EXPANSION CHARACTERISTICS OF AAR IN CONCRETE BY AUTOCLAVE METHOD

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ABSTRACT

We selected the autoclave method to accelerate alkali aggregate reactions in concrete, and studied the influences of treatment pressure, treatment time, and alkali content on the alkali aggregate reactions in concrete. As a result, it was found that these factors exhibit a pessimum value at the point of maximum expansion. We determined that when alkali aggregate reactions in concrete are accelerated by the autoclave curing method, an alkali content of a certain or greater level is required.

Through this experiment, we determined that expansion of concrete containing 2.5–3.0% alkali and treated in an autoclave at a 0.2 MPa for 4–8 hours is almost equal to that of concrete at the age of 6 months which has been accelerated at 40°C and a relative humidity of 100%.

Key words: Acceleration testing, alkali aggregate reactions (AAR), autoclave, pessimum value, residual expansion

INTRODUCTION

Alkali aggregate reactions (AAR) take place over a long time and are one source of damage to structural members of concrete which seriously affect the durability and load resistance of concrete structures.

The chemical method, mortar bar method, and concrete method have been established and proposed as methods for AAR. Among them, the concrete method is considered to be effective in judging AAR because it enables used concrete to be examined and the AAR can be judged with greater precision. However, even though the concrete method is an acceleration AAR method, it has the drawback of requiring at least half a year before results can be gathered.

In this study we considered the use of an autoclave to cure concrete at high temperatures and pressures as our testing method for AAR in early stage concrete. Firstly, we wished to understand the expansion characteristics of AAR in concrete in an autoclave. In addition, we studied the residual expansion when concrete was cured under conditions of 40°C and R.H. of 100% following its removal from the autoclave.

OUTLINE OF THE EXPERIMENT

Table 1 shows the material used in this experiment and the test conditions.

The following aggregates were used: non-reactive aggregate, bronzite andesite fine aggregate, and non-reactive fine aggregate for comparison. The bronzite andesite has caused damage in actual concrete structures and its reactivity has been determined using the JCI chemical method, mortar bar method and concrete method. First-class reagent NaOH was used to adjust the alkali content in the cement to an equivalent Na_2O content of 1.0, 1.5, 2.0, 2.5, 3.0, and 4.0%.

The treatment pressures and times used in the autoclave were set at 5 levels in the range from 0.10 to 0.30 MPa and in the range from 1 to 8 hours. The length changes in the specimens immediately after the autoclave treatment were measured. The residual expansion was measured every half month until the age of 3 months following the autoclave treatment while the specimens were stored in a curing tank at 40°C and a R.H. of 100%, and then measured every month after the age of 3 months. In addition, specimens for comparison at each alkali content were cured in a curing tank at 40°C and R. H. of 100% and measured for length change. This measurement was made after the concrete specimens were taken out of the curing tank and moved to a constant temperature room and the specimen temperature had decreased to 20°C.

Table 1 Materials and testing conditions

Cement		Ordinary portland cement (Na_2O eq. 0.33%)
Coarse aggregate		Non-reactive (Sp.Gr.=2.70, W.A.=0.65%, FM=6.64)
Fine aggregate		Reactive (Sp.Gr.=2.64, W.A.=1.48%, FM=2.61) Rc=67.5, Sc=301, Sc/Rc=4.46 Non-reactive (Sp.Gr.=2.66, W.A.=1.15%, FM=2.81)
Type of alkali added		NaOH
Total alkali content (Na_2O eq. %)		1.0, 1.5, 2.0, 2.5, 3.0, 4.0,
Mix proportion		W/C=0.54, s/a=43%
Dimensions of specimen		7.5 x 7.5 x 40.0 (cm)
Autoclave	Pressure (MPa)	0.10, 0.15, 0.20, 0.25, 0.30
	Period (Hour)	1, 2, 4, 6, 8,

TEST RESULTS AND CONSIDERATION

Expansion characteristics immediately after autoclave treatment

Influence of alkali content and treatment time

We studied the influence of alkali content and autoclave treatment time by on the expansion caused by AAR in concrete. We set the treatment pressure of the autoclave at 0.2 MPa.

