

**EFFECTS OF MOISTURE CONTROL AND INHIBITION
ON ALKALI SILICA REACTION**

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1. ABSTRACT

Generally, it is said that alkali silica reaction (hereinafter referred to as ASR) can be inhibited by maintaining the moisture content within a certain range. The majority of means developed and studied in recent years for inhibiting ASR utilize this mechanism. That is, to achieve ASR inhibition, the permeation characteristics of the coating material is adjusted so as to enable moisture migration control, which, in turn, enable the moisture content to be controlled. This report covers experiments conducted with the objective of clarifying the inhibiting mechanism. It has been confirmed that certain kinds of coating materials are capable controlling the moisture content, and that it is possible to obtain ASR inhibiting effects that correspond to the degree to which the moisture content has been inhibited.

2. INTRODUCTION

Recently, many cases of ASR-caused damages of concrete structures have been reported. This has spurred active research and development to establish means for inhibiting ASR. Means of inhibition studied until now mainly consist of coating the repair section with coating material to control moisture migration, aiming at maintaining the moisture content within a certain range to retard the progress of ASR. The practical effectiveness of such means is being verified by a number of experiments and reports. Yet, confirmation in terms of mechanism has not been necessarily sufficient. That is, it calls for further quantitative confirmation of, for example, 1) to what degree the moisture content should be kept to enable the ASR inhibiting effects to be manifested, 2) to what degree the moisture content can be inhibited by the moisture migration control functions possessed by the coating material, and 3) to what degree this will be eventually reflected on ASR inhibition.

The experiments conducted to enable quantitative confirmation are described below. In Experiment-1, the moisture content that permits ASR inhibition to be manifested was examined. Meanwhile, in Experiment-2, the state of moisture control manifested by coating materials as well as the expansion amount obtained then were examined to study the correlation between the two.

3. EXPERIMENT-1

3.1. OUTLINE

In an attempt to establish a correlation between the time dependent change in the

expansion amount and that in the moisture content obtained by the "heat-dry" method, several kinds of mortar specimen fabricated with reactive aggregates (hereinafter referred to as reactive mortar) were subjected to accelerated curing under constant-temperature and constant-humidity, with the moisture content externally adjusted by placing the specimens under a plural number of environmental humidity levels.

3.2. PROCEDURES

3.2.1. Expansion Amount Measurement Fabrication of the test specimens and measurements were performed in conformance to the Mortar Bar Method (Tentative Guidance of Ministry of Construction). Changes in weight were also recorded. The mix proportion was W/C=0.5, S/C=2.5, with the total alkali content set to 1.2% (0.5% compensated by adding NaOH). As for the aggregate, the four kinds aggregates (A through D) shown in Table 1 were used.

Table 1 Results of Chemical Method
(According to Tentative Guidance of Ministry of Construction)

	Rock	Sc/Rc ^{*)}	Judgment
A	Andesite	694/165	Potentially deleterious
B	Andesite	237/110	Potentially deleterious
C	Chert	108/ 15	Deleterious
D	Greywacke	33/ 14	Innocuous

Sc:Silica dissolved(mmol/l), Rc:Reduction in alkalinity(mmol/l)

3.2.2. Moisture Content Measurement by "heat-dry" method The test specimens, which were fabricated in an identical manner to the above specimens in terms of mix proportion and configuration were heated until they reached the state of constant volume at 110°C at the prescribed material age. The moisture content was obtained by dividing the reduced quantity by the constant-volume weight.

3.2.3. Accelerated Curing The condition were set to a constant-temperature, constant-humidity environment. The temperature was commonly set to 40°C, but for the humidity, four different conditions were set, 80, 90, 100%RH and "overwet". For the "overwet" state, the specimens were enclosed in a vinyl bag and roughly 20cc of pure water per specimen was added. Accelerated curing was started within 24 hours after fabricating and stripping the specimens from the forms.

3.3. RESULTS AND DISCUSSION

1) Fig.1 shows the time-dependent changes in the expansion amount, specimen weight, and moisture content under each humidity environment and as classified by aggregate.

