

EVALUATION OF ALKALI-AGGREGATE REACTION INHIBITORS BY PARTIAL IMMERSION TEST OF CONCRETE IN 2.5% NaCl SOLUTION

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ABSTRACT

This paper deals with the application of alkyl alkoxy silanes and lithium nitrite as chemical admixtures for inhibiting alkali-aggregate reaction, i.e., inhibitors in concrete. The effectiveness of the alkyl alkoxy silanes and lithium nitrite in preventing expansion due to the alkali-aggregate reaction is tested through the partial immersion of concrete containing a reactive andesite with the inhibitors in a sodium chloride solution for 91 days. It is concluded from the test results that the expansion of the concrete with hexyl trimethoxy silane, a kind of alkyl alkoxy silane, or lithium nitrite is about one-fifth of that of plain concrete. The air content of the concrete is increased by the addition of the hexyl trimethoxy silane, although it can be considerably decreased by the addition of a high-range water-reducing agent. The use of the high-range water-reducing agent with the hexyl trimethoxy silane does not prevent the alkali-aggregate reaction-inhibiting effect of the hexyl trimethoxy silane, and is recommended. The expansion of the concrete in the partial immersion test varies to a great extent, depending on the location of the measuring points on the concrete specimens.

*Keywords : Alkali-aggregate reaction, Concrete, Expansion, Inhibitors,
Partial immersion test in chloride solution*

INTRODUCTION

The alkali-aggregate reaction (AAR) problem in reinforced concrete structures has drawn worldwide attention in the construction industry in recent years. However, effective measures for inhibiting AAR have not been found till now, and it is most important in the current concrete technology to find out such measures for improving the durability of the concrete structures. The authors have already found that an alkyl alkoxy silane can be used as a chemical admixture to inhibit AAR (Ohama, Demura & Kakegawa, 1989). On the other hand, it was reported by some papers that AAR is promoted by the external sources of alkali to the concrete (Kawamura, Takeuchi & Sugiyama, 1994). In the present study, a partial immersion test of concrete in a chloride solution is discussed as a test method to check this fact.

In the present work, concrete specimens containing a reactive aggregate and various alkyl alkoxy silanes and lithium nitrite (as AAR inhibitors) are prepared, and evaluated for AAR by a partial immersion test in a chloride solution. The effects of the inhibitors with or without a high-range water-reducing agent on the expansion due to AAR are examined. Furthermore, the effectiveness of the partial immersion test as a rapid test is discussed.

MATERIALS

Cement

Ordinary portland cement as specified in JIS (Japanese Industrial Standard) R 5210 (Portland Cement) was used in all the concrete mixes. The properties of the cement are listed in Table 1.

Table 1 Physical properties and chemical compositions of the ordinary portland cement used.

Specific Gravity	Blaine's Specific Surface (cm ² /g)	Setting Time (h-min)		Compressive Strength of Mortar (MPa)		
		Initial Set	Final Set	3d	7d	28d
3.16	3330	2-15	3-15	15.79	25.99	41.48

Chemical Compositions (%)			Total Alkali Content (%)
MgO	SO ₃	ig.loss	R ₂ O
1.6	2.0	1.4	0.65

Aggregates

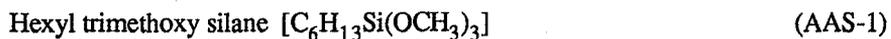
Hatsukari crushed andesite (size, 5-20mm) and Abukumagawa river sand (size, 2.5mm or finer) were used as nonreactive aggregates for all the concrete mixes. Takayama crushed andesite (size, 5-20mm as coarse aggregate and 2.5mm or finer as fine aggregate) was employed as a reactive aggregate for the concrete mixes. The properties of the reactive aggregate, tested according to Appendix 7 [Method of Testing Alkali-Silica Reactivity of Aggregate (Chemical Method)] of JIS A 5308 (Ready-Mixed Concrete) are listed in Table 2.

Table 2 Properties of reactive aggregate, checked by chemical method.

