DEVELOPMENT AND STANDARDIZATION OF A RAPID METHOD FOR IDENTIFICATION OF THE SUSCEPTIBILITY TO AAR IN CONCRETE

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A new rapid method for identification of the susceptibility to alkali-aggregate reaction (AAR) in concrete has been developed and standardized. Sixty-three kinds of air-entraining concrete mixes were examined by both the rapid method and a long-term expansion test in accordance with JASS 5NT-603 in order to determine the limit for evaluation of the susceptibility to AAR in a given concrete mix. By the rapid method, the susceptibility can be identified two days after making three cylindrical specimens of Φ100mm ×200mm. Additional alkali and a boiling procedure shall be applied for accelerating AAR in concrete. In order to evaluate the susceptibility, the relative dynamic modulus of elasticity after the boiling to that before the boiling shall be used.

INTRODUCTION

In order to develop and standardize a new rapid test method for identification of the susceptibility to AAR in concrete, investigations have been carried out in the committee held by National Ready Mixed Concrete Industry Association sponsored by Tokyo Electric Power Company under the guidance of Agency of Industrial Science and Technology in the Ministry of International Trade and Industry from fiscal 1989 to 1991.

For identification of the alkali-reactivity of aggregates, a new standard of rapid test method (JIS A 1804: Methods of test for production control of concrete — Method of rapid test for identification of the alkali reactivity of aggregates) was officially announced on 1st March 1992 according to the investigation carried out in the committee held by National Ready Mixed Concrete Industry Association sponsored by Agency of Industrial Science and Technology from fiscal 1986 to 1988 [1]. For identification of the susceptibility to AAR in concrete, a new method has been developed based on the rapid method for aggregates [2].

Investigations in this project include a laboratory test, a repeatability test and field tests. This paper deals with the laboratory test.

LABORATORY TEST

Materials and Procedures

Based upon the investigation on the rapid method carried out so far [3], sixty-three kinds of air-entraining concrete mixes were selected and examined by both the rapid method and a long-term expansion test in order to determine the threshold value for evaluation of the susceptibility by the rapid test. The long-term expansion test were carried out in accordance with JASS 5NT-603 in which three kinds of concrete prisms whose additional alkali were 1.2 kg/m³, 1.8 kg/m³ and 2.4 kg/m³ ($Na_2Oeq.$) by NaOH to each given freshly mixed concrete were stored at 40 ±2 ℃ by wrapping with wetting papers in polyethylene bags.

Materials used for the tests include cement (ordinary portland cement (high-alkali(H:R_2O=0.92%) & low-alkali(L: R_2O=0.59%) and portland blast-furnace slag cement(BB: R_2O=0.46%)), coarse aggregate (deleterious chert(A) identified by JIS Chemical method, JIS Mortar-bar method and JIS Rapid method, andesite(B) identified deleterious by both JIS Chemical method and JIS Rapid method and innocuous by JIS Mortar-bar method, and innocuous sandstone (C) identified by the three methods), fine aggregate (crushed agg. A, crushed agg. C, and innocuous sea-dredged sand (D) identified by the three methods), AE water-reducing agent and tap water. Test results on alkali-reactivity of aggregates are described in TABLE 1. Andesite B shows a pessimum behaviour as shown in Fig. 1.

TABLE 1 – Test results on alkali-reactivity of aggregates

Desig. of aggregate	Chemical method			Mortar-bar method		Rapid method			
	S_c (mmol/ℓ)	R_c (mmol/ℓ)	Judge-ment	Expansion at 6 months (%)	Judge-ment	Ultrasonic pulse velocity ratio (%)	Relative dynamic modulus of elasticity (%)	Length change (%)	Judge-ment
A	109	50	×	0.250	×	93	82	0.21	×
B	422	188	×	0.054	○	88	67	0.32	×
C	50	60	○	0.042	○	95	86	0.08	○
D	35	49	○	0.039	○	96	87	0.02	○

TABLE 2 – Total alkali content in each concrete mix ($Na_2Oeq.$: kg/m³)

Desig. of Cement	Unit weight of cement		
	300kg/m³	350kg/m³	400kg/m³
H	2.76	3.22	3.68
L	1.77	2.06	2.36
BB	1.38	1.61	1.84

Each concrete mix proportion was designed so that unit weight of water and fine aggregate ratio should be 185 kg/m³ and 45%, respectively. Three levels of unit weight of cement (300, 350, 400 kg/m³) were applied for concrete mix design. Seven kinds of combination of aggregates were selected and three kinds of cement were used. Consequently, sixty-three mixes were determined for the test and each concrete mix was designated as follows (ex. H-A-D-300):

Cement - Coarse aggregate - Fine aggregate - Unit weight of cement
(H, L, BB) (A-D, AC-D, C-AD, B-D, BC-D, C-BD, B-BD) (300, 350, 400 : kg/m³)

Aggregate AC, for example, indicates 50% in weight of each aggregate. Total alkali content in each concrete mix is shown in TABLE 2.

