

## **INHIBITING ALKALI-AGGREGATE REACTION WITH ALKYL ALKOXY SILANES**

Yoshihiko Ohama, Katsunori Demura, and Ichiro Wada  
College of Engineering, Nihon University  
Koriyama, Fukushima-ken 963, Japan

This paper deals with inhibiting alkali-aggregate reaction in concrete with alkyl alkoxy silanes. Mortar specimens containing a reactive aggregate are prepared with various contents of the alkyl alkoxy silanes, and cured under moist conditions or in an autoclave. The expansion of the specimens is measured through 365-day moist curing or autoclaving. From the test results, the expansion of the reactive aggregate-containing mortars with the alkyl alkoxy silanes is remarkably smaller than that of the mortar without the alkyl alkoxy silanes because of their water-repellent and air-entraining effects.

### INTRODUCTION

In recent years, alkali-aggregate reaction in reinforced concrete structures has become a serious social problem in the world. However, effective measures for preventing the alkali-aggregate reaction have not been found so far, and it is most important in the present concrete technology to find out such effective measures. The authors have already reported some chemical admixtures for inhibiting the alkali-aggregate reaction (1). The present paper deals with some trials to inhibit the alkali-aggregate reaction with alkyl alkoxy silanes.

Reactive aggregate-containing mortars are prepared with various contents of alkyl alkoxy silanes. Mortar specimens are molded, and cured under moist conditions or in an autoclave. The expansion of the specimens is measured through moist curing or autoclaving. The effect of the alkyl alkoxy silane addition on the inhibition of the alkali-aggregate reaction is discussed.

### MATERIALS

#### Cement and Aggregates

Ordinary portland cement with an alkali content of 0.65% as  $\text{Na}_2\text{O}$  equivalent, Toyoura standard sand as a nonreactive aggregate and opaline amorphous silica (size; 0.15-0.30mm) as an alkali-reactive aggregate were used in all the mortar mixes.

Alkyl Alkoxy Silanes

Five types of alkyl alkoxy silanes (AAS) were employed. The chemical formulations of AAS are listed below.

Metyl trimethoxy silane	$\text{CH}_3\text{Si}(\text{OCH}_3)_3$	(AAS-1)
Hexyl trimethoxy silane	$\text{C}_6\text{H}_{13}\text{Si}(\text{OCH}_3)_3$	(AAS-2)
Octyl trimethoxy silane	$\text{C}_8\text{H}_{17}\text{Si}(\text{OCH}_3)_3$	(AAS-3)
Decyl trimethoxy silane	$\text{C}_{10}\text{H}_{21}\text{Si}(\text{OCH}_3)_3$	(AAS-4)
Hexadecyl trimethoxy silane	$\text{C}_{16}\text{H}_{33}\text{Si}(\text{OCH}_3)_3$	(AAS-5)

TESTING PROCEDURES

Preparation of Specimens

The mix proportions of reactive aggregate-containing mortars were designed as shown in Table 1. The total alkali content of the mortars is adjusted to be 2.0% as  $\text{Na}_2\text{O}$  equivalent, using sodium hydroxide. A mixture of 90 wt% nonreactive aggregate and 10 wt% reactive aggregate was used as an aggregate for the mortars. In accordance with JIS R 5201 (Physical Testing Methods for Cement), the mortars were mixed using the mix proportions given in Table 1. Mortar specimens 40x40x160mm were molded, and then subjected to a 24-hour-20°C-100%R.H.-moist cure.

Measurement of Expansion

The measurement of the expansion of mortar specimens was conducted according to JIS (Japanese Industrial Standard) A 5308 (Ready-Mixed Concrete) Appendix 8 [Test Method for Alkali-Silica Reactivity of Aggregates (Mortar-Bar Method)] and a rapid test method proposed by Nishibayashi et al. (2). Immediately after moist cure, the initial length of the mortar specimens was measured by using a length comparator. Then the mortar specimens were subjected to a 40°C-100%R.H.-moist cure for 365 days, or

TABLE 1 - Mix Proportions of Reactive Aggregate-Containing Mortars with Alkyl Alkoxy Silanes

