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

RESEARCH ON INFLUENCE OF CYCLIC WETTING AND DRYING ON ALKALI-AGGREGATE REACTION

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Abstract

The study was planned to clarify and evaluate the behavior of concrete specimens using reactive aggregate when the specimens were exposed under an environment of drying and wetting, and to extend it to the development of an rapid testing method applying this knowlegde.

1. Introduction

The damage to a concrete structure from alkali-aggregate reaction caused by the expansion of the substance produced by the reaction, but a fairly long period of time is required until the expansion actually appears, while moreover, whether or not cracking damage of concrete will result even when expansion occurs will be influenced by various factors such as the strength of the concrete structure and the environment in which the structure is placed.

Cracking damage of concrete structure due to alkali-aggregate reaction is seen frequently at parts subjected to repetitions of wetting and drying, parts subjected to sunshine for long hours, and parts of drainage ditches and massive hydraulic structures such as dams where moisture is amply supplied, and in addition, where moisture is easily evaporated and alkali is concentrated.

The study reported here was planned as a part of a research project to discern the influence of environmental conditions on cracking damage of concrete produced by alkali-aggregate reaction. Thereupon, what kind of behavior is shown by concrete specimens using reactive aggregate when the specimens are put in an environment of cyclic wetting and drying was studied, and the degree of damage was evaluated.

2. Outline of Experiments

2.1 Materials

The aggregate used in these experiments were a reactive aggregate (Tl, Andisite, Sc=558(m mol/l), Rc=177(m mol/l)) used in a concrete structure and reported to have actually produced cracking damage, a non-reactive aggregate (NT, Sandstone), and a blended sand of non-reactive sand from a mouth of a river and dune sand as fine aggregate. The maximum size of the coarse aggregates was 20 mm in both case. The cement used was ordinary portland cement with alkali content 0.41 percent in terms of Na_2O equivalent. First grade reagent NaOH was selected as the alkali compound for adjusting total alkali of the concrete, and this was added to mixing water and used.

2.2 Testing Plan

The objective of these tests was to grasp the progress and degree of deterioration of concrete by measuring variation in physical properties in case

(2) Method of Testing

The mix proportions of concrete are given in Table 1.

Table 1 Mix proportion of concrete

Max. size (mm)	Slump (cm)	Air (%)	W/C	s/a (%)	Unit weight (kg/m³)			
					W	C	S	G*
20	12~15	2	0.54	43	190	350	756	0.388
20	12~15	2	0.45	40	203	450	660	0.380
20	12~15	2	0.39	37	212	550	569	0.374

* m^3/(concrete 1 m^3)

The designs were for unit cement contents of 350, 450, and 550 kg/m^3, with unit water contents selected by trial mixing to obtain slumps of 12 to 15 cm. These slumps were for cases when blending ratio of reactive coarse aggregate was 100 percent with no addition of excessive alkali, and adjustments for variations in slump due to changes in blending ratio of reactive aggregate or excessive addition of alkali were not made.

The blending ratios reactive aggregates were of the five levels of 0, 25, 50, 75, and 100 percent, while total alkali contents (Na_2O equivalent) were also of five levels; 0.5, 1.0, 1.5, 2.0, and 100 percent.

Specimens were of the three kinds of 10 x 10 x 40 cm, and for compressive strength tests, 10 x 20 cm.

Immediately after casting, specimens were hauled into a constant-temperature room (20°C, RH 100 percent), and on demolding at 24 hours, initial measurements were made of length and dynamic modulus of elasticity. Following measurements of initial values, the specimens were stored in their respective storage tanks and removed to the constant temperature room one day before making measurements.

The storage conditions were of the seven levels of 40°C and RH 100 percent (40°C), 20°C and RH 100 percent(20°C), 20°C and 1/2 in water (1/2 W), 20°C in sea water (1/2 S), 20°C and 1/2 sea water (1/2S), and outdoor exposure (E).

The items of measurements were length change, dynamic modulus of elasticity(E_D), compressive strength (28-day age), and cracking characteristics, the measurements being made at the ages of 14 days, 28 days, and subsequently, every month.

(3) Evaluation of Cracking

The traverse method was adopted as the method of evaluating cracking. This method consists of drawing a mesh of regular spacing on a specimen and making an evaluation by the number and widths of cracks intersecting the mesh. The procedure and indices of this method are described below.

[Procedure]

A reference line is drawn on the specimen with a pencil as shown in Fig. 1, and the number of cracks intersecting this reference line and the widths of the cracks are read by a crack scale and these are entered on recording paper according to longitudinal and transverse directions. This is done for the top surface, side surfaces 1 and 2, and the bottom surface.

