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ALKALI AGGREGATE REACTION : AN INVESTIGATION ON ITS CAUSES AND STRENGTH EVALUATIONS OF MATERIALS SUBJECTED TO ITS EFFECTS

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1. INTRODUCTION

Research thus far alkali-aggregate reaction has been carried out from several approaches and in general has had a two-part objective:

(1) Investigation on the primary factors underlying the occurrence of alkali-aggregate reaction.

(2) An understanding of the mechanical characteristics of concrete structures that have been subjected to the effects of alkali-aggregate reaction, leading to the establishment of a repair methodology for such structures.

The authors have been actively involved in research on this phenomenon since 1984, focusing in particular on alkali-silica reaction, with the aim of establishing a quality assurance system for the prevention of the material degradation in an early stage from alkali-aggregate reaction.

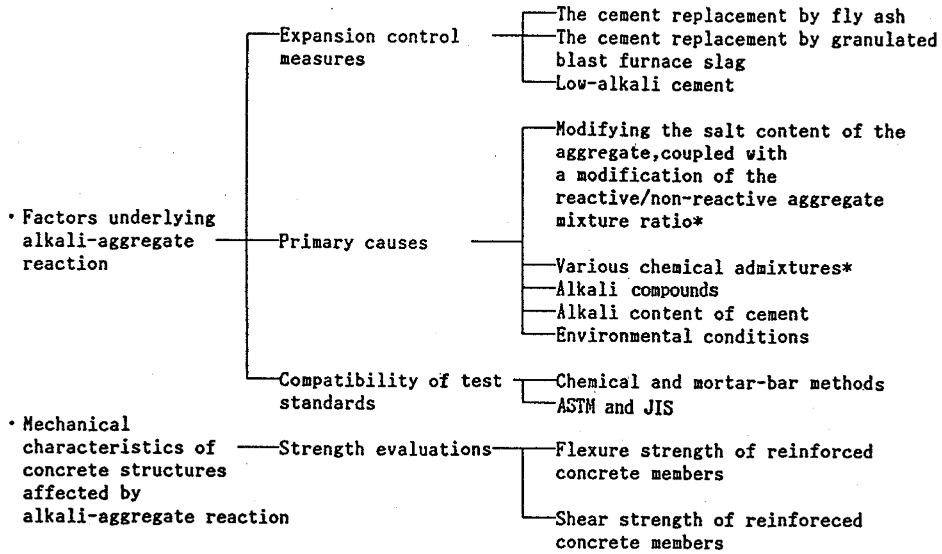
In the main, this research has been carried out using three separate approaches:

(1) Research on the causes of alkali-aggregate reaction was done through experiments on the effects of alkali, salt content, various chemical admixtures, mineral admixture, and alkali compounds, on alkali-aggregate reaction.

(2) Supplementing the above, long-term observations were carried out on the effect of environmental conditions on the phenomenon of alkali-aggregate reaction.

(3) Finally, to investigate on the mechanical characteristics of concrete structures that have been subjected to the effects of alkali-aggregate reaction, strength tests were conducted on reinforced concrete members that had been forcibly subjected to its effects.

This paper is focusing mainly on five of the topics shown in the right-hand portion of Fig.1: (1) The effects of the cement replacement by fly ash; (2) the effects of the cement replacement by granulated blast furnace slag; (3) the effects of environmental conditions on the phenomenon of alkali-aggregate reaction; (4) the flexure strength of reinforced concrete members; and (5) the shear strength of reinforced concrete members.



* A report of our findings on the effects of different amounts of salt and chemical admixtures on alkali-aggregate reaction was given previously at the 7th ICAAR.

Fig.1 An overview of research on alkali-aggregate reaction.

2. RESULTS AND CONSIDERATIONS OF EXPERIMENTS

(1) Investigations of control measures for inhibiting expansion

Effects of the cement replacement by fly ash and granulated blast furnace slag

Experiments on the effect of mineral admixtures on alkali-aggregate reaction were conducted by ASTM C-227 mortar-bar expansion tests. The admixtures used in these experiments were fly ash and granulated blast furnace slag, both produced in Japan.

