LONG-TERM ASR EXPANSION BEHAVIOR OF CONCRETE CUBES IN OUTDOOR EXPOSURE CONDITIONS

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ABSTRACT

Influences of sea water on the degree of damages in concrete structures affected by the alkali-silica reaction is one of concerns of many workers. In this study, the expansion behavior of a number of reactive aggregate-bearing concrete cubes with various alkali contents under a saline environment have been monitored for about 7 years along with the measurements of their expansions of concrete cubes placed in another environment without any supply of sea water. Effects of delicate differences in environments (micro climate) on the expansion of concretes cubes due to the alkali-silica reaction were also investigated in the exposure experiments. Expansions of concrete cubes coated with a polymer material were pursued to clarify the significance of water originally contained within concretes in the expansion of concretes due to the alkali-silica reaction and effects of coatings on the long-term expansion of the affected concretes. It was found that the concretes cubes started rapidly expanding around 5 years after the initiation of exposure. Expansions of concrete cubes were found to be highly sensitive to delicate local differences in environments even over such small concrete cubes. Coatings were effective in inhibiting expansion of concretes with relatively small amounts of alkalis, while not in concretes with a relatively large amounts of alkalis. In concretes with high alkali contents, coatings only delayed the initiation of active expansion in the concrete cubes.
Keywords: alkali-silica reaction, acrylic rubber, concrete cubes, exposure tests, natural environments, sea water

INTRODUCTION

Various informations obtained from exposure tests for concretes containing reactive aggregate in natural environments and careful observations of ASR affected concrete structures are useful in the repair and maintenance of the structures. Many workers (Lenzner et al. 1979), (Coombes 1976), (Flaganan 1981), (Semmelink 1981) showed that such environmental factors as the duration of sunshine, exposure conditions to rainfall and differences in local temperatures in a large concrete structure were more important than the alkali content in concrete. However, they have not explicitly showed the significance of such environmental factors in ASR deterioration in concrete.

The authors have presented the expansion behavior and the characteristics of cracking of andesitic reactive aggregate-containing concrete cubes with various unit alkali contents ranging from 2.9 kg/m^3 to 6.8 kg/m^3 under two different environments (Kawamura et al. 1992). The exposure tests in the natural environments have been continued thereafter.

In this paper, the differences between long-term expansions measured on two different faces in the concrete cubes and the effects of coatings and sea water on the expansion behavior are discussed.

EXPERIMENTAL

Materials

The cement used was ordinary Portland cement with an equivalent Na_2O percentage of 0.97. Its chemical compositions are given in Table 1. An andesitic crushed stone from Noto Peninsula in Ishikawa Prefecture was used as a reactive coarse aggregate. The main reactive components in this pyroxene andesitic rock were glass and cristobalite. The non-reactive coarse aggregate used was from the Hayatsuki river in Toyama Prefecture. The Hayatsuki river sand used as a fine aggregate was not reactive. The alkali reactivity of the andesitic aggregate evaluated according to ASTM C-289 and its chemical composition are presented in Table 2 and 3, respectively. Mix proportions of concrete are shown in Table 4. The alkali content in concretes ranged from 2.91 kg/m^3 to 6.79 kg/m^3 corresponding to the unit cement content from 300 kg/m^3 to 700 kg/m^3 in concretes. The ratio of the reactive coarse aggregate to the non-reactive one by mass was one.

Table 1 Chemical compositions of clinker (%)

Ig. loss	Insol.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	TiO_2	P_2O_5	MnO
0.5	0.1	21.2	5.0	3.1	64.9	1.5	1.9	0.51	0.70	0.30	0.09	0.06

Table 2 Alkali-reactivity of andesitic aggregate evaluated according to ASTM C-289

Soluble silica (mmol/l)	Reduction in alkalinity (mmol/l)
609	223

Table 3 Chemical compositions of andesitic aggregate (%)

Ig. loss	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	Cl
1.7	60.3	17.3	5.6	6.4	4.3	3.82	0.89	0.00