2) For every type of reactive aggregate (A, B and C), the test specimens invariably manifested their expansive properties in the humidity range of 90%RH, or more. This led the authors to presume that the expansion inhibiting effects (=ASR inhibiting effects) are manifested in the humidity range of 80 through 90%RH, which largely agrees with the results reported in existing literature¹⁾.

3) The moisture content measured at the point where the expansion inhibiting effects manifested were approximately 7-8wt%, and were found to be independent of the type of aggregate used. It was, therefore, presumed that expansion inhibiting effects can be obtained, provided that the moisture content is controlled to which the stated range.

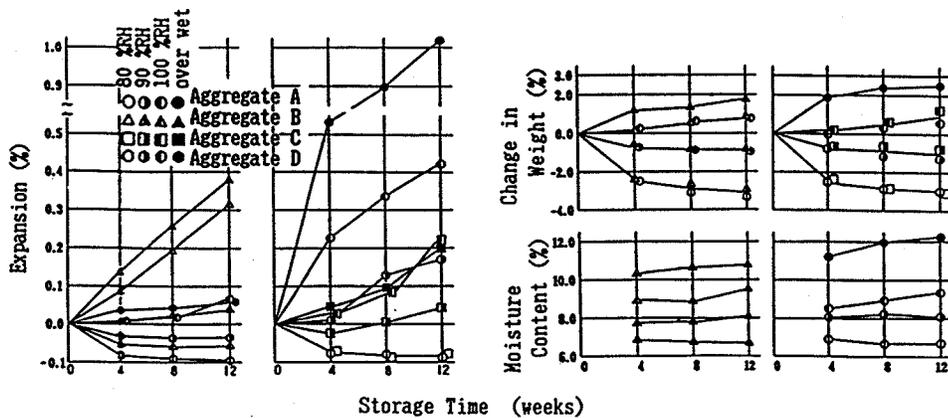


Fig.1 Change in Expansion, weight and moisture content (EXP1)
(Left= Aggregate B and D, Right= Aggregate A and C)

4. EXPERIMENT-2

4.1. OUTLINE

To examine the state of moisture control and the resulting expansion inhibiting effects during accelerated curing under a dry-wet repeating environment, the time-dependent changes in the moisture content and expansion amount were measured for reactive mortar specimens, which were coated in advance during the initial stage of curing with coating materials.

As for the coating material, a coating system was used, which combines a silane-based penetrating-type waterproofing material provided not only with impervious function to water but also with functions that do not impede the evaporating and diffusing actions of internal moisture, with a protective layer formed by a polymer cement-based coating material. Since the interior of actual structures are, more often than not, wet, it was considered that preventing ingress of water alone would not be enough to achieve the objective of inhibiting the expansion amount, and that functions for discharging the internal moisture which exists in an excessive amount are also needed.

The reason for adopting "dry-wet repeating conditions" as the accelerated curing environment is because acceleration is not only needed for ASR, but also for the test period in order to enable examination of the long-term tendency under actual environments within a short span of time. Further, as it was assumed that moisture distribution in the specimen would become irregular under the dry-wet repeating conditions, the state of change induced in the moisture distribution was confirmed by examining both the mean moisture content measured by the "heat-dry" method and the localized moisture content measured in the vicinity of an electrode embedded in the central area of the test specimen.

4.2. PROCEDURES

4.2.1. Expansion Amount Measurement Similar to Experiment-1, two kinds of aggregates (B and D) were used, and alkali compensation was made by adding NaCl.

4.2.2. Moisture Content Measurement by "heat-dry" method Conducted similarly to Experiment-1. The measuring timing, which is the same as that of the "electrode" method, was set to within 60 minutes of the final stage of the wet curing process.

4.2.3. Moisture Content Measurement by "electrode" method) The means adopted in the present measurements were borrowed from literatures 2, and consists of measuring the dielectric content in the cement matrix first, to estimate the moisture amount which is correlated with the dielectric constant.

4.2.4. Coating The test specimens were stripping from the form within 24 hours after its placement, and then cured for 7 days at 20°C, 100%RH. Then, the specimens were dried at 40°C for 18 hours, and coated. Details of the coating materials and specifications used are shown in Table 2.