Table 1 shows the characteristics of the aggregate used in the experiments. Table 2 shows the relevant parameters of the experiments. In Table 2 , the values for the cement alkali content are adjusted by the addition of NaOH; the figures below these in parentheses indicate the base alkali content of the cement.

Table 1 Characteristics of the aggregate

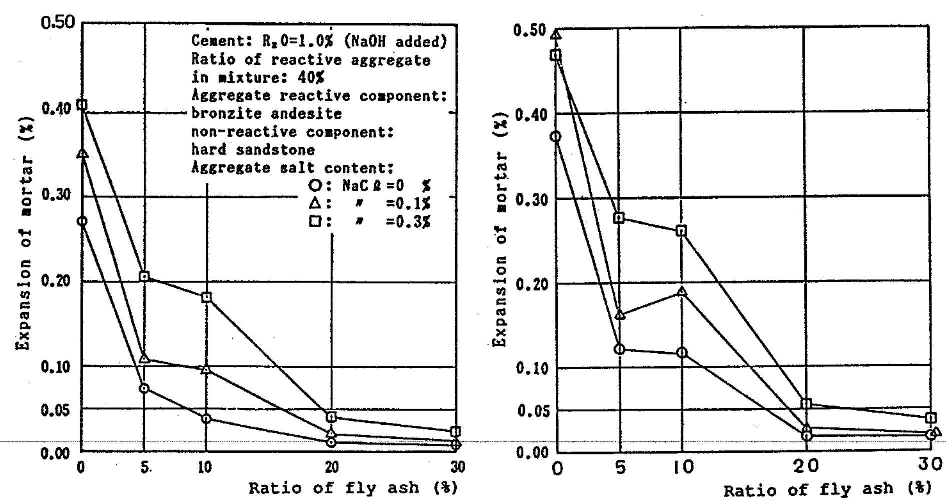
Type of rock	Chemical method (ASTM C 289)		Deleterious mineral (ASTM C 295)
	Sc/Rc	Judgement	
Bronzite andesite	539／198	Potentially deleterious	Crystobalite Trydymite
Hard sandstone	1／125	Innocuous	None

Table 2 Parameters of the experiment

Addmixture	Amount used (%)	Cement alkali content (%)	Aggregate used (%)	Aggregate salt content (%)	Test pieces	Mix proportion
Granulated blast furnace slag	20,30,40 50,60,70	1.0 (0.70)	Bronzite andesite : 40 Hard sandstone : 60	0 0.1 0.3	1"×1"×11.25"	C:A=1:2.25 W/C=0.42
Fly ash	5,10,20 30	1.0 (0.70)	Bronzite andesite : 40 Hard sandstone : 60	0 0.1 0.3	1"×1"×11.25"	C:A=1:2.25 W/C=0.42

The results of the experiments showed that, even for aggregate with salt content of 0.3%, effective expansion control could be obtained with minimum replacement ratios of 20% and 40%, for fly ash and granulated blast furnace slag respectively. At the test period of 36 months, the maximum expansion of the mortar-bar with replacement 20% by fly ash was 0.06%.

Figs.2 and 3 show the relationships between the expansion of mortar-bar and the replacement by fly ash and granulated blast furnace slag.



(Test period of 6 months) (Test period of 36 months)

Fig.2 Effects of the cement replacement by fly ash.