Figure 1 shows the relationship between expansion and alkali content over time under a treatment pressure of 0.2 MPa. This figure indicates that when the alkali content is 2.5% or less, expansion increases as treatment time increases. However, when the alkali content exceeds 2.5%, the expansion rate of concrete treated for 6 and 8 hours decreases. The greatest expansion occurs when the alkali content is 3.0% and the treatment time is 4 hours.

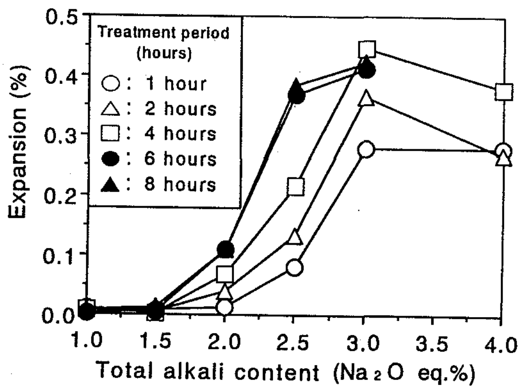

Fig-1 Relationship between expansion immediately after autoclave treatment and alkali content (Treatment pressure: 0.2 MPa)

We considered that a 3.0% alkali content is a pessimum value when the treatment pressure is 0.2 MPa.

The expansion volume due to AAR is controlled by the volume, viscosity, and stiffness of the gel produced by the reactions. The volume of the gel increases as the surface area of the reactive aggregate and alkali content increase. In addition, the viscosity and stiffness of the gel varies with its chemical composition. As the alkali content per reactive aggregate increases, the production volume of the gel increases, accompanying the increase in expansion. However, when there is a large amount of alkali, the reaction rapidly proceeds, but the ratio of SiO_2/Na_2O in the gel produced decreases and the gel softens at an early stage, therefore the expansion pressure decreases [T. Ming-Shu 1983, C. Chatterji 1978]. When the volume of reactive aggregate is equal, the rate of expansion increases as the alkali content increases to a certain value. However, if the alkali content exceeds a certain value, expansion pressure decreases due to softening of the gel, and expansion decreases. It is considered that this value is the pessimum value for alkali content, as shown in Figure 1.

Based on these observations, when the treatment pressure of the autoclave is fixed at 0.2 MPa, the expansion reaches its maximum value at an alkali content of 3.0% and a treatment time of 4 hours.

Influence of treatment pressure

We studied the influence of treatment pressure on AAR in concrete with an alkali content of 3.0%, and a treatment time of 4 hours. Figure 2 shows the relationship between the expansion and treatment pressure for concrete using reactive fine aggregate and for concrete using only non-reactive aggregates at a treatment time of 4 hours. This figure shows that maximum expansion appears when the treatment pressure is 0.2 MPa. Concrete containing only non-reactive aggregate does not exhibit any expansion at any treatment pressure. Therefore, the expansion in concrete containing reactive fine aggregate is considered to be due to AAR.

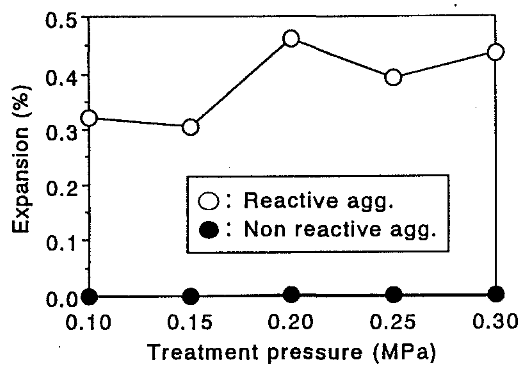

Fig-2 Relationship between expansion immediately after autoclave treatment and treatment pressure (Alkali content: 3.0%, treatment period: 4 hours)

Residual expansion

Expansion characteristics of the control specimen

Figure 3 shows the change in expansion over time for concrete specimens containing various alkali contents without autoclave treatment which were subsequently stored in an accelerating environment at 40°C

