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THE MECHANICAL BEHAVIOUR OF BEAMS COATED AFTER ALKALI SILICA REACTION DAMAGE

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1. INTRODUCTION

The alkali silica reaction (ASR) commonly causes such damage to concrete as cracking, strength deterioration and reduced elastic modulus. In the case of reinforced concrete, longitudinal cracking is often visible, due to the restrictive effect in the member. However, it has been reported that the ultimate flexural strength of beams damaged by ASR is no different from that of normal reinforced concrete, since a chemical prestressing effect occurs in the member as a result of concrete expansion[1]. Since this expansion due to ASR continues over the years and the properties of the concrete are continuously changing, any loss of chemical prestressing effect due to creep or decreased elastic modulus of the concrete may affect the mechanical behaviour of the member. On the other hand, various methods of coating have been tested with the aim of reducing expansion of concrete affected by ASR. the mechanical behaviour of members is influenced by this coating is not fully understood. This work focused on the mechanical behaviour of beams damaged by ASR, and investigated the effects of coating as a method of treatment.

2. EXPERIMENTAL

2.1. Test programme

Two sets of loading tests on the beams were carried out. The first took place 17 months after manufacture, and one control beam without reactive aggregate and two damaged beams were loaded (NR1,R1,R2). The second loading test was carried out at 45 months. One control beam of non-reactive concrete (NR2), two reactive concrete beams (R3, R4) and two coated beams of reactive concrete (CR1, CR2) were tested. One purpose of the later test was to assess the effects of the coating on the damaged beams.

2.2. Materials and Specimens

2.2.1. Materials Limestone was used as a non-reactive coarse aggregate for the control beam specimens. In the reactive concrete, crushed phroxene andesite formed the coarse aggregate, while non-reactive fine aggregate was used in both the reactive and non-reactive concrete. The ordinary portland cement used in the experiments had an alkali content of 0.84%.

2.2.2. Mix Proportion Table-1 shows the mix proportions. The alkali content per unit volume of concrete was 2.8 kg/m^3(Na_2O equivalent) in the mix with non-reactive aggregate. In concrete using the reactive aggregate, the total alkali content was controlled to 9.2 kg/m^3 by adding an excess of NaOH. It was reported that the reactive aggregate used has a pessimum condition of mixing ratio, and that a mix ratio of 30 - 50% with non-reactive aggregate causes the maximum expansion[2]. Therefore, additional alkali was necessary to achieve the greater expansion when using 100% reactive coarse aggregate.

Table 1. Mix proportion

Max. size of coarse aggregate (mm)	Slump (cm)	Air content (%)	W/C (%)	Weight (kg/m^2)			
				Cement	Fine aggregate	Coarse aggregate	NaOH
20	12	4	60.1	333	697	1041	8.31

Total alkali content :Na_2O eq. 9.24kg/m^3

2.2.3. Beam specimen
The specimen beam is a double-reinforced rectangular beam as shown in Figure 1. The beams were made as close in size to those in actual structures as possible, i.e. 25x50x400 cm. Steel bars 25mm in diameter with yield strength of 420MPa were used as the main reinforcement. The web reinforcement ratio was 0.3%, and the reinforcing bars were 10mm in diameter (yield: 399 MPa).

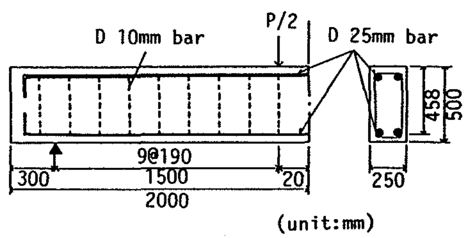


Figure 1. Beam specimen

2.3. Test method

2.3.1. Exposure test The specimen beams were exposed to natural weather conditions in the yard of Takenaka Research Laboratory. The strain in the concrete was monitored at six points in the longitudinal direction and at eight points in the vertical direction during the exposure period. The reinforcement bars in each beam were measured for strain over the first 440 days.

