EFFECT OF REACTIVE FINE AGGREGATE ON EXPANSION CHARACTERISTICS OF CONCRETE DUE TO ALKALI AGGREGATE REACTION

Shinzo Nishibayashi* and Kiyoshi Yamura**
* Department of Civil Engineering, Tottori University
** Department of Civil Engineering, Setsunan University

This study was planned to clarify the expansion characteristics of concrete using reactive fine aggregate due to alkali aggregate reaction. The experiments were carried out following parameters such as maximum size of coarse aggregate, the ratio of reactive to nonreactive in each fine and coarse aggregate, alkali content, cement content and size of specimen. The expansion characteristics, crack patterns and dynamic modulus of elasticity were examined by concrete prism specimens.

INTRODUCTION

In order to correctly determine the alkali-silica reactivity of concrete, it is necessary to conduct determination tests on concrete specimens. Many investigations and studies have been made up to the present concerning alkali-aggregate reaction (AAR) using concrete specimens, but almost all contained reactive coarse aggregate only. This tendency seems to be based on the fact that, in Japan, few examples of deterioration due to AAR of concrete structures containing reactive fine aggregate have been reported.[1] However, in the near future, the usage of new types of fine aggregate, such as crushed sand will increase because of the lack of conventional river sand, and as a result, the opportunities for invasion of reactive fine aggregate into concrete will be increased.

From this point of view, this study was planned to clarify the effects of reactive fine aggregate on the expansion characteristics of concrete due to AAR. At the same time, to develop a convenient method for estimating the cracking damage of concrete due to AAR, other expansion tests were carried out using small prism specimens of 4 × 4 × 16 cm made of micro concrete using 10 mm maximum size coarse aggregate.

MATERIALS

Materials

The aggregate used in these experiments were a reactive coarse aggregate (T2, Andisite, Sc=558(m mol/l), Rc=177(m mol/l))

TABLE 1 Test Plan

Aggregate	reactive (T2), non-reactive (NT)
Max. size of agg.(mm)	10, 20
Unit cement content(kg/m^3)	350, 450
Alkali content(eq.Na_2O %)	0.5 - 2.5
Ratio of reactive to non-reactive agg.(%)	0 - 100 (fine and coarse agg.)
Size of specimens(cm)	10 × 10 × 40, 4 × 4 × 16
Storage conditions	40 ℃, R.H. 100%
Items of measurement	expansion(length change),dynamic modulus of elasticity, cracking

TABLE 2 Mix Proportion of Concrete

Max.size (mm)	Slump (cm)	Air (%)	W/C	s/a (%)	Unit weight(kg/m^3)			
					W	C	S	G
10	12 - 15	2	0.53	50	185	350	315*	315*
			0.50	50	225	450	315*	315*
20			0.54	43	190	350	756	1033
			0.45	40	203	450	654	996

* : absolute volume

used in a practical concrete structure and reported to have actually produced cracking damage, a non-reactive coarse aggregate (NT, Sandstone) and crushed sand made from these coarse aggregate as fine aggregate. The cement used was ordinary portland cement with an Na_2O equivalent (R_2O) of 0.47%. First grade reagent NaOH was selected as the alkali compound for adjusting the total alkali content of the concrete, and this was added to the mixing water.

TEST PLAN AND CONCRETE MIX PROPORTION

Test Plan

The principal factors of this experiment were the proportions of reactive aggregate blended (both fine and coarse aggregate), maximum size of coarse aggregate, alkali content, cement content and size of specimen. The range of these factors is summarized in Table 1. The mix proportions of concrete are given in Table 2.

Specimens and measurement

The concrete specimens had dimensions of 10 × 10 × 40 cm and

4 × 4 × 16 cm. Immediately after casting, specimens were placed in a constant-temperature room (at 20 ± 3 °C and 85% relative humidity), and at 24 hours after placement, the molds were released, and initial measurements were determined. The specimens were then placed in a tank at 40 °C and 100% RH. The items of measurement were length change,dynamic modulus of elasticity (E_D) and cracking characteristics. Measurement were made at the ages of 14 days, 28 days and subsequently, every month.

RESULTS AND DISCUSSION

Expansion Characteristics

Some examples of the expansion over time of the concrete specimens are shown in Fig.1. Numbers of each line in this figure represent following conditions.

