8th ICAAR 1989 KYOTO
8th Internationl Conference
on Alkali-Aggregate Reaction

SHORT-TERM EVALUATION OF MORTAR BAR TEST BY ACOUSTIC EMISSION

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1. INTRODUCTION

The mortar bar test (ASTM C 227 and JIS A 5308 Appendix 8) is the most widely empoyed for determining the potential alkali reactivity of cement-aggregate combinations. Several effects of measuring parameters on the reactivity are already clarified [1]. Although the method is known as reliable, it takes a period between three and six months to obtain conclusive results. Therefore, there exists the practical need to develop a short-term and reliable method for determining the reactivity of aggregates.

The chemical test (ASTM C 289 and JIS A 5308 Appendix 7) takes only one day to obtain the results, but it is known that some of quartz-bearing rocks may be classified as non-reactive. In this point of view, a short-term mortar bar test is desirable. In one method, mortar bars was autoclaved [2]. Although the compounds generated in the autoclave process were verified as similar to those observed in the standard test at 40°C and R. H. 100%, accelerated factors are not clarified yet and the proposed criterion is still tentative. Others propose a method to store mortar bars in alkali solution at high temperature [3],[4]. In this case, however, the compounds generated in mortar bars may not be identical to those in the standard test. To be consistent with the standard test, the measuring conditions are preferably unchanged.

In the standard procedure of the mortar bar test, measured quantity is the elongation length due to the expansive reaction. The mechanism of the expansion is well known to depend on microcracking due to volumetric change of the compounds. It implies that the crack detection in the curing process could be more sensitive to the reactivity of aggregates than the expansion measurement. It leads to a short-term evaluation of the mortar bar test based on acoustic emission (AE). Since AE phenomena are defined as elastic waves emitted by crack nucleation, no particular procedures to accelerate the reaction process are necessary. Based on this idea, a method to estimate the reactivity in two-week measurement is studied. Results include the rate process analysis of AE activity, the prediction analysis of the expansion, and the evaluation by an expert system.

2. MORTAR BAR TEST

Mortar bar tests were performed in accordance with JIS A 5308-1986, Appendix 8 "Mortar Bar Test". Aggregates were crushed by using a jaw crusher and sieved out. Then, fine aggregates were blended to have a specified grading curve. Normal low-alkali type of Portland cement was employed, of which alkali contents were measured as 0.47 % of equivalent sodium oxide by the JSCE Standard test. Adding 1 N NaOH to water, total alkali contents were ajusted at 1.2 %. Mix proportions of cement, water, and fine aggregate was 1 : 0.5 : 2.25.

A basic study was carried out on two kinds of aggregates. One is the aggregate of pyroxene andesite, which was estimated as potentially deleterious by the chemical test. The other was the aggregate of crushed stone classified as non-deleterious. To investigate the reactivity of aggregates, the standard test was performed. Three mortar bars of dimensions 4 cm x 4 cm x 16 cm were cast and then demoulded after 24 hours. These were cured at 40°C and R. H. 100 % in the controlled furnace. Their lengths were measured by using a vertical dial gauge comparator readable up to 0.001 mm. After the zero reading was taken at 24 hours, lengths were measured at two weeks, four weeks, eight weeks, three months, and six months elapsed. Results of the expansion are shown in Fig. 1. Since the expansion of pyroxene andesite is over 0.05 % at three months, it is classified as reactive. The expansion of crushed stone is less than 0.04 % at six months and non-reactive.

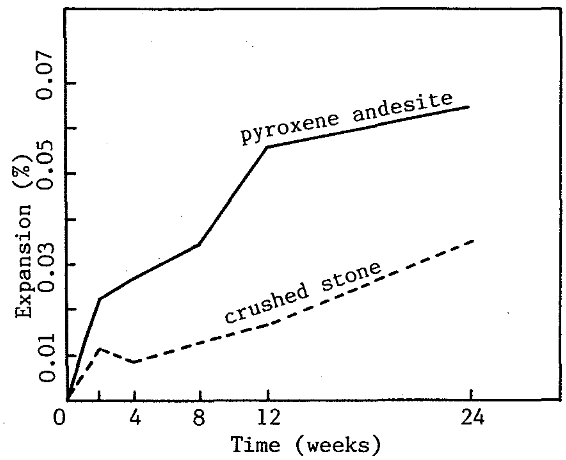

Fig. 1 Results of mortar bar tests for reactive and non-reactive aggregates.

