A Rapid Method of Determining the Alkali-Aggregate Reaction in Concrete by Autoclave

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ABSTRACT

This study was planned to clarify the behavior of mortar using reactive aggregate cured in an autoclave and to develop a rapid method of determining the alkali-aggregate reaction.

INTRODUCTION

In order to prevent concrete damage from alkali aggregate reaction, it is important to know the potential reactivity of aggregate in advance and to take the necessary precautionary measures against possible damage due to alkali aggregate reaction.

ASTM chemical and mortar bar methods have been adopted widely throughout the world for determining the potential reactivity of aggregates. However, the mortar bar method is time consuming. Therefore, it is of practical importance to develop a rapid, simple, and reliable method of determining the potential reactivity of an aggregate.

Consequently, this study was initiated to clarify the behavior of mortar using potentially reactive aggregate cured in an autoclave and to develop a rapid method of determining the occurrence of alkali aggregate reaction.

TEST PROGRAM AND CONDITIONS

The scope of the tests performed is summarized in the **Table.**

(1) Materials

Normal portland cement having an alkali content of 0.5 percent as Na_2O equivalent, two kinds of reactive aggregate and a non-reactive crushed sand were used. The grading of the sand conformed to the value specified by ASTM. To control the total alkali content in mortar NaOH was used in all test series and NaCl, KOH, and KCl were also used in some tests.

(2) Mix proportion

The mortar was proportioned so as to have a constant water cement ratio of 0.45 and various total alkali contents. The ratio of cement to sand, C : S, was kept constant at 1 : 2.25. No control of the flow of mortar was carried out in this test, because all aggregates were used in a saturated surface dry condition when mixing mortar.

(3) Specimens

The specimens having dimensions of 4 x 4 x 16 cm as specified by JIS were used in this test series, and were subjected to the autoclave treatment after being held for 24 hours in a mold and 1, 3, and 6 days (thus, mortar age was 2, 4, and 7 days) in water of 20°C and after treatment in 40°C and R.H. 100 percent.

(4) Conditions of autoclave treatment

A large cooking pressure pot was used as the autoclave kiln, of which the height and diameter were each about 30 cm, and the pressure control valve and the pressure gauge (0 to 0.7 MPa) were fitted to the lid of the pot. Both steam and boiling were selected as the conditions in the autoclave kiln, and the pressure at the corresponding temperature was taken. (0 (atmospheric, 100°C), 0.05 MPa (about 105°C), 0.1 MPa (110°C), 0.15 MPa (120°C) and 0.2 MPa (about 130°C)). Specimens pre-cured under standard curing condition (20°C in water) were given the general test, but the specimens pre-treated at 40°C and R.H. 100 percent, for 7, 14, and 28 days were also tested.

(5) Measurement

Length changes (expansion) using Stanton's mortar bar equipment modified for JIS specimens were measured. These measurements were made with the specimen in the saturated condition (20°C and R.H. 100%), just after demolding, just before and after the accelerated treatment and after storing in the testing tub at a high temperature and humidity (40°C and R.H. 100%) for the specified period.

Table Testing plan and conditions

Items	Elements	Conditions
Materials	Cement	Normal portland cement (Na_2O.eq.: 0.5 %)
	Reactive aggregate	A: Sc=807, Rc=119 B: Sc=337, Rc= 66
	kinds of alkali	NaOH, NaCl, KOH, KCl
Mix proportion of mortar	Total alkali content (Na_2O.eq.)	0.5(cement), 1.0, 1.5, 2.0, 2.5, 3.5, 5.0(%)
Conditions of specimen	pre-curing (20℃ in water)	24 hr. and 1, 3 and 6 days after demolding
Accelerated treatment (autoclaving)	condition	steam, boiling (in water)
	pressure (MPa) (temperature, ℃)	0(atmosphere, 100), 0.05 0.1(110), 0.15, 0.2(130)
	period (hr.)	1, 2, 4, 6, 8
	pre-treatment (40℃, R.H.100%)	7, 14 and 28 days
Measuring	expansion (length change)	after treatment and each one week

RESULTS AND DISCUSSIONS

1. The effects of pressure and period of autoclave treatment

An example of the effect of pressure is shown in **Fig.1.** The expansion in the two hour treatment increases with the rise in pressure, but maximum expansion appears at 0.15 MPa when the six hour treatment is carried out.

