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A Time-Dependent Chemo-Mechanical Analysis of Alkali-Silica Reaction for the Disparate Geometry of Concrete Meso-Structure

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Abstract

Complex chemophysics of alkali-silica reaction (ASR) in Portland cement concrete deteriorates concrete service life and requires quantitative assessment. Within this context, the developed model provides a new perspective from mesoscale chemo-mechanical scheme for a better understanding of ASR kinetics. The simulated results shows how ASR expansion as well as ASR-induced damage progresses in concrete structure based on different composition of reactive aggregate and alkali hydroxide concentrations. This model can be used as an effective tool in the field of concrete materials to predict the service life, as well as on time maintenance decision of concrete structure.

Comments

This work has been published in *Construction & Building Materials.*

Please see the following ScholarWorks record for more information:

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A Time-Dependent Chemo-Mechanical Analysis of Alkali-Silica Reaction For The Disparate Geometry of Concrete Meso-Structure

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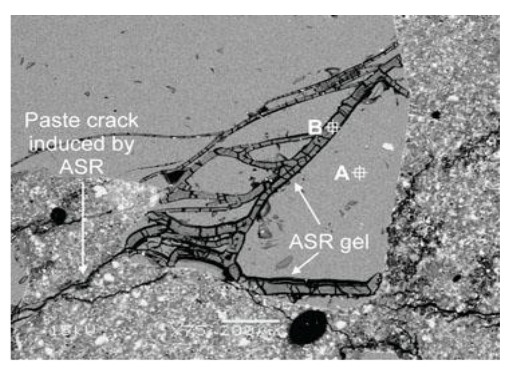
INTRODUCTION& MOTIVATION

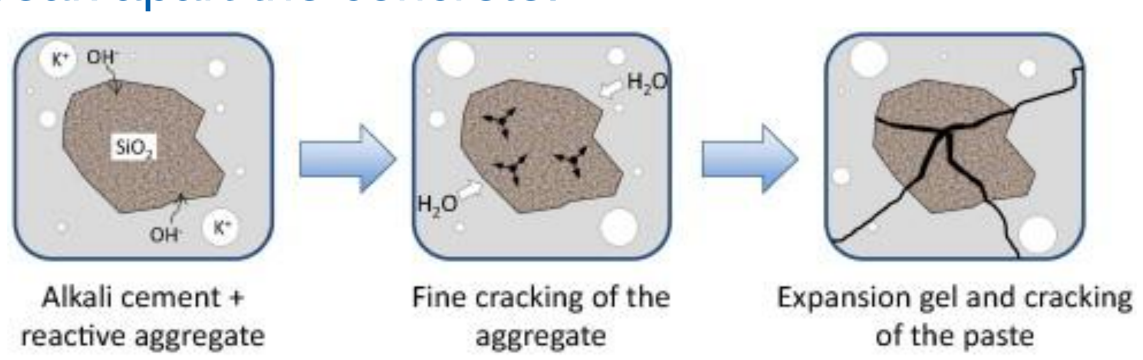
Portland cement concrete is a common construction material that is frequently used due to its durability, long service life and great economy. However, chemical reactions between reactive aggregate particles & cement paste lead to concrete degradation over time. Alkali-silica reaction (ASR) is one of those undesirable chemical reactions. ASR damage is caused internally and becomes visible when the structure is already damaged. It is a threat to socio-economic development of society. ASR is called as Concrete Cancer.

WHAT IS ASR?



Step 1: Silica in aggregates reacts with alkali in cement to produce a gel.

Step 2: The gel absorbs water, causing expansion and hydraulic pressures sufficient to fracture and break apart the concrete.



ASR DAMAGE

A threat to:

- Concrete Pavement & Bridges
- Nuclear Plant, Dams
- Airport Runway
- Other Concrete infrastructures

Nuclear Power Plant in Seabrook,

Pavement Damage due to ASR

CNN Newsletter April 3, 2019

47,052 bridges need urgent repairs in USA.