3. ACOUSTIC EMISSION MEASUREMENT

3.1 Rate Process Analysis

AE observation in the mortar bar test was originally planned in two phases. In the first phase, AE activity was investigated during the curing process. Although more AE events were observed in the reactive aggregate than the non-reactive aggregate, a quantitative discrepancy was not found. Not only the reactive aggregate, but also the non-reactive aggregate generates AE in the curing process. It results from the fact that some shrinkage may occur under the condition of 40°C and R. H. 100 %. Because unstable expansions were often observed until one week elapsed, it was considered that two-week observation was at least necessary to quantify the amount of microcracking.

In the second phase, uni-axial compressive tests of mortar bars were carried out at the age of two weeks. During the test, AE event counts were recorded. To qunatify the AE activity under uniaxial compression, the rate process theory was previously introduced [5]. Since microcracks are considered to be generated due to volumetric changes of the compounds and to propagate easily due to loading, AE activity could depend on the amount of the compounds.

According to the rate process, the probability function f(V) of AE occurence from load level V (%) to V+dV (%) is represented,

$$f(V)dV = dN/N. \qquad (1)$$

Here N is total AE event counts up to load level V (%), which is normalized by the failure load. Then, function f(V) is assumed, as follows;

$$f(V) = a/V + b, \qquad (2)$$

where a and b are constants. In Fig. 2, two possible relations between function f(V) and load level V (%) is shown. When the value of "a" is positive, the probability of AE generation is very high in the low load level. In contrast, AE activity is quite low in the low level, when the value of "a" is negative. Since the value of "a" is considered to depend on the number of microcracks, the degree of the reactivity is possibly estimated on the basis of the value "a". From eqs. (1) and (2), a relationship between the number of accumulated AE cunts N up to load level V (%) is obtained, by referring to an integral constant as C,

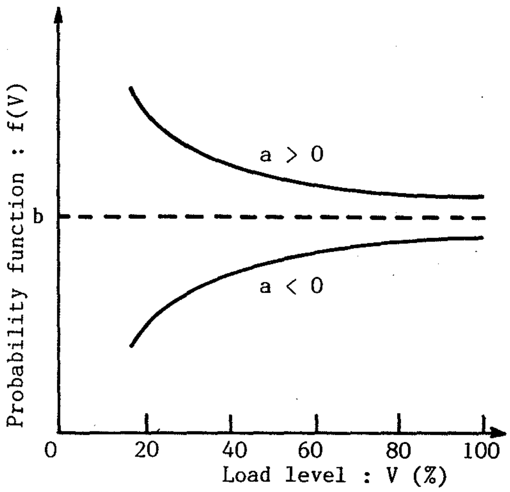

Fig. 2 Relations between probability function f(V) and load level V (%) in the rate process.

$$N = C\ V^{a} \exp\ (\ bV\ ). \qquad (3)$$

3.2 Test Procedure

It is found that losses of engineering properties do not all occur at the same rate or in proportion to the expansion [6]. According to this research, properties mainly affected by the aggregate reaction were flexual strength and dynamic modulus of elasticity, while compressive strength was not a good indicator. Consequently, although a proposed procedure includes the uniaxial compression test, strengths were not taken into account.

AE behavior under compressive loading is analyzed by eq. (3). Mortar bars were cut into three pieces as shown in Fig. 3 right after the two-week strorage in the furnace. Then, loading surfaces were polished into parallel and a uniaxial compressive spesimen of 8 cm length was made. A Teflon sheet of 0.1 mm thick with silicon grese were inserted between a loading plate and a specimen.

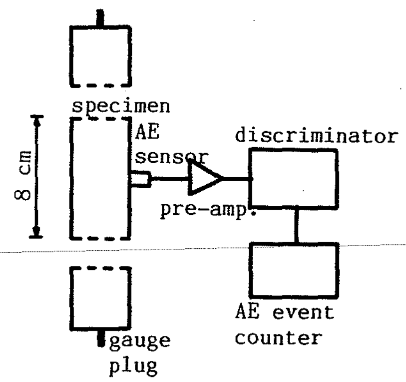

Fig. 3 Uniaxial compressive test of a mortar-bar specimen.

In the uniaxial compressive tests, AE events were detected by AE sensor of 1 MHz resonance, which was attached at the half length of the specimen. The frequency band was selected from 10 kHz to 300 kHz, which corresponds to the the flat response range of the AE sensor employed. Total gain of a pre-amplifier and a discremi-nator was 60 dB. AE events over 120 mV threshhold were selected by the discreminator and counted by a counter. All tests were performed within 2 hours, after mortar bars were taken from the furnace.