2.3.2. Loading tests The specimen beams were tested in symmetrical two point loading with a moment span of 40 cm and shear span of 150 cm as shown in Figure 1. Load, deflection, concrete strain, and reinforcement strain were measured. In addition, the strain distribution in the moment span was measured to calculate the curvature and the position of the neutral axis. The beams were tested until failure after being loaded and unloaded twice at the following loads, i.e. the calculated cracking load (65.2kN), the design load (141kN), one and 150% of the design load (191kN), and the yield load (235kN).

2.3.3. Coating Two coating materials were chosen from the results of experimental work carried out separately[3]. One is a sheet coating which shuts off all moisture movement, and can be expected to offer complete waterproofing. The other is an elastomeric silicone coating which is slightly permeable to vapour, but impermeable to water. Coating to the beams was carried out by trained engineers at 440 days.

3. RESULTS AND DISCUSSION

3.1. Compressive properties of concrete

Compressive tests were conducted at 28 days, 17 months, and 45 months. Although cast cylindrical specimens were used for 28 day and 17 month tests, core samples were taken for the later tests at 45 months. As shown in Table 2, there was no change in the compressive strength of non-reactive concrete between 17 months and 45 months. The elastic modulus of the reactive concrete at 45 months had decreased to one third of the initial value.

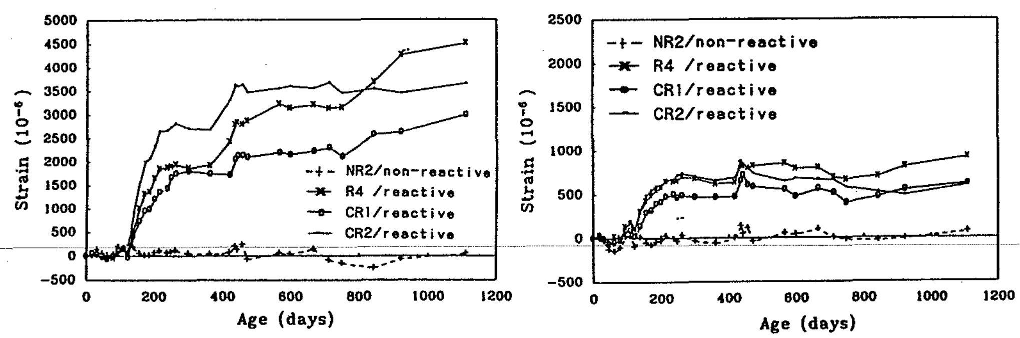
Table 2. Compressive properties

Age	Non-react. concrete		Reactive concrete	
	Compressive strength (MPa)	Elastic modulus (GPa)	Compressive strength (MPa)	Elastic modulus (GPa)
28days	8.5	33.2	18.1	27.3
17months	27.5	37.0	23.8	16.0
45months	27.5	33.3	14.1	9.0

Table 3. Results of the Loading test

Beam name	Used aggregate	Coating	Tested age (mon)	Cracking load (kN)	Yield load (kN)	Ultimate load (kN)	Deflection at the design load (mm)	Residual Deflection (mm)
NR1	non-reactive	non-coating	17	65	237	272(233)	1.72	0.42
NR2	non-reactive	non-coating	45	42	235	270(239)	1.50	0.45
R1	reactive	non-coating	17	-	235	271(230)	1.37	0.22
R2	reactive	non-coating	17	-	245	274(230)	1.46	0.17
R3	reactive	non-coating	45	-	235	266(219)	1.17	0.16
R4	reactive	non-coating	45	-	237	260(219)	1.16	0.17
CR1	reactive	coated	45	-	232	257(219)	1.15	0.15
CR2	reactive	coated	45	-	245	272(219)	1.19	0.34

* The values in parenthesis show the calculated values



(a) vertical strain (b) longitudinal strain

Figure 2. Concrete strain of the beams during the exposure period

3.2. The strain in the exposed beams

The longitudinal and vertical strain as measured on the concrete surface of the exposed beams is shown in Figure 2-a and 2-b, respectively. Compared with the vertical strain changes in the non-reactive concrete beams of $\pm 200\times 10^{-6}$, the reactive concrete beams exhibit extremely large values of expansion strain, i.e. 2000 to 4500 $\times 10^{-6}$. It was noted that the strain in the specimens of reactive concrete tended to increase in the summer, particularly at the age of 100 to 200 days. The expansion strain in the longitudinal direction is one third to one fifth of that in the vertical direction because of the restricting effect of the reinforcement.

