RELATION BETWEEN DISSOLUTION OF AGGREGATE IN ALKALI SOLUTION
AND MORTAR-BAR EXPANSION

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ABSTRACT

The relationship between the expansion due to alkali silica reaction of
mixed aggregates in mortar-bars and the solubility of those aggregates in
alkali solution have been studied.   The mixed aggregates used are produced from
rocks which contain alkali reactive silica minerals, and non reactive rocks.
A quick method for approximate evaluation of the deleterious extent of
mixed aggregates in concrete according to their solubility in alkali solution is
compared with the mortar-bar method which requires an examination period of at
least 6 months.
The results obtained show that the alkali silica reactivity of mixed
aggregates containing chert can be evaluated by their solubility in alkali
solution. However, no direct correlation is found between reactivity and
solubility of andesite, which is recognized to have a pessimum proportion.

1. INTRODUCTION

The use of mixed aggregates in concrete occurs, when mixed aggregates are
produced from river gravels or quarried materials from different rock layers in
quarry beds.
These mixtures are often composed of mixed aggregates from alkali silica
reactive rock and non reactive rock.
In general, the alkali silica reactivity of aggregates to be used to
produce concrete has been evaluated by both ASTM C289 chemical and ASTM C227
mortar-bar methods.
The results of testing for reactivity of aggregates by the chemical method
are obtained in several days, whereas those by the mortar-bar method take at
least 6 months.
Expansion due to alkali silica reaction is not directly proportional to the
degree of chemical reaction.   Therefore, several accelerated testing methods for
alkali silica reactivity of aggregate have recently been proposed.
If conditions are standardized, it may be assumed that the amount of silica
dissolved per day for mixed aggregates in alkali solution multiplied by the
reactive silica contents of those will be proportional to the expansion due to
alkali silica reaction in a mortar-bar.   Thus the expansion over a period of 6
months can be estimated in terms of the percentage of reactive silica contents

multiplied by dissolved silica percentage per day of the mixed aggregates.

Thus also reactive silica content analysis of mixed aggregates and measurement of the solubility of alkali reactive silica in alkali solution may provide a means of evaluating the deleterious extent of mixed aggregates in concrete.

The work reported here represents an attempt to find a method of estimating in a few days the alkali silica reactivity of mixed aggregates containing reactive and non reactive materials.

2. MATERIALS AND EXPERIMENTAL TECHNIQUES

It has been found that the expansion due to alkali silica reaction is closely correlated to the total alkali content as an equivalent percentage of Na_2O.

Ordinary Portland cement with an alkali content of 0.65 percent of equivalent Na_2O was used as a source of high alkali cement. To enrich the equivalent Na_2O content from 0.65 percent to 1.2 percent, calculated volumes of NaOH solution of known concentration were added to the mortar mixtures, by percentage 0.55 equivalent Na_2O.

For the mortar-bar method, high Na_2O equivalent alkali percentage cement is recommended for mortar components. The tentative value of Na_2O equivalent is proposed as 1.2 percent by Japan Concrete Institute.

Five sources of aggregates were used for this study : a single batch of a highly alkali silica reactive andesite, two batches of medium reactive cherts and two batches of non reactive sandstones.

The results of petrographic examinations and chemical reactivity measurements according to ASTM C289 are summarized in Table 1.

Table 1 Petrographical Characteristics of Aggregates

Aggregate Identity No.	Rock Type	Mineral Composition				Content of Siliceous Material (wt%)				Chemical Method	
		Siliceous Material	Feldspar	Chlorite	Mica	Quartz	Crypto-crystalline Quartz	Cristobalite	Volcanic Glass	Sc	Rc
A1	Bronzite Andesite	+ +	+ + +	−	−	1.4	−	12.0	23.9	676	195
C2	Chert A	+ + + +	(+)	(+)	(+)	4.5	86.3	−	−	134	29.8
C3	Chert B	+ + + +	−	−	−	32.8	61.0	−	−	58.0	35.0
S4	Sand-stone C	+ + +	+ +	(+)	(+)	63.1	−	−	−	21.2	39.8
S5	Sand-stone D	+ + + +	−	−	−	97.5	−	−	−	28.5	21.8

The value of intensity: + + + +=100~90, + + +=90~60, + +=60~30, +=30~10, (+)=10~0, −=0.
Sc: Dissolved Silica (mmol/L), Rc: Reduction in Alkalinity (mmol/L)

A petrographic examination of two sandstones (S4,S5) failed to reveal any alkali reactive silica and according to ASTM C289, (S4) and (S5) were classified as non reactive aggregates. Andesite (A1) was an aggregate which was considered potentially deleterious and the two cherts (C2,C3) were considered deleterious but with different levels of alkali reactivity.

The siliceous material content of each aggregate was obtained by phosphoric

acid method [1]. The procedure of phosphoric acid treatment was shown in Figure 1. X-ray diffraction analysis and petrographic examination by polarizing microscope were conducted according to ASTM C295 to establish the residues of phosphoric acid analysis of each aggregate. The content of non reactive quartz, cryptocrystalline quartz, crystobarite and volcanic glass in each aggregate were obtained.

