# CONCREEP 10

## *Mechanics and Physics of Creep, Shrinkage, and Durability of Concrete and Concrete Structures*

PROCEEDINGS OF THE 10TH INTERNATIONAL CONFERENCE ON MECHANICS AND PHYSICS OF CREEP, SHRINKAGE, AND DURABILITY OF CONCRETE AND CONCRETE STRUCTURES

September 21-23, 2015
Vienna, Austria

SPONSORED BY
RILEM
Engineering Mechanics Institute of ASCE

EDITED BY
Christian Hellmich
Bernhard Pichler
Johann Kollegger

**Published by the American Society of Civil Engineers**

# Uniaxial Restraint Tests under High-Stress Conditions and a Chemo-Hygral Model for ASR Expansion

Y. Takahashi[1]; K. Shibata[2]; M. Maruno[2]; and K. Maekawa[2]

[1]Department of Civil Engineering, The University of Tokyo, Hongo 7-3-1, Bunkyo-Ku, Tokyo 113-8656, Japan (corresponding author). E-mail: takahashi@concrete.t.u-tokyo.ac.jp
[2]Department of Civil Engineering, The University of Tokyo, Hongo 7-3-1, Bunkyo-Ku, Tokyo 113-8656, Japan.

**Abstract**

For evaluating damages of structural concrete by ASR, an analytical platform to rationally deal with the complex interaction of multi-scale chemo-physics events is being developed. For experimental verification of the predictive model proposed, ASR expansion tests under several magnitudes of confinement are conducted and the results are compared with the multi-scale simulation. It is experimentally found that the highly deviatoric compression may bring about isotropically confined ASR expansion. The poro-mechanics based multi-phase modeling can simulate this nonlinearity by considering the quasi-hydro static pressure of created ASR gels in concrete composites and its injection into the micro-pores.

## INTRODUCTION

Although alkali silica reaction (ASR) is one of the major deteriorations of concrete and has been intensively studied in the past decades, practical methods to simulate structural performances of ASR deteriorated concrete are under investigation owing to its complexity of solid concrete and ASR gel's kinematics inside pores. The authors have been developing a model for ASR reaction and its mechanistic actions based upon Biot's solid-liquid interaction model as shown in Figure1 (Takahashi et al. 2014). The gel product is thought to be an agent to migrate inside micro pores and cracks, and the concrete constitutive law of sparse cracking is integrated with the motion of ASR gels (Maekawa et al. 2008). Here, the pressure dependent absorption

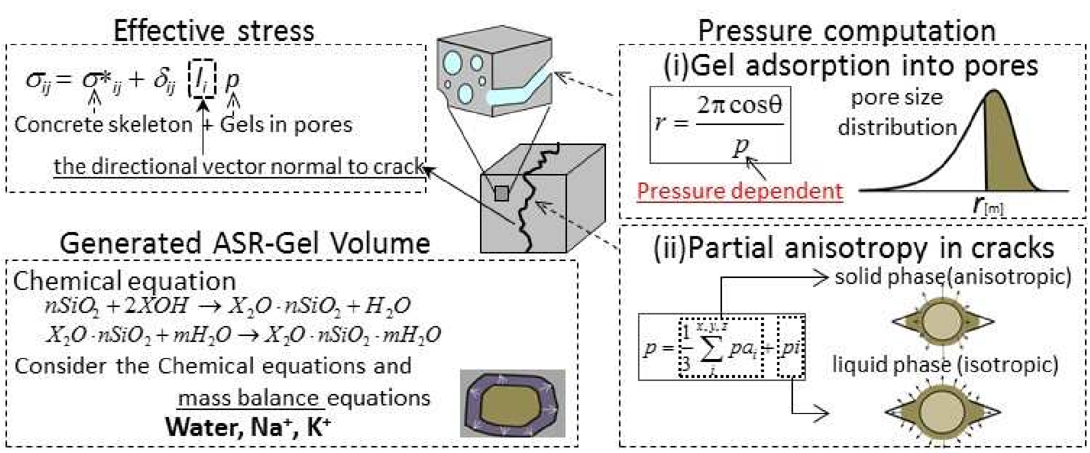


**Figure 1. Models for ASR deterioration**

of gels into cement micro-pores is focused on for consideration of the complex anisotropy of confined concrete with ASR. ASR expansion tests under several grades of confinement are reported in this study and their results are used for experimental verification of the ASR modeling proposed for structural concrete.

## EXPERIMENT

**Objective and test conditions.** ASR-induced expansion tests were conducted in order to investigate the anisotropy of the expansions. Prism specimens were made in the size of 10*10*40cm (Figure 2) with the aggregate, which is reactive with alkali and additional sodium hydroxide was applied to accelerate ASR. The mix proportion is shown in Table 1. The reactive aggregates were originally evaluated as harmless. After 28days sealed curing, specimens were subjected to three levels of restraints. The first is free expansion case, the second is the one with restraint by a steel bar, and the last is the case with 6.2 MPa of additional stress by pre-stressing. After inducing these restraints, specimens were stored inside the ASR-activated environments, i.e., the temperature is kept constant at 40°C and the specimens were wrapped by wet clothes in order to supply enough water which may be consumed through ASR. Under these conditions, strains on the surfaces of the specimens and weight change were measured periodically. By using a contact-type strain gauge with chip targets attached on the specimens, space averaged strain were measured in both longitudinal and vertical directions (Figure 1).

