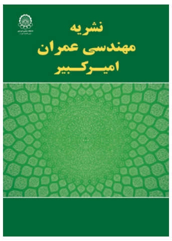

Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 49(1) (2017) 11-14
DOI: 10.22060/ceej.2016.701

Investigation of the Effect of Alkalai-Silica Reaction on the Structural Behavior of Reinforced Concrete Beams Using the Finite Element Method

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ABSTRACT: Many structures, such as dams, bridges and hydraulic structures suffer deterioration induced by alkali- aggregate reaction (AAR) which impairs the durability and safety of installations. Alkali-silica reaction (ASR) is an internal chemical reaction that appears in concrete between certain forms of siliceous aggregates and the alkaline pore solution in concrete. The result is a more or less crystallized silica - alkaline product which can exert pressures on the surrounding matrix. ASR induces concrete expansion and generally leads to loss of strength and cracking. The structural behavior of concrete which has been affected by ASR is difficult to model due to various random parameters that govern this chemical process. The aim of this paper is to investigate the effect of ASR on behavior of reinforced concrete beams using three methods. For this purpose, 100x150x1100-mm concrete beams were built in the laboratory and reinforced with different ratio of compression and tension bars. Then ASR and creep strains were modeled by reducing the elastic modulus of concrete and applying equivalent tension force. For the purposes of verifying the numerical methods involved, fourteen beams were conditioned in a suitable environment using similar dimensions and loading system. Experimental results on reactive concrete samples were simulated so as to test whether the model was capable of describing the behavior of affected reinforced concrete beams under service loads. The comparison reveals that finite element model had good compatibility with acquired test results.

Review History:

Received: 17 November 2013
Revised: 22 October 2015
Accepted: 20 January 2016
Available Online: 3 September 2016

Keywords:

Alkali Silica Reaction (ASR)
Finite Element Analysis
Finite Element Modeling
Modeling of ASR
Reinforced Concrete Beams

1- Introduction

Structural problems related to alkali-aggregate reaction (AAR) have been detected in concrete structures since the beginning of the 20th century, but it was not before 1940 that it was first identified by Stanton [1]. Since then, many efforts have been made to minimize its deleterious effects on concrete. Gel exudation, swelling and cracking are often associated with AAR development. All types of concrete structure may be affected, although structures in direct contact with water, such as dams and bridges, are particularly susceptible to AAR development, given that moisture conditions play an important role in this chemical process. Presently, the only way to obtain AAR safe concrete is by identifying the potential reactivity of aggregates and/or adding pozzolanic admixtures to the material. Nevertheless, a great number of operating structures made of reactive concrete still constitute a matter of concern. As in most cases, it is impossible to interrupt AAR, the only way to lessen its harmful effects is by taking remedial measures whose effectiveness depends strongly on an adequate prediction of the stress and strain field development.

AAR depends on the availability of three factors: alkalis liberated from cement during hydration, siliceous minerals present in certain kinds of aggregates and water. Several microscopic and random factors are involved in AAR expansion, such as concrete porosity, amount and location of reactive regions in the material and permeability. These parameters, added to concrete's intrinsic heterogeneity, turn simulating AAR expansion into a rather complex task. For concrete structures such as dams or bridges, there is a strong need for numerical models taking into account the mechanical effects of alkali-silica reaction (ASR). ASR is difficult to model due to random distribution of the reactive sites and the imperfect knowledge of these chemical reactions. Many researchers have modeled this phenomenon. Some researchers have modeled this reaction by a hygro- chemo-mechanic with considering humidity gradient [3,5,6]. A few researchers have considered a macroscopic model developed within the framework of a smeared crack finite element approach [2]. Thermal loading is another method used by other researchers [4]. In this paper, ASR strains were modeled using the results of conventional RC structural analysis of the tested beams.