Table 2 Coating Specifications

no	Coating material	Rate of Use (kg/m ²)
1	MATERIAL A	0.37
2	MATERIAL A	0.74
3	Base Coat) MATERIAL A	0.24
	Second Coat) MATERIAL B	2.1
	Finishing Coat) MATERIAL A	0.12

MATERIAL A (Silane-based penetrating-type waterproofing material)

: Standard Rate of Use (kg/m²)= 0.37
 : Solids Content (wt%) = 40

MATERIAL B (Flexible acryl-polymer-cement coating material)

: Standard Rate of Use (kg/m²)= 2.1
 : Solids Content (wt%) = 83

4.2.5. Accelerated Curing A dry-wet repeating environment was adopted. As for the temperature, humidity and cycle time, those described in an existing literature³⁾ which takes into account the temperature and humidity cycles of actual outdoor environments were basically used, being finally determined after making some slight modifications. Table 3 lists the conditions set.

Table 3 Conditions of Accelerated curing (dry-wet repeating)

no	Period	Condition of "wet"	Condition of "dry"
1	1- 8 ws	40°C,100%RH,22hs	40°C,60%RH,4hs + 20 C,60%RH,22hs
2	9-12	Pure-water-shower,5ms + 40°C,100%RH,18hs	20°C,60%RH,6hs
3	13-16	= no.2	40°C,30%RH,6hs

4.3. RESULTS AND DISCUSSION

1) Fig.2 shows the time-dependent changes in the expansion amount and weight of each test specimen. Meanwhile, Fig.3 shows the time-dependent change in the moisture content measured by the "heat-dry" method, and by the "electrode" method at a depth of 2cm in the central area of the specimen. Further, for Coating Specification NO.1 and the uncoated test specimens, the states of moisture migration during the NO.3 process of the dry-wet repeating conditions was obtained from the moisture content measured by the "electrode" method at depths of 0.5, 1.0 and 2.0cm, and by the weight change as shown in Fig.4.

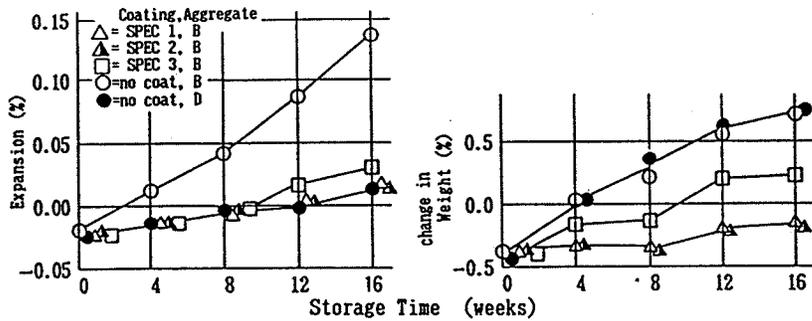


Fig. 2 Change in Expansion and Weight (EXP2)

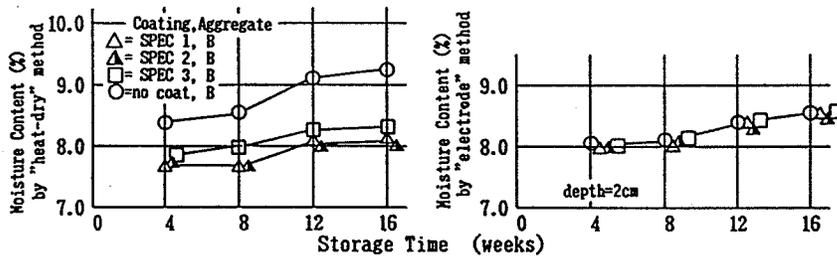


Fig. 3 Change in Moisture content (EXP2)

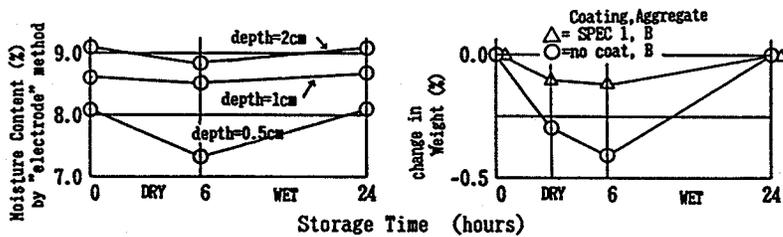


Fig. 4 Change in Weight and Moisture Content by "electrode" Method for 1 Cycle of dry and wet (EXP2)

