Durability of Cement Mortars and Concretes Exposed to Biological Attack as One of the Sustainability Parameter – A Correlation Analysis

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Abstract
Among the pillars of the sustainability, the aspect of prolongation of life of constructions has to be involved. Focus on sustainability leads to study of durability of building materials. Phenomenon called bio-corrosion can result in structure deterioration. Special attention is paid to oxidation of hydrogen sulfide to sulfuric acid by bacteria community established on a concrete surface. The type of the binder and composition of aggregate is a very important factor for investigation of the bio-corrosion processes of concrete. In this paper, a comparison of deleterious processes proceeded in cement composites exposed to bacterial influence was investigated. Concentrations of dissolved ions (Ca, Si) in leachate (as an indicator of bio-corrosion) after 270-day exposure to *Acidithiobacillus thiooxidans* were measured every 7 days during the experiment. The samples of cement mortars and concrete composites were compared. The correlation analysis was confirmed to be a useful tool to help the interpretation of the experimental findings.

Keywords: bio-corrosion, *Acidithiobacillus thiooxidans*, leaching,sulfate.

1. Introduction

One of the pillars of the sustainability of building materials is durability. It is stated when the buildings are durable they are sustainable, so the same relation should be found in the building materials. Sewage networks are often deteriorated the by the corrosion of concrete due to in-situ production of sulfuric bacteria. The production of H_2SO_4 is the result of the processes which are responsible for microbial induced corrosion-biocorrosion. Bacteria deteriorates the concrete by produced sulfuric acid when H_2S presented at sewers is broken down (Scrivener and De Belie, 2013). Concrete with supplementary cementitious materials, such as granulated black furnace slag (GBFS) belongs to the family of the materials that has the potential to provide low-carbon, high-performance alternatives to Ordinary Portland Cement (OPC) binders, contributing to the durability and thus to the sustainability of the construction (Mangat and Lambert, 2016). Appropriate usage of natural resources, reuse and recycling are very important activities directly connected with sustainability of the construction materials. The sustainability assessment of cement production in relation to prepare the most appropriate mixture respecting the required attributes of the concrete is studied in many scientific manuscripts (Ondrejka Harbulakova et al. 2017; Mangat and Lambert, 2016; Estokova et al. 2016). The main objective of this paper is to analyze a relationship between deterioration of cement mortars and concrete composites exposed to the bacterial influence with regard to the sustainability aspect. The method of mathematical analysis using correlation coefficient was chosen to increase the understanding of the interactions between concrete/mortars and the microorganisms causing concrete bio-corrosion.

2. Experimental

The concretes prisms were prepared in two mixtures for two sets of specimens. The first mixture was prepared only with ordinary Portland cement (OPC) (C0 sample) while second mixture consisted of 95 wt.% of granulated blast furnace slag (GBFS) and 5 wt.% of OPC (C95 sample). The water/cement ratio was equal to 0.55 in both mixtures. The prisms were cut into smaller samples with dimension 50x50x10 mm to be tested in the bacterial experiment. Cement mortars were prepared also in two different mixtures with the same w/c ratio = 0.55. The first mixture was with the OPC, sand and water (M0 sample). The second mixture was set similarly, but with 95 wt.% of GBFS and 5 wt.% of OPC (M95 sample). The dimension of the mortar prisms were 160x40x40 mm. After hardening for 24 hours, the specimens were cured in water for 28 days according to EN 196-1. Consequently, all specimens were brushed, sterilized in 70 % ethanol and dried at 80°C to constant weight. After ensuring the sterile condition before the start of the corrosion experiments, the specimens were kept in thermostat with bacteria *A. thiooxidans* at temperature of 28°C and pH of 4, over a period of 9 months. pH was kept at the constant level during the experiment and the activity of bacteria was controlled. *A. thiooxidans* were isolated from acid mine water and cultivated by Medium S nutrient. More detailed experimental information are given in our previous paper (Estokova et al. 2016) where the samples were investigated at the same pH. A chemical composition of samples´ leachates and pH were investigated every month. Chemical composition of the leachates was determined by X-ray fluorescence analysis. A correlation analysis was the tool for investigation of deterioration caused by biological effect on concrete/mortars specimens. Using the Software Excel 2010 by Microsoft, calculation of linearity and correlative closeness of calcium and silicon leached-out masses from both sets of concrete/mortars specimens was done.

3. Results and Discussion

The XRF-measured dissolved amounts of the calcium and silicon ions were considered as the parameters indicating the decomposition of the cement matrix. Considering the solubility of the main oxides of the concrete, Ca^{2+} compounds, preferably portlandite, was readily soluble at all acid pH levels as shown in Estokova et al. (2016) and each mole of calcium which dissolved could neutralize 2 moles of the acid. (Scrivener and De Belie, 2013). Consequently, after the calcium hydroxide exhausting, the calcium-silicate-hydrates decomposed as well as releasing the other calcium and silicone. Al_2O_3 and Fe_2O_3 are virtually insoluble even in low pH. Al_2O_3 is virtually insoluble above pH 4, but below this pH dissolves to neutralize 3 moles of acid. Considering the pH kept on value minimum equal to 4, only Ca^{2+} and Si^{4+} ions have been investigated in the correlation analysis as reported in Tables 1 and 2.

Table 1. Correlation of Ca dissolution between the concrete and cement mortar samples

	C0/M0	**C95/M95**
Correlation coefficient	0.68	0.84
Correlation type	fully linear	fully linear
Correlative closeness	significant	high

As is seen in Table 1, the high correlation was found when compared the leaching of calcium from concrete and cement mortars with the 95 wt. % of slag. This finding confirms the general knowledge that cement matrix is the part of the concrete which degrades mainly under *A. thiooxidans* bacterial attack. There was no significant difference in calcium leaching from slag-based samples of different sizes. Weaker dependence was found on samples without slag addition which could be linked to the differences in samples sizes. The relation between several sizes and shapes of concrete composites and the deleterious effect of sulfuric acid was also investigated by Hewayde, 2005. It was proven by other authors (Ehrich et al., 1999; Monteny et al. 2001) that different size and shape of tested composites can result in differences in measured parameters.

Regarding the Si releasing from cement mortars and concrete samples, no dependence was obtained in case of the samples without slag (C0/M0) while only slight one in case of the slag-based samples. For both the elements analyzed, calcium and silicon, the same trend was observed that the slag samples had a better correlation. That can point to the higher importance of aggregates in the neutralization capacity in the OPC samples. In the case of a biocorrosion the presence of lime and alumina is very welcome because of a high neutralization capacity. It was confirmed by De Belie et al. (2004) that usage of limestone and dolomitic aggregate gives much better attributes to concrete from the biocorrosion point of view.

Table 2. Correlation of Si dissolution between the concrete and cement mortar samples

	C0/M0	**C95/M95**
Correlation coefficient	-0.23	0.43
Correlation type	inversely linear	full linear
Correlative closeness	non	medium

4. Conclusion

The bio-corrosive deterioration of the concretes and cement mortars with the same GBFS proportions (0 and 95%, respectively) was evaluated by leached-out masses of calcium and silicone. Findings revealed that in the case of samples without slag there were significant differences in the amounts of calcium and silicon leached out of the concrete compared to cement mortars.

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