2- Experimental program

A laboratory study was carried out to investigate the effect of deleterious ASR expansion on the structural behavior of

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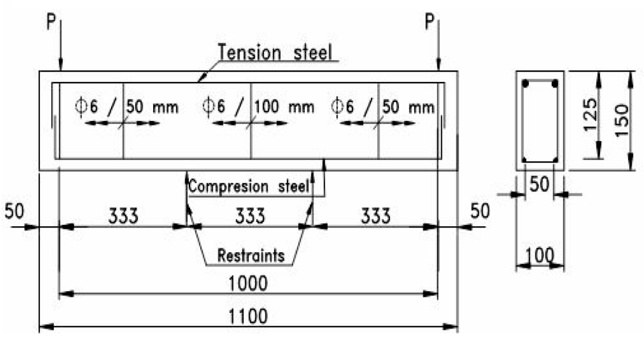

Fig. 1. Reinforced concrete beams

reinforced concrete beams and on mechanical properties of concrete cylinders made with the same concrete mixture. The specimens were made with reactive or non-reactive aggregates. All beams had 100×150 mm cross-sectional areas and internal reinforcement. The beams were 1100 mm long, and reinforced with different ratios of compression and tension steels (see Fig. 1). The beams were standard cured and then to simulate in-service conditions, fourteen beams were held under load that caused flexural cracking while being conditioned. Beams and concrete cylinders were kept under long-term observation at 38 ºC and 100 percent relative humidity.

During the long-term reaction period, concrete strain and steel strain were measured regularly. The strain of concrete beams was measured along the compression and tension zones in the middle of the beams. Steel strains were monitored by strain gauges mounted on the middle of bars. Test specimens are listed in Table 1.

3- Structural analysis

Using the measured values of concrete and steel strains obtained from the tests conducted in this study, a conventional Reinforced concrete (RC) structural analysis of the tested beams was carried out. The elastic modulus of the concrete was then calculated from the equilibrium of moments. Using the equilibrium of forces and the calculated value of the concrete elastic modulus, the equivalent axial tensile force can then be evaluated. Reduction in elastic modulus of concrete is mostly due to creep. There are increasing in equivalent axial force in reactive aggregate beams due to ASR strains which will have major structural implications on the performance of the beams. The highest value of this axial force for R2 and R4 beams are 44.7 kN and 31.2 kN respectively. Using compressive reinforcement in R4 beam causes this reduction in axial force. The important role of compression reinforcement is more confirmed when the

Table1- Test specimens

Concrete specimens		Specimens size	Aggregate	Tension reinforcement	Compression reinforcement
	R1		Reactive	2Φ8	-
	N1		Non-reactive	2Φ8	-
	R2		Reactive	2Φ10	-
	N2		Non-reactive	2Φ10	-
	R3		Reactive	2Φ12	-
	N3		Non-reactive	2Φ12	-
Beams	R4	100×150×1100 *mm*	Reactive	2Φ10	2Φ8
	N4		Non-reactive	2Φ10	2Φ8
	R5		Reactive	2Φ12	2Φ8
	N5		Non-reactive	2Φ12	2Φ8
	R6		Reactive	2Φ12	2Φ10
	N6		Non-reactive	2Φ12	2Φ10
	R7		Reactive	2Φ12	2Φ8
	N7		Non-reactive	2Φ12	2Φ8
Concrete cylinders	R	100×100 *mm*	Reactive	None	None
	N		Non-reactive	None	None
	R	150×300 *mm*	Reactive	None	None
	N		Non-reactive	None	None

highest value of equivalent axial force in R5 and R6 beams compared to R3 beam are 41.9 kN, 36.4 kN and 58.8 kN, respectively.

4- Numerical simulation of beams subjected to ASR

The finite element mesh used for the simulation in Ansys program. The elastic modulus of steel bar is 210 GPa. The tension steel bar area and compression one are accordance with Table 1. Initial elastic modulus of concrete is about 24.3 GPa. Beams are subjected to two point external load to simulate service conditions in step 1. For other steps, calculated reduced elastic modulus of concrete and obtained equivalent force accompany with service loads are used.