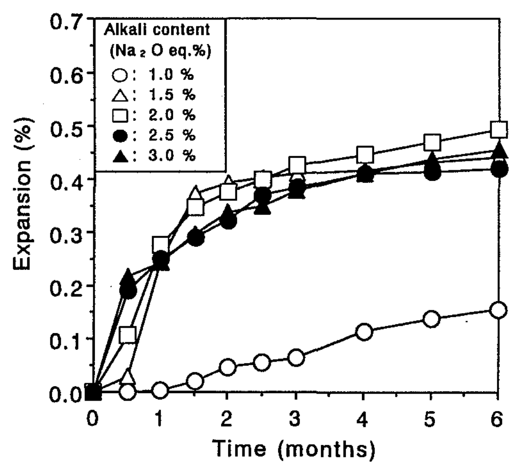

Fig-3 Expansion over time (Control specimen)

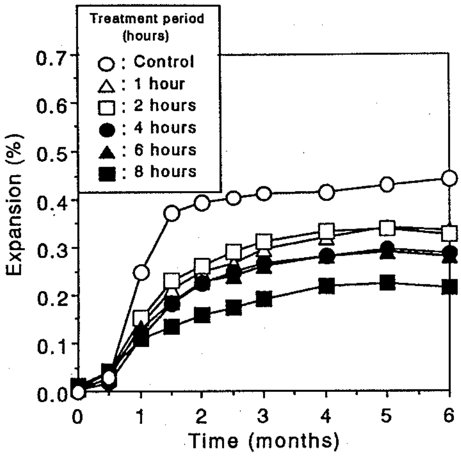

Fig-4 Expansion over time (Alkali content: 1.5%, treatment pressure: 0.2 MPa)

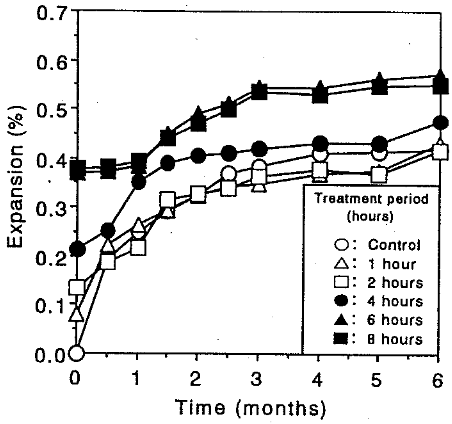

Fig-5 Expansion over time (Alkali content: 2.5%, treatment pressure: 0.2 MPa)

and 100% R.H. The figure illustrates that the specimens with a 1.0% alkali content started expanding at the age of 1 month. After that, the rate of expansion slowly increased to 0.15% at the age of 6 months. The expansion rate of the specimens with a 1.5–3.0% alkali content rapidly increased at an early age, and after that, slowly increased up to the age of 6 months. The specimens with a 2.0% alkali content showed the greatest expansion. As mentioned in *Influence of alkali content and treatment time*, it is considered that when a large amount of alkali exists, the ratio of SiO_2/Na_2O increases, the gel softens, the expansion pressure decreases, therefore, expansion is maximized at an alkali content of 2.0%; that is the pessimum value.

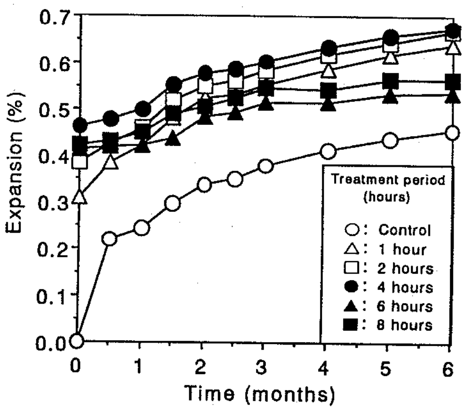

Fig-6 Expansion over time (Alkali content: 3.0%, treatment pressure: 0.2 MPa)

Residual expansion in concrete treated by autoclave curing

Figures 4 to 6 show the change in expansion over time of specimens with 0.5, 2.5, and 3.0% alkali contents respectively at a treatment pressure of 0.2 MPa, non–treatment and treatment time are indicated as parameters.