4. PREDICTION ANALYSIS

A formula to predict the expansion due to alkali-aggregate reaction was proposed [7], but it was only available for the latter behavior of the expansion. The proposed function was of the root square in respect to elapsed time. Here, a new formula based on the rate process is proposed to predict the six-month expansion. Because the expansion witin two weeks are only measured in the present procedure, the prediction for the six-month expansion is critical for the evaluation of the reactivity.

In eqs. (1) and (2), the number of AE, N, is replaced by the expansion E and the load level V is replaced by time t. To represent an early behavior of the expansion, we add another term which linearly increases in respect to time. Then, we have,

$$dE/E = f(t)dt, \tag{4}$$

$$f(t) = a/t + b + ct. \tag{5}$$

Substituting eq. (5) into eq. (6) and solving the diffrential equation, we obtain,

$$E = D\ t^a \exp(\ bt + ct^2/2), \tag{6}$$

where D is the integral constant. By using data of observed expansions, constants a, b, c, D are determined from the least square method. Comparisons between measured curves and determined curves by eq. (6) were performed and good correlations were confirmed. It was found that the early behavior is associated with the exponential terms, while the final expansion is related with the t^a term.

5. RESULTS AND DISCISSION

Examples of AE activity in the uniaxial compressive tests are shown in Fig. 4. Hatched histgrams show total AE event counts up to each loading level

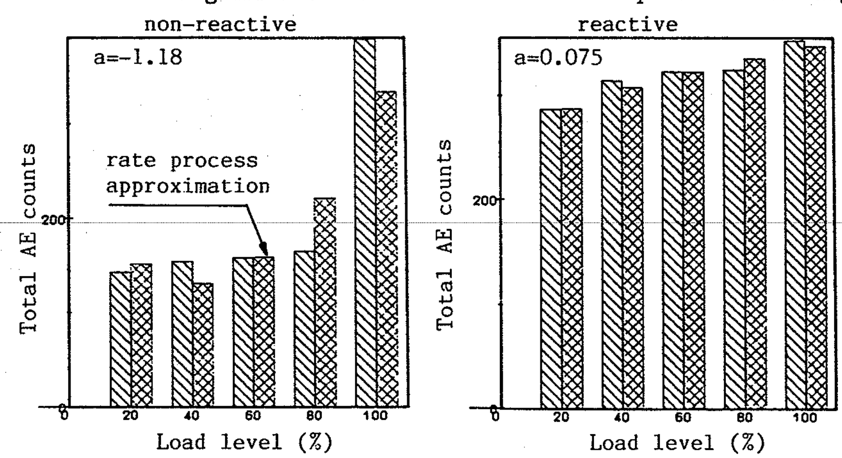

Fig. 4 AE activity in the uniaxial compressive tests of mortar-bar specimens.

of 20 %, 40 %, 60 %, 80 % and 100 %. As can be seen, the mortar bar of the reactive aggregate shows high AE activity in the low load level, while high AE activity is only observed prior to the final failure in the case of the non-reactive aggregate. To quantify this discrepancy of AE activities, total AE event counts are approximated by eq. (3). The constants a, b, C are determined by the least square method. Double-hatched histgrams in the graphes show determined curves by eq. (3). It is clearly observed that the value of "a" is negative for the non-reactive aggregate, while the value of "a" is positive for the reactive aggregate. It confirms the applicability of the rate process analysis to the classification of the reactivity.

During the mortar bar tests of two weeks, the expansions of bars were measured in every the other day. From these data, predicted functions were determined, based on eq. (6). An example of the reactive aggregate is shown in Fig. 5. The predicted function is denoted in the graph. To predict the final expansion, time t in the exponential function was fixed to fourteen days, because it was known to be only dominant in the early behavior. In this figure, since the measurement was started after two weeks in the standard test, the early behavior is a little different from the case of two-week measurement, but the final expansion is estimated in good agreement with six-month expansion.

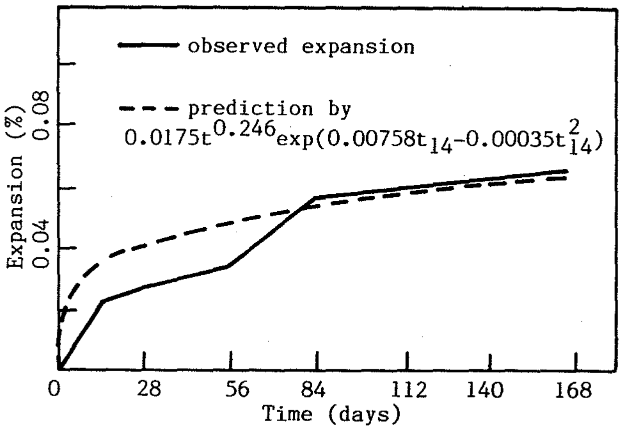

Fig. 5 Expansion of the reactive andesite and a predicted from the two-week measurement.