2) From the time-dependent changes in the weight of the coated specimen (Fig. 2) and those in the moisture content obtained by both measuring systems (Fig. 3), some moisture controlling effects believed to have derived from the moisture migration control functions of the coating material were recognized. The degree of such effects as determined by the weight change for 16 weeks, was found to be approximately 1/2 to 1/3 of that in the uncoated specimens, and in terms of absolute values, was approximately 8wt% as determined by the moisture content measured by the "heat-dry" method. Further, judging from the time-dependent change in the expansion amount (Fig. 2) measured under the same condition, some expansion inhibiting effects were also recognized. The degree of such effects as determined by the expansion amount for 16 weeks, was found to be approximately 1/4 to 1/5 of that of the uncoated specimens.

3) Comparison of the moisture content obtained by the "heat-dry" method and the localized moisture content obtained by the "electrode" method for the central area of the specimen at a 2cm depth reveals that the former always takes a value lower by several percents in the first decimal place than that of the latter for coated specimens. This led the authors to suppose that the moisture content for the surface area is lower than that for the central. Meanwhile, for the uncoated specimens a reversed state was recognized. This state is presumed to indicate that the functions of the coating material that allows the internal moisture to evaporate and diffuse enables the surface moisture to evaporate, and that the coating material's impervious functions to water enables that particular state to be maintained even under wet environment.

4) The moisture content obtained by the "heat-dry" method for the specimens which exhibited the expansion inhibiting effects was approximately 8wt%. This largely agrees with the results obtained in Experiment-1 - "the moisture content that enables the expansion inhibiting effects to be manifested is independent of the aggregate type and is approximately 7 to 8wt%." In short, by controlling the moisture content, the authors were able to gain expansion inhibiting effects that correspond to the degree of the moisture content controlled.

5) In accelerated curing, in which dry and wet cycles are combined, it has been reported that moisture migration accompanied with alkali ions takes place and that the repetition of concentration and diffusion of these ions at the surface area can possibly promote ASR⁴⁾. Accordingly, the present experiments were conducted with the assumption that the expansion inhibiting effects may not be gained even should the moisture content be successfully stabilized, by the moisture migration control functions of the coating materials, within the range where the expansion inhibiting effects are manifested. However, in the expansion amount comparison conducted with respect to uncoated specimens of the same moisture content, it was found that the expansion amounts obtained under the dry-wet repeating environment of Experiment-2 was smaller than those obtained under the constant-temperature, constant-humidity environment of Experiment-1. And the expected tendency was not recognized.

5. CONCLUSIONS

1) Expansion inhibiting effects can be gained by controlling the moisture content in mortar. Under the test conditions adopted in the present experiments, the effects were gained when the moisture content were inhibited to approximately 7-8wt%.

2) (Under the dry-wet repeating curing conditions of the present experiments), the moisture content in the mortar was successfully controlled by the moisture migration control functions of the coating materials employed. Expansion inhibiting effects corresponding to the degree to which the moisture contents was inhibited were also gained.

6. REFERENCE

- [1] Hakon Olafsson, The Effect of Relative Humidity and Temperature on Alkali Expansion of Mortar Bar, Proc. of 7th I.C.A.A.R., p461, 1987. (for books)
- [2] E. Kamata, et al., Method of Moisture Content in Concrete, CAJ Review of the X X X Original Meeting Technical Session, p28, 1976. (for books)
- [3] T. Miyagawa, et al., Repair of Concrete Structure Damaged by Alkali-Aggregate Expansion, Proc. of J.C.I. 9th Conference, 9, 1, p621, 1987. (for books)
- [4] Nixon, Collins and Rayment, The Concentration of Alkalies by Moisture Migration in Concrete - A Factor Influencing Alkali Aggregate Reaction, Cement and Concrete Research, 9, p417, 1979. (for journals)