Type of Reactive Aggregate	Dissolved Amount of Silica (Sc) (mmol / l)	Decrease in Alkali Concentration (Rc) (mmol / l)	Interpretation of Result
Andesite	461	121	Deleterious

Chemical admixtures

Three types of alkyl alkoxy silanes (AAS) and lithium nitrite (LiNO₂) were used as chemical admixtures for inhibiting AAR. The chemical formulae of the silanes are listed below.



Hexyl triethoxy silane [$C_6H_{13}Si(OC_2H_5)_3$] (AAS-2)

Hexyl triethoxy silane emulsion [$C_6H_{13}Si(OC_2H_5)_3$ content, 40.0%] (AAS-E)

A commercial polyalkylaryl sulfonate-type high-range water-reducing agent (WRA) was employed for the preparation of concrete containing AAS-1.

TEST PROCEDURES

Preparation of specimens

Specimens for length change test

In accordance with JIS A 6204 (Chemical Admixtures for Concrete), concretes with various inhibitors were mixed by adjusting the slump at 8.0 ± 1.0 cm in the mix proportions of base concrete as given in Table 3. AAS-1 and AAS-2 were added to the concretes at 1.0% of cement, and AAS-E was applied to the concrete at 1.0% of cement as an effective hexyl triethoxy silane content of the emulsion. $LiNO_2$ was also added to the concrete as Na/Li molar ratio was 1.0. The total alkali content of the concretes was adjusted to be 2.5% as Na_2O equivalent, using a 1N aqueous solution of the sodium hydroxide specified in JIS K 8576 (Sodium Hydroxide). A mixture of 20wt% nonreactive fine aggregate (river sand) and 80wt% reactive fine aggregate (Takayama crushed andesite), and 95wt% nonreactive coarse aggregate (Hatsukari crushed andesite) and 5wt% reactive coarse aggregate (Takayama crushed andesite) was used as an aggregate for the concretes. Concrete specimens 100x100x400mm were molded, and then subjected to a 7-day-20°C-80%RH-moist plus 7-day-20°C-50%RH-dry cure. Gauge plugs were embedded in the concrete specimens as shown in Fig.1 at a moist curing period of 5 days.

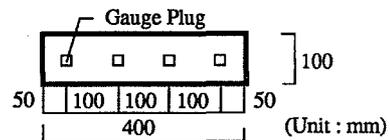


Fig. 1 Positions of embedded gauge plugs in concrete specimen.

Table 3 Mix proportions of base concrete containing reactive aggregate.

Slump (cm)	Air Content (%)	Water-Cement Ratio (%)	Sand Percentage (%)	Unit Water Content (kg/m^3)	Mix Proportions (kg/m^3)				
					Cement	Fine Aggregate		Coarse Aggregate	
						Nonreactive	Reactive	Nonreactive	Reactive
8.0	2.0	60.0	45.0	180	300	162	649	979	52

Specimens for compressive strength test

Concrete cylindrical specimens 100x200mm were molded by using the same concrete as stated above, and then subjected to a 28-day-20°C-80%RH-moist cure.

Measurement of expansion

The measurement of the expansion of concrete specimens was conducted according to the contact gauge method specified in JIS A 1129 (Methods of Test for Length Change of Mortar and Concrete). After dry cure, the initial length of the concrete specimens was

measured, and then the concrete specimens were partially immersed in a 2.5% NaCl solution for 91 days as their half length was underwater as shown in Fig.2. Their expansion was measured at immersion periods of 14, 28, 42, 56, 70, 84 and 91 days. The cracks of the concrete specimens were observed at an immersion period of 91 days.

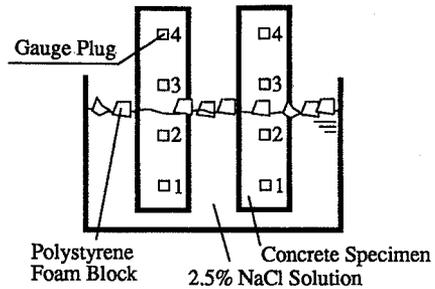


Fig. 2 Partial immersion of concrete specimens in 2.5% NaCl Solution.

