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[1150] 補強鉄筋がアルカリ骨材反応によるコンクリートの膨張に及ぼす影響

EFFECT OF STEEL REINFORCEMENT ON CONCRETE EXPANSION DUE TO ALKALI SILICA REACTION

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1. INTRODUCTION

Alkali Aggregate Reaction is well known to denote a chemical reaction that involves alkali primarily derived from concrete pore solutions and certain types of reactive mineral constituents of aggregates. Several types of alkali aggregates reactions have been discovered including alkali silica reaction(ASR), details of which are given in the literature(3).

Occurence of this chemical reaction is partly due to the facts such as increase in alkali contents in cements due to various factors including use of economical cements manufacturing methods, use of higher cement contents of concrete in some applications and use of some kinds of aggregates with unknown service behavior .

In 1940, the first papers recognizing the Alkali Aggregate Reaction were published by Stanton (1,2), and after that research has been undertaken to develop means of identifying the potentially reactive aggregates and reactive components in the cement paste.

With regard to the reaction mechanism, it is well known that initially an alkaline silicate gel is formed which then imbibes water from the pore solution and increases in volume. If the increase in volume cannot be accomodated in surrounding porous space, swelling of the gel exerts expansive pressure that leads to cracking of concrete.

Although there is an extensive literature to explain this reaction in plain concrete and mortars, there is lack of available data dealing with reinforced concrete members. It is very important to identify the adverse effects of ASR in RC members in order to maintain or rehabilitate the affected members.

The effect of the presence of steel reinforcing bars on the deterioration of the RC beams(columns), due to ASR, is presented in this paper. Several reinforced concrete specimens were cast, changing amount of reinforcement and alkali content, and cured in different curing conditions. The expansion, dynamic Young's modulus and weight change of each specimen were measured and steel strains monitored continuously. It was observed that the crack pattern in the reinforced concrete specimens was influenced by the rate of expansion and detailing of the reinforcements etc. Steel strains and concrete expansions showed a similar trend to

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each other as the reaction proceeds. From the data, it was concluded that the presence of reinforcing bars within the concrete contributes to restrict the expansion caused by ASR.

Table 1. Details of specimens

Type	Steel ratio (%)	Longitudinal bars Nos. - mm	Alkali	Curing
1. Series A			2%	40°C water
A26	0.63	2 - 6		
A46	1.26	4 - 6		
A0	0	-		
AS2*	1.26	4 - 6		
AS4*	1.26	4 - 6		
AS6*	1.26	4 - 6		
A213	2.53	2 - 13		
A4610	2.06	2 - 6 and 2 - 10		
A210	1.427	2 - 10		
A410	2.85	4 - 10		
2. Series D			2%	40°C moist
D4610	2.06	2 - 6 and 2 - 10		
D410	2.85	4 - 10		
D46	1.26	4 - 6		
D0	0	-		
3. Series E			1%	40°Cwater
E4610	2.06	2 - 6 and 2 - 10		
E410	2.85	4 - 10		
E46	1.26	4 - 6		
E0	0	-		

Notes:
* AS2, AS4 and AS6 have 2, 4 and 6 links of diameter 6 mm at 375, 125 and 75 mm respectively.

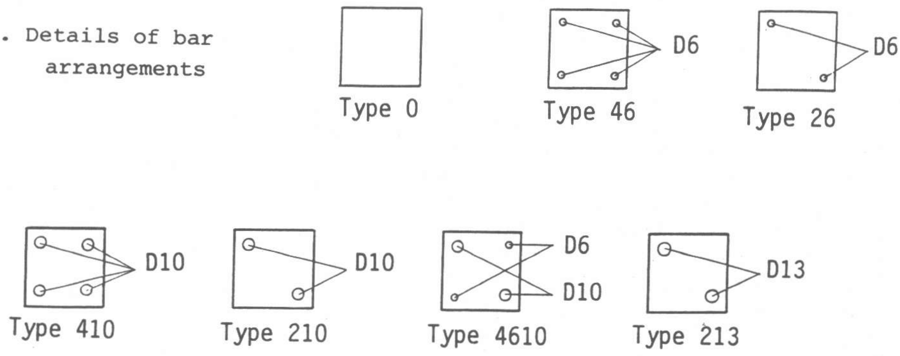
2. EXPERIMENTAL PROGRAMME

Reactive aggregates, sizes (5-20mm), andesite from Yamagata prefecture and normal river sand have been used in this investigation. Portland cements had an alkalinity of 0.77% Na_2O equivalent. The alkalinity of the concrete was then increased to required percentage by adding aqueous solution of sodium hydroxide. The water cement ratio of the concrete mix was 0.5 and cement content of the concrete was 385.4 kg/m^3.