Rapid Method

By this method, the susceptibility to AAR in a given concrete mix can be evaluated two days after making specimens. In order to accelerate AAR in concrete, additional alkali of 9 kg/m³ ($Na_2Oeq.$) shall be added to a given freshly mixed concrete by using NaOH powder. After mixing again, three cylindrical specimens of Φ 100mm ×200mm shall be cast and cured for two days in a moist cabinet at a temperature of (20 ±3)℃, for the second day remove the molds and keep in water at a temperature of (20 ±3)℃. They are then boiled in water at a gauge pressure of 0.049MPa for two hours. In order to evaluate the susceptibility, threshold value 80% of the relative dynamic modulas of elasticity after the boiling to that before the boiling shall be tentatively used.

Test Results and Discussions

Test results are summarized in TABLE 3. Figs. 2 and 3 show the results of the rapid test and the expansion test, respectively. Relationships between the rapid test results and the expansion test results are shown in Fig. 4. TABLE 4 indicates the relationships of judgement between by the rapid test and by the expansion test. Incidentally, according to the long-term expansion test in JASS 5NT-603, the limit of 0.10% of estimated 6 month-expansion values at 3.0 kg/ m³ of additional alkali by extrapolation from both 6 month-expansion values at 1.8 kg/m³ and 2.4 kg/m³ of additional alkali shall be used for the judgement of the susceptibility to AAR in concrete. According to the results, the following facts can be drawn.

1) Several concrete mixes with total alkali content less than 3 kg/ m³ such as H-A-D-300, H-C-BD-300, L-C-BD-350, L-C-BD-400, are evaluated susceptible to AAR not only by the rapid test, but also by the long-term expansion test.
2) According to the facts mentioned below, 80% of the relative modulus of elasticity is appropriate for the limit to evaluate the susceptibility to AAR in concrete by the rapid method.
3) 83% of the relative modulus of elasticity is considered more suitable for the strict limit to prevent AAR in high durability needed concrete structures such as nuclear power stations.
4) Evaluations of the susceptibility to AAR by the rapid test coincide with ones by the expansion test in 43 cases out of 63 cases.
5) Out of 20 cases in which both results don't coincide with each other, in 16 cases

TABLE 3 – Test results according to the rapid test and the expansion test

Concrete mix	Unit weight of cement (kg/m³)	Rapid test: Relative dynamic modulus of elasticity (%) and judgement[1]	Expansion test: Expansion at 6 months (%) and judgement *2 — Additional alkali content: 1.2kg/m³	1.8kg/m³	2.4kg/m³	3.0kg/m³ *3
H-A-D	300	77.9 ×	0.003	0.024	0.078	0.132 ×
	350	82.2	0.020	0.069	0.094	0.119 ×
	400	83.0	0.041	0.099	0.125 ×	0.151 ×
L-A-D	300	83.9	0.004	0.007	0.010	0.013
	350	83.5	0.007	0.012	0.030	0.048
	400	85.2	0.010	0.012	0.037	0.062
BB-A-D	300	84.1	-0.001	0.001	0.003	0.005
	350	85.3	-0.001	-0.003	-0.004	-0.005
	400	84.0	0.000	-0.002	-0.004	-0.006
H-AC-D	300	76.1 ×	0.008	0.010	0.014	0.018
	350	80.9	0.012	0.023	0.054	0.085
	400	80.9	0.024	0.042	0.075	0.108 ×
L-AC-D	300	82.6	0.011	0.014	0.021	0.028
	350	84.5	0.011	0.012	0.015	0.018
	400	84.3	0.013	0.019	0.019	0.019
BB-AC-D	300	85.8	0.006	0.006	0.006	0.006
	350	86.3	0.005	0.005	0.009	0.013
	400	88.9	0.006	0.006	0.006	0.006
H-C-AD	300	84.5	0.007	0.029	0.035	0.041
	350	81.9	0.010	0.069	0.090	0.111 ×
	400	80.1 ×	0.018	0.108 ×	0.155 ×	0.202 ×
L-C-AD	300	85.4	0.012	0.009	0.014	0.019
	350	87.0	0.012	0.013	0.019	0.025
	400	85.8	0.018	0.033	0.049	0.065
BB-C-AD	300	91.1	0.009	0.008	0.009	0.010
	350	92.8	0.009	0.009	0.010	0.011
	400	91.9	0.006	0.007	0.008	0.009
H-B-D	300	81.3	0.002	0.005	0.012	0.019
	350	80.6	0.003	0.014	0.034	0.054
	400	84.2	0.012	0.038	0.057	0.076
L-B-D	300	83.6	0.002	0.002	0.004	0.006
	350	84.5	0.002	0.004	0.005	0.006
	400	85.0	0.002	0.011	0.014	0.015
BB-B-D	300	90.1	-0.003	0.002	0.003	0.004
	350	90.4	0.001	0.001	0.003	0.005
	400	89.1	0.002	0.000	0.001	0.002