- Rhode Island (23%)
- West Virginia (19.8%)
- Iowa (19.3%)
- South Dakota (16.7%)
- Pennsylvania (16.5%)

Bridge Collapse in Tennessee

RESEARCH GOAL

- To generate concrete meso-structure based on cement-aggregate proportion.
- To develop a computational model as per ASR kinetics that can visualize damage propagation and predict concrete service life.

ASR MODEL: GOVERNING EQUATION SETS

Mass balance and Momentum balance:

$$\frac{\partial}{\partial t}(c_i) + \nabla\cdot(-D_i\nabla c_i) + \boldsymbol{u}\cdot\nabla c_i = R_i$$

Darcy's Law:

$$\frac{\partial}{\partial t}(\varepsilon_p\rho) + \nabla\cdot(\rho\boldsymbol{u}) = Q_m$$

$$\boldsymbol{u} = -\frac{\kappa}{\mu}\nabla p$$

- For Unsaturated Condition.

$$D = 2.021\times\varepsilon_{vol} - 0.195$$

$$\varepsilon_{vol} = \varepsilon_{gel} + \varepsilon_{stress}$$

$$\varepsilon_{gel} = \frac{\rho_{gel}}{\rho_c + \rho_{gel}}$$

$$\rho_{gel} = [\text{Expanded ASR gel}]\times M_{gel}$$

$$\frac{\partial}{\partial t}(u) + \nabla\cdot(-D_{gel}\nabla[\text{ASR gel}]) + \boldsymbol{u}\cdot\nabla u = f(u)$$

$$\frac{\partial}{\partial t}(\varepsilon_p\rho) + \nabla\cdot(\rho\boldsymbol{u}) = Q_m$$

$$\boldsymbol{u} = -\frac{\kappa}{\mu}\nabla p$$

$$Q_m = 0.018\times f_{[H2O]}$$

$$\varepsilon_{stress} = \varepsilon_{11} + \varepsilon_{22} + \varepsilon_{33}$$

$$u = [[\text{Siloxane}], [\text{ROH}], [\text{ASR gel}], [\text{Silanol}], [\text{H2O}], [\text{Expanded ASR gel}]]^T$$

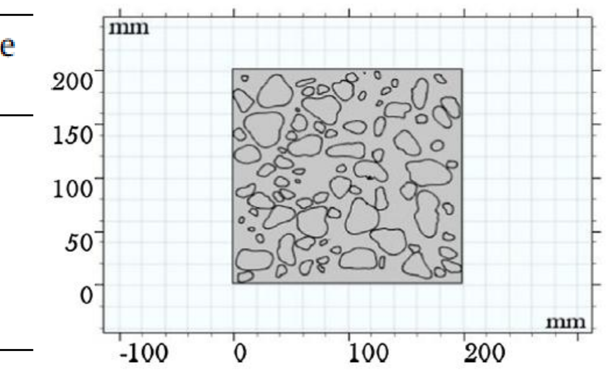
$$\begin{aligned}
f_{[\text{Siloxane}]} &= -k_1[\text{Siloxane}][\text{ROH}]\\
f_{[\text{ROH}]} &= -k_1[\text{Siloxane}][\text{ROH}] - k_2[\text{Silanol}][\text{ROH}]\\
f_{[\text{ASR gel}]} &= k_1[\text{Siloxane}][\text{ROH}] + k_2[\text{Silanol}][\text{ROH}] - k_3[\text{ASR gel}][H_2O]\\
f_{[\text{Silanol}]} &= k_1[\text{Siloxane}][\text{ROH}] - k_2[\text{Silanol}][\text{ROH}]\\
f_{[H_2O]} &= k_2[\text{Silanol}][\text{ROH}] - k_3[\text{ASR gel}][H_2O]\\
f_{[\text{Expanded ASR gel}]} &= k_3[\text{ASR gel}][H_2O]
\end{aligned}$$

- i = Denotes Each Species, respectively
- C = Concentration of species
- Di = Diffusion Coefficient
- u = Velocity Field
- R, f(u) = Source Term
- Qm = Discharge
- P = Developed Pore Pressure
- D = Damage Function

PREDICTIVE MODEL

A 200mm*200mm Concrete block was considered.