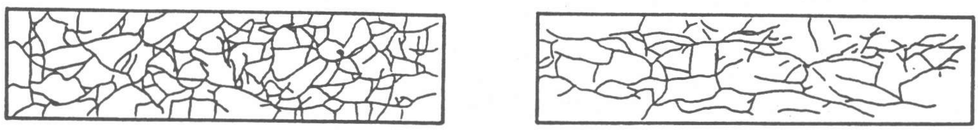
Prisms of 10cmx10cmx40cm were cast, in such a way that each prism had two studs at the centres of the 10cmx10cm faces for length measurements. Each type had two specimens and total number of specimens was 36, details of which are given in Table 1. Reinforcing bars at symmetrical locations have been embedded in each RC beam with a 10mm cover distance(see Fig. 1). All the prisms were cured under wet gunny bags (20°C) for the first seven days and then one series(D) of specimens was moist cured at 40°C and others(A and E) were cured in a water tank at the same temperature.

At least 24 hrs. before the measurements, specimens were removed from the curing tanks and brought into a room with constant temperature(20°C) and RH(60-70%). Expansion, dynamic Young's modulus, and weight gain were measured at selected intervals, and steel strains were monitored continuously at the centres of two longitudinal bars placed at symmetrical locations of each RC specimen.

Fig 1. Details of bar arrangements



3. RESULTS AND DISCUSSION



(a). A0 (b). A410

Fig 2. Crack patterns after 21 weeks

Fig. 2 shows the pattern of cracks on RC beams, made with concrete, cured in water at 40°C, containing 2% of alkali, due to ASR. After 3 or 4 weeks, cracks appeared only on the specimens made with concrete containing 2% alkali and cured in water at 40°C. Fig. 3 indicates that the average crack widths were less than 0.06 mm. From the observed data, it was found that the average longitudinal crack spacing was 17.09 mm and transverse crack spacing 22.56 mm for RC specimens of A series while the corresponding values for control specimen (A0), were 16.00 mm and 16.90 mm respectively. It is also obvious from the Fig. 2, that there were not as many cracks in the RC specimen due to ASR as in the plain concrete specimen. This result indicates that the steel reinforcing bars restrained the expansion caused by ASR.

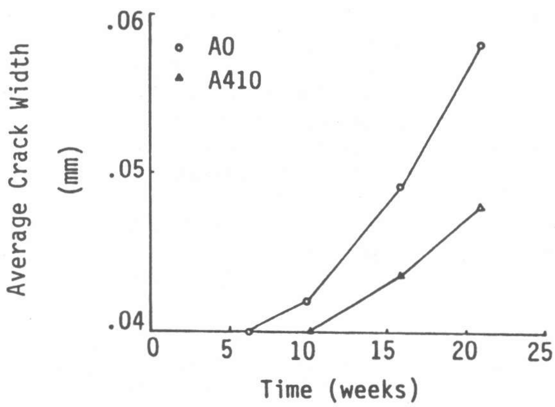


Fig 3. Average crack width

It was observed that many cracks in RC beams are formed between and approximately parallel to the reinforcing bars (see Fig. 2). Since ASR causes triaxial expansion, longitudinal steel bars may not restrain the transverse expansion and thus, many cracks are formed approximately parallel to the longitudinal bars. These cracks sometimes affect the outside appearance of structures.

Fig. 4 shows the variation of dynamic Young's modulus with time for concrete, cured in water at 40°C, containing 2% of alkali. It is evident that increase in the deterioration occurs after two to four weeks. Reduction in dynamic Young's modulus due to ASR was smaller for RC beams than that for plain beams. This may be caused by the induced prestressing force in concrete by restriction of steel bars which leads to reduce the width of the cracks and amount of cracks in affected concrete(see Fig. 2 and Fig. 3) and this, therefore, decreases the reduction in stiffness.