5- Results and discussion

Figs. 2-7 show the concrete strains obtained from numerical simulation and test results. It is clear from these figures that there are good agreements between experimental data and the model in tension zones. The differences in tension strains for R1 to R6 beams in the model compared to test results are 20, 12, 12, 9, 10, 8.5 percent, respectively. In the compression zones, the program results can show the behavior of beams but differences between experiments and the model are more significant compared to tension zones. The differences in compression strains for R1 to R6 beams in the model compared to test results are 46, 42, 42, 37, 27, 21 percent respectively. These high differences are caused by applying the equivalent force on the middle point of beam section in spite of the fact that the ASR strains are higher in compressions zones than tension ones. Considering the equivalent force in neutral axis might be a method to reduce the compression strains. It is found from these figures that using compression steel bar causes the significant compatibility between experimental and model results. In R6 beam with highest compression steel bar, the differences between experimental results and the model results in tension and compression zones are 8.5 and 21 percent, respectively .These values for R3 beam with no compression steel bar are 12 and 42 percent.

6- Conclusions

The modeling presented in this paper aims to describe the evolution of the behavior of ASR affected concrete. This modeling has been implemented into Ansys program. Numerical simulations for six beams loaded by service condition and submitted to ASR have been carried out. The comparison between measured and predicted results show the better agreement in tension zones compared to compression zones. Acting the equivalent force in neutral axis of beams might improve the strains in compression zones.

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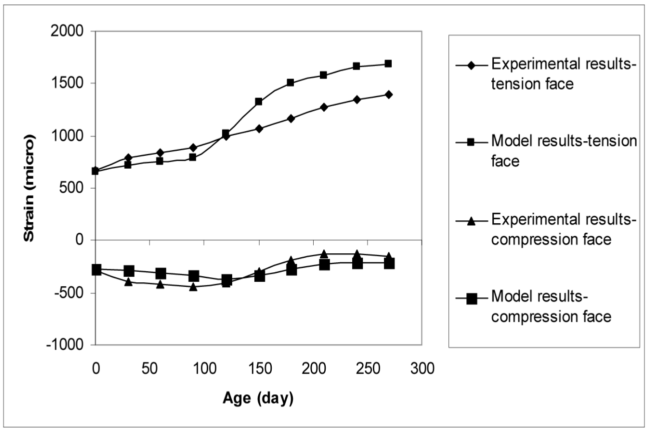