Alkali cont. - Reactive agg. cont. - Reactive agg. cont.
(%) (coarse agg. (%)) (fine agg. (%))

From this figure, it is clear that the expansion of concrete containing only reactive fine aggregate grows largely in the early period. It becomes constant at a rather early stage, until six months of storage. On the other hand, the expansion of concrete containing only reactive coarse aggregate grows slowly, but contines for a long period, for more than one year. In specimens containing both reactive coarse and fine aggregate, the expansion is rather small and becomes constant in the early stage. For concrete with a maximum size of 10mm (micro concrete), the tendency for growing expansion is almost the same as that with a maximum size of 20mm (normal concrete), except that the value of expansion of micro concrete is slightly smaller than that of normal concrete for the same alkali content. The expansion of concrete for small specimen of 4 × 4 × 16 cm is considerably small and becomes constant in the early stage of storage.

Fig.2 shows the relationship between the expansion of concrete and the ratio of reactive to non-reactive aggregate. When no reactive fine aggregate is included, the expansion becomes larger with increases in the reactive coarse aggregate. For concrete containing only reactive fine aggregate, the expansion of concrete becomes extremely small as the reactive coarse aggregate content increases. This suggests that with 100% of reactive fine and coarse aggregate, the reactive surface area of the aggregate is extremely large and the alkali in the concrete is rapidly consumed through reaction, resulting mainly in a high calcium alkali silica gel, which doesn't cause large expansion. Fig.3 shows the relation between the expansion of concrete and the ratio of reactive to non-reactive aggregate in both fine and coarse aggregate. From this figure, it is clear that the expansion of concrete containing reactive fine aggregate is relatively large but that it varies widely with the proportion of reactive aggregate. In this experiment, the pessimum values of reactive fine aggregate were 75 - 100% when no reactive coarse aggregate was included, and it shifted to 50% for a reactive coarse aggregate content of 50%. For concrete with 100% reactive coarse aggregate, the expansion was rather small and clear pessimum value of the reactive fine aggregate content could not be found.

The relationship between the expansion of concrete and the alkali content of concrete is shown in Fig.4. The expansion of concrete with 100% reactive fine aggregate becomes larger with the increases in the alkali content of concrete whether including reactive coarse aggregate or not. As for the rate of increasing expansion with the increase in alkali content, concrete with no reactive coarse aggregate showed large values in the range of relatively low alkali content and slightly small values in the range of high alkali content. On the other hand, concrete with a reactive coarse aggregate content of 100% showed a constant value in the range of alkali content of more than 1.0%. As a result, the expansion of concrete with a reactive fine aggregate content of 100% and no reactive coarse aggregate showed double that containing a reactive coarse aggregate content of 100% for a alakli content of 1.5%, but for an alkali content of 2.5%, the expansion of the former one was less than that of the latter one.

Dynamic modulus of elasticity

Some examples of the change in the dynamic modulus of elasticity over time are shown in Fig.1. From this figure, it is clear that basically the dynamic modulus of elasticity is decreasing during the period that the expansion is growing. The change in the dynamic modulus of elasticity is expressed as the result of reciprocal action of the progress of hydration of cement paste and deterioration of concrete due to AAR. There is a case in which the dynamic modulus of elasticity becomes large in spite of the slight increase of expansion in the early period of storage. Fig.5 shows the relationship between the dynamic modulus of elasticity and the expansion of concrete. There exists a negative correlation between these parameters.

Cracking Chracteristics

The traverse method was adopted for the evaluation of cracking.[2)] The relation of the expansion of concrete with the number of cracks and the average crack width are shown in Figs.6 and 7. These figures show a strong positive correlation between the expansion of concrete and the number of cracks and the average crack width. At the same time, there appears a tendency that the number of cracks in concrete containing no reactive coarse aggregate is larger than that containing reactive coarse aggregate for the same expansion level. For the average crack width, there exists a reverse tendency. These are especially clear in the range of low expansion. This means that many but thin cracks develop in the concrete with reactive aggregate only for the fine aggregate in the early period of storage.

Usage of small test specimens made of micro concrete

Generally, the evaluation of AAR using concrete requires relatively large size specimens, which requires large equipment. It would be very convenient if specimens for mortar testing (4 × 4 × 16 cm) could be used. The maximum size of aggregate would have to be restricted to 10 mm for 4 × 4 × 16 cm specimens. Here, the usage of 4 × 4 × 16 cm specimens of concrete with a maximum size aggregate of 10 mm was examined. From Fig.1, it is clear that the expansion of concrete in 4 × 4 × 16 cm specimens made of micro concrete is considerably small, and develope in an earlier period of storage than 10 × 10 × 40 cm specimens made of normal concrete. The general tendency for each condition is similar to that obtained from normal specimens, and a large amount of expansion can be expected by high alkali addition. Fig.8 shows the relationship between the expansion of concrete obtained from 4 × 4 × 16 cm specimens made of micro concrete and 10 × 10 × 40 cm specimen made of normal concrete. There exists a close relation between both expansions, especially in the range of expansion of normal specimens of 0.1 - 0.2%. This means that the development of expansion of concrete of more than 0.1% , can be judged by the results obtained from 4 × 4 × 16 cm specimens made of micro concrete. In this experiment, 4 × 4 × 16 cm specimens made of micro concrete were successfully used to determine the alkali-aggregate reactivity of concrete.

