

# **Inhibition of Alkali-Silica Reaction by Nonpozzolanic Mechanisms**

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## ABSTRACT

Results to date of nonpozzolanic alkali-silica reaction inhibition mechanism studies are reported. ASTM C441 mortar bars made with a high alkali cement were used to test the abilities of a variety of admixtures to reduce expansion caused by the alkali-silica reaction. Some of the materials tested are new to concrete technology. Others are currently used in concrete but were applied in novel ways. A number of possible inhibition mechanisms were tested for effectiveness against expansion caused by reaction of alkalis with pyrex-glass aggregates.

## INTRODUCTION

A number of methods are currently used to minimize or prevent the alkali-silica reaction in concrete. Obviously, when possible, the problem is avoided by using known, non-reactive aggregates or minimized by use of low alkali cements and judicious mix design. When potentially reactive combinations of aggregate and cement must be used, a variety of cement additives are useful in reducing the expansion which may be encountered in concrete. High and low lime fly ashes, granulated blast furnace slag, silica fume and a variety of natural pozzolans are commonly used for this purpose. All these materials appear to reduce expansion by tying up alkalis in their hydration products and by reducing the permeability of the concrete to water. Both processes help prevent the formation of expansive alkali-silica gels in the concrete's mortar fraction.

One of this study's goals was to study the expansive mechanism of the alkali-silica reaction. Since the early 1950's with the work of McCoy and Caldwell (1951), a number of admixtures for the prevention of alkali-aggregate reactions have been tested. Many materials such as salts of barium and lithium, and some air entraining, water reducing, and retarding admixtures have shown ability to reduce expansion due to one or more alkali-aggregate reaction type (Ramachandran, 1984). Rather than retrace these steps, it was decided to find a method which would render the alkalis in concrete inactive by chemical means. A large number of organic and inorganic materials selectively react with alkalis at the pH of pore water in concrete. A number of those materials were selected for testing in mortar.

## MATERIALS

All mortar tests were conducted using the same cement. Table 1. presents the ASTM C150 analysis for a sample of that material. Of major interest was the fact that the cement was a Type I with 0.26% Na<sub>2</sub>O and 1.14% K<sub>2</sub>O. Total alkalis expressed as Na<sub>2</sub>O were equal to 1.01%. Alkali sequestrants tested included three crown ethers,  $\beta$ -cyclodextrin and two proprietary, inorganic sequestrants capable of removing alkalis from solution at high pH. Initial tests were run in ASTM C441 mortar bars made with crushed Pyrex glass aggregate and stored under ASTM specified conditions.

Table 1. ASTM C150-85A potential compounds and percent alkalis for cement used in this study.

Bogue Potential	
%C <sub>3</sub> S	47
%C <sub>2</sub> A	22
%C <sub>3</sub> A	13.7
%C <sub>4</sub> AF	6
%Na <sub>2</sub> O	0.26
%K <sub>2</sub> O	1.14
%Total Alkalis as Na <sub>2</sub> O	1.01

## RESULTS

Crown ethers are a group of alkaline stable, cyclic polyethers capable of complexing alkalis in solution. Three crown ethers were tested. At all doses the results for each material were, as illustrated in Figure 1, equal to plain.

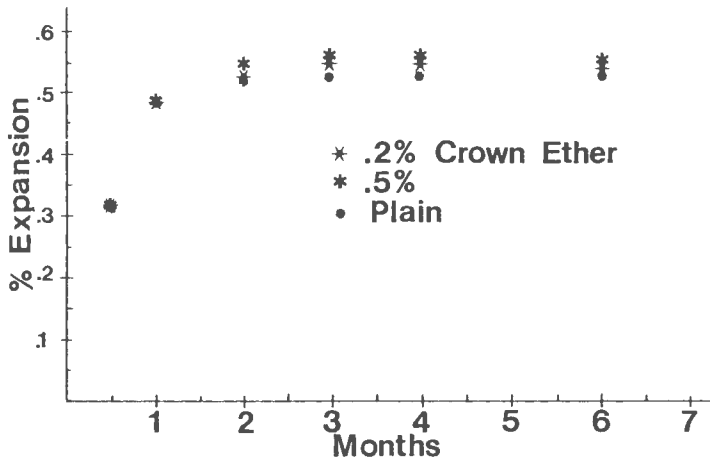


Figure 1. Representative expansion data for ASTM C441 mortar bars made with crown ethers compared to a plain mix.