As shown in **Fig.2**, there is a tendency for the expansion in both aggregates to increase when the period of treatment becomes longer. But the rate of increase in expansion decreases gradually and becomes eventually constant when the treatment period is in excess of four hours. It seems that this phenomenon is caused by the destruction of the reactive compound in aggregate or of alkali in the cement during the autoclave treatment. Also, it is clear that the expansion during steam treatment only is smaller than that with pressure, and the expansion due to the steam treatment is larger than that with boiling. From Fig.1 and 2, it appears that the pressure of 0.1 to 0.15 MPa and a time of 4 to 5 hours is the optimum condition for the autoclave treatment.

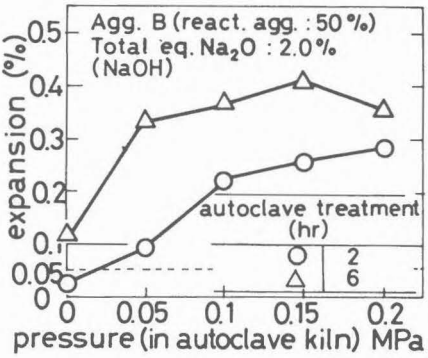


Fig.1 Relationships between expansion and pressure

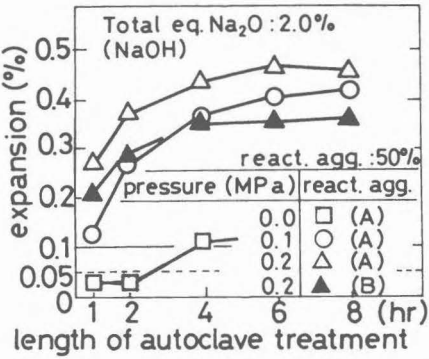


Fig.2 Expansion and length of autoclave treatment

2. Effects of alkali

Alkali content

When the total alkali content is over 1.0% (Na_2O equivalent) the expansion increases considerably, but it reaches a maximum value at about 2.5%, and decreases at an alkali content of more than 3.0%. Therefore, a pessimum in alkali content exists at about an Na_2O eq. of 2.5%. Moreover, this testing condition is rather milder than that of other researchers who use over 150°C (more than 0.3 MPa)[1]. Under the conditions used in our test it is unlikely that non-reactive aggregates would appear to be expansive even with high alkali contents.

Kinds of alkali

As shown in **Fig.3**, when NaOH is used as the additional alkali, a large expansion appears just after treatment, but using NaCl, the expansion appears first at seven days and its subsequent increase is almost linear. The expansion of both NaOH and NaCl is almost the same at 28 days. On the other hand, the expansion of mortar with KOH is much less than that with NaOH and NaCl, and no effect on expansion is caused by KCl.