Type of AAS	AAS Content (wt% of Cement)	Cement : Aggregate (By Weight)	Reactive Aggregate Replacement (%)	Water-Cement Ratio (%)	Air Content (%)	Flow
---	0	1 : 2.25	0	65.0	4.0	169
---	0			65.8	4.2	170
AAS-1	0.5			63.4	9.8	172
	0.7			62.9	9.3	166
	1.0			63.4	9.0	167
AAS-2	0.5			57.6	11.0	168
	0.7			57.6	10.8	170
	1.0			57.6	10.2	174
AAS-3	0.5	1 : 2.25	10	63.4	9.6	167
	0.7			63.6	9.6	170
	1.0			65.9	9.5	174
AAS-4	0.5			64.2	9.6	174
	0.7			63.4	9.5	172
	1.0			63.4	9.5	165
AAS-5	0.5			63.4	9.8	171
	0.7			63.4	9.3	174
	1.0			62.6	9.0	171

autoclaving at 128°C under a pressure of 2.5 kgf/cm<sup>2</sup> for 4 hours. After the desired moist curing period or autoclaving, the mortar specimens were stored at 20°C and 100%R.H. for 24 hours for cooling, and their expansion was measured by use of the same comparator.

#### Determination of Pore Size Distribution

The samples taken from 1-day moist-cured reactive aggregate-containing mortars with AAS-2 contents of 0, 0.5 and 1.0% were cleaned by acetone, and then treated by the D-dry method. The pore size distribution of the samples was determined in the pore radius range of 3.75 to 43000 nm by using a mercury porosimeter. The total pore volume of the samples was also calculated.

#### TEST RESULTS AND DISCUSSION

Fig.1 shows the moist curing period vs. expansion of reactive aggregate-containing mortars with AAS at 40°C and 100%R.H. Fig.2 represents the AAS content vs. 365-day expansion of the reactive aggregate-containing mortars with AAS. The expansion of the reactive aggregate-containing mortar without AAS (AAS content, 0%) increases sharply with additional moist curing period, and becomes nearly constant at a moist curing period of 182 days. The expansion at 182 days is about  $55 \times 10^{-4}$ . The expansion of the reactive aggregate-containing mortars with AAS increases gradually with additional moist curing period, and is much smaller than that of the mortar without AAS at the respective moist curing periods regardless of the type of AAS and AAS content. The 365-day expansion of the reactive aggregate-containing mortars with AAS is  $30 \times 10^{-4}$  or less, and tends to decrease with an increase in AAS content. However, the effectiveness of AAS against the expansion due to an alkali-aggregate reaction depends on the type of AAS used. Particularly, the 365-day expansion of the reactive aggregate-containing mortars with AAS-2 contents of 0.5% or more or an AAS-5 content of 1.0% is less than 1/10 of that of the mortar without AAS, and is similar to that of a mortar without the reactive aggregate.

Fig.3 illustrates the AAS content vs. expansion after the autoclaving of the reactive aggregate-containing mortars with AAS. The reactive aggregate-containing mortar without AAS (AAS content, 0%) provides a large expansion of  $67 \times 10^{-4}$  after autoclaving. By contrast, the expansion after autoclaving of the reactive aggregate-containing mortars with AAS is almost the same as that of a mortar without the reactive aggregate. Differences in the expansion after autoclaving between the mortars with AAS are hardly recognized, though the expansion of the mortars after moist cure is affected by the type of AAS. It is considered that the autoclaving of the reactive aggregate-containing mortars with AAS accelerates not only the alkali-aggregate reaction but also the expansion-preventing effect of AAS.

In general, AAS is used as a barrier penetrant to improve waterproofness of cement mortar and concrete because of its water-repellent effect. The cement mortar and concrete are also provided superior water repellency by the addition of AAS (3). The



AAS-2 contents of 0, 0.5 and 1.0%. The total pore volume of the mortars with AAS-2 is about 1.3 times that of the mortar without AAS. It is generally well-known that the addition of air-entraining agents to the cement mortar and concrete with reactive aggregate prevents the expansion of the mortar and concrete because the air voids entrained by the agents relieve the expansion pressure developed by the water absorption of alkali-silica gel (5). Such effectiveness is expected for the addition of AAS to the above reactive aggregate-containing mortars. However, the same superior expansion-preventing effect as AAS has not been reported for the air-entraining agents till now (5).