Table 4 Mix proportions of concrete

Type of concrete	W/C (%)	s/a (%)	Water (kg/m^3)	Cement (kg/m^3)	River sand (kg/m^3)	Reactive coarse aggregate (kg/m^3)	Non-reactive coarse aggregate (kg/m^3)
C300	50	40	150	300	778	601	601
C400	50	40	200	400	693	535	535
C500	50	40	250	500	607	469	469
C600	50	40	300	600	522	404	404
C700	50	40	350	700	437	338	338

Procedures

Concrete specimens for the outdoor exposure tests were 220 mm cubes. As shown in Fig. 1, in a series of concrete specimens, all the faces except the face of casting of concrete were coated with a highly elastic acrylic rubber type material after the initial curing in a moist environment (about 85% R.H.) at 20 °C for 28 days. The thickness of overall coatings on concrete cubes was about 1 mm. In the other series of concrete specimens, all the faces of concrete cubes were coated. After coating, gauge plugs were stuck on the face of casting and one of the four sides with a separation of 150 mm to measure length changes on the faces of concrete cubes by the contact-type strain gauge, as shown in Fig. 1. Measurements of length changes on a side of concrete cubes were made in the direction of casting of concrete.

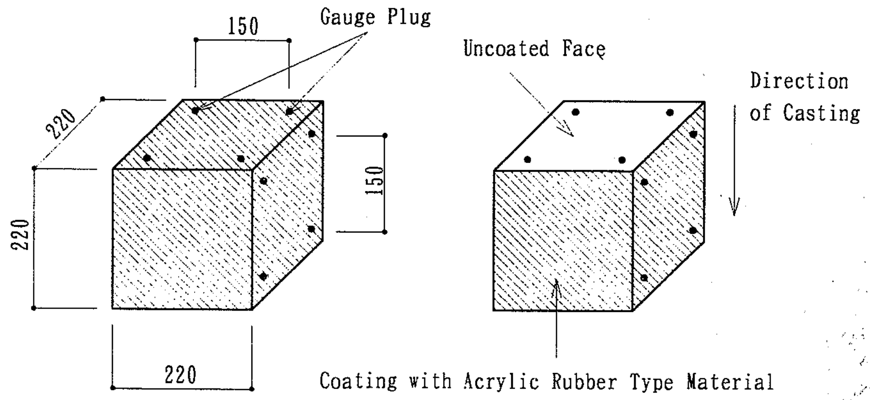

Fig. 1 Schematic diagrams of concrete specimens exposed to natural environments.

In order to investigate influences of sea water spray on the expansion of concrete cubes, these concrete cubes were placed in the two different locations, i.e. on the seashore facing the Sea of Japan near Kanazawa and on the roof of a building in Kanazawa University campus which is far from the sea. All of the concrete cubes were set so that the face of casting of concrete was top. The bottom of the cubes has kept direct contact with the concrete roof and the sea sand bed. Length changes of specimens were measured approximately every two months. The expansion behavior of concrete cubes has been monitored for about 7 years.

RESULTS AND DISCUSSION

Expansion behavior of concrete cubes on the roof

Expansions measured on the exposed uncoated face of concrete cubes placed on the roof of a building are plotted against time, as shown in Fig. 2. Concretes with a unit cement content of 600 and 700 kg/m^3 stared expanding around 240 days after the initiation of exposure. Expansion progressed rapidly in summer and slowly in winter. Expansion curves for concretes with a unit cement content of 500, 600 and 700 kg/m^3 leveled off after about 900 days exposure; for the concrete with a unit cement content of 400 after about 1100 days exposure. Fig. 3 shows expansion curves obtained by measurements of length changes on a side of cubes. It is found from these two figures (Figs. 2 and 3) that expansions measured on the top face of the cubes earlier started and earlier terminated than those measured on a side of the cubes. The early initiation and the rapid increase of expansions measured on the exposed top faces show that the percolation of water through cracks on the uncoated faces caused by drying-wetting repetitions accelerated the expansion due to the alkali-silica reaction in portions near the surfaces. Length changes measured on a side of the concrete cubes stand for average expansions along the direction of casting of concrete (Fig. 1), because expansion was supposed to vary with the distance from the uncoated top surface. Thus, slow increases over long periods in expansion curves obtained by measurements of length changes on a side of the cubes indicate that the limited supply of water to portions away from the top face, particularly around the bottom in the concrete cubes, delayed expansion. The differences between the expansion behavior on the top face and on the side in the same concrete cubes, suggest that, in ASR affected concrete structures, different portions of concrete behave differently with the depth from surface.