As for the specimens with a 1.5% alkali content, the expansion of the specimens treated by autoclave curing are smaller than that of the control specimens at any treatment time. In particular, the longer the treatment time, the smaller the expansion. In addition, the residual expansion of the specimens with a 2.5% alkali content treated for a long time exhibited a greater expansion than that of the control specimens. This tendency was more pronounced when the alkali content was 3.0%. All specimens treated by autoclave curing exhibited higher expansion than the control specimens.

That is, when alkali content is low in comparison to reactive aggregate content, the extent of final expansion of the specimens treated by autoclave curing decreases, but when sufficient alkali content is provided, greater expansion occurs than for specimens not treated by autoclave curing.

It is considered that the gel in the specimens treated by autoclave curing has a greater calcium content than that of the specimen not by autoclave curing, that is, a lot of high-calcium-based gel is produced. [S. Nishibayashi 1987, 1988]

When the alkali content is low, the alkali silicate gel produced by alkali aggregate reactions obtains calcium ions from an early age, therefore, the proportion of high-calcium content gel (exhibiting low expansion) increases. We think this is the reason why the expansion decreases after autoclave treatment. On the other hand, when the alkali content is high, alkali aggregate reactions occur rapidly and the gel volume increases at an early age, so expansion after autoclave treatment increases. In addition, as the treatment time is lengthened, more alkali ions are consumed during autoclave treatment and more calcium ions elude, and the rate of increase in the expansion after autoclave treatment declines.

Influence of treatment pressure on residual expansion

Figure 7 indicates that maximum expansion appears at the treatment pressure of 0.2 MPa immediately after autoclave treatment. After that, the expansion of the specimens treated by autoclave curing is greater than that of the control specimens. In addition, the trend of the increase in expansion is roughly the same level, regardless of the treatment pressure.

Expansion development immediately after autoclave treatment

Figures 8, 9, and 10 show the relationship between the ratio of ($\varepsilon_6/\varepsilon_0$) between the expansion rate (ε_6) of the control specim at the age of 6 months (ε_6) and the expansion rate immediately after autoclave treatment (ε_0), and the treatment time, treatment pressure, and additional alkali content.

Based on Figure 8, showing the relationship between ($\varepsilon_6/\varepsilon_0$) ratio and treatment time, it is determined that when the alkali content is 2.5%, 50% of the expansion of a 6-month control specimens developed at a treatment time of 4 hours, and 90%

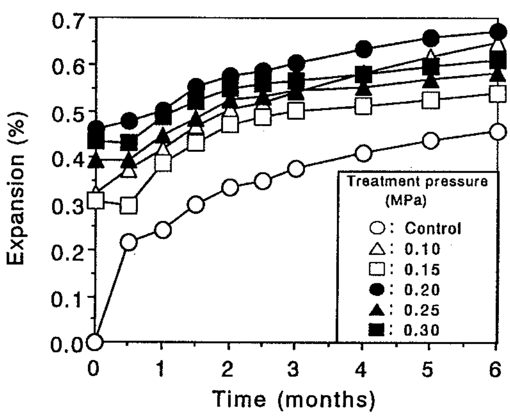

Fig-7 Expansion over time (Alkali content: 2.5%, treatment period: 4 hours)

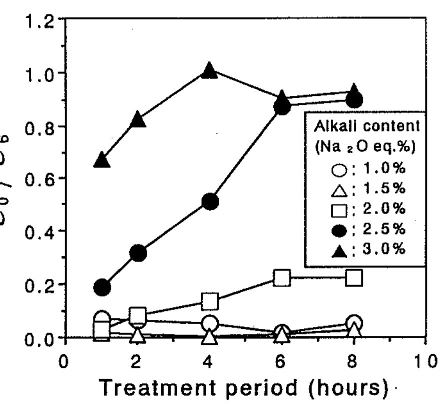

Fig-8 Relationship between ε_0/ ε_6 and treatment period (Treatment pressure: 0.2 MPa)

ε_0 : Expansion immediately after autoclave,

ε_6 : Expansion at 6 months

of the expansion of the same control specimens was developed at 6–8 hours of treatment. In addition, when the alkali content is 3.0%, 70% expansion was developed at a treatment time of 1 hour, and 90% expansion at 2 hours.