TABLE 3 (Cont.) – Test results according to the rapid test and the expansion test

Concrete mix	Unit weight of cement (kg/m³)	Rapid test: Relative dynamic modulus of elasticity (%) and judgement *1	Expansion test: Expansion at 6 months (%) and judgement *2 — Additional alkali content 1.2kg/m³	1.8kg/m³	2.4kg/m³	3.0kg/m³ *3
H-BC-D	300	80.6	-0.005	-0.002	0.029	0.060
	350	80.3 ×	0.007	0.035	0.047	0.059
	400	80.9	0.044	0.076	0.079	0.082
L-BC-D	300	79.2 ×	-0.003	-0.000	0.007	0.014
	350	82.4	-0.000	0.003	0.021	0.039
	400	82.4	-0.002	0.010	0.033	0.056
BB-BC-D	300	87.3	0.002	-0.001	0.002	0.005
	350	88.7	0.000	0.001	0.003	0.005
	400	89.6	-0.003	0.000	0.003	0.006
H-C-BD	300	61.4 ×	0.023	0.096	0.166 ×	0.236 ×
	350	53.6 ×	0.043	0.144 ×	0.232 ×	0.320 ×
	400	54.1 ×	0.123 ×	0.187 ×	0.252 ×	0.317 ×
L-C-BD	300	63.4 ×	0.018	0.016	0.038	0.060
	350	59.9 ×	0.011	0.038	0.069	0.100 ×
	400	56.8 ×	0.020	0.056	0.095	0.134 ×
BB-C-BD	300	64.1 ×	0.018	0.017	0.025	0.033
	350	62.6 ×	0.021	0.025	0.024	0.023
	400	60.0 ×	0.023	0.020	0.041	0.062
H-B-BD	300	65.3 ×	0.019	0.025	0.030	0.035
	350	62.2 ×	0.023	0.040	0.038	0.036
	400	60.8 ×	0.021	0.035	0.057	0.079
L-B-BD	300	72.9 ×	0.023	0.023	0.025	0.027
	350	67.8 ×	0.025	0.025	0.025	0.025
	400	65.0 ×	0.023	0.020	0.050	0.080
BB-B-BD	300	76.4 ×	0.021	0.022	0.020	0.018
	350	73.1 ×	0.021	0.023	0.018	0.013
	400	71.8 ×	0.020	0.018	0.019	0.020

Note) *1 × : 80 % and less of relative dynamic modulus of elasticity
*2 × : 0.1 % and more of expansion
*3 estimated values at 3.0 kg/m³ of additional alkali by extrapolation in accordance with JASS 5NT-603

rapid test results show the safe-side evaluations and in the rest 4 cases show the dangerous-side evaluations.

6) In 13 cases out of the 16 cases showing the safe-side evaluations by the rapid test, fine aggregate combination of BD is used for the concretes. Concrete with this combination shall be considered sensitive to AAR with additional alkali, and the concretes in the expansion test are considered to be late-expansive. Concerning the rest 3 cases, the rapid tests show the values near the limit and are considered
allowable error.

7) In the 4 cases showing the dangerous-side evaluations, the rapid test results show the values near the limit and are considered to depend on the fluctuation of alkali-reactivity of chert aggregates.

