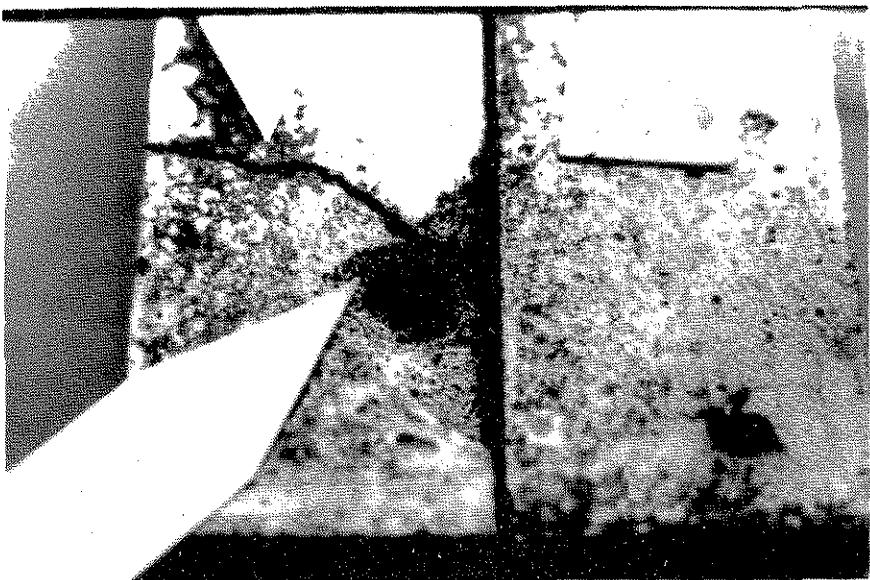


Figure 4. Shale induced popout. The crack is a hairline fracture, which has been traced over with a marker.

these limits. This would seem to indicate an insufficient quantity of deleterious particles present in the aggregates.

This conclusion was also verified by the rapid chemical testing method, ASTM C289, which indicated that, of the thirty-one samples tested, none could be conclusively considered to be reactive.

The occurrence of small, but minor surface popouts due to expanding shale particles, and discoloration, attributed to the presence of iron oxides, should be considered a cosmetic deficiency. It should be remembered that, for severe concrete damage to occur, there should be some indication of growth of the mortar bars. Small popouts, with no bar growth, must indicate the presence of minor amounts of alkali reactive aggregate, i.e., something below the threshold quantity required to cause damage. However, the cosmetic deficiency would be quickly noticed by the public, should these popouts occur statewide.

#### RECOMMENDATIONS AND EXPECTATIONS

On the basis of the evidence presented in this report our recommendation is to increase the level of allowable alkalies in portland cement to 0.90 of a percent. If this alkali limit is accepted, we must also expect the possibility of some future problems.

While the trend does not seem to have caused a noteworthy upsurge in alkali-related problems in the recent past, scattered reports of such problems continue. It is probably too soon for occurrences of distress associated with the recent upsurge in alkali contents of portland cements to have manifested themselves since a lag time of several years are generally required before such distress is noted. Nevertheless, it would not be surprising if a number of recently completed structures eventually show such distress, especially where

adherence to the optional limitation of 0.6% total alkali content is not traditionally practiced.

Those structures which are above ground will probably not experience many problems, even if a high alkali cement and reactive aggregate are combined. Structures above ground will be exposed to drying conditions which may prevent the alkali-aggregate reaction from occurring at a sufficient rate to do damage. Structures below the water table probably will not suffer distress due to dilution of the gel to a sol which will escape from the matrix.

The major areas of concern will be from the elevations of structures a few inches above ground level to elevations just above the water table. This may, in high water table areas, affect p.c.c. paving. Should a reactive aggregate be combined with a high alkali cement, this high humidity area may suffer some damage. This damage may consist of whitish spots and some minor popouts on the surface of the concrete. Damage on structures such as retaining walls may also provide an indication of an alkali reactive aggregate occurring in Iowa.

