Study on a Rapid Test Method for Evaluating the Reactivity of Aggregates

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ABSTRACT

In this paper, a rapid test method is proposed based on some experiments on accelerative conditions of the mortar bar test. The rapid test is an accelerated mortar bar test, in which specimens were immersed in NaOH solution under elevated temperature at early age and then cured under high humidity and elevated temperature. The method was found to be effective to accelerate the reaction from the analysis of dissolved silica and pore solution. In order to confirm the relationship between the rapid test and the mortar bar method, some andesite aggregates which authors could obtained in Japan were tested by both the rapid test and the ASTM mortar bar test. The rapid test showed a good corelation with the ASTM mortar bar test.

INTRODUCTION

The deterioration of concrete structures due to alkali silica reaction has been reported in Japan since 1980. It has also become clear that the aggregate used in the concrete of deteriorated structures was an andesite containing cristobalite or volcanic glass. The mortar bar test method is considered to be the most reliable method for evaluating the reactivity of those aggregates at present. The mortar bar method, however, requires a long test period. Therefore, to evaluate the reactivity more rapidly, a new test method which can be conducted in short period is required. In this paper, a new rapid test is proposed, and the effectiveness of the method is discussed.

EXPERIMENTAL

Test program

As reported by Diamond(1), the process of alkali silica reaction is considered to consist of two stages. The first stage is concerned with generation of gel due to the reaction between meta-stable silica in aggregate and alkali in pore solution. At the second stage, the gel expands by absorbing moisture. Therefore, two different acceleration procedures corresponding to above stages are adopted. The first accelerative step is the immersion of specimens in NaOH solution, and the second step is the storage of specimens under elevated temperature and high humidity. Experiments conducted in this

paper consist of three series of tests (Test-A, Test-B, Test-C).

Test-A is conducted in order to evaluate the optimum conditions for the acceleration of expansion. As shown in Table-1, main factors are temperature, immersion period of specimens in NaOH solutions, and NaOH concentration in the solutions. Based on the results of this test, a rapid test is proposed.

Test-B is conducted to investigate chemically the effects of the conditions to accelerate the reaction. Amount of dissolved silica and reduction in alkalinity are analyzed chemically on the same aggregates used for the rapid test. Also, at steps of the rapid test, pore solution is expressed from the hardened mortar and analyzed to determine the concentrations of alkali metal ions.

In Test-C, the reactivity of andesite aggregates under the different conditions as shown in Table-2 is tested by both the rapid test and ASTM mortar bar test to find corelation between these methods.

Table-1 Test program (Test-A,B)

No.	Aggre-gate	Alkali contents Na_2O eq.	Immer-tion time (hr.)	NaOH Concent-ration (N)	Temp. (°C)
1			6	1	80
2	Ande-	1.08%	12	1	80
3	site	in	24	0	80
4	20%	cement	24	0.5	80
5	+	+	24	1	40
6	River	0.62%	24	1	60
7	sand	NaOH	24	1	80
8	80%	(Test-A)	24	2	80
9			48	1	80

Materials and Specimens

Ordinary Portland cements were used and sodium hydroxide was added in mix water to adjust the alkali concentration in mortar. In Test-A, Teshima andesite was used as a reactive aggregate, and Oigawa river sand was used as a non-reactive aggregate. This andesite aggregate contained cristobalite and volcanic glass, and was evaluated as potentially deleterious by the chemical methods. This aggregate was evaluated as deleterious also by the mortar bar method when the alkali content was over 1.1% (Na_2Oeq. in cement). Mix ratio of reactive aggregate to non-reactive aggregate was maintained at 8:2 by weight in Test-A. The aggregates used in Test-C is shown in Table-2. The specimen size was 2.5 by 2.5 by 28.5 cm. Mortar was mixed and placed according to ASTM C227.

