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A comparative study on the durability of geopolymers produced with ground glass fiber, fly ash, and glass-powder in sodium sulfate solution

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HIGHLIGHTS

- Resistance of geopolymers against sodium sulfate (Na_2SO_4) solution was studied.
- Effects of Na_2SO_4 solution on the microstructure of geopolymers were evaluated.
- Ground glass fiber and fly ash-based geopolymers performed well in Na_2SO_4 solution.
- Glass powder-based geopolymer showed a poor performance in Na_2SO_4 solution.

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ABSTRACT

An experimental investigation was conducted to investigate the performance of geopolymers made with three different precursors consisting of fly ash, Ground Glass Fiber (GGF), and Glass-Powder (GLP) exposed to sodium sulfate solution. Precursors were activated using either sodium hydroxide solution or combinations of sodium hydroxide and sodium silicate solution with varying levels of sodium and silica content. Among the mixtures with each of the three precursors, mortar mixtures with the highest compressive strength were selected to test their resistance against exposure to a 5% sodium sulfate solution. Changes in the weight and compressive strength of the specimens were monitored up to 120 days of exposure. In addition, change in the microstructure of geopolymer samples and mineral phases was investigated using SEM-EDX and XRD analyses, respectively. Further, techniques such as mercury intrusion porosimetry (MIP) spectrometry and inductively coupled plasma mass spectrometry (ICP-MS) were used to study the pore structure and the leachability of elements from geopolymers, respectively. Results of this study revealed that the GGF and fly ash-based geopolymers performed significantly better in comparison to the GLP-based geopolymer, when exposed to the sodium sulfate solution. The durability of GGF and Fly ash based geopolymer samples could be related to their stable aluminosilicate gel that develops upon geopolymerisation as well as the low amount of calcium oxide in the geopolymer systems. On the other hand, the poor performance of the GLP-based geopolymer could be related to the less stable geopolymerisation products which result in increased porosity, and the high amount of available alkalis present in the raw GLP.

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1. Introduction

Sulfate attack is known as one of the major durability problems affecting the performance of portland cement concrete [1]. This chemical attack is mainly associated with the formation of non-cohesive and expansive by-products such as gypsum and ettringite; which lead to cracking and softening of the paste matrix

resulting in mass loss and reduction in the mechanical properties of the portland cement concrete [2]. In order to mitigate durability issues associated with sulfate attack, use of adequate amounts of supplementary cementitious materials (SCMs) such as slag is practiced [3]. According to Neville [4], the use of SCMs as cement replacement material can help the mitigation of sulfate attack by reducing the amount calcium aluminate (C_3A) and calcium Hydroxide (CH), which prevents the formation of deleterious compounds such as gypsum and ettringite. Considering the deterioration of concrete in the high sulfate environment, evaluation of the performance of any cementitious materials against a sulfate-rich environment is critical.

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Geopolymer-based concretes have recently attracted attention as a potential replacement for portland-cement based concrete, particularly in applications where aggressive chemical environments are encountered. Typically, geopolymers are produced by the alkali activation of silica and alumina-rich materials using alkaline activators such as sodium hydroxide or sodium silicate solutions. This results in the production of an amorphous three-dimensional alumino-silicate network, known as the geopolymer [5]. As it has been reviewed and summarized by Bašcarević [6], efforts to study the durability performance of geopolymer concrete and mortar against aggressive environments have been conducted by exposing test specimens to different sodium sulfate-rich solutions such as sodium sulfate and magnesium sulfate solutions. However, thus far most of the studies were conducted on fly ash or meta-kaolin based geopolymers [7–13]; and no such durability studies have been conducted on geopolymers produced with glass-based precursor materials such as ground glass fibers (GGF) and ground soda-lime glass powder (GLP). The purpose of this investigation is to evaluate the performance of geopolymers produced using GGF and GLP precursors when exposed to sulfate rich environment. In this study a 5% sodium sulfate solution was used to simulate a sulfate-rich environment.

1.1. Background

In recent years, large numbers of studies have been conducted to evaluate the potential of geopolymer-based concrete as an alternative to portland cement concrete [14–25]. In these studies, the use of geopolymer concretes in specific applications such as precast concrete products, sewer pipes, culverts, railway sleepers, pre-fabricated units for housing market, etc. [14–19], repair or a retrofitting material for existing portland-cement-concrete elements or structures [20–22], and as a repair coating or a construction material in marine sites [23–25], has been reported, either in a laboratory [14,17,20–24] or a commercial scale [14–16,18,19].