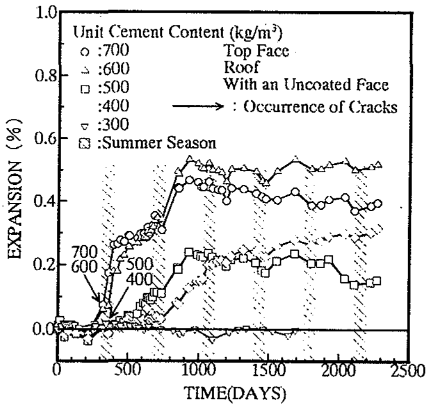

Fig. 2 Expansion curves obtained by measurements of length changes on the top face of concrete cubes with an uncoated face placed on the roof.

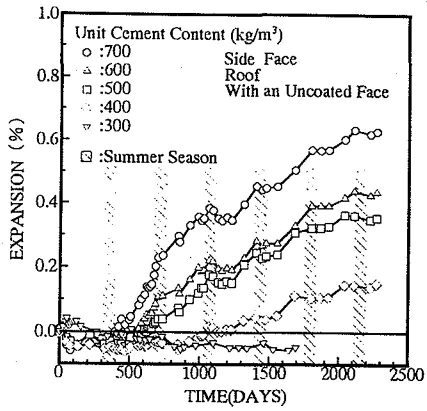

Fig. 3 Expansion curves obtained by measurements of length changes on a side face of concrete cubes with an uncoated face placed on the roof.

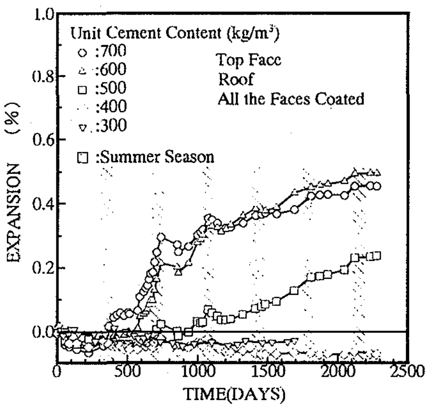

Fig. 4 Expansion curves obtained by measurements of length changes on the top face of concrete cubes coated overall the faces placed on the roof.

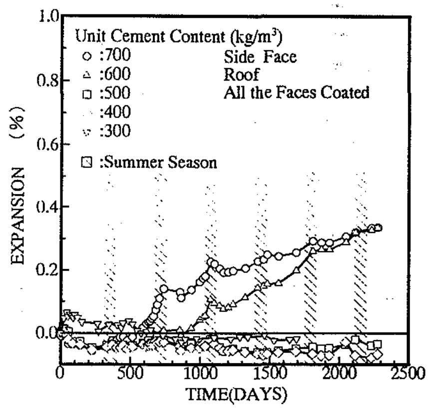

Fig. 5 Expansion curves obtained by measurements of length changes on a side face of concrete cubes coated overall the faces placed on the roof.