Geometry Sets	Cement to Aggregate Ratio (C/A)
Case 1	1.13
Case 2	1.61
Case 3	2
Case 4	0.5
Case 5	1



Damage Function: $D = \begin{cases} 0 & \text{when}, \varepsilon_{gel} \le 0.1\% \\ w & \text{when}, \varepsilon_{gel} > 0.1\% \end{cases}$

For validation predictive model was run for 400 days.

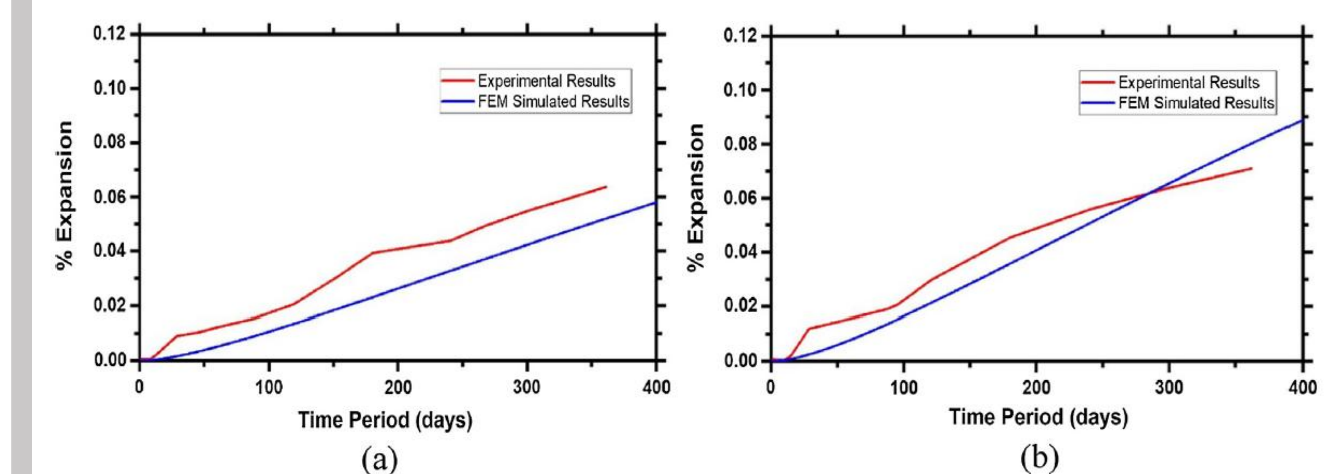


Fig.: Comparison of FEM simulated data with the experimental data as per case 4 (C/A: 0.5): (a) 20 degC ROH 0.8 mol/m3, (b) 20 degC ROH 1.2 mol/m3

RESULTS & DISCUSSIONS*

A 30 years simulation period as well as 10 case studies corresponding to concrete domain and ROH concentration, provide an in depth view of concrete degradation with the progression of time.