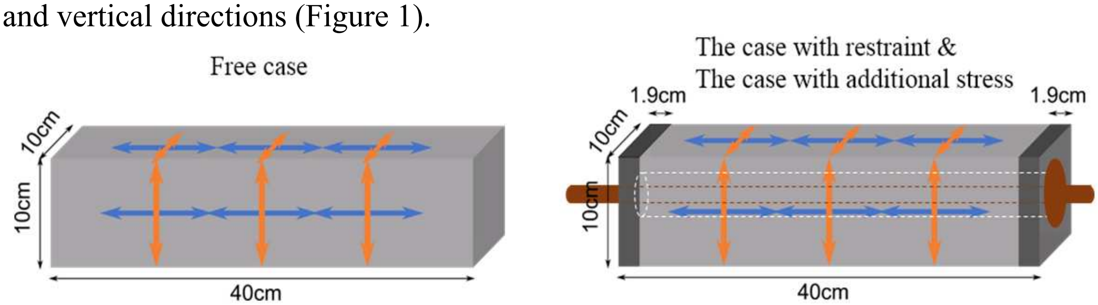


**Figure 2. Dimensions of specimens.**

**Table 1. Mix proportion**

| W/C | W | C | S | G | $Na_2Oeq$ |
|---|---|---|---|---|---|
| 55% | 170 kg/m$^3$ | 309 kg/m$^3$ | 853 kg/m$^3$ | 983 kg/m$^3$ | 6.1 kg/m$^3$ |

**Test results.** Figure 3 shows the weight changes of the specimens. The results of 3 specimens are almost the same. It means that the water adsorption from wet clothes mostly coincides with each other. Then, the degree of ASR and the corresponding moisture states are thought to be similar among these cases. Figure 4 shows the development of the

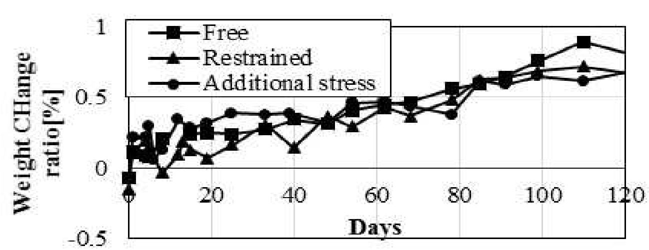


**Figure 3. Weight change of specimens.**

strains in both longitudinal and transverse directions. The isotropic free expansion case indicates approximately 800μ by volume.

Significant anisotropy in expansion was observed in the case with restraint as shown in Figure 4(ii). The absolute expansion is smaller than that of the free case in the longitudinal direction, while it is larger than the free case in the vertical direction. It is due to the restraint by steel bar and such a behavior is well-known as anisotropic effect caused by liquidity of ASR gel.

The response of the case with additional compressive stresses (Figure 4(iii)) differs from the simple restraint case. Not only in the longitudinal direction but also in the vertical one, the expansion is considerably decreased in comparison with other cases. This fact cannot be simply explained only by the change of the ASR-gel movement directions. It appears that some of the generated ASR-gel is not obviously active but firmly fixed on the aggregates. The gel adsorption into the pores of concrete mixture leads to less expansion in such a large stress conditions.

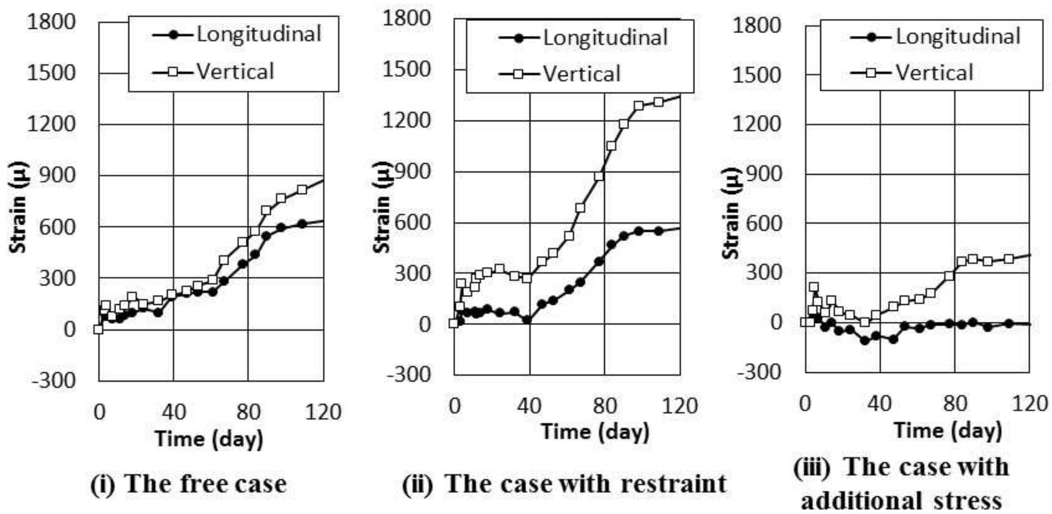


**Figure 4. Measured expansion in each restraint condition**

**Comparative analysis.** Figure 5 shows the analytical results which simulate the uniaxial restraint experiments. Reactivity of aggregate or physical properties of ASR-gel cannot be modeled precisely, so those variables are determined by sensitivity analyses using the experimental data for the free case. The applicability of the models can be confirmed with comparing the behaviors in restraint conditions.