Compressive strength test

Concrete specimens were tested for compressive strength according to JIS A 1108 (Method of Test for Compressive Strength of Concrete).

TEST RESULTS AND DISCUSSION

Fig.3 shows the expansion of concrete containing a reactive aggregate without inhibitor during partial immersion in a 2.5% NaCl solution. The expansion of the concrete containing the reactive aggregate without any inhibitor is increased with additional immersion period. This tendency is marked at immersion periods of 42 days or more. The expansion between Plugs 1 and 4 reaches 0.15 % at an immersion period of 91 days. In general, the expansion of concrete due to alkali-silica reaction is attributed to the water absorption of the alkali-silica gel formed by the reaction. At any measuring point, the expansion of the concrete is found to be governed by the formation of the alkali-silica gel up to an immersion period of 42 days, and then to be done by the expansion of the gel due to its water absorption. The expansion depends to a considerable extent on the location of the measuring points. The expansion between Plugs 1 and 2 (wet part) or Plugs 2 and 3 (wet-dry boundary part) is larger than that between Plugs 3 and 4 (dry part). The continuous supply of alkali (Na^+) and water to the concrete by capillary action from the NaCl solution between Plugs 1 and 2 or Plugs 2 and 3 causes the larger expansion, though some water evaporates on the dry part between Plugs 2 and 3 (most of the concrete between Plugs 2 and 3 would be wet, particularly below the surface). The smaller expansion between Plugs 3 and 4 occurs because the water absorption of the alkali-silica gel is inhibited by the high evaporation speed of water in a dry condition. Accordingly, it is necessary to consider a difference in the expansion due to the location of the measuring points in the partial immersion test. From such results, the

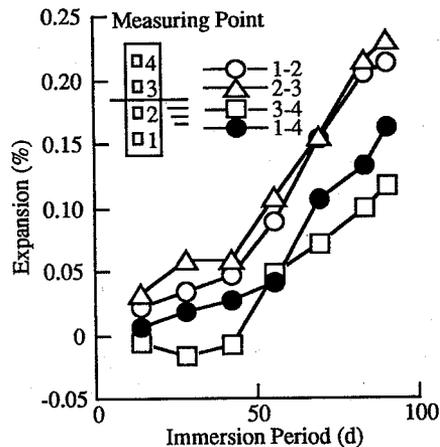


Fig. 3 Expansion of concrete containing reactive aggregate without inhibitors during partial immersion in 2.5% NaCl solution.

From such results, the

effectiveness of various inhibitors is discussed by using the measurement data of the expansion between Plugs 2 and 3 in this study.

Fig.4 represents the expansion of concretes containing a reactive aggregate with inhibitors during partial immersion in a 2.5% NaCl solution. The expansion of the concrete with AAS-1 or LiNO_2 is increased to some extent with additional immersion period, and becomes nearly constant at an immersion period of 84 days. At immersion periods of 84 days or more, the expansion of the concrete with AAS-1 is almost the same as that of the concrete with LiNO_2 . Their expansion at an immersion period of 91 days is approximately 0.05 %, and is about one-fifth of that of the concrete without any inhibitor (plain concrete). Such marked reduction in the expansion by use of AAS-1 is ascribed to the water repellency which is given to the surface layers of the reactive aggregate, cement hydrates and alkali-silica gel in the concrete (Ohama, Demura & Kakegawa, 1989). The effectiveness of LiNO_2 against the expansion is the same as the results in a previous paper (Saito, Kitagawa & Hasaba, 1992). On the other hand, the expansion of the concrete with AAS-2 or AAS-E is greatly increased with additional immersion period, and is nearly equal to that of the plain concrete at an immersion period of 91 days. The effectiveness of AAS-2 or AAS-E against the expansion is hardly recognized.