Figs. 5 and 6 show the variation of the compressive strength and Young's modulus with time for concrete, cured in water at 40°C, containing 2% and 1% of alkali. It was observed that the static Young's modulus decreased as the age of the specimens increased for a particular period. This may be due to the fact that the large amount of cracks causes to increase in deformation when loading the specimens. But compressive strength remained constant for that period of time and after that both of them increased slightly.

Compressive strength of specimens made with concrete containing 2% alkali and cured in water at 20°C was 265 kgf/cm^2 and 341 kgf/cm^2 while the corresponding values for concrete containing 1% alkali with the same curing condition was 427 kgf/cm^2 and 570 kgf/cm^2, at the ages of 4 and 21 weeks respectively. This result indicates that the increase in alkali content causes decrease in compressive strength, because presence of considerable amount of alkali may change the hydration process.

Tensile strength of

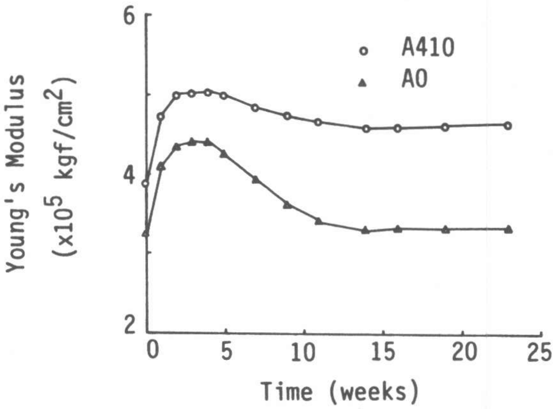


Fig 4. Dynamic Young's modulus

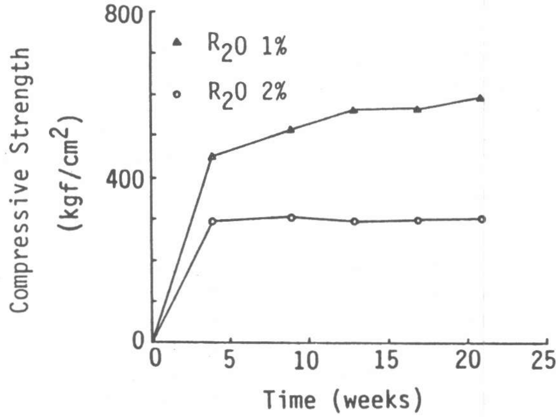


Fig 5. Compressive strength

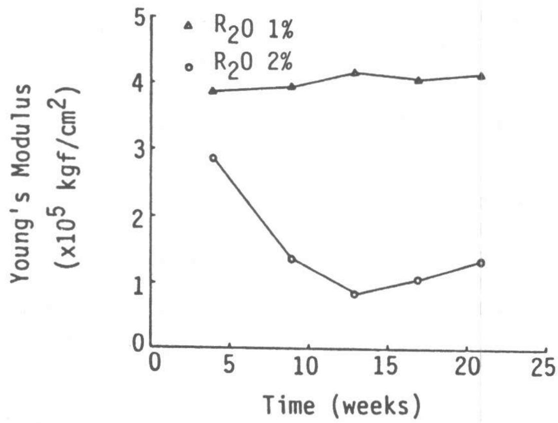


Fig 6. Static Young's modulus

concrete is substantially reduced by ASR(5). Reduction in strength and Young's modulus due to ASR may affect the load carrying capacity of RC columns.

Fig. 7 shows the variation of expansion with time for concrete, cured in water at 40°C, containing 2% of alkali content. It is observed that the shear reinforcement has little effect on longitudinal expansion but may affect the transverse expansion and cracking. Thus heavily reinforced concrete in both directions may show smaller expansions due to ASR.

Fig. 8 shows the variation in steel strain with time for concrete containing 2% of alkali. Concrete expansion and steel strain were almost the same. This result confirms that their bond characteristics were not affected by ASR.