Table-2 Test program (Test-C)

No.	Aggregates	Mix ratio of Aggre-gate	Alkali in * Cement (%)	Note
1	River sand-Oigawa	100	1.7	Non-reactive
2	Dasite-Ejima	100	1.7	reactive
3	Sand stone	100	1.5	
4	Andesite-Teshima-a	100	1.5	
5	Andesite-Tottori	100	1.5	
6	Andesite-Hokkaido	100	1.5	
7	Andesite-Teshima-b	100	1.7	
8	No.6+No.1	40:60	1.7	
9	No.6+No.1	20:80	1.7	
10	No.6+No.1	10:90	1.7	
11	No.6	100	1.1	
12	No.6+No.1	40:60	1.1	
13	No.6+No.1	20:80	1.1	
14	No.6+No.1	10:90	1.1	
15	No.6+No.1	20:80	0.8	
16	No.6+No.1	20:80	0.5	
17	No.6+No.1	20:80	1.7	+5% flyash
18	No.6+No.1	20:80	1.6	+10% is
19	No.6+No.1	20:80	1.4	+25%added
21	Andesite + No.1 Techima-c	20:80	1.7	
22	No.21	20:80	1.7	

* The values indicate the sum of the original alkali contents in cement and the added contents of NaOH.
(Na_2Oeq.%)

Test Method

The procedure of Test-A was as follows. As shown in Fig.1, the specimens were demoulded at 24 hours after placing mortar, the initial lengths were measured. Then, the specimens were immersed in NaOH solution at the elevated temperature for the programmed period. Before the first measurement, the specimens were cooled for 24 hours in the container of 20°C and R.H.100%. Secondly, the specimens were sustained for 72 hours in the container of 80° C and R.H.100%. Finally the specimen lengths were
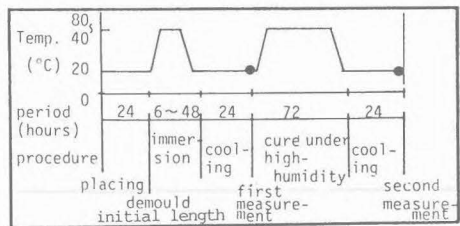

Fig.1. Test procedure of the rapid test

measured again after cooling for 24 hours under 20°C and R.H.100%.

In Test-B, to analyze dissolved silica and the reduction in alkali, the analytical method specified in the chemical method (ASTM C-289) was used. Pore solution of the mortar was expressed by a high pressure vessel, and the concentrations of alkali metal ions in it was determined by flame emission.

The conditions of the rapid test in Test-C were as follows. The alkali concentration of the solutions for the immersion was 1N, the period of immersion was 24 hours, and the temperature was 80°C.

RESULT AND DISCUSSION

Accelerative factors on expansion(Test-A)

Temperature: Fig.2 presents the re-
lationship between expansion and tempe-
rature, where NaOH concentration in the
solution is 1N, the period of immersion
is 24 hours. In the range beyond 40°C,
the expansion increased progressively
along with temperature. Thus, tempera-
ture affected significantly the result.
Oberholster,et.al.(2) also reported that
the expansion was highest at 80°C when
the specimens were immersed in 1N NaOH
solution and stored in ovens at 70°C,80°
C, 90°C, for 12 days. Our experimental
results give a fairly good agreement
with their results.

Fig.2. Effect of temperature in the rapid test

Immersion period: Fig.3 indicates the
effect of the immersion period on the
expansion of the specimens in the rapid
method, where the alkali concentration
is 1N. On the first measurement after
the immersion, the expansion of the
specimens increased after longer immer-
sion. Fig.3 also indicates that the
effect of the immersion period on the
results of the second measurement is
very small compared with those of the
first measurement.

Fig.3. Effect of immersion period in the rapid test

NaOH concentration in the solutions:
Fig.4 shows the expansion plotted
against variation of NaOH concentration
of the solution, where the specimens
were immersed at 80°C for 24 hours. The
specimens show the largest expansion
when NaOH concentration is 0.5 to 1N. It
seems that a pessimum condition of NaOH
concentration exists on the expansions.
Those results coincide fairly well with
those of Oberholster, et al(2).