Fig.5 illustrates the visible cracks due to AAR of concretes containing a reactive aggregate with inhibitors after partial immersion in a 2.5% NaCl solution for 91 days. No visible cracks could be found in the concrete with AAS-1 or LiNO_2 regardless of wet and dry conditions. By contrast, many visible cracks could be seen in both wet and dry parts of the

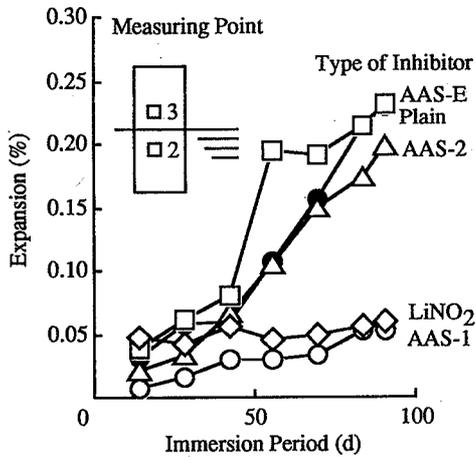


Fig.4 Expansion of concrete containing reactive aggregate with inhibitors during partial immersion in 2.5% NaCl solution.

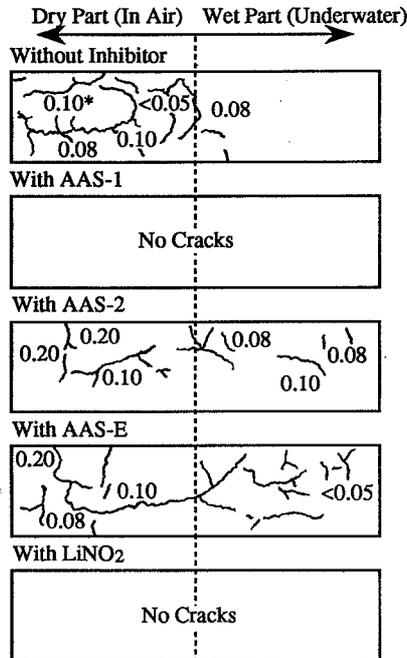


Fig.5 Visible cracks of concrete specimens containing reactive aggregate with inhibitors after partial immersion in 2.5% NaCl solution for 91 days.

Note, * : Crack width (mm).

concrete with AAS-2 or AAS-E, and in the dry part of the concrete without any inhibitor (plain concrete). It is suggested that almost no cracks in the wet part of the concrete without any inhibitor are caused by a composite effect of the prevention of water evaporation and the acceleration of cement hydration, though the expansion of the wet part is larger than that of the dry part. Because there is no differential movement between the inside and outside of the concrete in the wet part, but there is a difference in the dry part.

Fig.6 exhibits the compressive strength of concretes containing a reactive aggregate with inhibitors. The compressive strength of the concrete with AAS-2, AAS-E or LiNO_2 is nearly equal to that of the concrete without any inhibitor (plain concrete). However, the compressive strength of the concrete with AAS-1 is decreased to about 75% of that of the plain concrete. This is attributed to an increase in the entrained air content of the concrete due to the surface activity of AAS-1. A high-range water-reducing agent was added to the concrete to decrease the increased air content due to the addition of AAS-1.

Fig.7 indicates the compressive strength of concretes containing a reactive aggregate with AAS-1 and a high-range water-reducing agent (WRA). In addition, Fig.8 represents the expansion of the concretes containing a reactive aggregate with AAS-1 and the high-range water-reducing agent during partial immersion in a 2.5% NaCl solution. The increased air content of the concretes due to the addition of AAS-1 is decreased by the addition of the high-range water-reducing agent irrespective of AAS-1 content, and the compressive strength of the concretes is higher than that of plain concrete. However, the use of the high-range water-reducing agent with AAS-1 has approximately doubled the

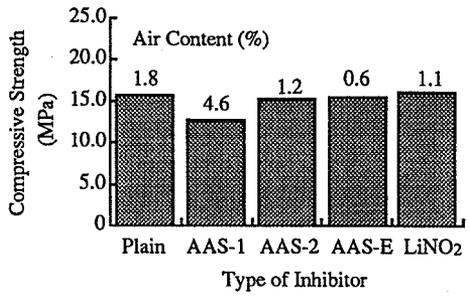


Fig. 6 Compressive strength of concretes containing reactive aggregate with inhibitors.