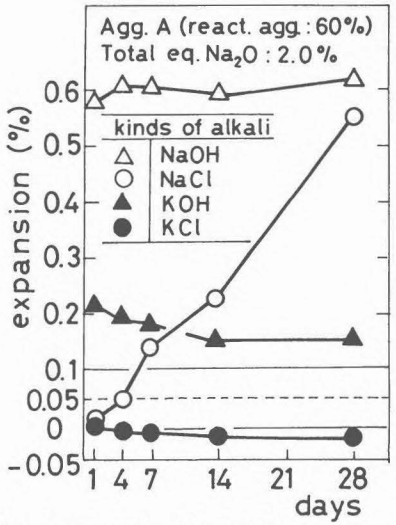


Fig.3 A relation between the expansion and kinds of added alkali

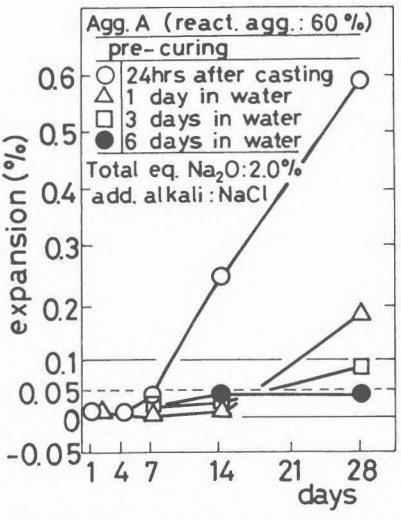


Fig.4 Effect of pre-curing on the expansion

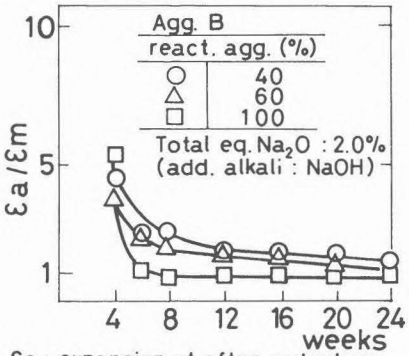
3. Effects of pre-curing and pre-rapid treatment

Effects of pre-curing

Using NaOH almost the same expansion appears after treatment regardless of the pre-curing period, but using NaCl, as shown in **Fig.4**, considerable expansion appears at one day pre-curing and the expansion is gradually less with an increase of the pre-curing period in water.

Effects of pre-rapid treatment

When the specimen is stored at 40°C and R.H. 100% before autoclaving treatment, the expansion due to autoclaving decreases with the increase of period stored at 40°C and R.H. 100%, and the total expansion due to both treatments is almost the same.



εa : expansion at after autoclave treatment

εm : expansion at each ages due to mortar bar test (ASTM)

Fig.5 An example of relation between expansion ratio and elapsed time

4. Relationships between the rapid test and the ASTM mortar bar test

From the relationships between the ratio of expansion ($\varepsilon_a/\varepsilon_m$) and lapse of time as shown in **Fig.5**, it can be seen that the expansion due to the accelerated treatment by autoclaving is almost equal to that obtained from normal ASTM mortar bar tests after about 20 weeks. Therefore, it seems that the accelerated test by means of autoclaving treatment can be effectively applied

to estimate at an early stage the reactivity of aggregate and the degree of expansion.

CONCLUDING REMARKS

In this study, the conditions affecting the expansion of mortar bars during autoclaving were investigated experimentally. The conclusions are summarized as follows:

(1) Maximum expansion was observed under 0.15 to 0.20 MPa pressure in the autoclave kiln.

(2) The length of autoclave treatment was four to five hours.

(3) An adequate starting age for the autoclave treatment for specimens was 24 hours after casting the mortar.

(4) The level of expansion obtained at half and one year under normal storage conditions (40°C and R.H. 100%) was obtained by this autoclave method with added NaOH in only five hours.

It was confirmed, from the chemical analysis, that the compound formed by the autoclave treatment was the same as that for the normal rapid treatment at 40°C and R.H. 100%.

The following conditions for the autoclave rapid method are suggested from this study:

(1) Total alkali content as Na_2O eq. is about 1.5%.

(2) NaOH is the most suitable alkali to be added.

(3) The specimen should be pre-cured for 24 hours after casting.

(4) The autoclave treatment should be maintained for four to five hours.

(5) The pressure in the kiln during autoclave treatment is about 0.15 MPa.

ACKNOWLEDGMENTS

This project was made possible by a grant from the Ministry of Education, Japan, and testing was done at the Civil Engineering Laboratory of Tottori University.

The authors express their gratitude to research fellows at the laboratory for their enthusiastic cooperating in the study.

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1) Tang Ming-Shu and et al. 1983. A Rapid Method for Identification of Alkali Reactivity of Aggregate, Cem. Concr. Res.., Vol.13, No3, 417-422.