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Numerical model of the alkali-silica reaction development with external source of alkalis

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Abstract

Experimental research, in which mortars prepared with reactive aggregates have been exposed to different conditions, has been performed. The samples have been stored in water or 1M NaOH water solution at 80ºC. Based on the observed strains, ASR extent has been calculated. Mathematical model of combined action of hygro-thermal, chemical and mechanical phenomena has been developed to analyze evolution of the ASR reaction. It is based on mechanics of multiphase porous media. Development of the ASR depends on the alkali content. Diffusion of alkalis from the cement paste to the aggregate grains is considered. Both external alkali sources and alkali binding by the formed ASR gel are taken into account. The proposed mathematical model has been validated by comparison with the experimental results.

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Keywords: alkali-silica reaction; chemical degradation; porous media mechanics

1. Introduction

The alkali-silica reaction (ASR) occurs in the reactive aggregates only after reaching sufficient alkali content. Threshold alkali concentration, above which the reaction takes place, has been already examined in the past. Rivard *et al.* [1] reported that the alkali-silica reaction occurred in the experimental research at 38ºC when alkalinity of the

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pore solutions, extracted from concrete, was higher than 270 mmol/l and 250 mmol/l. Multon and Sellier [2] reported, based on the results of Kim *et al.* [3], that the threshold alkali content is higher than 325 mmol/l, 275 mmol/l, 222 mmol/l for temperature of 20ºC, 38ºC and 55ºC, respectively.

Although laboratory methods of reactivity determination are commonly used, they have been often criticized. One of the reasons for this is that alkali leaching may occur in high relative humidity [4]. This phenomenon is of particular significance for the laboratory tests, in which small specimens are stored in water or in high relative humidity. Therefore, the specimens which are defined as reactive in one test, may be identified as non-reactive in real structures or other tests.

In the present work, mathematical model describing the ASR evolution at the mesoscopic scale, taking also into account diffusion of alkalis at the macroscopic scale caused by external source of alkalis, has been proposed. In order to validate the model, experimental research, in which specimens have been stored either in NaOH water solution or water, has been performed. Based on the observed expansions, ASR extent has been calculated.

2. Experimental research

In the research, cement CEM I 42.5 N-NA has been used. Content of alkalis has been increased to 1.2% Na_2O_{eq} by addition of NaOH to the mixing water. Two mortar series have been prepared with w/c ratio equal to 0.47 and a/c ratio equal to 2.25. In mortar M1, aggregate composed mainly of quartz mica schist, quartz, marble, limestone and gneiss has been applied. Main components of the aggregate used in mortar M2 were quartz and limestone.

Mortar bars have been cast and conditioned according to the RILEM AAR-2 method [5]. After casting, the specimens of sizes 40x40x160 mm^3 have been stored under plastic sheet for one day at 20°C. Afterwards, they have been demolded and stored in the containers filled with distilled water of temperature 20°C, which have been placed in the oven at 80°C for one day. After that period, the initial measurements of length have been taken. Half of the specimens (denoted as '-R') has been stored in 1M NaOH water solution at 80ºC, as it is recommended in the RILEM AAR-2 method. The other specimens have been stored in water at 80°C ('-NR'). Therefore, in the series '-R' some alkalis should diffuse from the container towards the reactive aggregates, what should accelerate reaction development. Meanwhile, in the latter specimens alkali leaching should occur at the specimens' surfaces. Ratio of volume of liquid to volume of specimens was equal to 4:1. For each series, three samples have been tested. Average strains obtained are presented in Figure 1.

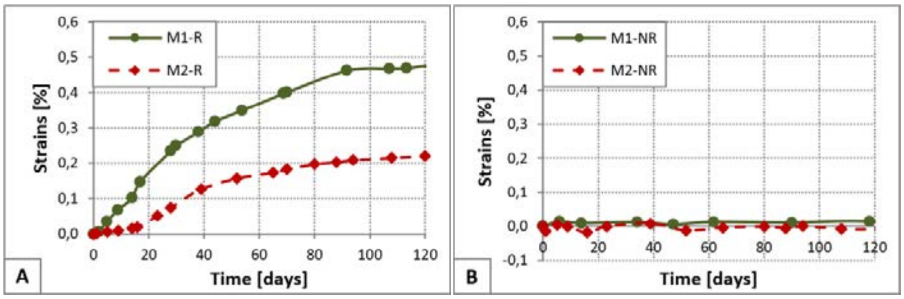

Fig. 1. Average strains of the samples stored in 1M NaOH water solution (A) or water (B).

For the samples in which the reaction took place, ASR can be calculated according to the equation [6]:

$$\Gamma_{ASR}\left(t\right)=\frac{\varepsilon_{ASR}\left(t\right)}{\varepsilon_{ASR}\left(t=120\text{ days}\right)}, \tag{1}$$

where $\varepsilon_{ASR}\left(t\right)$ is average expansion obtained after given exposure time (t). Average ASR extent, obtained for