#### CONCLUSIONS

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

(1) The expansion of reactive aggregate-containing mortars through 365-day moist cure or autoclaving for accelerating alkali-aggregate reaction is markedly decreased by the addition of alkyl alkoxy silanes. The most effective alkyl alkoxy silane to inhibit the expansion due to alkali-aggregate reaction is hexyl trimethoxy silane.

(2) The addition of alkyl alkoxy silanes to reactive aggregate-containing mortars gives them effective water repellency and air entrainment, which prevent the formation of alkali-silica gel and relieve the expansion pressure of the gel.

(3) Effectiveness of alkyl alkoxy silanes against the inhibition of alkali-aggregate reaction can not be evaluated by the autoclaving of reactive aggregate-containing mortars. Because the autoclaving of the reactive aggregate-containing mortars with the alkyl alkoxy silanes accelerates not only the alkali-aggregate reaction but also the expansion-preventing effect of the alkyl alkoxy silanes.

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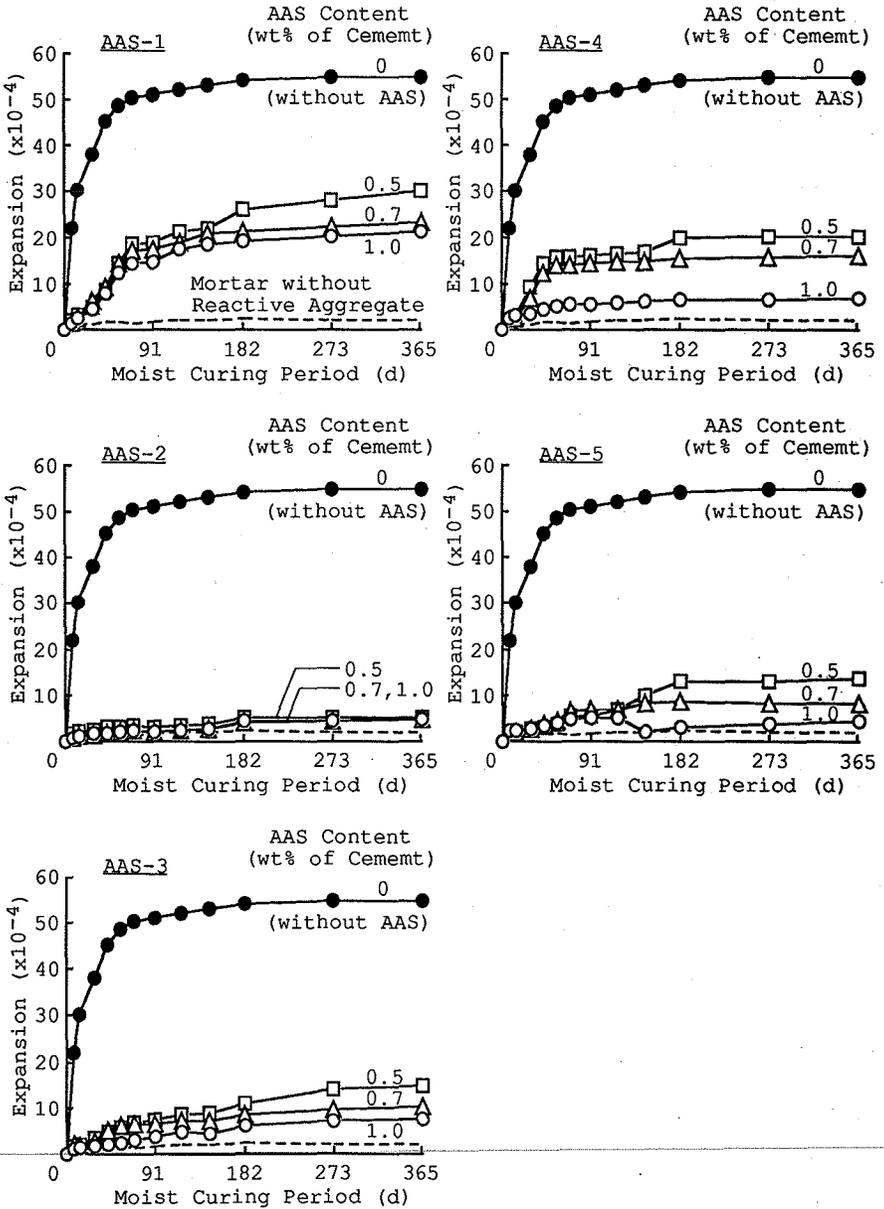


Fig.1 Moist curing period vs. expansion of reactive aggregate-containing mortars with AAS at 40°C and 100%R.H.

