Tran-SET
Transportation Consortium of South-Central States

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Modeling Sulfate Attack in Modern Concrete for Building Sustainable and Resilient Infrastructure

Key Points

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17CTAM01

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Lead Institution:
Texas A&M University

Funds Requested to UTC:
$25,000

Funding Source(s):
Tran-SET
Texas A&M University

Total Project Cost:
$50,000

Brief Project Description

This project will develop a coupled diffusion-binding-poromechanical model to determine crack initiating stresses induced by the formation of expansive ettringite caused by sulfate attack.

Problem Statement

According to the nation's existing highway and transit condition and performance report published by the Federal Highway Administration (FHWA), over $35 billion was spent in 2012 in replacing and rehabilitating the existing pavements and bridges [1]. Even though the concrete structures are built conforming the building codes and recommendations, much of the rehabilitation is due to the material deterioration exposed to aggressive environments. Sulfate attack is known to be the most widespread form of chemical degradation of concrete that appears in regions where concrete is exposed to soil or water containing sulfates and manifested either in the form of large expansion accompanied by internal stresses leading to cracks or softening and disintegration of the cement matrix. While most previous research deals with the experimental determination of concrete susceptibility to sulfate attack, these tests require months to perform; with little data available for modern materials for which increasing substitution of cement is utilized to reduce energy consumption and environmental emission. Moreover, the alternative recommended accelerated tests do not mimic the field conditions.

Based on the previously performed experimental studies, the current design code prescribes a maximum allowable limit for the tricalcium aluminate phase in cement to mitigate the problem. This limit prohibits practitioners from using local raw materials and researchers from engineering binders with broad chemical and physical properties. Therefore, a mechanistic based fundamental model is required to account for the effect of the variability in raw materials and environmental exposure on the damage propensity by sulfate attack. A mechanistic model will allow engineers to understand the underlying mechanism dictating the damage evolution process by sulfate and guide them to develop new binding materials and build economic and durable infrastructure.

Objective

The primary objective of this proposed research project is to develop a chemo-poro-mechanical model to predict internal stresses induced by the formation of expansive agents (e.g., ettringite) and the subsequent expansion triggered by the sulfate attack. A sensitivity analysis will be performed to determine the effect of the environmental exposure (e.g., species and concentration of the sulfate ions) and the poro-mechanical properties (e.g. porosity, permeability, and compressibility) of various phases (cement mortar, aggregate, pore solution, and ettringite) to provide guidelines on how to control material parameters to mitigate damage susceptibility of concrete to sulfate attack. The sulfate attack can also cause decalcification of the cement matrix without showing any significant expansion and lead to disintegration of the matrix. The proposed work will only deal with the analysis of the expansive stress caused by the ettringite formation. The softening of materials due to decalcification of the cement matrix is subject to more rigorous analysis and thus will not be considered in this work.

Intended Implementation of Research

In order to disseminate the developed model and research results to public, student, researchers, and practitioners, a project website featuring the final report will be developed.

Workforce development: The members (graduate students and post-doctoral researchers) working on this research project will develop a new modeling skill specializing in multi-physics, multi-phase material modeling. They will also learn poro-mechanics, a relatively new field to the concrete society. The undergraduate student workers will learn experimental techniques on measuring material deterioration due to sulfate attack.

Education: Sulfate attack is a major problem of cement based materials and therefore is an exciting learning topic for civil and materials engineering undergraduate and graduate students. The developed research can be potentially included in the undergraduate and graduate curriculum as an emerging technology for mitigating the problem. The project website will serve as a learning tool and will provide free access to public, students, researchers, and engineers.

Anticipated Impacts/Benefits of Implementation

A website containing the model and the research study will be developed for all users. It is expected that the simulated results for a variety of material constituent properties, cement type, and environmental exposure (sulfate ion concentration and type) will serve as a database for modern materials for which experimental data are dearth. Use of the model and such database will allow engineers to use local materials, engineer binders with broad physical and chemical properties, and build economic and durable infrastructure with definite prediction on the future performance. Utilization of raw materials and no restriction on the cement chemical composition will in turn reduce construction and maintenance cost, energy consumption, and environmental emissions.

Weblinks:

http://transet.lsu.edu/research/research-in-progress/

https://rip.trb.org/view/1467368