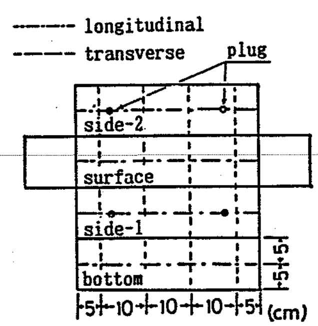

Fig. 1 Base lines for measurement of crack

[Indices]

Number of Cracks

Crack Width (mm)

Maximum Crack Width (mm)

Average Crack Width (mm)

$$= \frac{\text{(Crack Width x Number of Cracks)}}{\text{Total Number of Cracks}}$$

Average Crack Spacing

$$= \frac{\text{Length of Reference Line}}{\text{Number of Cracks}}$$

3. Expansion characteristics of Concrete Specimens

Tests varying blending ratio of reactive aggregates, quantity of alkali addition, and storage conditions in many ways to grasp the expansion characteristics of concrete using the three varieties of reactive aggregate (O, Tl, T2) due to alkali-aggregate reaction were performed.

(1) Time-dependent Change in Percentage Expansion (ε) and E_D (Fig. 2)

From Fig. 2, it can be seen that the behavior of variations in ε and E_D differ according to variety of reactive aggregate.

(2) Influence of Alkali Content

An example of the relation between total alkali content and time-dependent changes in ε, and ε at the various ages are shown in Figs. 3 and 4. From Figs. 3 and 4, expansion due to alkali-aggregate reaction increases abruptly when alkali content exceeds a certain limit value and within the scope of the experiments reported, it is considered that the limit value exists in a renge of total alkali content of 2.75 to 4.50 kg/m^3.

(3) Influence of Storage Conditions

As an example of the relation between storage conditions and amount of expansion is shown in Fig. 5. Expansion behavior differs remarkably according to the curing conditions, and it may be seen that the dependence of alkali-aggrigate reaction on environmental conditions in extremely.

4. Cracking Characteristics

An example of cracking produced due to alkali-aggregate reaction is shown in Fig. 6. The results of examination of these cracks by the traverse method are as followed:

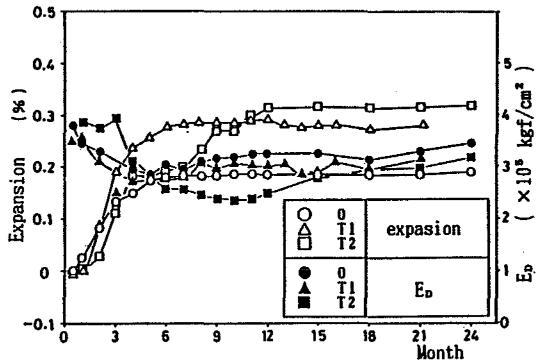

Fig. 2 Change of expansion and E_D with passage of time

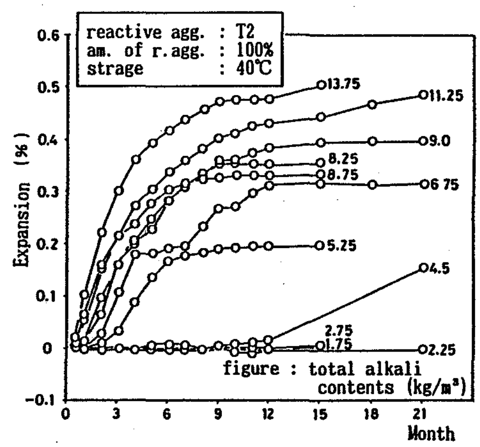

Fig. 3 The expansion of concrete specimen with various total alkali contents

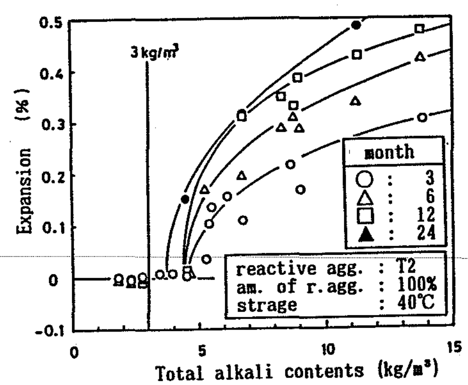

Fig. 4 Relationship between the expansion and total alkali content in concrete

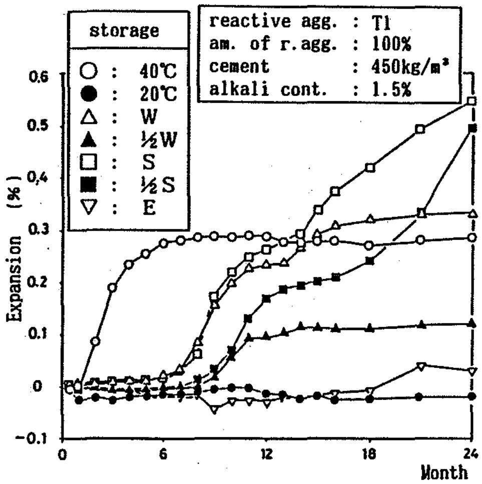

Fig. 5 Expansion in various storage condition

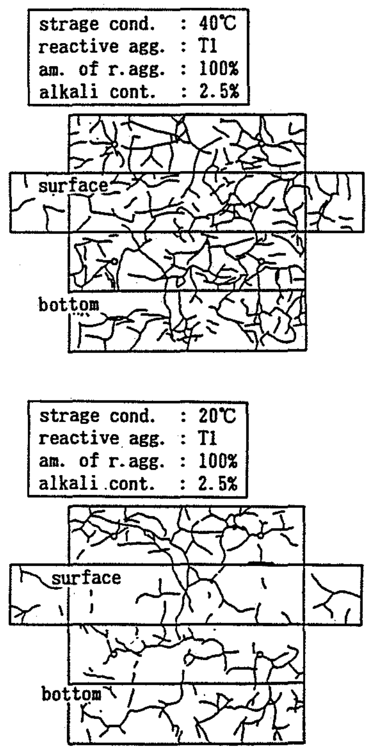

Fig. 6 Patterns of crack

(1) Many of the cracks were formed parallel to the longitudinal directions of the specimens and crack widths were similarly large, but with advanced age the widths of cracks formed perpendicular to the longitudinal direction became larger. The number of cracks and crack widths at the top surface were larger than at other surfaces. This is thought to have been due to the bleeding that occurred after placement.

(2) Cracking characteristics differed depending on the variety of the reactive aggregate and the blending ratio.

(3) Cracking characteristics differed depending on the storage conditions, and especially, with specimens stored under conditions of 1/2 fresh-water immersion and 1/2 sea-water immersion, the features were that cracks were more numerous in the parts immersed in water, and the cracks were formed along the boundary lines between the parts in air and in water.

(4) Many of the concrete specimens showed cracking at ε between 0.04 and 0.06 percent, and crack width increased rather than number of cracks with increase in ε. With specimens subjected to fresh-water immersion and sea-water immersion, secondary reaction products adhered to the surfaces and it was difficult to confirm the number of cracks and crack widths.

Next, the cracking characteristics were examined for specimens subjected to 40°C storage and outdoor exposure.

The various indicators such as ε, E_D, and cracking characteristics were considered. The relation of ε with number of cracks and average crack spacing are shown in Figs. 7 and 8, and the relations of $R.E_D$ with maximum crack width in Fig. 9.

These figures show a strong positive correlation between ε and number of cracks, and that there was a trend for the number of cracks to increase with increase in ε. And it can be seen that in inverse proportion to average crack spacing, crack spacing became smaller as expansion rate increased. Next, with

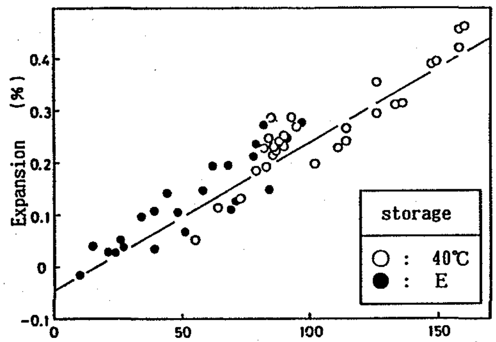

Fig. 7 Relationship between the expansion and numbers of crack

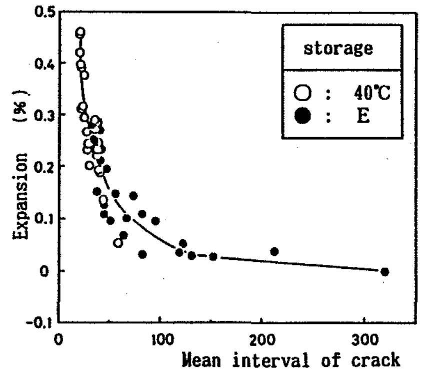

Fig. 8 Relationship between the expansion and mean interval of crack

regard to the correlation between E_D and number of cracks, regression lines were sought separately and studied since the trends differed slightly for 40°C curing and outdoor exposure. According to this study, decrease in E_D with increase in number of cracks was greater for outdoor exposure. As a whole, whereas specimens cured at 40°C had large numbers of cracks with small widths, cracks with large width were formed in outdoor exposure specimens, and it is thought decrease in E_D became prominent because of this.