Fig. 2. Comparison between experimental and model results for R1 beam

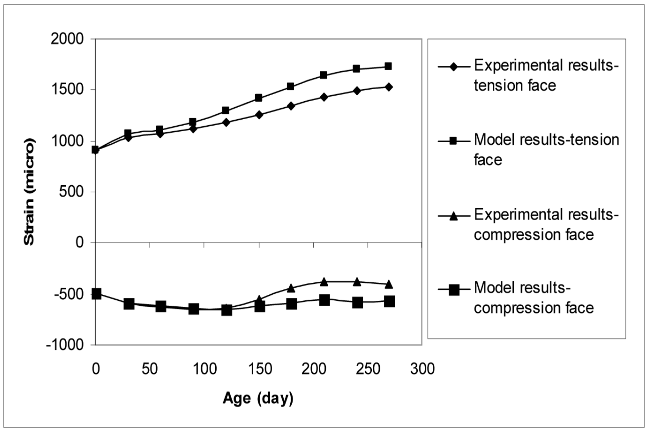

Fig. 4. Comparison between experimental and model results for R3 beam

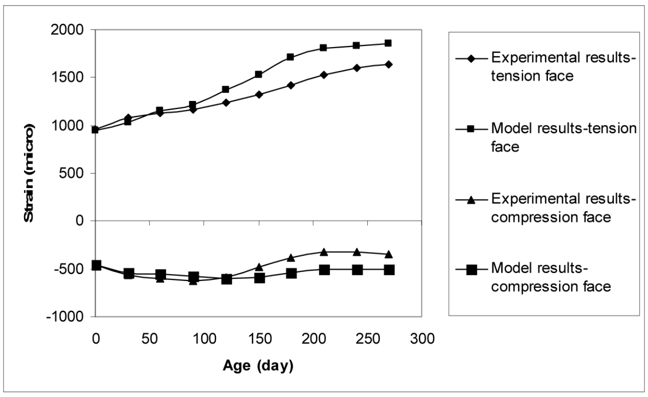

Fig. 3. Comparison between experimental and model results for R2 beam

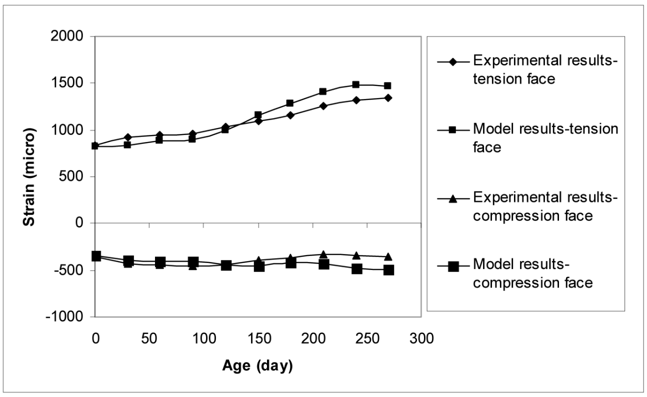

Fig. 5. Comparison between experimental and model results for R4 beam

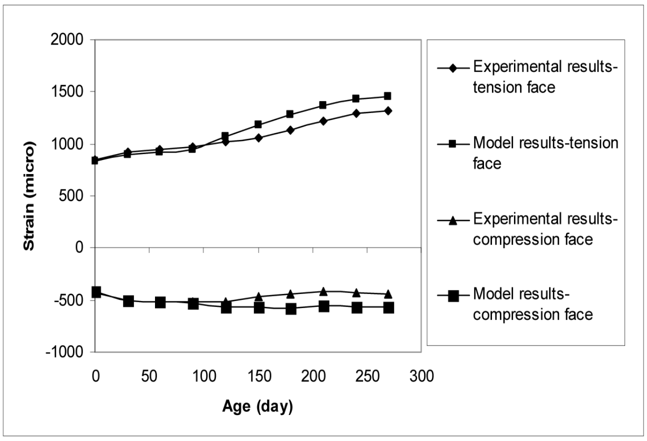

Fig. 6. Comparison between experimental and model results for R5 beam

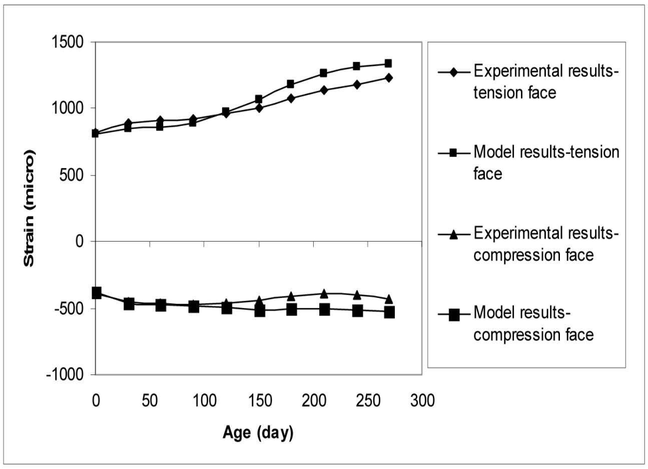

Fig. 7. Caption: R7 should be replaced by R6

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Please cite this article using:
S., Hajighasemali, A. A., Ramezanianpour, V., Lotfi, M. H., Kashefizadeh, “Investigation of the Effect of Alkalai-Silica Reaction on the Structural Behavior of Reinforced Concrete Beams Using the Finite Element Method”. *Amirkabir J. Civil Eng.*, 49(1) (2017) 23-33.
DOI: 10.22060/ceej.2016.701