TABLE 4 – Relationships of judgement between by the rapid test and the expansion test

Desig. of coarse aggregate	Unit weight of cement (kg/m³)	Desig. of cement																	
		H						L						BB					
		Desig. of fine aggregate																	
		D		AD		BD		D		AD		BD		D		AD		BD	
		J	R	J	R	J	R	J	R	J	R	J	R	J	R	J	R	J	R
A	300	×	×					○	○					○	○				
	350	×	○					○	○					○	○				
	400	×	○					○	○					○	○				
B	300	○	○			○	×	○	○			○	×	○	○			○	×
	350	○	○			○	×	○	○			○	×	○	○			○	×
	400	○	○			○	×	○	○			○	×	○	○			○	×
C	300			○	○	×	×			○	○	○	×			○	○	○	×
	350			×	○	×	×			○	○	×	×			○	○	○	×
	400			×	×	×	×			○	○	×	×			○	○	○	×
AC	300	○	×					○	○					○	○				
	350	○	○					○	○					○	○				
	400	×	○					○	○					○	○				
BC	300	○	○					○	×					○	○				
	350	○	×					○	○					○	○				
	400	○	○					○	○					○	○				

Note) J : Judgement by JASS 5NT-603 , ○ : Durable to AAR
R : Judgement by the Rapid test , × : Susceptible to AAR

CONCLUSIONS

According to the laboratory test, a new rapid test for evaluation of the susceptibility to AAR in a given freshly mixed concrete was tentatively standardized as shown in Fig. 5. After completing both a repeatability test and field tests, a final draft of standard of the rapid method will be established.

REFERENCES

1. Kishitani, K., and Kobayashi, M., 1989, Proc. of 8th Int. Conf. on AAR, 357. 351.
2. Tamura, H., Takahashi, T., and Ohashi, M., 1989, Proc. of 8th Int. Conf. on AAR,
3. Tamura, H., Takahashi, T., and Ohashi, M., 1992, Proc. of Int. Conf. of Advances in Concrete Technology, Athens, Greece.

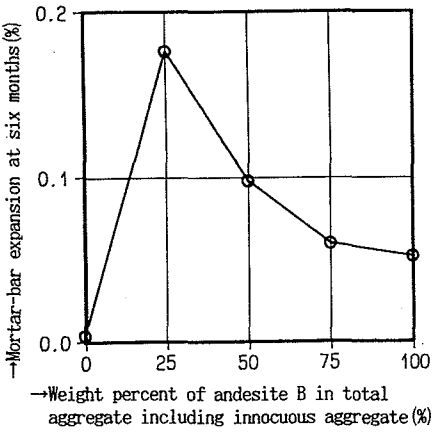


Figure 1 Pessimum behaviour of agg. : B (Relationship between mortar-bar expansion at six months and weight percent of andesite B in total aggregate (innocuous aggregate + andesite B))