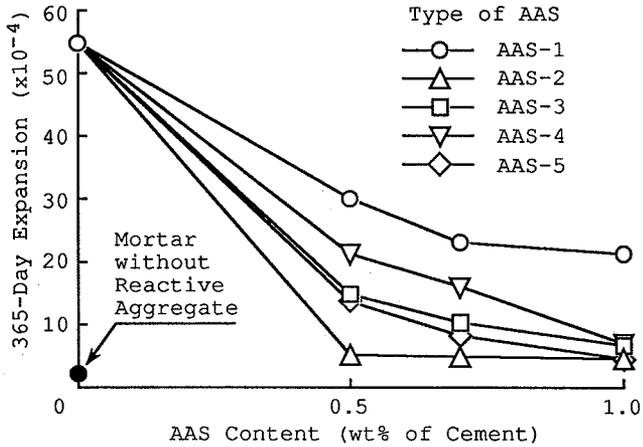


Fig.2 AAS content vs. 365-day expansion of reactive aggregate-containing mortars with AAS.

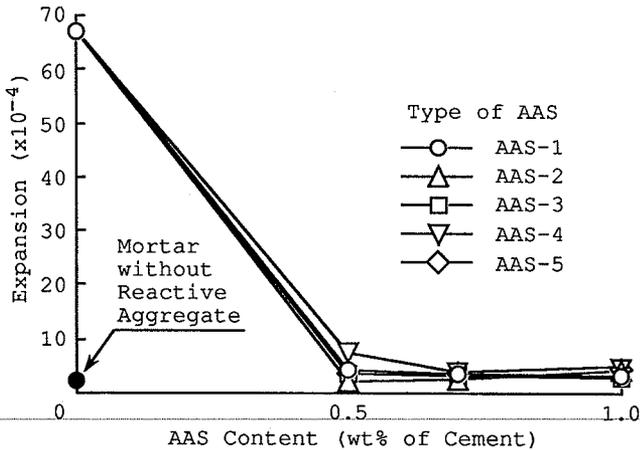
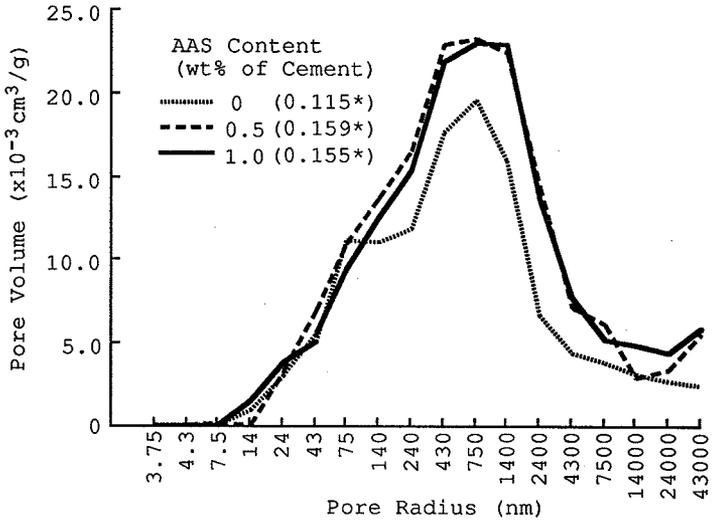


Fig.3 AAS content vs. expansion of reactive aggregate-containing mortars with AAS after autoclaving.



Note; \*:Total pore volume (cm<sup>3</sup>/g)

Fig.4 Pore size distribution of reactive aggregate-containing mortars with AAS-2 contents of 0, 0.5 and 1.0%.