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Implementing ANN to minimize sewage systems concrete corrosion with glass beads substitution

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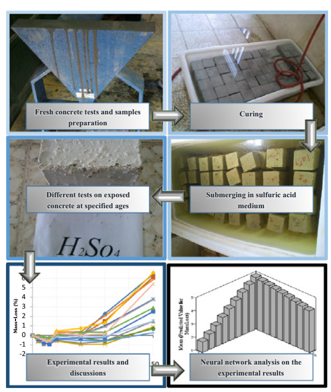
HIGHLIGHTS

- Mass-loss increases with decreasing volume of permeable pores.
- Durability may be monitored by recording RCS-Losses for future performance prediction with ANN.
- Glass powder and microsilica enhance the durability of sewer concrete.
- With respect to ANN, lower compressive strength leads to enhanced durability in H_2SO_4 Medium.

GRAPHICAL ABSTRACT



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ABSTRACT

Sewage system collapse is a widespread problem due to induced sulfuric acid corrosion by sulfur-oxidizing bacteria. Numerous studies tried to enhance concrete performance which led to contradictory results; this matter signifies on dissimilar laboratory conditions and results analysis methods. Glass is known as one of the most resistant materials against sulfuric acid (H_2SO_4) attack; it can be assumed that concretes containing glass powder have acidic resistance as well. The high silica content in both glass powder and microsilica clear the way for comparing their effects on the durability of self-consolidating and ordinary concretes with the same packing density in the H_2SO_4 medium. Different concrete relationships were elicited among concrete characteristics by performing statistical analyses. Artificial neural networks (ANN) was employed to predict the mass-loss and volume-loss in the specimens. It was found that both the substitutional materials used were capable of enhancing sewer durability.

1. Introduction

Self-Consolidating Concrete (SCC) signifies one of the most outstanding advances in concrete technology in recent decades [1]. It was originally introduced by Professor Ozowa in Japan in 1989 and later developed by Bartos, Grauers, Okamura and Ouchi [2]. Recently, this type of concrete has found wide applications in

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many construction projects for different purposes [3], especially in sewage systems where ordinary concrete may not be spread all over the forms due to small spacing between the steel bars. This widespread use of SCC in the construction industry is expected to continue in near future, thanks to its many technical and economic advantages in structure service life [2,4]. SCC is associated with higher initial costs compared to ordinary concrete due to the relatively high use of cementitious materials and chemical admixtures, depending upon the quality and compositions of the mixture and their sources [2,5,6]. Adding a large volume of powdered materials like glass filler and silica fume can, however, reduce the costs (for glass powder usage) while it also overcomes the problem of segregation (for microsilica usage) in concrete [2]. Environmental pollution as well as the high volume and cost of waste disposal in recent years have encouraged researchers to develop methods of reusing waste materials. Some researchers have proposed to use waste glass as aggregate, filler, or supplementary cementitious material in concrete and asphalt not only to reduce the cost of concrete but also to provide a solution for waste disposal and the related environmental problems [7–13]. As SCC gains ground in the construction industry, concerns about the risk of concrete exposure to adverse conditions and its service-life increase accordingly. It is, therefore, vital to evaluate the long-term properties and service performance of concrete such as durability under different corroding conditions. To the best of the authors' knowledge, no study has been reported in the literature on the use of glass powder as a cement replacement in SCC mixtures under severe acid attack. Besides, high amount of SiO2 in Microsilica and glass powder encouraged the researcher of this study to make a detailed comparison between these two substances. Lower price of glass powder, high resistance to sulfuric acid and huge production of this kind of waste which is more than 7040 thousand of ton per year just in the United States in 2014 [14], are the reasons to study the concrete performance containing these two pozzolans in sulfuric acid medium. Hence, the present study was designed and implemented to evaluate the behavior of SCC subjected to sulfuric acid (H_2SO_4) attack by using locally available materials. Degradation of concrete members exposed to aggressive H_2SO_4 environments is a key issue in concrete durability that affects the performance and maintenance costs of vital civil infrastructures [3]. H_2SO_4 is classified as one of the most aggressive natural threats that usually originates from groundwater, chemical waste, industrial processes, sulfur-oxidizing bacteria in sewer crowns, urban activities, or through the oxidation of sulfur-bearing compounds (e.g., pyrite) in backfill [3,15]. The decomposition of organic matter in sewage forms H2S (gas) which can be converted into sulfuric acid by some bacterial activities. Corrosion of concrete due to sulfuric acid can be summarized as Eqs. (1)–(3) [16]:

$$Ca(OH)_2 + H_2SO_4 \rightarrow CaSO_4 \cdot 2H_2O \quad (1)$$

$$CaSiO_2 \cdot 2H_2O + H_2SO_4 \rightarrow CaSO_4 + Si(OH)_4 + H_2O \quad (2)$$

$$3CaO \cdot Al_2O_3 \cdot 12H_2O + 3(CaSO_4 \cdot 2H_2O) + 14H_2O \rightarrow 3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O \quad (3)$$

Acid attack may affect the processes of decomposition and leaching of the constituents of cement paste. A large portion of the additions to the SCC paste may be positively or negatively influenced by their resistance to acid attack [15]. Kanellopoulos et al. [17] reported the results of research aimed at determining the relationship(s) among various durability indicators for the specific filler additives used in the mix designs. Such relationships, if existent, may be exploited for the assessment of SCC durability without the need to rely on time-consuming experimental procedures. Venkateswara Rao et al. [18] designed an experiment to investigate concrete durability in which they tested three grades of SCC from low to high strength. They found that the loss in durability reduced in almost all the cases examined as the concrete grade rose. Furthermore, comparison of SCC and ordinary concrete mixes showed the good performance of SCC versus ordinary concrete. Tamimi et al. [19] investigated the acid resistance of SCC and Ordinary Concrete (OC). The SCC samples were prepared with carboniferous limestone powder as a replacement for cement and OC samples were made with Portland cement only. Their investigation indicated that the SCC outperformed the OC in an H_2SO_4 medium although they were slightly more vulnerable to hydrochloric acid attack. Durning, Hicks and Mehta [20,21] reported that concrete resistance to H_2SO_4 attack could be increased by using microsilica because of the reduced calcium hydroxide content and the lower permeability of the concrete. This is while Monteny et al. [22] maintained that application of microsilica would reduce resistance to acid attack due to the greater acid penetration stemming from the higher capillarity absorption. Yamoto and Emoto [23] showed that the serviceability span of concrete structures could be doubled by substituting 30% of cement with the silica fume. Jiang et al. [24] showed the cracks and corroded parts are due to expanded iron formation and not related to gypsum and ettringite. As durability is the main incentive in the invention of self-consolidating concrete [25], the present manuscript provides the results of a new investigation carried out to reveal the influence of fine glass powder (glass beads) and microsilica on the durability of SCC concrete in a H_2SO_4 medium. The objectives of the experiments were to compare the relative performance of SCC with different doses of cement replacements under H_2SO_4 attack to that of OC and find the optimum contents with the same laboratory conditions. Previous studies have failed to take into the account the concrete structural packing (same laboratory conditions) which is of great importance for concrete porosity and absorption. The main objective of the present study was therefore to develop a constant packing model which could be exploited toward a better comparison of SCC and OC. Consequently, the effects of glass powder and microsilica were determined independently from packing effects. Different specimens of SCC were made with three different proportions of glass powder and microsilica as the cement replacement. As the complex and formidable task of interpreting the huge number of results expected from this study would be beyond human ability, artificial neural networks (ANN) was employed to find the best way of interpreting the results. The same procedures are adopted by many researchers in predicting concrete properties [26–34], but none of them considered the concrete specification to reduce the corrosion.

2. Materials

2.1. Cement

Concrete specimens were made by mixing ordinary Portland cement Type II with drinkable water at a temperature of 21 ± 2 °C. The chemical and physical properties of the cement used is reported in Table 1.

2.2. Aggregates

Fine calcic aggregates used in this investigation had a maximum size of 4.75 mm with a specific gravity (SSD) and water absorption of 2.62 and 5.6%, respectively. Type 1 coarse calcic aggregates (4.75–12 mm) with a specific gravity (SSD) of 2.62 and a water absorption of 0.9% were also used. Type 2 coarse calcic aggregates (12–19 mm) used had a specific gravity of 2.69 and a water