To confirm the reactivity, all results are compared with the data of the standard test. But, the short-term evaluation of the reactivity has to be applicable to practical cases. The chemical test takes one day and the present method takes two weeks. From these data, the reactivity has to be evaluated. In this viewpoint, a knowlege-based system or an expert system is desirable to interpret the results and predict the reactivity. A commercially available system "Exsys Professional" was introduced to evaluate the results, and an expert system based on the present procedure was developed.

Results of the estimation by the expert system is shown in Table 1. Besides pyroxene andesite and crushed stone, another andesite and chert were examined. Aggregate of andesite was also estimated as potentially deleterious by the chemical test, while that of chert was estimated as deleterious. After two-week measurement, the six-month expansions of all aggregates were determined, based on eq. (6). Results are indicated in the third column. The final expansions by the standard test are shown in the final colum for the comparison. Good correlations between the real expansion and the predicted one are observed. After the uniaxial compressive tests, the values of "a" in eq. (3) were also determined. The average value of three mortar bars are shown in the table. For the cases of reactive aggregates, positive or quite small negative values is obtained. The possibility of alkali-aggregate reaction was estimated by the expert system. Final results are shown in the fifth column. Reasonable estimation is obtained.

Table 1 Prediction by an expert system

	Chemical test	Predicted elongation	Value of "a"	Score for reactivity	Elongation at 6 months
Pyroxene andesite	potentially deleterious	0.060 %	0.030	80 %	0.065
Crushed stone	non-reactive	0.034 %	-0.905	0 %	0.035
Andesite	potentially deleterious	0.277 %	-0.073	80 %	0.261
Chert	deleterious	0.254 %	-0.008	96 %	-

6. CONCLUDING REMARK

A short-term evaluation of the mortar bar test is proposed, based on two-week measurement. The curing conditions keep unchanged and the reactivity is evaluated by the rate process analysis of AE activity in the uniaxial compressive test at two weeks. The final expansion at six weeks is predicted, and all results are incorporated in to an expert system to evaluate the reactivity. Although further basic research is definitely required, a great promise for the short-term evaluation of the mortar bar test is shown.

ACKNOWLEDGEMENT

Materials of all aggregates were offered by Mr. S. Kobayashi in Tyuken Consultant Co. Experiments and anlyses were performed under the collaboration of Mr. T. Baba. The author wishes to thank both of them for their valuable assistance.

REFERENCES

[1] S. Nishibayashi and K. Yamura,"Study on the Evaluation of Alkali Reactivity in Aggregate," Concrete Journal, Vol. 26, No. 6, 77-84, 1988 (in Japnese).

[2] S. Nishibayashi, K. Yamura and K. Nakano," Rapid Test Method of Determining the Alkali-Aggregate Reaction by Autoclave," Concrete Journal, Vol. 26, No. 5, 73-83, 1988 (in Japanese).

[3] R. E. Oberholster and G. Davies,"An Accelerated Method for Testing the Potential Alkali Reactivity of Siliceous Aggregates," Cement and Concrete Research, Vol. 16, 181-189, 1986.

[4] A. Shayan, R. G. Diggins, I. Ivanusec and P. L. Westgate,"Accelerated Testing of Some Australian and Overseas Aggregates for Alkali-Aggregate Reactivity," Cement and Concrete Research, Vol. 18, 843-851, 1988.

[5] M. Ohtsu, T. Sakimoto, Y. Kawai and S. Yuji,"AE Observation of Core Tests for the Deterioration Evaluation in Concrete Structures," Progress in Acoustic Emission IV (Proc. 9th International AE Symposium), JSNDI, 358-365, 1988.

[6] N. Swamy and M. M. Al-Asali,"Engineering Properties of Concrete Affected by Alkali-Silica Reaction," ACI Materials Journal, Sept.-Oct., 367-374, 1988.

[7] T. Uomoto and K. Kawai,"Prediction of Concrete Expansion Caused by Alkali Aggregate Reaction," Proc. JCI Sympo. on Prediction and Design for Service Life of Concrete Structures, 31-38, 1988.