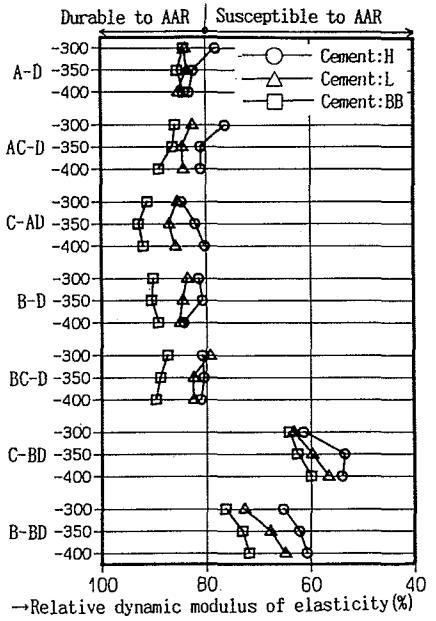


Figure 2 Rapid test results

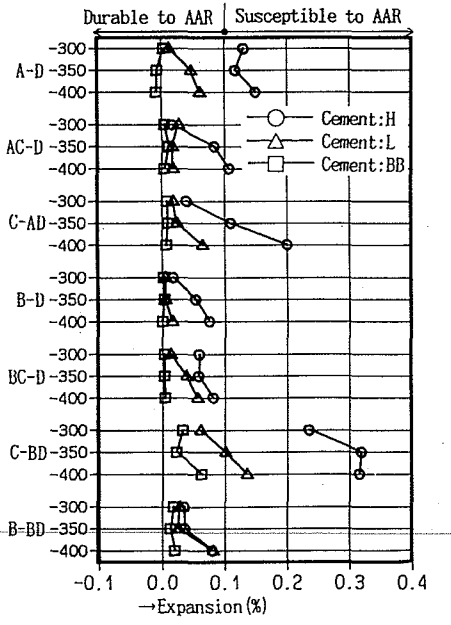


Figure 3 Expansion test results

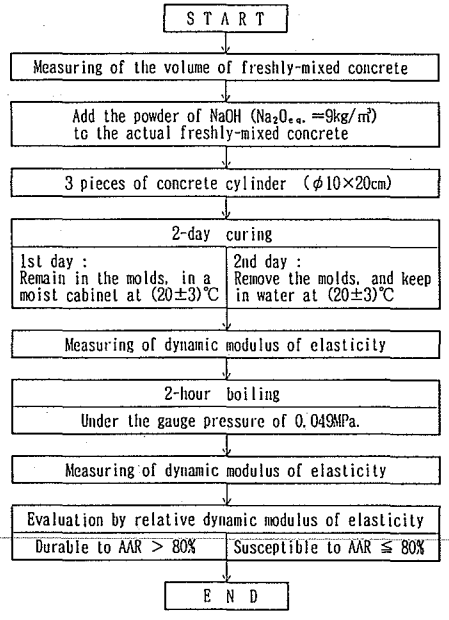
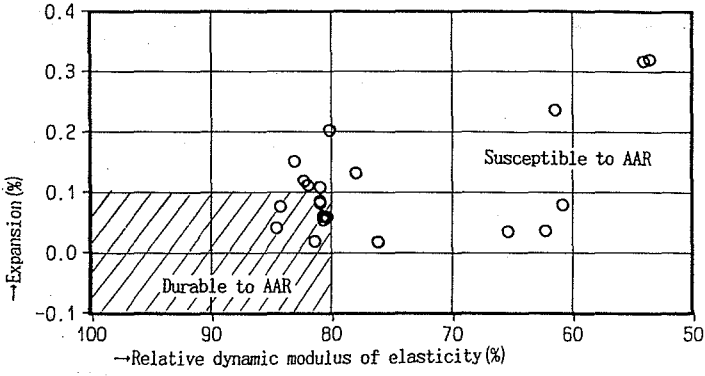
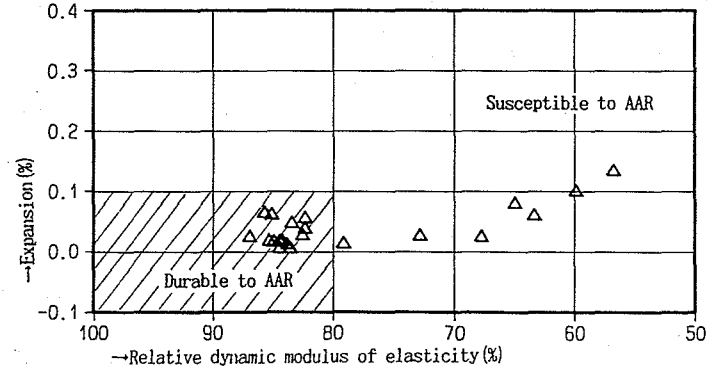


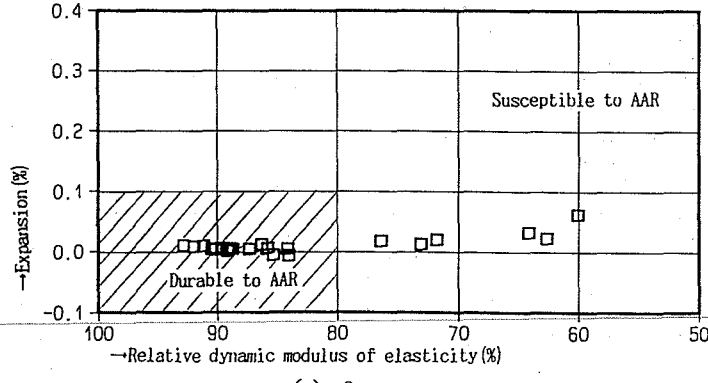
Figure 5 Flow of the rapid test procedure



(a) Cement : H



(b) Cement : L



(c) Cement : BB

Figure 4 Relationships between rapid test results and expansion test results