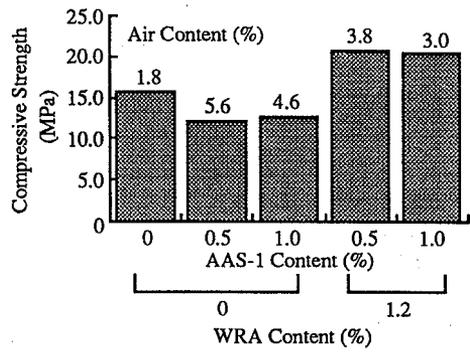


Fig.7 Compressive strength of concretes containing reactive aggregate with AAS-1 and high-range water-reducing agent.

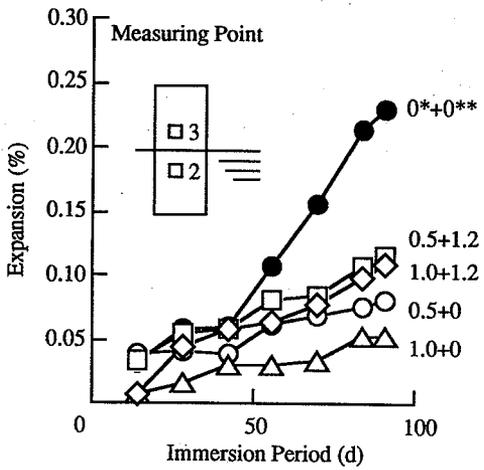


Fig. 8 Expansion of concretes containing reactive aggregate with AAS-1 and high-range water-reducing agent during partial immersion in 2.5% NaCl solution.

Notes, * : AAS-1 content (%).
 ** : WRA content (%).

expansion compared to no use of the water-reducing agent. Maybe the content of the water-reducing agent needs to be optimised in respect of the expansion, air content and compressive strength. It is evident from the results that AAS-1 with the high-range water-reducing agent can be used as an effective chemical admixture for inhibiting AAR in concrete.

CONCLUSIONS

The conclusions obtained from the above-mentioned test results are summarized as follows :

- (1) In the partial immersion test of concrete specimens in a 2.5% NaCl solution for AAR evaluation, the expansion of the concrete varies to a great extent, depending on the location of the measuring points on the specimens. The measurement of the expansion between Plugs 2 and 3 of the specimens is recommended in the test.
- (2) Of the inhibitors used in this study, hexyl trimethoxy silane (AAS-1) and lithium nitrite (LiNO_2) are most effective against the inhibition of AAR in concrete. However, as the concrete strength reduction due to air entrainment is expected in the use of the hexyl trimethoxy silane, the addition of the silane with a high-range water-reducing agent to the concrete is recommended. The content of the water-reducing agent needs to be optimised with respect to expansion, air content and compressive strength.

REFERENCES

Kawamura, M., Takeuchi, K. & Sugiyama, A. 1994, 'Mechanisms of the Influence of NaCl Externally Supplied on the Expansion of Mortars Due to the Alkali-Silica Reaction (in Japanese)', *Journal of Materials, Concrete Structures and Pavements*, Japan Society of Civil Engineers, V-25 (502), 93-102.

Ohama, Y., Demura, K. & Kakegawa, M. 1989, 'Inhibiting Alkali-Aggregate Reaction with Chemical Admixtures', *Proceedings of the 8th International Conference on Alkali-Aggregate Reaction*, eds K.Okada, S.Nishibayashi & M.Kawamura, Kyoto, Japan, 17-20 July, Elsevier, London, 253-258.

Saito, M., Kitagawa, A. & Hasaba, S. 1992, 'Effectiveness of Lithium Nitrite in Suppressing Alkali-Aggregate Expansion (in Japanese)', *Journal of the Society of Materials Science, Japan*, 41 (468), 1375-1381.