For the case with additional stress, the analysis successfully reproduced the expansion behavior in both longitudinal and transverse directions. Without modeling the gel absorption considering the gel pressure, such like behaviors cannot be simulated. Focusing on the amount of gel absorption in the computation (the graph is shown in Figure 6), the absorbed amount at day 120 is about 25% larger in the additional stress case than the free case. Such difference in adsorbed amount can create the significant behavior change in expansion. It is confirmed that analytical model of pressure dependency of gel absorption is needed for ASR-induced expansions.

For the case with simple restraint, the anisotropic expansion (Figure 4(ii)) is not well simulated (Figure 5(ii)), while such like anisotropy in uniaxial restraint experiments can be reproduced with current models in past research by Takahashi et al.. The difference between past and this research is the final expansion amount of free cases; 3500μ in past research and 800μ in this research. Further research about the gel properties focusing on such a moderate ASR expansion cases seems to be needed.

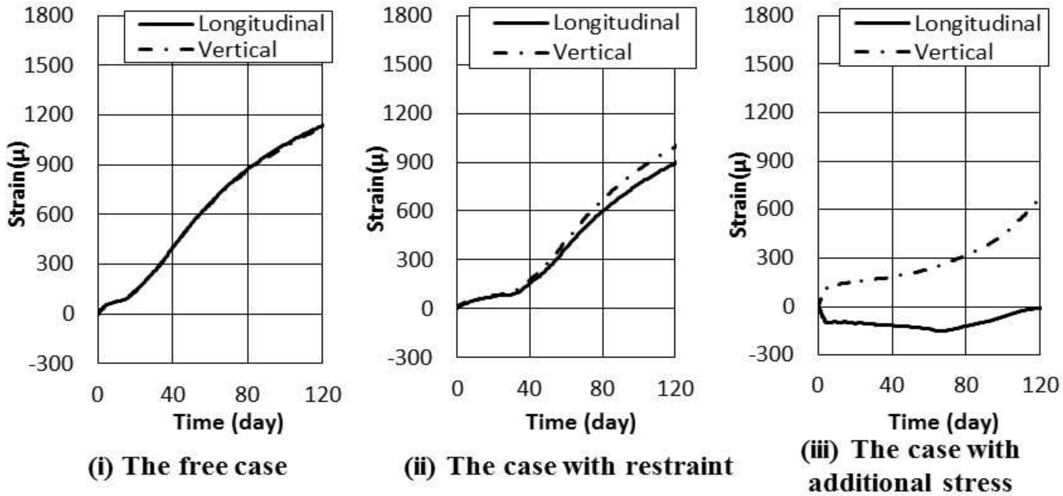


**Figure 5. Simulated expansion in each restraint condition**

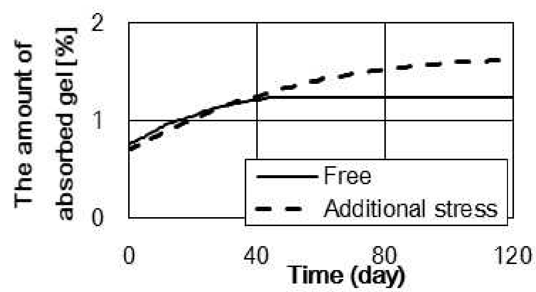


**Figure 6. Gel absorption to pores**

## CONCLUSIONS

ASR expansion and the uniaxial confinement experiment by steel rods are conducted for experimental verification of the ASR modeling based upon the multi-scale formulation. The significant anisotropic expansion in restraint conditions was experimented. In the case where additional stress is applied further on the pre-expanded concrete, the characteristic expansion was observed and the experimental isotropic and anisotropic deformation is fairly simulated especially by considering the absorption into pores according to the ASR-gel pressure.

## REFERENCES


Maekawa K., Ishida T. and Kishi T. (2008). Multi-Scale Modeling of Structural Concrete, Taylor and Francis

Meakawa K. and Fujiyama C. (2013). Rate-dependent model of structural concrete incorporating kinematics of ambient water subjected to high-cycle loads, Engineering Computations, Vol. 30, Iss: 6, 825-841

Takahashi, Y., Shibata, K., Maekawa, K. (2014). Chemo-hygral modeling and structural behaviours of reinforced concrete damaged by alkali silica reaction, Proceedings of ACF2014, pp.1274-1281

Tsukada T., Koga H., Hayakawa T., Watanabe H. and Kimura Y. (2010). Basic study about expansion and restriction of structural concrete deteriorated with alkali silica reaction, Proceedings of JSCE, V-276, 551-552 (in Japanese).