Mortar-bars were prepared from the blended materials of reactive and non reactive aggregates combined with Portland cement with 1.2 percent equivalent Na_2O. At least six specimens were cast from each of the mixtures. The proportions for all mixtures corresponded to one past of cement to 2.25 parts of aggregate by weight. The amount of water was determined to maintain the consistency within the specified range in ASTM C227. Measurement of the increase in length of mortar-bars was conducted in accordance with Method C227.

Weigh out 2.00g test sample finer than the 0.074mm sieve, and place it in a 1000mL reaction container. Add 90mL of phosphoric acid in the container.

↓

Place the container on a hot plate and heat it for 12 min.

↓

Cool the container for 50min. under running tap water having a temperature below 25 °C.

↓

Add 400mL of hot water having a temperature of 65°C and 40mL of hydrofluoroboric acid(1+3) in the container.

↓

Agitate the container for 5min. and settle it for 60min.

↓

Add 40mL of hydrofluoroboric acid(1+3) in the container.

↓

Filter the solution in the container using a porcelain Gooch crucible with analytical grade filter paper No.5C. Wash the residue with hydrochloric acid(1+9) and hot water having a temperature of 65°C.

↓

Ignite the residue at 950°C for 2h.

↓

Weigh the residue

↓

Analyze the residue by X-ray diffraction

Figure 1: Procedure of Phosphoric Acid Treatment

3. RESULTS AND DISCUSSIONS

3.1 Mortar-bar expansion test results for each aggregate

Results of expansion measurements for each aggregate are shown in Figure 2.

3.1.1 From the figure 2 it can be seen that maximum expansions were reached in about 6 months, after which the expansions appeared to remain nearly constant for at least 12 months.

3.1.2 Mortar-bars produced with sandstones (S4,S5) did not expand nor show any sign of alkali silica reaction.

3.1.3 A mortar-bar containing andesite (A1) started to expand at first, however this expansion ceased at a relatively early period of examination.

3.1.4 The potentially deleterious aggregate (A1) gave relatively low expansion in mortar-bar even though extremely reactive with alkali.

3.1.5 In particular chert (C2) was found to show deleterious expansion in the mortar-bar of 1.2 percent Na_2O equivalent cement.

3.1.6 On the basis of the present results, there does not appear to be a good correlation between alkali reactive silica content in each aggregate and expansion over a 6 month period.

3.2 Mortar-bar expantion test results for mixed aggregates

A series of mortar-bars were cast in which the reactive aggregates (A1,C2,C3) were substituted on a weight basis for the inert aggregates (S4,S5). Mixing and storage were conducted according to ASTM C227. The test results are illustrated graphically in Figure 3.
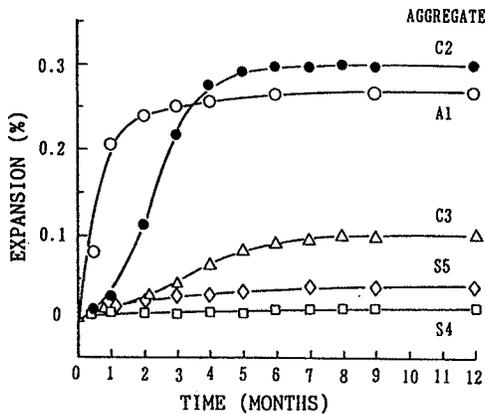
Figure 2: ASTM C227 mortar-bar test results for reactive and non reactive aggregates up to a test period of 12 months
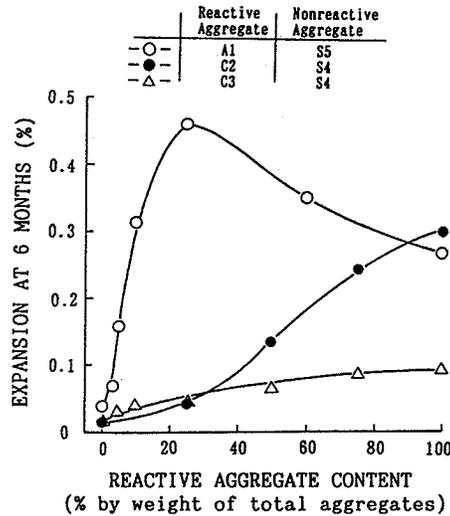
Figure 3: Influence of reactive aggregate content upon expansion

3.2.1 Measurement of mortar-bar expansion for mixed aggregates of andesite (A1) and sandstone (S5) showed maximum expansion at some intermediate proportion of reactive aggregate (A1) component to total mixed aggregates. This is termed the pessimum proportion.

3.2.2 The mortar-bar expansions of mixed aggregates of chert (C2 or C3) and

sandstone (S4) tended to increase as the proportion of reactive aggregates (C2 or C3) replacing mixed aggregates was increased.