CONCLUDING REMARKS

In this study, the effects of reactive fine aggregate on the expansion characteristics of concrete due to alkali aggregate reaction were investigated experimentally. The conclusions of the present study are summarized as follows:

(1) The expansion of concrete containing only reactive fine aggregate grows large especially in the early period of storage, and becomes constant at a rather early stage.

(2) The expansion of concrete containing reactive fine aggregate is relatively large but it varies widely with the proportion of reactive aggregate.

(3) Many but thin cracks develop in concrete containing only fine reactive aggregate due to alkali aggtregate reaction.

(4) 4 × 4 × 16 cm specimens made of micro concrete can be used to determine the alkali-aggregate reactivity of concrete.

REFERENCES

1. Ono, K.,"Damages of Concrete Structures in Japan due to Alkali Aggregate Reaction", pp.50-56, Concrete Journal, Vol.24,No.11, 1986.

2. Nishibayashi,S. et al.,"Evaluation of Cracking of Concrete due to Alkali-Aggregate Reaction",8th International Conference on Alkali-Aggregate Reaction, Kyoto, pp.759-764.

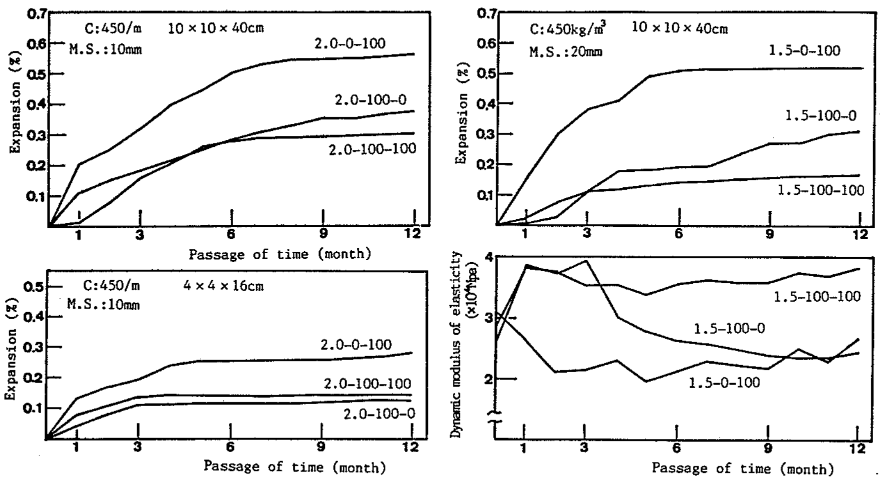

Fig.1 Change of expansion and dynamic modulus of elasticity with passage of time

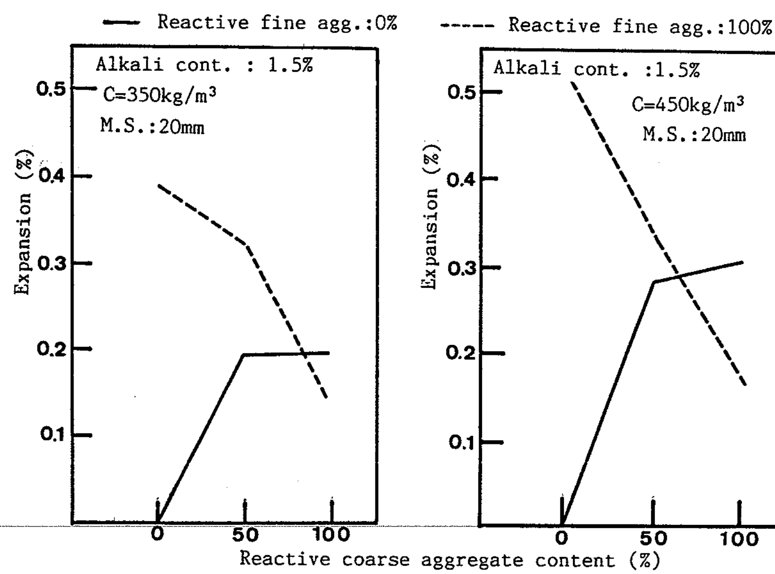

Fig.2 Relationship between the expansion of concrete and the ratio of reactive to