Expansion curves obtained by length measurements made on the top faces and the side faces in concrete cubes coated over all the faces placed on the roof are given in Figs. 4 and 5, respectively. As shown in Fig. 4, expansions measured on the top face of concrete cubes with a unit cement content of 700 kg/m^3, 600 kg/m^3 and 500 kg/m^3 coated on all over the faces commenced around 350 days, 570 days and 1000 days after exposure. On the other hand, as shown in Fig. 5, the commencement of expansion on the side was considerably delayed as compared with measurements on the top face in the same specimen. At first, expansions measured on the top face and a side in concrete cubes were expected to be similar to each other. These great differences in expansion behavior may be caused by differences in average surface temperatures between the top face and the side throughout year. Namely, higher surface temperatures on the top face due to stronger sunshine for longer periods on average must have accelerated the alkali-silica reaction in portions near the top face. This result is an evidence for a hypothesis that, within a relatively large ASR affected concrete structure, expansion progresses differently from part to part.

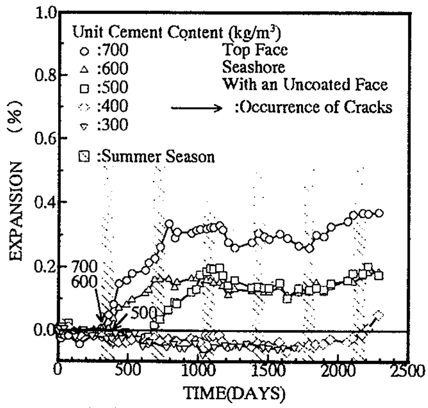

Fig. 6 Expansion curves obtained by measurements of length changes on the top face of concrete cubes with an uncoated face placed on the seashore.

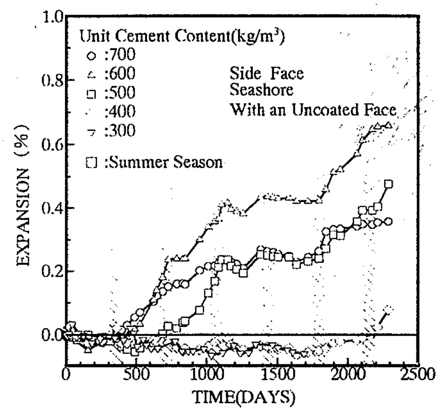

Fig. 7 Expansion curves obtained by measurements of length changes on a side face of concrete cubes with an uncoated face placed on the seashore.

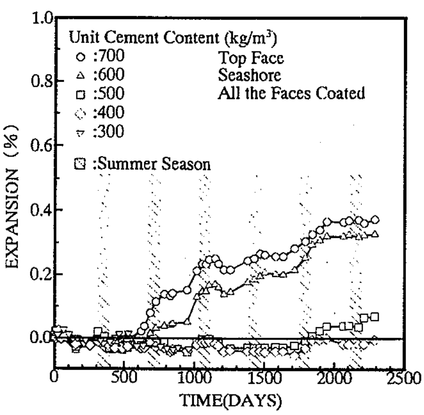

Fig. 8 Expansion curves obtained by measurements of length changes on the top face of concrete cubes coated overall the faces placed on the seashore.

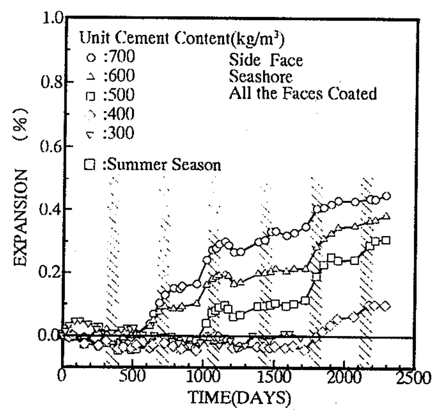

Fig. 9 Expansion curves obtained by measurements of length changes on a side face of concrete cubes coated overall the faces placed on the seashore.

Expansion behavior of concrete cubes on the seashore

Figs. 6 and 7 show expansion curves obtained by measurements of length changes on the uncoated top face and a side of concrete cubes placed on the seashore, respectively. The characteristics of expansion behavior in concrete cubes on the seashore are similar to those in concrete cubes on the roof (Figs. 2 and 3). However, it is found from Figs. 2, 3, 6 and 7 that, as a whole, expansions of concrete cubes on the seashore were smaller than on the roof. Furthermore, the fact that expansions on a side of cubes resumed around 1700 days after exposure, deserves attention.