From the relation between R.E_D and maximum crack width (Fig. 9), it can be recognized that in case alkali content was high, large cracks were formed even though decrease in R.E_D was small, while on the other hand, when alkali content was low, decrease in R.E_D and increase in crack width progressed simultaneously.

As for the relations of average crack width with ε and E_D, distinct correlations were not recognized.

Next, the product of average crack width and number of cracks, namely, the total crack width was considered. McGowan & Vivian showed that there is a strong correlation between crack width and ε in case of mortar, and drew the conclusion that expansion of mortar is essentially brought about by enlargement of crack width[2]. According to the relation between percentage and total crack width obtained in these tests (Fig. 10), it is shown that total crack width increases if ε is increased and there is a strong positive correlation, and this satisfies the theory of McGowan & Vivian. Further, a study was made of the relation between total crack width

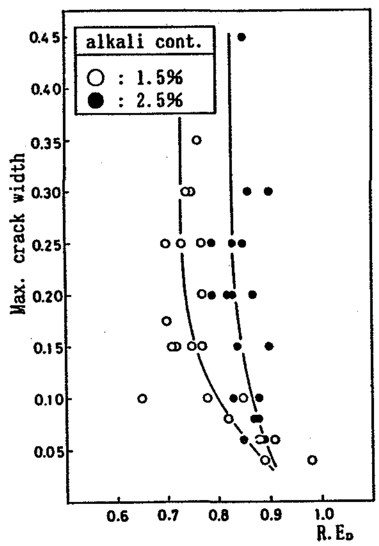

Fig. 9 Relationship between maximum crack width and R.E_D

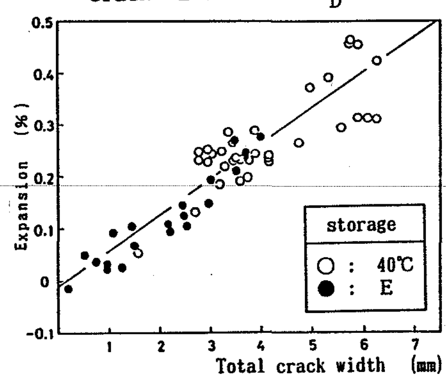

Fig.10 Relationship between the expansion and total crack width

and amount of expansion with regard to the cracking which occurred between measuring points.

Fig. 11 indicates amount of expansion (mm) on the ordinate, and total crack width (mm) between measuring points on the abscissa. This shows that almost all of the plotted points are above the straight line for amount of expansion : total crack width = 1:1, and it can be seen that amount of expansion is larger than total crack width. And judging by the regression line, the total crack width becomes a fairly small value at approximately 50 percent of the amount of expansion. It has been reported that according to the experiments of Diamond & Thaulow, the total sum of crack widths was far smaller than the expansion measured[3], and the results of these experiments support this theory.

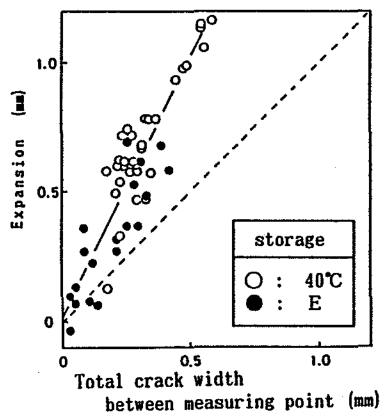

Fig.11 Relationship between the expansion and total crack width between measuring point

Consequently, when amount of expansion is increased, the total crack width becomes large, and there is a fairly strong correlation between the two, but the total sum of crack widths does not directly amount to quantity of expansion.

5. Conclusion

Various studies were made by concrete specimens on the expansion characteristics and cracking characteristics of concretes using three varieties aggregates. The results obtained in these experiments are cited below in the way of a conclusion.

(1) Expansion increases suddenly when alkali content exceeds a certain limit value, that is, the total alkali content of about 3 kg/m^3.

(2) Expansion behavior differs according to the storage conditions, that is alkali-aggregate reaction is extremely dependent upon environmental conditions.

(3) When the quantity of expansion increases, total crack width becomes larger, and a fairly high correlation can be recognized between these two, but the total sum of crack width does not directly amount to the quantity of expansion.

References

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