Based on the relationship between ($\varepsilon_6/\varepsilon_0$) in Figure 9, it is determined that when the alkali content is 3.0%,
the same expansion as that of the control specimens at the age of 6 months was developed at a treatment pressure of 0.2MPa, and at other treatment pressures, more than 50% of the expansion of the control specimens at the age of 6 months was obtained.

Fig. 10 shows the relationship between alkali content and ($\varepsilon_6/\varepsilon_0$). When the alkali content is 2.5%, the degree of expansion development varies with treatment time; the shorter the treatment time, the less the expansion development (0.5 at 4 hours, 0.9 at 6 and 8 hours). When the alkali content is 3.0%, more than 0.6 times the expansion development was determined at any treatment time. At the treatment time of 4 hours the same expansion development as that of the 6-month old control specimens can be expected.

Based on these results, it was determined that when alkali content is 3.0%, the same expansion as that of the specimens at the age of 6 months by ordinary acceleration testing at 40°C and R.H. of 100% was obtained by autoclave treatment at a pressure of 0.2 MPa and a treatment time of 4 hours.

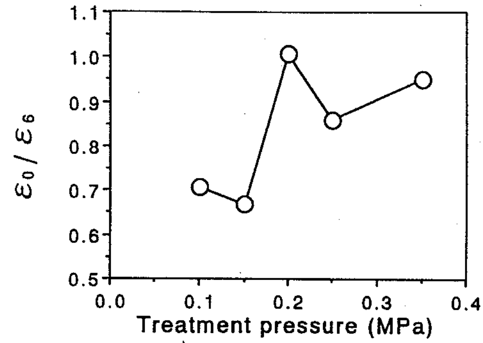

Fig-9 Relationship between ε_0 / ε_6 and treatment pressure (Treatment period: 4 hours, alkali content: 3.0%, time: 6 months)

ε_0 : Expansion immediately after autoclave,

ε_6 : Expansion at 6 months

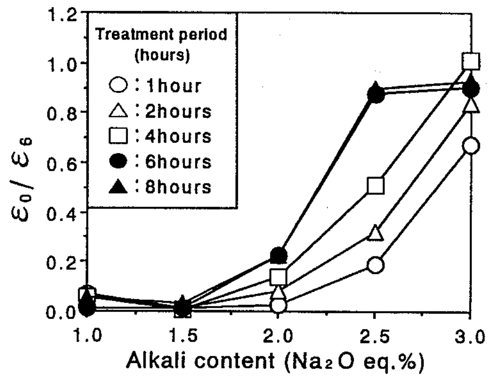

Fig-10 Relationship between ε_0 / ε_6 and alkali content (Treatment pressure : 0.2 MPa)

ε_0 : Expansion immediately after autoclave,

ε_6 : Expansion at 6 months

CONCLUSION

In this study we selected autoclave treatment to accelerate AAR in concrete and studied the characteristics of AAR expansion in concrete under high-temperature / high-pressure conditions and the residual expansion characteristics. The following results were obtained:

1) In order to accelerate AAR by autoclave treatment, we have to consider alkali content, treatment pressure, and treatment time as factors to maximize the expansion of concrete. We determined pessimum values for alkali content, treatment pressure,

and treatment time.

2) When concrete with a lower alkali content is treated by autoclave curing, the rate of expansion immediately after autoclave treatment decreases. The rate of residual expansion decreases compared to concrete not subjected to autoclave treatment. Therefore, when autoclave curing is adopted for acceleration of AAR, the alkali content should be higher than 2.5%.

3) In this experiment, the same expansion as found in specimens at the age of 6 months after accelerated testing at 40°C and a 100% R.H was obtained under an autoclave treatment pressure of 0.2 MPa, a 4-hour treatment time, and a 3.0% alkali content.

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