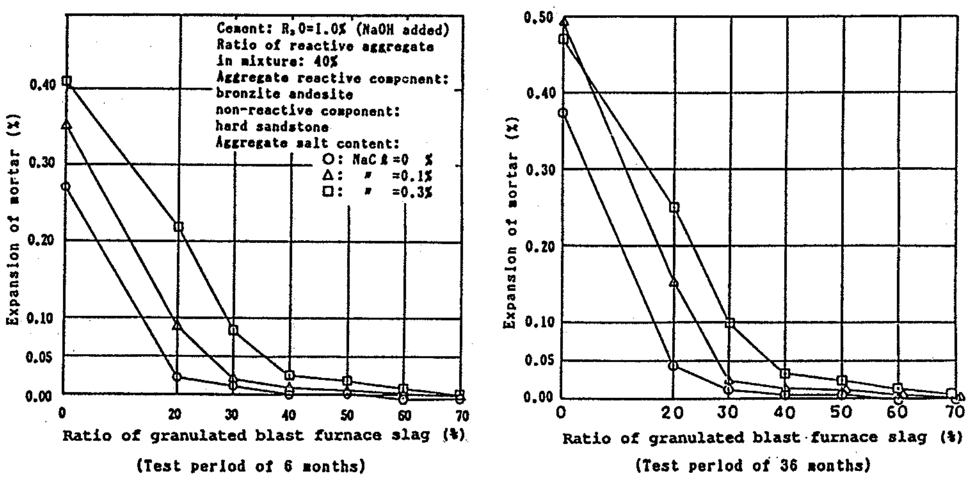


Fig.3 Effects of the cement replacement by granulated blast furnace slag.

(2) Investigations of the causes of alkali-aggregate reaction
The effects of environmental conditions

Environmental effects on alkali-aggregate reaction were studied by using test plain concrete samples containing reactive aggregate and stored in six different experimental environments: (1) above-ground, (2) buried, (3) partially buried, (4) submerged in saltwater,(5) partially submerged in saltwater, and (6) submerged in freshwater. (See Fig.4.)

Measurements were conducted on these test samples of crack length and density.

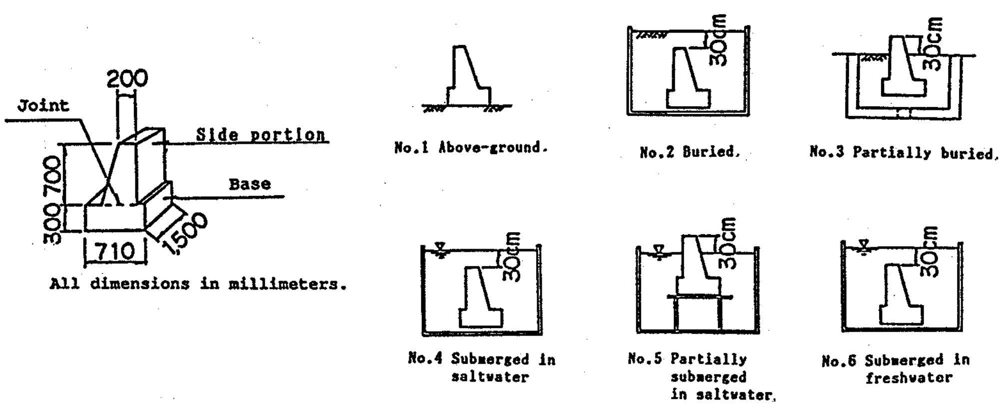
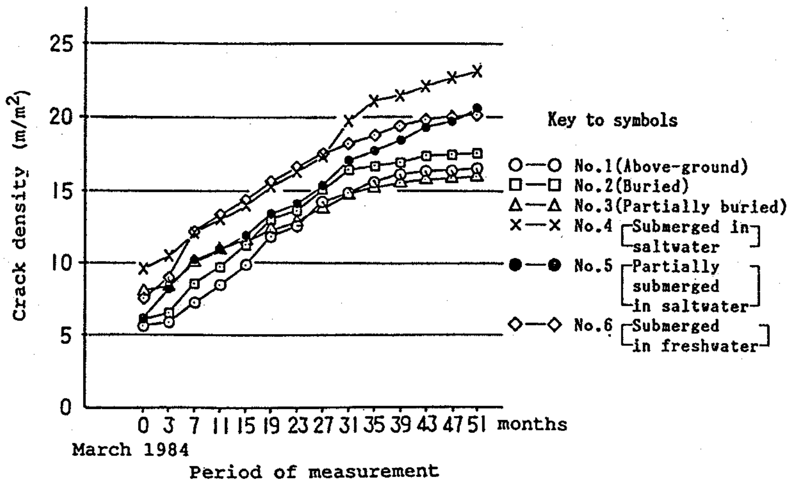