3.3. Influence of the coating on expansion strain

Two beams were coated at 440 days. The effect of the coating on expansion is not obvious in Figure 2 because of the spread in strain values among the specimens. When the strain is measured from the date of coating, however, it is seen that the strain in the coated beams was lower than that in non-coated beams as shown in Figure 3. In the beam coated with elastomeric silicone, the vertical strain tended to rise after 300 days, but the rate of increase is clearly less than that in non-coated beams. There is not sufficient evidence in this result to judge which coating is superior, but the coating treatment does at least restrain the expansion due to ASR.

3.4. Potential expansion of the reactive concrete at 45 months

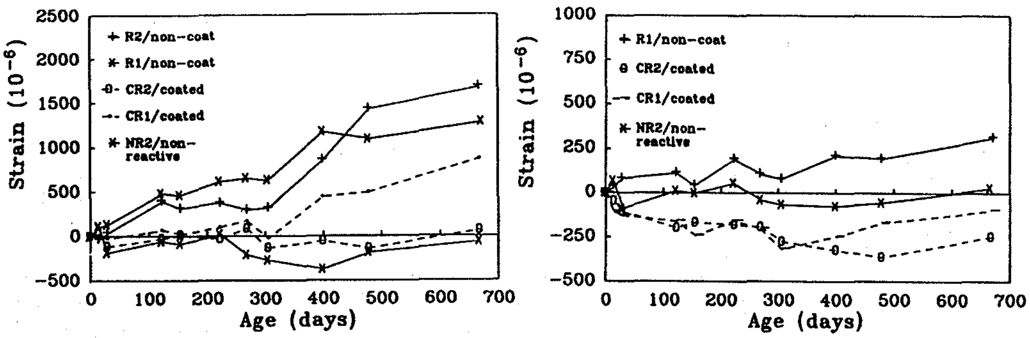
Specimens were taken from the core of hardened concrete. In order to measure the potential activity, these core specimens were subjected to accelerating conditions of 40°C, 100% R.H., and the strain was measured. The concrete specimens continued to expand about 400 $\times 10^{-6}$ even within the short period of three months.

3.5. Flexural behaviour

The test results are given in Table 3. The specimen beams all failed in the flexural mode. The crack distribution after loading is schematically in Figure 4. The spacing of cracks in all beams was almost the same, but shear cracks were not obvious in the reactive concrete beams. The reason may be that chemical prestressing in the vertical direction compensates the diagonal shear tension or that the cracks caused by ASR widened and absorbed the shear deformation.

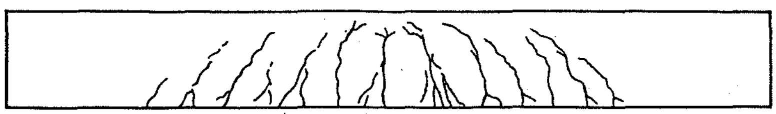
Figures 5-1 and 5-2 are the load-deflection curves of the beams tested at 17 months and 45 months, respectively. There were no systematic differences between the load deflection curves of the non-reactive beams at 17 months and at 45 months. Similarly, the load-deflection curves of the reactive concrete beams measured at 17 months were almost the same as those measured at 45 months.

In contrast, it can be seen that there is a considerable difference in load-deflection curves between the non-reactive beams and the reactive concrete beams. In the non-reactive concrete specimens, the flexural rigidity of the beam suddenly decreases at cracking load and gradually falls until the yield load is reached. On the contrary, a sudden decrease in flexural rigidity is not observed at the cracking load in the case of reactive concrete beams. The initial rigidity of the reactive concrete beams is much greater than the post-cracking rigidity of non-reactive concrete beams, despite the presence of many cracks in the reactive concrete beams before loading. The residual strain

