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Structural and Physical Aspects of Construction Engineering

Using Mathematical and Numerical Methods Towards on the Pipelines´ Material Sustainability

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Abstract

This paper is focused on the statistical analysis of a correlation between the selected corrosion parameters of concrete composites with 10 wt.% of coal fly ash replacement exposed to de-ionized water (pH value of 6.25), 0.5% solution of H_2SO_4 (pH value of 0.99) and 0.5% solution of $Al_2(SO_4)_3$ (pH value of 3.22). Experiments runs in five consecutive phases over a period of 50 days. Dissolved amounts of Ca, Si, Fe and Al due to the aggressive media exposure, from the cement matrix into leachates, were measured in the experiment by X-ray fluorescence (XRF). Analyzing the concentration of selected ions considering mutual dependences on time (measured after each phase) is presented in the paper. Correlation between differential dissolved masses of the chemical elements considering each aggressive media are calculated and discussed.

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1. Introduction

Concrete often undergoes to significant alterations that can have significant adverse consequences on its engineering properties when is exposed to interaction with the service environment. Many studies are aimed on investigation of the durability of hydrated cement systems and their constituent phases.

External sulphate attack is not completely understood. Sulphate corrosion from the external environment is one of the most common types of concrete deterioration and typically it occurs where water containing dissolved sulphate penetrates the concrete. It causes the changes in composition and microstructure of the concrete. These changes may

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vary in type or severity but commonly include extensive cracking, expansion and loss of bond between the cement paste and aggregate. Alteration of paste composition, with monosulphate phase converting to ettringite and, in later stages, gypsum formation. The necessary additional calcium is provided by the calcium hydroxide and calcium silicate hydrate in the cement paste. The effect of these changes is an overall loss of concrete strength [1].

The assessment of the condition or health of pipeline systems is very difficult given that they are typically buried and therefore not readily accessible for visual inspection [2]. From a corrosion perspective, the sewage is no more corrosive than ordinary "fresh" water, i.e., water that is neither acidic nor alkaline. Wastewater is aerated in most parts of the wastewater system, at least where the biological reactions do not consume all the dissolved oxygen. In areas where waste water is not aerated, it produces much more corrosive conditions for many materials [3]. Rozière, E. et al. 2009 [4] exposed concrete specimens to external sulphate attack at two levels of sulphate concentration to provide long-term data that can be used to study the relevance of the accelerated tests and models which are being developed. Results from both series of tests show a correlation between the resistance to leaching and the resistance to external sulphate attack. Yuguo, Y. et al. 2015 [5] used a numerical method and analysis procedure to investigate the calcium leaching and external sulphate attack on cement paste. Modelling includes three modules (diffusion, chemical and damage quantification module). The details of the multi-ionic transport model STADIUM® intended to describe the degradation of cement-based materials exposed to aggressive environments are reported by Samson and Marchand 2007 [6]. The main algorithm is based on an operator splitting approach. The model is compared to experimental results of hydrated cement pastes exposed to pure water and sodium sulphate solutions.

Degradation experiments conducted under saturated and unsaturated conditions were studied in research by Y. Maltais et al. 2004 [7]. At the end of the exposure period, microstructural alterations were investigated by microprobe analyses, scanning electron microscope observations and energy-dispersive X-ray analyses. Test results provide information on the basic aspects of various degradation phenomena, such as decalcification and external sulphate attack. Experimental results were also compared with results obtained by a numerical model. The analysis reveals that the intricate microstructural features of the degraded samples could be accurately reproduced by the model. Different methods of maintaining the reliability of critical infrastructure were presented in [8, 9,10].

The objective of the paper is applying a mathematical approach using simple numerical investigation of the concrete´s corrosion parameters, represented by dissolved masses of main components and pH of media, under sulphate attack. Determination of concentrations of selected ions considering mutual dependences on both time are presented in the paper. Correlation analysis between the chemical elements´ differential concentration increments considering each aggressive media are calculated and discussed.

2. Material and Methods

Concrete´s corrosion parameters – dissolved masses of calcium, silicon, aluminium, and iron and the pH values of the leachates were obtained by an experimental research. Concrete cylinder samples of a 32 mm diameter and 15 mm height were formed as a drilled core from concrete cubes (150x150x150 mm) using drilling mechanism STAM. Concrete consisted of a mixture where 10 wt. % of cement was replaced by coal fly ash. Used coal fly ash with volumetric weight of 2381 kg/m^3 originates from black coal's burning process. The coal fly ash was used for cement composite preparation without any modification. The cylinder specimens were rid of impurity, dried at 105 °C to a constant weight and then immersed into three aggressive media representing three models of corrosion: de-ionized water with pH value 6.25 was used to simulate a corrosion caused by leaching, 0.5% solution of H_2SO_4 (a pH value of 0.99) was used to simulate an acidic corrosion, and 0.5% solution of $Al_2(SO_4)_3$ (a pH value of 3.22) was used to simulate a sulphate corrosion. The solution of 0.5% H_2SO_4 was prepared by dissolving of 98% H_2SO_4 of analytical grade in de-ionized water. The solution of 0.5 % $Al_2(SO_4)_3$ was prepared by dissolving 171.1g of $Al_2(SO_4)_3$ in distilled water and filled up to volume of 1000 mL.

Laboratory experiments simulating the corrosion processes proceeded over a period of 50 days in five consecutive phases consisting of the following steps:

- 1st - 7th day: exposure of the concrete samples to the liquid medium;
- 8th day: removal of the concrete samples from the liquid medium;
- 8th - 9th day: drying the samples at room temperature and afterwards removing of precipitations by little brush;