Fig.4. Effect of NaOH concentration in the rapid test

Proposed test conditions for the rapid test

The results obtained in Test-A clearly show the expansion in the mortar bar test is accelerated by some conditions. Based on these results, a rapid test to evaluate the reactivity of aggregates is proposed from a practical view point. The temperature and the NaOH concentration were selected as 80°C
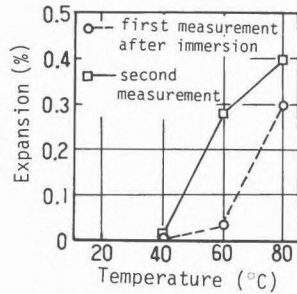
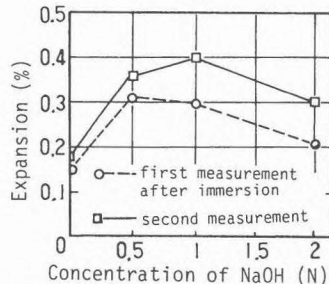and 1N, respectively to get the largest expansion. The immersion period of 24 hours was adopted considering working time and the effect of expansion.

Chemical effects of the accelerative conditions (Test-B)

Fig.5 shows the results in the amount of dissolved silica(Sc) and the ratio of Sc to the reduction of alkali(Rc), (Sc/Rc) plotted against the temperature, Both Sc and Sc/Rc increases with the elevation of temperature. When Fig.5 and Fig.2 are compared, it is seen that there is a fairly good corelation between the amount of dissolved silica and the expansion at the first measurement.

In Fig.6, Sc and Sc/Rc increase with time. The dissolution speed of Sc before 12 hours is greater than that after 12 hours. When the dotted line in Fig.3 and the results in Fig.6 are compared, the inclination of Sc curve is steeper than that of expansion curve particularly at short periods. This means that expansion may occur following dissolution of silica.

In Fig.7, Sc and Sc/Rc are plotted against the variation of NaOH concentration in the solution. In the range of 0 to 2 N of NaOH concentration, the values of Sc and Sc/Rc increase when the NaOH concentration increases. A Comparison of Fig.4 and Fig.7 indicates that the value of Sc and Sc/Rc did not always correspond to the expansions of mortar bars.

Those results clearly show that the accelerative conditions in the rapid test are effective for accelerating the reaction. However, Sc or Sc/Rc have not always a good correlation with the expansion.

Table-3 shows that the results of analyzed alkali concentration in the pore solutions at the different stages of the rapid test. The increase of the alkali concentrations in pore solutions due to the immersion was recognized.
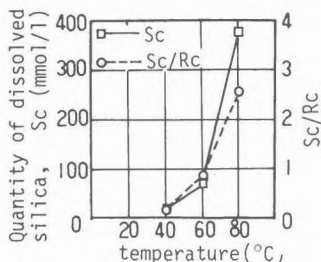

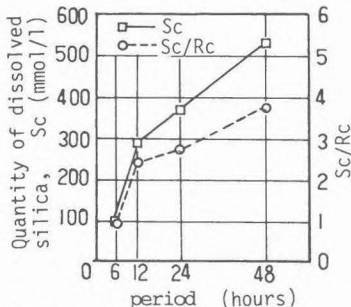Fig.5. Effect of temperature in the chemical method
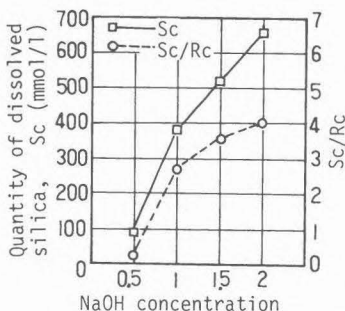