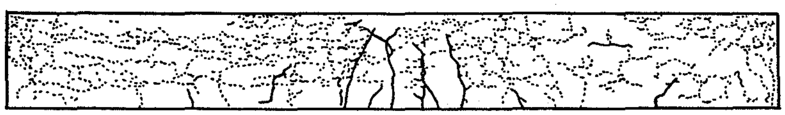


(a) Vertical strain (b) Longitudinal strain

Figure 3. Concrete strain after coating

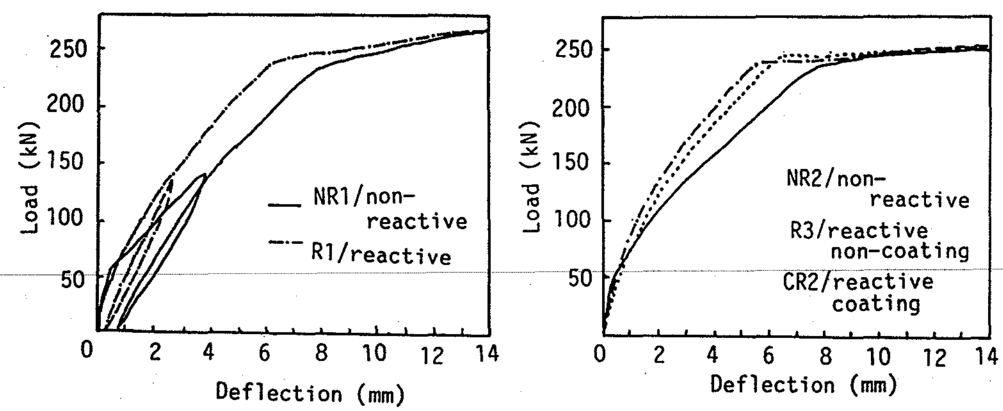


a) NR-1 (non-reactive)



b) R-1 (reactive)

Figure 4. Crack pattern of the loaded beams



(a) at 17 months (b) at 45 months

Figure 5. Loaded-Deflection curves

in the reactive concrete beams under cyclic loading is lower than that in non-reactive specimens as shown in Table 3. These results are thought to be effects of the chemical prestress provided by the expansion strain of reactive concrete.

In the case of the reactive concrete beams loaded at 17 months, the chemical prestress has been calculated to be about 3 to 6 MPa, based on the reinforcement strain measured during the exposure period. In the loading test at 45 months, it was expected that a loss of chemical prestress might affect the mechanical behaviour of the beams, but the results from the beams tested at that time(R3 and R4) were almost identical as those of R1, R2 beams tested at 17 months. The reason is thought to be the compensating effect of new prestress produced in further expansion canceling the prestress lost during the period. The non-coated reactive concrete beams, for example, expanded about 1500 to 2000 $\times 10^{-6}$ in the vertical direction, and a few hundred microns in the longitudinal direction in the period after 17 months.

The neutral axis of the damaged beams did not move from the centre until the load reached 100 kN, so this load level is considered to be the decompression condition.

It was noted that the deflection of the reactive concrete beams tended to be plastic, when a large load was sustained. This implies that the structure damaged by ASR may be affected by a sustained high load .

With regard to the effect of coating, there were no differences between the coated beams and non-coated beams in terms of ultimate load, yield load and deflection behaviour. Since the coated beams did not expand enough to produce new chemical prestress after the date of coating, some loss of chemical prestress was anticipated. However, as the test results show, the mechanical behaviour was affected very little by the coating process. The damage caused by ASR is not a problem as regards mechanical behaviour, but the coating treatment does effectively prevent expansion due to ASR and protects the reinforcements in concrete from corrosion.

4. CONCLUSION

Reinforced concrete beams damaged by ASR were loaded in flexure after exposure to natural weather conditions for 17 months and 45 months. The ultimate flexural strength of the beams damaged by ASR was almost the same as that of the unaffected beams. Chemical prestress introduced by the expansion due to ASR made the beams more elastic at the design load level. Since the expansion due to ASR continues for a long time, the chemical prestressing effect is unlikely to be lost with the lapse of time. Although coatings did not affect the mechanical properties of the beams, they may be expected to minimize concrete expansion and deterioration due to ASR.

5. REFERENCE

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