Mortar bars fabricated with  $\beta$ -cyclodextrin were found to be so extremely retarded as to be impractical for testing.

The two proprietary inorganic sequestrants were found to have little effect on the plastic properties of mortar. Further, tests showed that they significantly reduced expansion relative to plain in C441 mortar bars (Figure 2.).

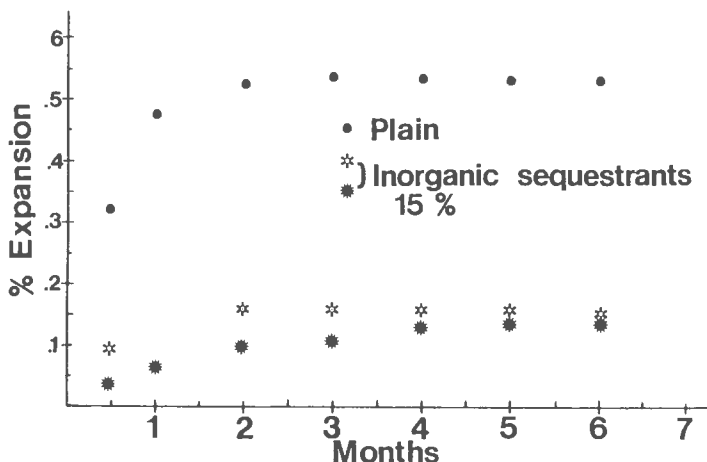


Figure 2. Representative expansions of ASTM C441 mortar bars made with inorganic sequestrants compared to a plain mix.

ASTM C311 tests for pozzolanic activity were made on these two solid materials. The pozzolanic activities were found to be 59 and 88. The material with an activity index of 88 may well have reduced expansion by the pozzolanic reaction. The nonpozzolanic material was hypothesized to reduce expansion by removing alkalis from the pore water.

In order to test the hypothesis that the nonpozzolanic sequesterant removed alkalis from the pore water the following experiment was conducted. A 2 mm x 3 mm piece of nonpozzolanic sequesterant was imbedded in 15 grams of cement paste with a 0.5 w/c. The cement used was the same cement used for the C441 mortar bar tests. After setting, the paste was water cured for a week, then alternately dried and wetted for two weeks at a time. After two months the specimen was sawed open, exposing the sequesterant inside. The specimen was prepared for energy dispersive x-ray spectrometry (EDS). EDS was used to test for potassium and sodium levels along a line from the paste into the sequesterant. EDS analyses were conducted on a PGT EDS with a 1 mil window, an accelerating voltage of 15 KeV, and a take-off angle of  $30^\circ$  at 2,000 counts/second for 100 seconds. Figure 3 illustrates the negligible difference in alkali levels between paste adjacent to the sequesterant and away from it after 2 months of curing. Sodium levels remained below the point of detectability ( $=0.5\%$ ) but potassium showed definite signs of concentration around the sequesterant. Figure 4 demonstrates the change in alkali levels in the sequesterant after 2 months in cement paste. As in the paste, the level of sodium in the sequesterant remained below the detection limit for the instrument, but potassium levels were markedly increased.

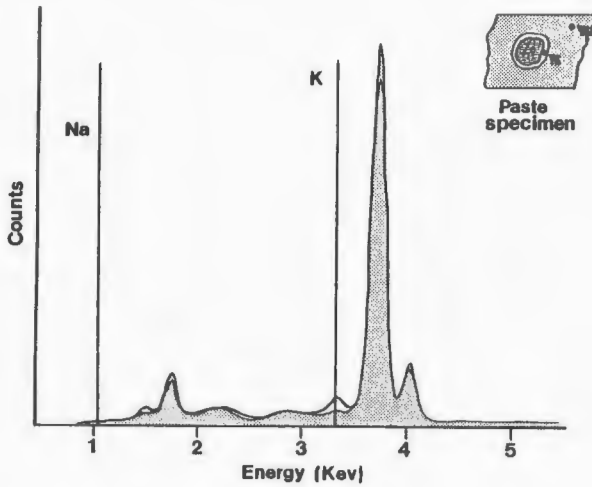


Figure 3 EDS spectra of cement paste after 2 months curing in regions adjacent to sequestrant and well removed from it.