3.3 Dissolved silica of mixed aggregates

The mixed aggregates of different proportions to each aggregate shown in Table 1 were produced. Aggregates that had been crushed and sieved to pass a 0.3mm sieve and be retained on a 0.15mm sieve, were mixed, and then 2.00g of each weighed sample was placed in reaction containers containing 25ml of the 1.000 normal NaOH solution. The dissolved silica was measured at 24 hour intervals in accordance with ASTM C289 at 40 C. When the amounts of dissolved silica of mixed aggregates tested were plotted against immersion time in 1 normal NaOH solution, linear proportionality was obtained for about the initial 200 hours. From these results, the solubility percent of silica for mixed aggregates per day were calculated. Figure 4 showed a relationship between percentage of silica dissolved per day and percentage of reactive aggregate in mixtures.

3.3.1 As shown in figure 4, for mixture containing (A1) and (S5), the higher the content of reactive aggregate (A1) of the mixture, the larger the solubility percentage of silica per day. Linear proportionality was shown in solubility percentage of silica per day against the reactive aggregate content percentage by weight of total mixed aggregates.

3.3.2 The relationships between reactive aggregates(C2 or C3) and non reactive aggregate (S4) were similar to those of the mixture of (A1) and (S5).

3.4 Expansion of mortar-bar cast from mixed aggregates

Figure 5 was obtained from the relationship between expansion at 6 months and the value of percentage of silica dissolved per day multiplied by the percentage of reactive silica in each mixture.

	Reactive Aggregate	Nonreactive Aggregate
−O−	A1	S5
−●−	C2	S4
−△−	C3	S4

REACTIVE AGGREGATE CONTENT
(% by weight of total aggregates)
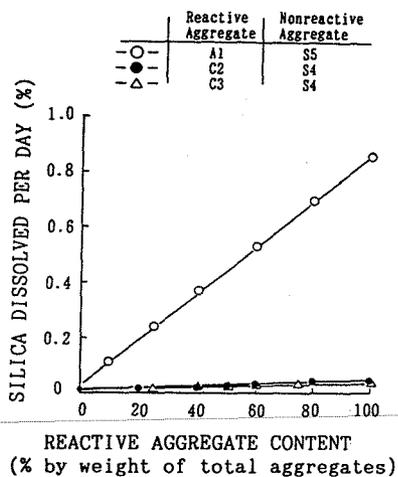
Figure 4: Silica dissolved per day versus reactive aggregate content of mixed aggregate

	Reactive Aggregate	Nonreactive Aggregate
−O−	A1	S5
−●−	C2	S4
−△−	C3	S4

SILICA DISSOLVED PER DAY (%)
MULTIPLIED BY REACTIVE SILICA (%)
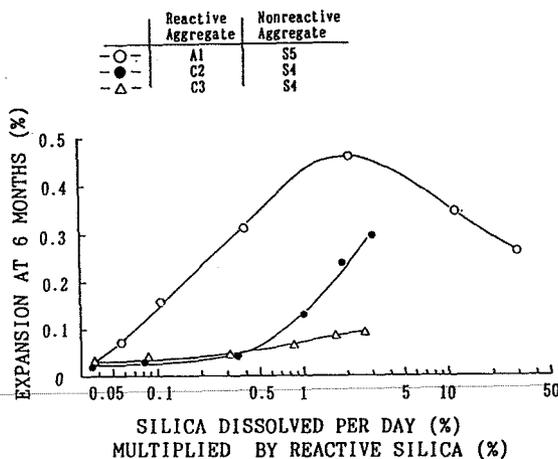
Figure 5: Relationship between expansion at 6 months and value of percentage of silica dissolved per day multiplied by percentage of reactive silica in each mixture

3.4.1 From the amounts of silica dissolved per day multiplied by the

percentage of reactive silica in each mixture, the expansions at 6 months for mixed aggregates of (C2) and (S4), and for those of (C3) and (S4) were estimated, and hence the deleterious characteristics of mixed aggregates were approximately evaluated.

3.4.2 As for andesite, which had a pessimum proportion, this relationship was not applicable.

3.5 Polarizing microscopic examination

A staining technique for the identification of alkali-silica gel in concrete and aggregate was reported [2], and various types of reaction products were identified and distinguished by the microscopic examination of the dyed thin sections made from mortar-bars [3].

The aggregates shown in Table 1 were embedded in epoxy resin matrix, and thin sections for polarizing microscopic examination were prepared. These sections were immersed in 1 normal NaOH solution, and petrographic examination by polarizing microscope was conducted.

The results obtained from this examination showed that alkali reactive aggregate (A1) was dissolved considerably, (C2) and (C3) were dissolved slightly, and non reactive aggregates (S4) and (S5) were not dissolved at all.

4. CONCLUSIONS

Based on the test results presented in this paper, the following conclusions were reached :

1. For the mixed aggregates of alkali reactive chert and non reactive sandstone, the expansions of mortar-bars at 6 months were evaluated with the value of percentage of silica dissolved per day multiplied by the percentage of reactive silica in each mixture.

2. For the mixed aggregates of reactive andesite and non reactive sandstone, the expansion of mortar-bar could not be estimated as those above mentioned.

3. The alkali reactivity of different aggregates used in mortar-bars could be petrographically evaluated by means of polarizing microscope technique for thin sections made from transparent alkali-resistant epoxy resin matrix in which each aggregate was embedded, observing them with appropriate intervals of immersion time in alkali solution.

5. REFERENCES

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