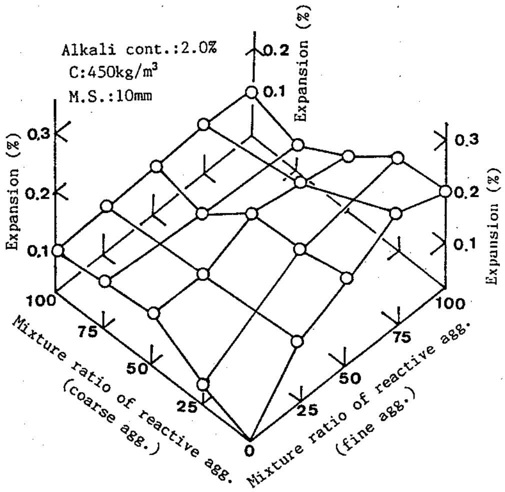

Fig.3 Relationships between expansion and mixture of reactive aggregate

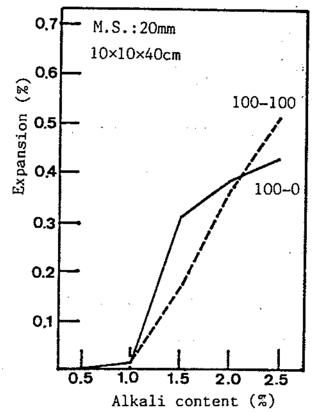

Fig.4 Relationship between expansion and alkali content

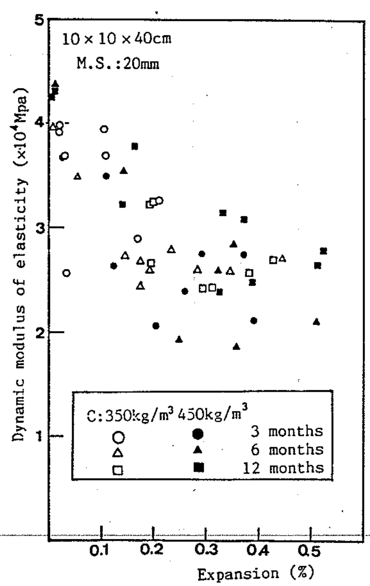

Fig.5 Relationship between dynamic modulus of elasticity and expansion

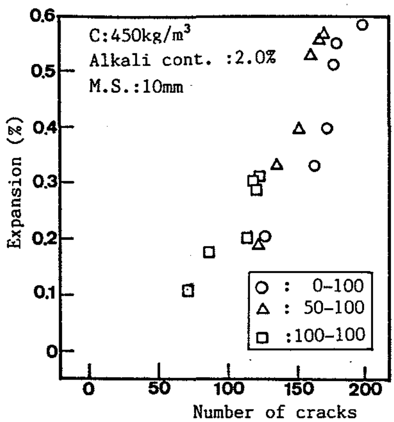

Fig.6 Relationship between expansion and number of cracks

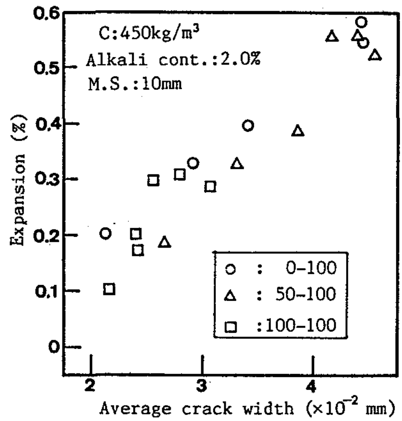

Fig.7 Relationships between expansion and average crack width

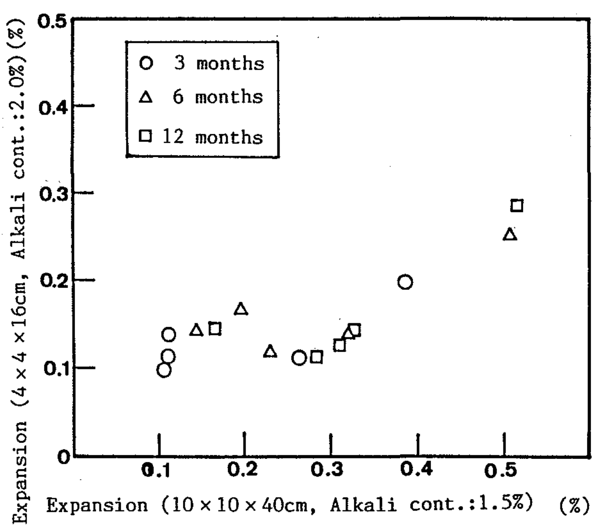

Fig.8 Relationship between expansion of normal specimens and 4×4×16cm specimens