Expansions measured on the top face and a side face of concrete cubes coated over all the faces placed on the seashore are plotted in Figs. 8 and 9. Comparison between these results obtained on the seashore and the roof (Fig. 4) shows that expansions measured on the top face in concrete cubes on the seashore were smaller than in concrete cubes on the roof. However, in measurements on a side face of concrete cubes, concretes with a unit cement content of 700 kg/m^3, 600 kg/m^3 and 500 kg/m^3 on the seashore showed considerably greater expansions than those on the roof. The resumption of expansion in these concrete cubes around 1700 days after exposure is clearly shown in Fig. 9. Especially, even the concrete with a unit cement content of 400 kg/m^3 started expanding around 1700 days.

Effects of environments on expansion

Comparison in expansion between concrete cubes with an uncoated face placed on the seashore and the roof (Figs. 2, 6, 4 and 8) shows that expansions measured on the top face of concrete cubes on the roof were considerably greater than on the seashore. It is found from temperatures measured on the surface of concrete cubes (Table 5) that such greater expansions found in concrete cubes on the roof were due to the higher temperatures on the surfaces of specimens.

Table 5 Average temperatures on the surface of concrete cubes placed on the roof and the seashore (1992)

		January	August
Roof	Atmospheric temperature	8 °C	35 °C
	Surface temperature	9 °C	42 °C
Seashore	Atmospheric temperature	8 °C	33 °C
	Surface temperature	9 °C	37 °C

As to the expansion on a side of concrete cubes, expansions of concretes on the roof were not so different from those on the seashore except that concrete cubes coated over all the faces on the seashore showed greater expansion than on the roof (Figs. 3, 7, 5 and 9). This phenomenon was supposed to reflect some changes of environmental conditions and damages of coatings on the concrete cubes. Detailed investigations on the state of test specimens and environmental conditions of the exposure experiment site were carried out around 1700 days after the initiation of exposure. During the first several years, concrete cubes were at the waterside and underwent occasionally sea water spray. However, around 1700 days after the initiation of exposure, the situation of the seashore has changed so much, and parts near the bottom in individual concrete cubes were embedded in the sea sand bed imbibing sea water. In the investigations, some parts of coatings in concrete cubes were found to have peeled off. Judging from the results obtained on the investigations, sea water must have intruded into the lower parts of concrete cubes. It may be estimated that the acceleration of the alkali-silica reaction due to the supply of sea water to some parts of concrete cubes led to increases in expansions measured at a side of concrete cubes.

Effects of coatings on expansion due to the alkali-silica reaction

Comparison in expansion between the concrete cubes coated over all the faces and the ones with an uncoated face give us informations on the effects of coatings on the expansion behavior of ASR affected concretes. As described previously, while the rapid expansion in concrete cubes with an uncoated face early commenced and early terminated, the late commencement of expansion in concrete cubes coated over all the faces was followed by a steady increase with time resulting in almost the same expansions as those in concrete cubes with an uncoated face about 6 years after exposure. This result indicates that coatings can delay the commencement of expansion, but that eventually can not reduce the expansion of concrete. It is also evidenced by this result that ASR reacting concretes can expand without the supply of water from surroundings.

CONCLUSIONS

(1) Expansions measured on an uncoated top face of concrete cubes placed on the roof earlier started and earlier terminated than those measured on a side of the concrete cubes. However, expansions measured on a side of the concrete cubes steadily increased with time over long periods.
(2) The commencement of expansion on a side of concrete cubes coated over all the faces placed on the roof was considerably delayed as compared with the expansions measured on the top face in the same specimen.
(3)Expansions measured on a side of concrete cubes placed on the seashore were considerably greater than those on the roof. These differences in expansions of the concrete cubes between the two different environments may be due to the intrusion of sea water through damaged parts of the coatings on the concrete cubes.
(4) Coatings can delay the commencement of expansion, but can not reduce the eventual expansion of concrete.

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