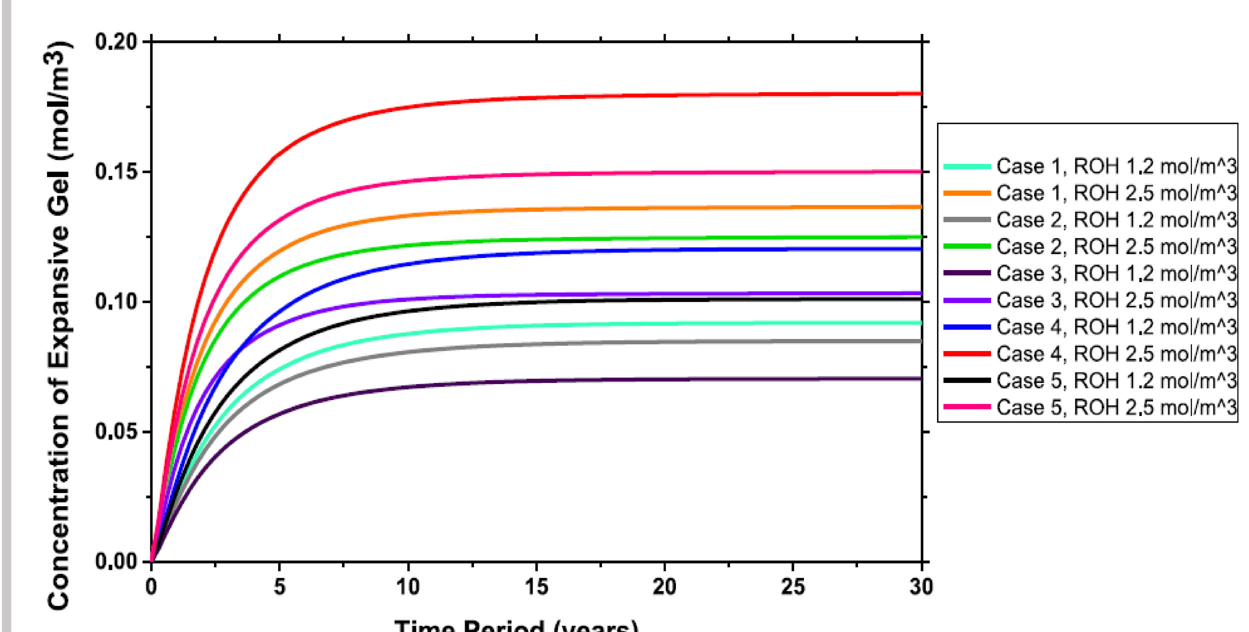


Fig.: Concentration of expansive ASR gel (mol/m3)

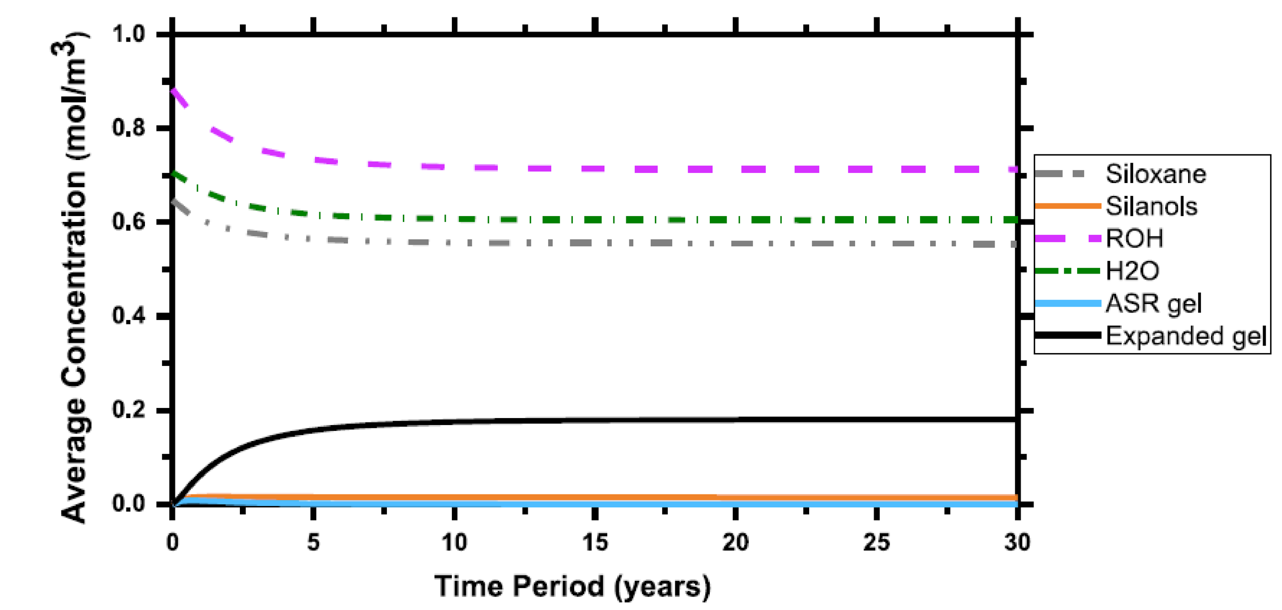


Fig.: Comparison between concentrations of all six species (mol/m3))

