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Influence of temperature on expansion due to the alkali-silica reaction and numerical modelling

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Abstract

Temperature in some accelerted tests is critically important for assessment of the expansive potential of concrete subjected to alkali-silica reaction (ASR) as it drives the kinetics of expansion. However, whether the temperature influences the magnitude of the final expansion remains unclear because the speed of expansion and the final expansion are not proportional. In this study, the expansive behaviors of laboratory tests and field-exposure tests in several previous studies are summarized for comparison. It was confirmed that ASR expansion might be reduced from the increase in temperature. Then, additional experiments coupled with a numerical simulation were performed. In the numerical analysis, a simplified damage model was used to express a reduction in the expansive ability of ASR gel due to an interaction between the viscoelasticity of the ASR gel and microstructural damage of the aggregate and paste. The parameters of the damage model were identified from the experiments. The results indicate that for a given reaction ratio, expansion is reduced at higher temperatures. The interaction between the viscoelastic behavior of ASR gel and microstructural damage of the aggregate and paste control the late-stage expansion rate and explicit modeling of such an interaction is necessary for refined numerical prediction of expansion behavior.

***Keywords**: temperature, ASR expansion, numerical simulation, alkali-wrapped concrete prism test.*

1. INTRODUCTION

Temperature has a significant impact on the expansive behavior of concrete due to the alkali-silica reaction (ASR). It is therefore critical to understand the sensitivity of the ASR expansion of concrete to temperature. Although there have been many studies on the influence of temperature on the expansion rate and the final expansion, the relationship between the rate of expansion and the final expansion and their sensitivities to temperature remain unclear.

In this study, the results of our previous study are firstly reviewed using additional data from field exposure tests. Then, to validate the results of the previous study, the results of the alkali-wrapped concrete prism tests (AW-CPTs) at different temperatures are presented. Furthermore, results of numerical simulations considering the chemical reaction and expansion are presented. Finally, the influence of temperature on ASR expansion is discussed. This extended abstract presents the important point of modelling a reduction in the expansive ability of ASR gel due to gel exuded from the expansion sites.

2. NUMERICAL SIMULATION

Numerical simulation consists of three main models: reaction model, alkalinity model and expansion model. Especially, expansion model plays a critical role to estimate the expansion of concrete.

The stress imposed on the aggregates due to ASR gel formation, σ_{ASR}, can be described as

$$\sigma_{ASR} = S_{gel} V_{gel} \times 1000, \quad (1)$$

where σ_{ASR} is the stress on the aggregates (MPa-gel), S_{gel} is the stiffness per mol of ASR gel in the mortar (GPa/mol/m^3-mortar) and V_{gel} is the total amount of ASR gel in the mortar (mol/m^3-mortar).

Since the elastic modulus of aggregate is large, the elastic deformation of aggregate before cracking is negligible and thus is assumed to be zero for simplification. When the stress is greater than the critical

tensile stress of the aggregate, ASR gel formed in the aggregates began to cause overall expansion of the mortar, giving

$$\varepsilon = \langle \sigma_{ASR} - \sigma_{cr} \rangle^{+} E_d / E_{agg}, \quad (2)$$

where ε is expansion of the mortar, σ_{cr} is the critical tensile stress for aggregates to be cracked (MPa), E_{agg} is a modulus of the damaged aggregate (GPa), E_d is a variable for the conversion of the stress imposed on the aggregates to the expansion of the mortar (-), and $\langle X \rangle^{+}$ is the positive part of X.

Per the above formulation, when E_d is constant the ASR expansion is linearly related to the reaction ratio. However, this does not reflect actual expansion. Aggregate and paste are damaged by ASR expansion and this damage simultaneously reduces the restraint on the ASR gel with the increase in expansion. Therefore, the expansive pressure on the ASR gel is released and reaction kinetics no longer controls the expansion behavior. To express the microstructural damage and resultant reduced expansive pressure of the ASR gel, a damage model is introduced as a simplifying assumption, with

$$E_d = E_0 \times \exp(-\omega \times \langle \alpha_i - \alpha_{th} \rangle^{+}), \quad (3)$$

where, α_{th} is the expansion above which the viscoelasticity of the ASR gel dominates the expansion due to reduced confinement as a result of damage, E_0 is the initial value without damage, and ω is a material parameter representing the rate of damage evolution, which strongly relies on the acceleration conditions of the test.

The numerical results are shown in Figure 1. The legend “linear” assumes that ASR expansion is linearly related to the reaction ratio. The legend “nonlinear”, on the contrary, assumes that expansive ability of ASR gel is reduced with increasing reaction ratio. Especially, at higher temperatures, E_d/E_0 is drastically reduced with increasing reaction ratio. This result can be interpreted as excessively high temperatures causing considerable amounts of ASR gel to exude from the reaction site (gel pocket) and ASR gel losing its expansive ability even with a small reaction. From the numerical results, when damage model is implemented to consider the viscoelastic behavior of the ASR gel and microstructural damage of the aggregate or paste, the simulation agreed with the experimental results. Therefore, such consideration will be necessary for refined numerical prediction.

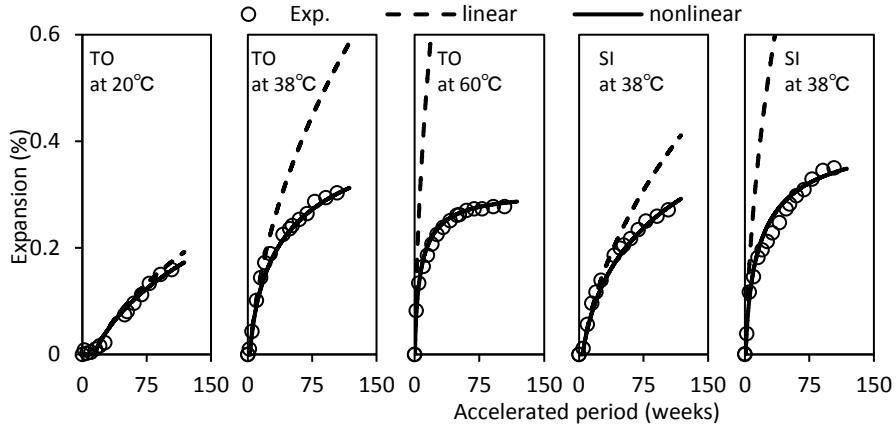

Figure 1 Results of the numerical simulation.

3. CONCLUSIONS

A simplified numerical simulation considering chemical reaction kinetics and the expansion of ASR gel was presented. To express a reduction in the expansive ability of ASR gel due to gel exuded from the sites, a simple damage model was implemented in the numerical framework. By fitting the parameters of the damage model to the experimental results, it was clarified that the expansive ability of ASR gel is considerably reduced at higher temperatures. Therefore, it may be concluded that the interaction between the viscoelasticity of ASR gel and microstructural damage of the aggregate or paste is necessary to be explicitly considered for refined modeling of ASR expansion.

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