Based on literature review, precursor materials such as fly-ash, slag, meta-kaolin and their combinations are the most widely used materials to manufacture geopolymer concrete [26–32]. In addition, several other waste or industrial by-products such as: waste paper sludge ash [33], spent fluid catalytic cracking catalyst [34] waste glass-powder [35], palm oil fuel Ash [36], kaolinitic clay [37], a combination of natural pozzolan and slag [38], blends of clay and fly ash [39], and vitreous calcium alumino-silicate [40] have been studied by other authors to produce geopolymer concrete. In addition to these materials, recent studies have shown that ground glass fiber (GGF) can be effectively activated by an alkali activator to produce a geopolymer mortar [41].

Each year, a large amount of glass fiber is produced around the world for use in various applications. The production process of high-quality glass-fiber is often associated with generation of hundreds of thousands of tons of waste glass fiber that is deemed off-specification, due to strict technical requirements. The waste glass fiber is typically disposed off in landfills. It has been reported that, in the United States alone around 250,000 tons to 500,000 tons of waste glass fiber ends-up in landfills each year [42]. Considering the chemical composition of this material, which is rich in silica, alumina, and calcium, it could be potentially used as a supplementary cementitious material (SCM) or as a precursor for the production of geopolymer [43,44]. Recent studies have shown that activation of GGF using a sodium hydroxide solution, without the need for a sodium silicate solution, can produce a geopolymer mortar mixture with high early strength as high as 80 MPa after only 3 days [41].

Unlike portland cement paste in which calcium silicate hydrate (CSH) is the main constituent of the hydration product, geopoly-

mers are made of an amorphous alumino-silicate matrix [45,46]. Therefore, the durability of geopolymers in aggressive environments can be expected to be different from that of portland cement-based materials. Several studies have reported findings on different durability aspects of geopolymer concrete. Studies on the durability properties such as resistance against alkali-silica reaction (ASR) of aggregates [47–49], resistance against acid attack [9,50–53], sulfate-rich solutions [7–13], freeze and thaw [11,54], etc. have shown superior performance of geopolymers produced from precursors such as fly ash, bottom ash, meta-kaolin, slag etc., compared to portland cement concrete.

Considering the differences between the chemical nature of the matrix in portland cement and geopolymer concretes, particularly due to the lower amount of calcium in geopolymers, the behaviors of these materials (portland cement and geopolymers) are found to be different when exposed to a sulfate rich media [55]. Monitoring the changes in material properties such as compressive strength [7,12,13,36,56,57], length of specimens (i.e. expansion) [52,57,58], porosity and microstructure [58,59] have been used to study the behavior of geopolymers when exposed to a sulfate solution such as sodium sulfate or magnesium sulfate. In most of these studies, it was observed that geopolymers had a better performance when compared to portland cement concrete, i.e. lower expansion, lesser degree of loss in compressive strength, and minimal change in the microstructure of the matrix. The better performance of geopolymer samples has been attributed to factors such as: lower amount of calcium oxides in the structure of geopolymers [8,36,37,56,57], further geopolymerisation while exposed to the sulfate solution [7,11], formation of new crystals in the structure of the exposed samples [9], and the cross-linked structure of the alumino-silicate gel of geopolymers [36,55].

Despite its better performance in comparison to portland cement mixtures, in some cases, reduction (or fluctuation) in the mechanical properties has been reported for the geopolymer samples which were subjected to sulfate solutions [8,9,12,13]. In these studies, such behavior was mainly attributed to the leaching of alkalis from the geopolymer into the sulfate solution, which alters the structure of geopolymer and negatively affects the mechanical properties. Other observations have also reported the formation of ettringite and gypsum in the matrix of geopolymer exposed to sulfate solution, which leads to expansion and consequent mechanical degradation of the geopolymer [10,13,57,58]. However, the formation of these products was mostly observed when samples were exposed to the magnesium sulfate solution [10,13,55], while it was not the case for the samples exposed to the sodium sulfate solution; as no or very small traces of gypsum and ettringite were seen in these samples [7,10,11,36,55].

Effect of sulfate solution on the geopolymers has been reported to depend on the cations accompanying the sulfate in the solution (i.e. Na or Mg) [10,12]. Some studies [10,55,57] reported magnesium sulfate solutions to be more aggressive towards geopolymer samples in comparison to sodium sulfate solution, while other studies [12], reported more damaging effect of sodium sulfate solution on geopolymer samples compared to magnesium sulfate solutions. Considering the dissimilar effects of these two different solutions and the associated mechanism of damages from these solutions, present study will focus only on the effect of a 5% sodium sulfate solution on a GGF and GLP-based geopolymer. In addition, results from glass-based geopolymers were compared with a fly ash-based geopolymer to investigate how different precursors affect the properties of geopolymers exposed to a sodium sulfate solution. Although, parallel studies on the effects of magnesium sulfate solutions on geopolymers were conducted, the findings from those studies are not presented here and will be presented in future.

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