The use of fly ash in concrete mixes as an energy and cost saving option may alleviate part of the problem of alkali-aggregate reactivity. Fly ash reacts chemically to consume the alkali produced by cement hydration leaving insufficient amounts of alkali to cause alkali-aggregate reactivity. Replacement of portions of the cement with fly ash may provide a means of disposal of fly ash, and a way to deal with possible alkali-aggregate reactivity.

Limiting the alkali content of the cement does not guard against the potential introduction of additional alkalies from other sources such as deicing salts, etc.

With the continued growth of energy constraints, we can expect a progressive increase in alkali contents of most cements in the upcoming years.

In most of Iowa's concrete mixes any type of reactive sand is not present in the concentration that it was in the mortar bar test. It seems reasonable to assume that since there is less of a concentration of reactive aggregate, there is less likelihood of severe alkali-aggregate reaction.

In addition, most of our sands are used in concrete made with limestone. Previous testing of limestone according to the rock cylinder method indicated that our limestones were not reactive. This further enforces the idea of a dilution effect upon any reactive sand which may occur.

In examining our test records, we found that most of these cosmetic deficiencies (popouts, discoloration, etc.) began to occur when cement was used at an alkali content of 0.89% and higher.

Finally, the usefulness of any alkali content limitation specified ceases when it becomes uneconomical for the cement producer to provide cement that meets the limit.

Should a new upper limit be adopted, we may experience the following effects on field performance.

1. The use of high-alkali cement will require some minor adjustment in admixture dosage rates. High alkali cements normally require slightly higher dosage rates. Also, those admixtures containing  $\text{CaCl}_2$  will diminish the beneficial effects of using pozzolanic materials in the concrete mix.

2. Slightly higher amounts of dry shrinkage of the concrete. Possibly a slightly higher addition rate of gypsum to the cement by the cement producers will help control this problem.
3. Slightly higher early strengths may be obtained with high-alkali cement in concrete. However, we may expect a slight decrease in the 28-day strengths.

In summary, the use of high-alkali cement has some positive and negative factors. The use of high-alkali cement can only be proven good or bad by field performance records. Based on Iowa's test results, we conclude our specifications should be changed to adopt a higher limit for alkali content in cement.

If it is possible to increase the alkali and maintain a quality product, then every effort should be made to do so.

## REFERENCES

1. Section 4101.01, Standard Specifications for Highway and Bridge Construction, Series of 1977, Iowa Department of Transportation.
2. AASHTO Designation: M85, Standard Specifications for Portland Cement, Standard Specification for Transportation Materials and Methods of Sampling and Testing, Part I Specifications, American Association of State Highway and Transportation Officials, Washington, D.C.
3. ASTM Designation: C150, Standard Specifications for Portland Cement, 1980 BOOK of ASTM Standards, Part 13, American Society for Testing and Materials, Philadelphia, PA 1980.
4. H. C. Alsted Nielsen, Extract of a lecture given in August 1975, Symposium on Alkali-Aggregate Reaction Preventive Measures, August 1975, Reykjavik, Iceland.
5. Isenberger, Kenyon, "Alkali Reactivity Studies on Carbonate Rock", Research Project R-207, Iowa State Highway Commission, August 1971.
6. Duncan, M.A.G.: E. G. Swenson: J. E. Gillot and M. R. Foran 1973, "Alkali-Aggregate Reaction in Nova Scotia. I. Summary of a Five-Year Study". Cement and Concrete Research 3:55-69.
7. Halstead, W. J.: B. Chaiken, Chemists, 1953. A Review of Fundamental Research on the Alkali-Aggregate Reaction, Highway Research Board Research Report 18-C. "The Alkali-Aggregate Reaction in Concrete", HRB publication 616 pp 47-51, 1958.
8. Vivian, H. E., "Alkali-Aggregate Reaction". Extracted from a lecture given in August, 1975. Symposium on Alkali-Aggregate Reaction Preventive Measures, August 1975, Reykjavik, Iceland.