Fig.6. Effect of period in the chemical method

Fig.7 Effect of NaOH concentration in the chemical method

Table-3 Alkali concentrations in pore solutions

condition (age)	Mix ratio of reactive aggregate								
	0%			20%			100%		
	Na^+	K^+	$Na+K^+$	Na^+	K^+	$Na+K^+$	Na^+	K^+	$Na+K^+$
before immersion (1day)	0.42	0.15	0.57	0.53	0.16	0.69	0.37	0.11	0.48
immediately after immersion (2days)	0.88	0.17	1.05	0.63	0.11	0.74	0.58	0.10	0.68

* The alkali content of mortar is 1.7% of the cement weight.
  (1.08% in cement, 0.62% as NaOH, $Na_2Oeq.\%$)

A comparison of the results on reactive and non-reactive aggregate shows that alkali was consumed during the test. The results mean that the immersion helps the reaction between silica and alkali metal ions at early age.

Relationship between the rapid test and the mortar bar test (Test-C)

A comparison between the proposed rapid method and the mortar bar method is shown in Fig. 8 with the effect of mix ratio of reactive aggregate (andesite No 7-No.10 in Table 2). Both the mortar bar and the rapid test methods show the same pessimum condition, which is 20% mix ratio of the reactive aggregate. Fig.9 shows the relationship between the rapid test and the mortar bar test. The results of the rapid test indicate a good linear relationship with those of the mortar bar method.

The regression equation is as follows,
$$y = 1.158x + 0.0518 \quad (\text{unit:}\%)$$
where, x: expansion in the mortar bar method, y: expansion in the rapid test, and the regression coefficient is 0.95. The rapid test tends to give a higher expansion compared with the mortar bar method. In the rapid test, the corresponding value to the critical value (0.10%) of the mortar bar method was calculated at 0.168% from the equation.
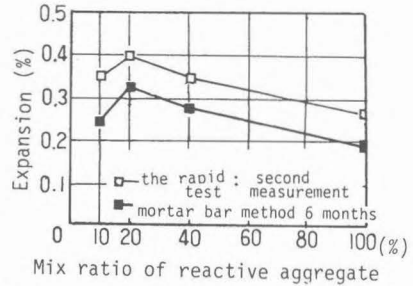

Fig.8
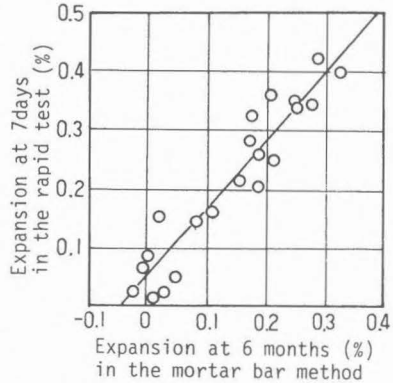Pessimum conditions on the rapid test and on the mortar bar method

Fig.9   Relationship between the rapid test and the mortar bar method

CONCLUSIONS:

Some experiments were conducted on the accelerative conditions for the mortar bar test, and a rapid method was proposed. The following results were obtained.
(1) The test method where specimens are immersed to NaOH solution at early age and then sustained under elevated temperature and high humidity is effective to accelerate the reaction and the expansion of mortar bars.
(2) The proposed test conditions are selected as follows. The temperature is 80°C, the immersion period is 24 hours, and the NaOH concentration is 1N.
(3) The results of the rapid test have a good correlation with those of the mortar bar method. That test could evaluate the reactivity of aggregates at 7 days.

Since these results were based on limited aggregates in Japan, other experiments are now being conducted to confirm whether the rapid test can evaluate the reactivity of various aggregates.

REFERENCE

(1) Diamond,S.,et.al,1981, Proc. 5th Conf. AAR, Cape Town, pp S252/22
(2) Oberholster,R.E.,et.al., 1986, C.C.R.,Vol.16, No.2, pp181-189
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