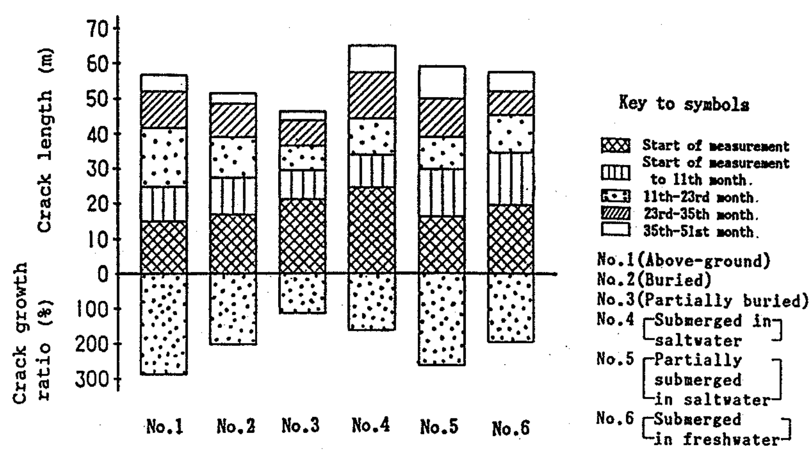
Fig.4 Schematic diagram of test samples and environmental conditions.

Thus far, over a measured period of 4.3 years, the results of the measurements in these environmental experiments have indicated that the effects on alkali-aggregate reaction attributable to such differences in environmental conditions may be considered insignificant. (See Figs. 5 and 6.)



The crack density is calculated as the length of the crack which width exceeds 0.02mm, divided by the surface area of the side portion of the test sample.

Fig.5 Variations in crack density.



(Crack growth ratio=(increase in crack length over the 51-months period/the length of the crack at the start of measurement) × 100.)

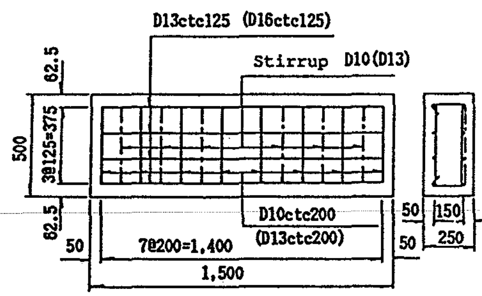
Fig. 6 Variations in crack length depending upon enviromental conditions.

(3) Research on strength evaluations

The flexure strength and shear strength of reinforced concrete members

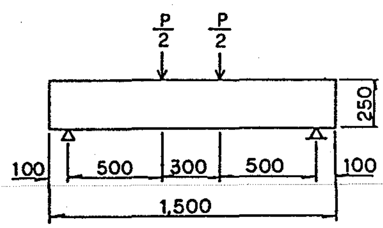
To test flexure strength of reinforced concrete members that have been subjected to alkali -aggregate reaction, nine beams were fabricated to be used in the experiments. The dimensions of these beams were B×H×L=0.5m×0.25m×1.5m. (See Fig.7.) Five of the beams were fabricated from a mixture containing reactive aggregate and NaCl (total amount of alkali (R_2O)=12.4kg/m^3).
The remaining four beams were made of non-reactive aggregate. Three kinds of steel ratio were tested; 0%, 0.51%, and 0.79%. Loading tests were conducted after cured for 19 months. The beams containing reactive aggregate just befor the loading test showed expansion strain of the order of 1200-2300×10^{-6}.

And compressive strength of the concrete containing reactive aggregate, measured separately by standard cylindrical specimen, showed remarkable reduction to 35% compared with that of containing non-reactive aggregate. (See Fig.9.) The results of the loading tests on the reinforced concrete beams made of reactive aggregate, however, showed that the maximum reduction of flexure strength was only 20%. (See Fig.10.)



All dimensions in millimeters.

Fig.7
Detail of the reinforced-concrete test-beams.



All dimensions in millimeters.

Fig.8
Detail of loading for flexure test.