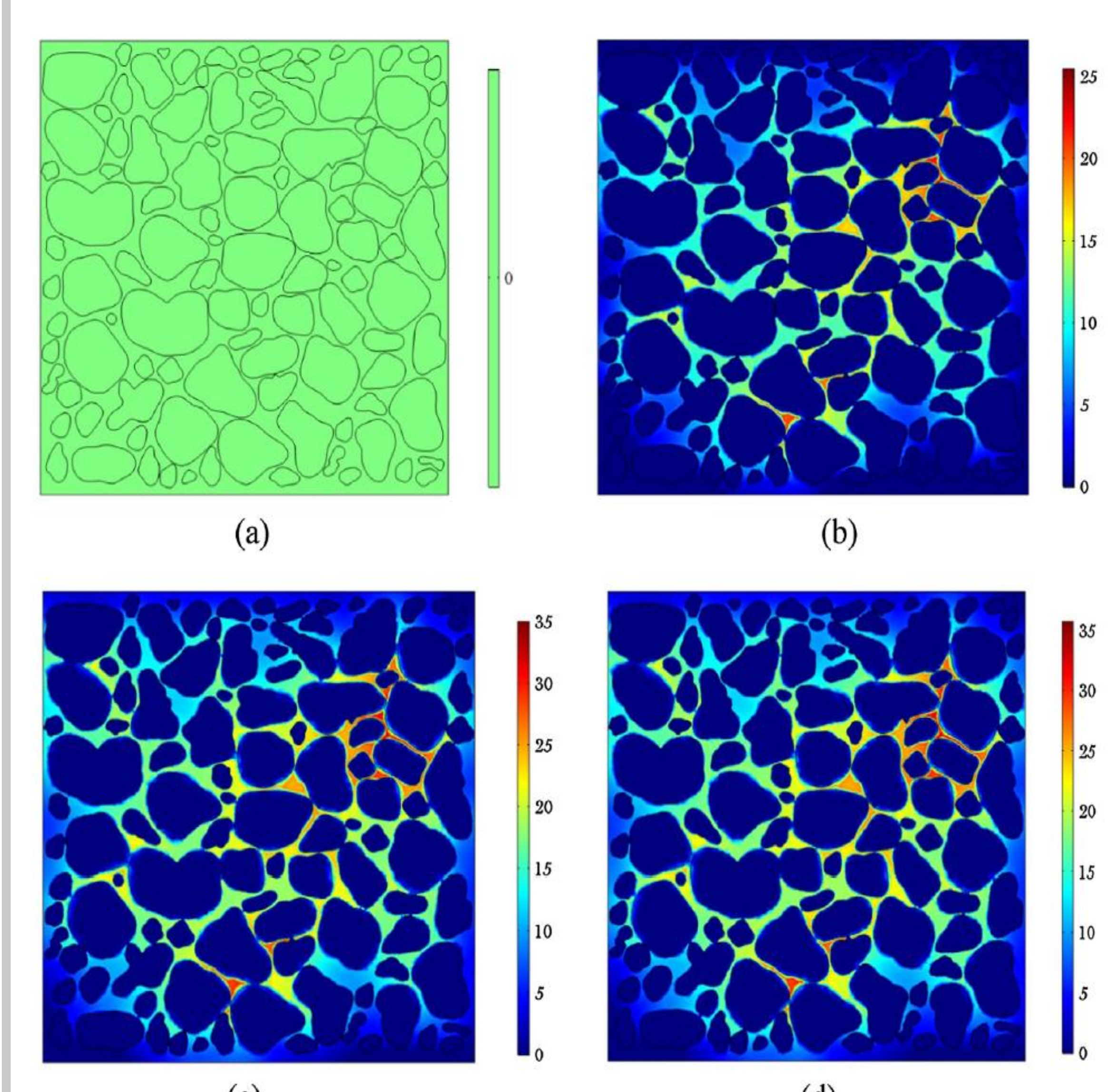


Fig.: Damage in concrete domain due to ASR gel case 4 with ROH of 1.2 mol/m3: (a) 0, (b) 5, (c) 15, and (d) 30 years..

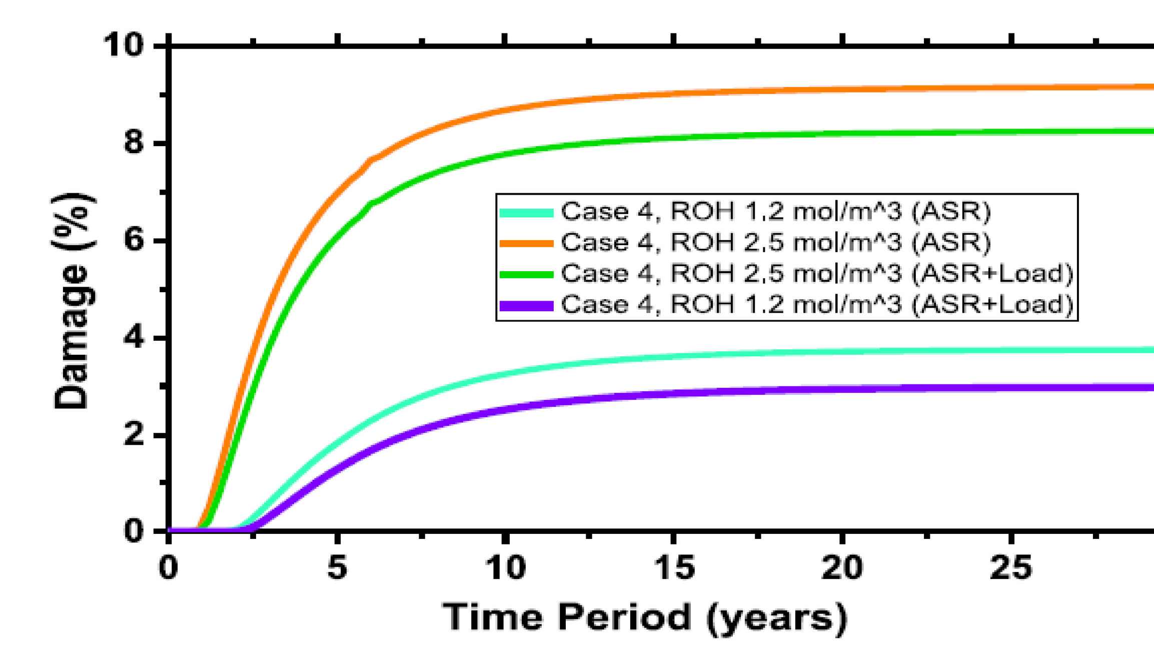


Fig.: Percentage of damage in concrete domain for case 4.

HEIGHLIGHTS

- ✓ An effective tool to predict service life of concrete.
- ✓ Applicable to any concrete structures, i.e., Pavement. Bridges, Dams. Nuclear reactor etc.
- ✓ Can act as a guideline for government or construction industries.
- ✓ Potentially minimize time consuming and costly lab tests.

FUTURE GOALS

- ✓ Create Database from developed model based on case study
- ✓ Develop an artificial neural network (ANN) interface to predict service life..

*Rahman, Md. Asif, Yang Lu, "A Time-Dependent Chemo-Mechanical Analysis Of Alkali-Silica Reaction For The Disparate Geometry Of Concrete Meso-Structure," Journal of Construction and Building Materials, Volume 211, 30 June 2019, Pages 847-857.