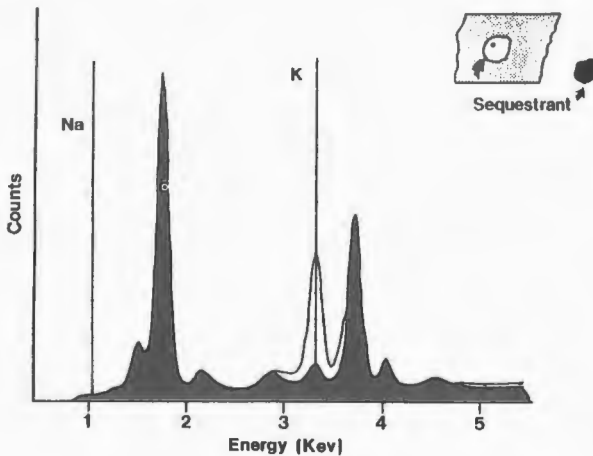


FIGURE 4. EDS spectra of sequestrant in cement paste after 2 months of curing, and before placement in paste.

No in-house standards were available at the time of this study to quantify the changes seen in these spectra. The qualitative changes of  $K^+$  levels in the paste and sequestrant were so great that they presented some interesting questions. While this material reduced expansion due to alkali-silica reaction in C441 mortar bars and appeared to do so by removing potassium ions from solution without lowering sodium levels, what

would happen if natural aggregate were used? ASTM C227 mortar bars were made using the same sequestrant and cement as before, mixed with a reactive aggregate from Texas. They gave preliminary indications that pyrex glass was not the only aggregate protected by this material (Figure 5.).

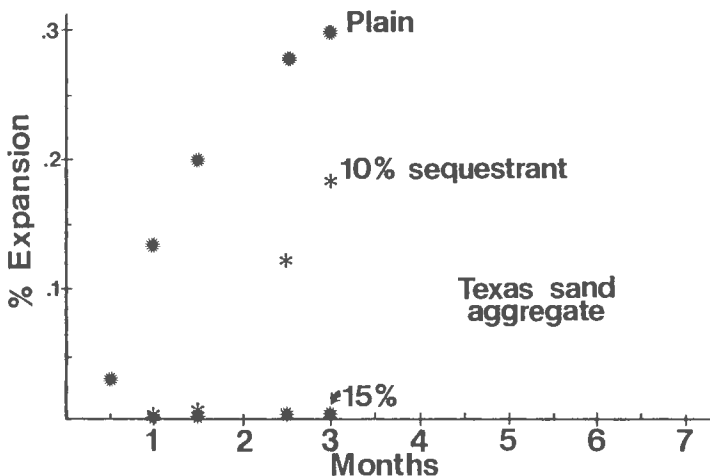


FIGURE 5. Expansions of ASTM C227 mortar bars made with inorganic sequestrant and reactive sand compared to a plain mix of reactive sand.

#### CONCLUSION AND FUTURE WORK

When this program began and materials were acquired for testing, it was assumed that both sodium and potassium contributed to the alkali-silica reaction. The EDS data collected during this study indicated that removal of potassium alone from the pore waters of this cement's paste was sufficient to prevent expansion due to alkali-silica reaction. It was concluded that removal of potassium by the sequestrant tested may be sufficient to prevent the alkali-silica reaction. This was, of course, based on only one cement with its sodium and potassium levels. Further tests are planned on cements with higher  $\text{Na}_2\text{O}$  levels and with a sequestrant specific for sodium in order to clarify the questions raised by the observations made here.

#### REFERENCES

- McCoy, W.J., and Caldwell, A.G. 1951. Journal of the American Concrete Institute. 47: 693-706.
- Ramachandran, V.S. 1984. Concrete Admixtures Handbook: Properties, Science and Technology. Noyes Publications; Park Ridge, New Jersey, USA.