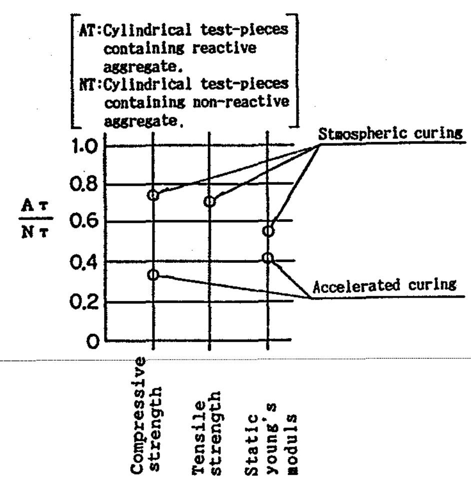


Fig.9 Results of experiments on cylindrical test-pieces.

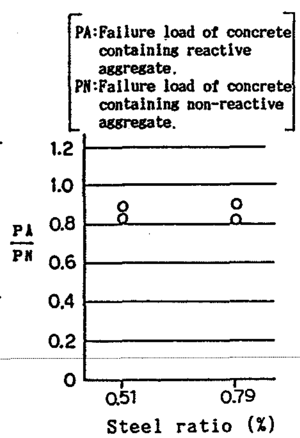


Fig.10 Results of flexure tests.

Similarly, ten reinforced-concrete test-beams were fabricated for shear test using the shear span depth ratio of 1.5. The dimensions of these beams were B×H×L=0.15m×0.3m×1.8m. (See Fig.11.) Five of the beams were fabricated from a mixture of reactive aggregate, NaOH, and NaCl (total amount of alkali (R_2O)=8.0kg/m^3). The remaining five were made of non-reactive aggregate.
The reduction of shear strength of the former beams never exceeded 15% of the latter beams.

In addition, punching shear strength was tested using four reinforced-concrete test-slabs. The dimensions of these slabs were B×L×t=1.2m×1.2m×0.15m. (See Fig.12.) Two of these slabs were fabricated using a reactive aggregate mixture.
The remaining two were made of non-reactive aggregate. The punching shear strength of the former slabs were nearly equal to that of the latter slabs.

The facts described above lead to the conclusion that the reinforcing bars imparted sufficient prestress force to the test-beams, effectively constraining, the expansion that would otherwise have resulted from the alkali-aggregate reaction.

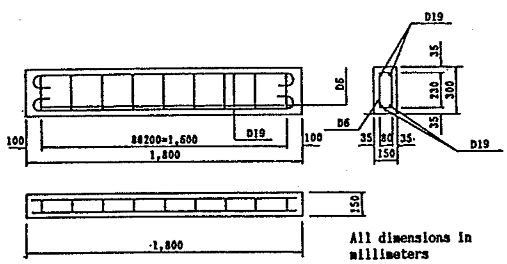


Fig. 11 Detail of shear test beams.

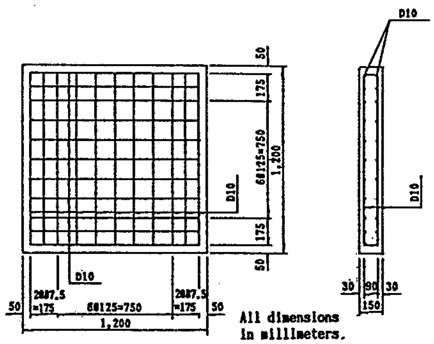


Fig. 12 Detail of punching shear test slabs

Table 3 Shear-strength test results

Type of sample		※Reactive / Non-reactive	Type of failure
Beam	st.@100	0.96	Bending failure (Almost to the point of shear failure)
	st.@200	0.97	Shear failure, or bending and shear failure occurred nearly simultaneously.
	st.(none)	0.87	(Same as above)
Slab		1.04	Cracks from bending occurred at first, finally followed by punching shear failure.

※Failure load ratio

st=Stirrup pitch (mm)

3. SUMMARY

This report covers a portion of the research on alkali-aggregate reaction carried out by the authors over the period 1984-88. Future plans call for further research on the methodology for diagnosis and repair of structures affected by alkali-aggregate reaction, in addition to the eventual establishment of a quality assurance system for the prevention of material failure resulting from this phenomenon.