Fig. 9 shows the variation of expansion with pecentage of steel ratio for concrete, cured in water at 40°C, containing 2% of alkali. It is evident that expansion of concrete caused by ASR was restrained by reinforcing bars. It is also evident that increase in percentage of steel above a value about 1.26 has little effect on restraining expansion. Induced prestressing forces may be the same for all specimens with same concrete mix and curing condition regardless of the amount of steel reinforcements.

Specimens made with concrete having 2% alkali content and cured in water at 40°C, showed the highest expansion.

It has been reported that the expansive forces are able to initiate severe cracking in RC structures, and even in prestressed structures(6). The measured crack depth of Hanshin Expressway in Japan which was affected by ASR, was about 10

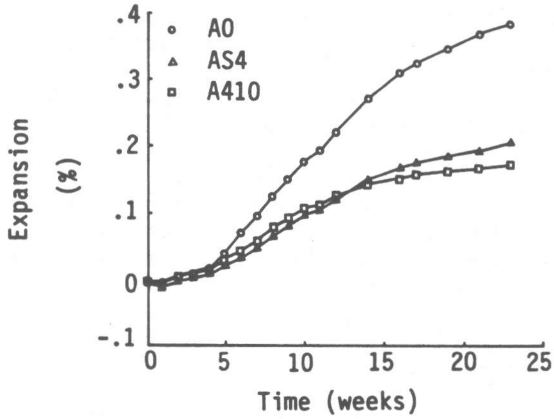


Fig 7. Concrete expansion

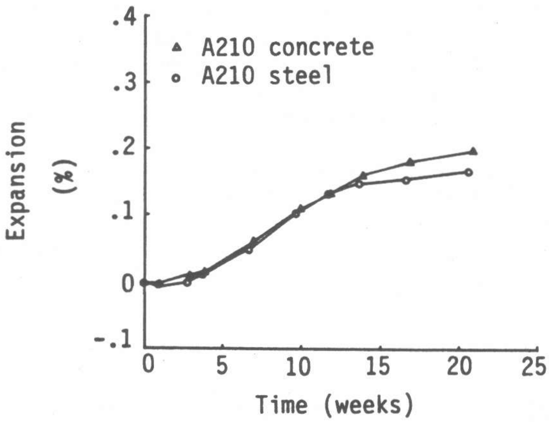


Fig 8. Concrete and steel strains

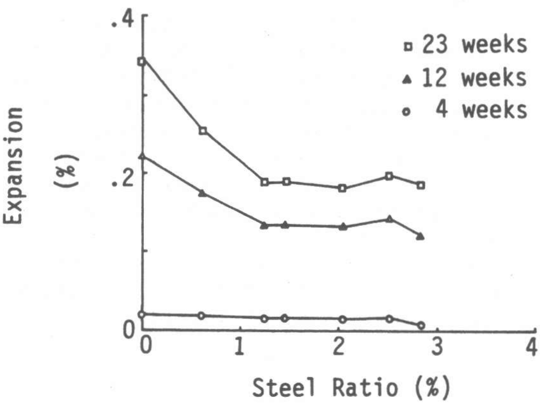


Fig 9. Effects of steel ratio

cm(7). This was almost equal to the cover depth to the reinforcing bars. These cracks may lead to corrosion of steel bars and eventually affect the durability of RC structures.

Considering these adverse effects, the benefit of reducing the ASR expansion of RC structures is very important. In practice, the main emphasis has been on the use of low-alkali cement. It has also been known that use of reactive pozzolona is effective in preventing ASR. However, in some special cases, such as structures exposed to sea water, these methods are not effective . It has been pointed out that even if low-alkali cement is used, the internal migration and concentration of alkali may initiate the ASR(4).

4. CONCLUSIONS

Within the scope of this investigation following conclusions can be drawn.

1. Cracks are formed between and approximately parallel to the steel reinforcing bars in RC beams and columns due to ASR.
2. Modulus of elasticity decreased with time and compressive strength remained constant.
3. Steel reinforcements embedded in concrete can restrain the expansion due to ASR.
4. Increase in steel percentage above a certain value has little effect on restraining ASR expansion.
5. Stirrups have little effect on restraining longitudinal expansion.
6. The bond characteristics of concrete and steel are not affected by ASR.

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