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Magnesium sulfate resistance of geopolymer mortar

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HIGHLIGHTS

- The performance of geopolymer mortar in magnesium sulfate solution was evaluated.
- Effect of curing temperature, NaOH molarity on sulfate resistance were studied.
- Increasing curing temperature up to 90 °C improves strength and durability properties.
- Addition GGBS and silica fume yields better properties compared to fly ash only.
- Various geopolymer mortars achieved higher sulfate resistance than OPC mortar.

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ABSTRACT

Sulfate attack is one of the reasons which cause deterioration and damages of concrete structures throughout the world. Thus, sulfate attack resistance is an important durability and serviceability concern for materials used in construction. Various geopolymer mortars and OPC mortars were manufactured to evaluate magnesium sulfate resistance. This paper studied the effect of curing temperature, sodium hydroxide solution molarity, alkaline solution to binder ratio and binder type on magnesium sulfate resistance of geopolymer mortar and make a comparison between OPC mortar and various geopolymer mortars. Specimens were immersed in 10% magnesium sulfate solution up to 48 weeks. The evaluated properties in this study were water absorption and voids ratio, visual inspection, microstructure of specimens, weight change, compressive strength, flexural strength and expansion strain. Results indicated that increasing curing temperature, sodium hydroxide solution molarity and decreasing alkaline solution to binder ratio enhanced magnesium sulfate resistance of geopolymer mortar. Mixes containing 50% fly ash, 35% ground granulated slag (GGBS) and 15% silica fume achieved the best performance in magnesium sulfate solution. Generally, various geopolymer mortars achieved better performance in magnesium sulfate solution compared to OPC mortars.

1. Introduction

Concrete is considered one of the most important materials used in construction all over the world. Ordinary portland cement (OPC) is used as the binder to produce the concrete. The demand of concrete is increasing continuously for the need of development of infrastructure facilities [1]. The environmental issues associated with the production of OPC are well known. Despite portland cement concrete has many advantages, it has been proven that portland cement concrete suffers from different problems such as durability, when exposed to sea water, sulfuric soils or freezing weather, and carbon dioxide emission during cement manufacturing process. Many concrete structures have shown serious deterioration before their intended service life, especially those are constructed in a corrosive environment [2].

Portland cement has harmful impacts to the environment due to its significant contribution to the amount of greenhouse gas, resulting from the high volume of carbon dioxide emitted during its production, which represents about 65% of global warming.

The production of ordinary portland cement is responsible for two ecological problems; it consumes a lot of energy and releases a large amount of carbon dioxide as previously noted consequently [3]. Therefore, the need for alternative binders able to achieve a sustainable and ecologically aware concrete proved to be essential to reduce the huge emission of CO_2 which linked to portland cement industry and reach good durability characteristics when exposed to aggressive environment. In 1978, Joseph Davidovits has led researchers to the discovery of green (eco-friendly) concrete, commonly named “geopolymer concrete”.

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Davidovits proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin or in by product materials such as fly ash, blast furnace slag, and rice husk ash to produce binders. He named the term 'geopolymer' because the chemical reaction that occurs in this case is a polymerization process [4,5]. Unlike ordinary portland cements, geopolymers do not form calcium silicate-hydrates (CSHs) for matrix formation and strength, but use the polycondensation of silica and alumina precursors and a high alkali content to obtain structural strength. Therefore, in some studies geopolymers are sometimes referred to as alkali activated aluminosilicate binders [4,6,7].

Heat-cured low-calcium fly ash-based geopolymer concrete showed high-early strength gain, excellent resistance to sulfate attack, good acid resistance, undergoes low creep, and suffers very little drying shrinkage [8]. Curing temperature plays an important role in improving the microstructure and mechanical strength of geopolymer system. Generally, higher temperature accelerates polymerization process compared to ambient temperature. As fly ash based geopolymer paste reacts slowly at low ambient temperature when compared to heat cured specimens [9], these mixes are usually subjected to curing temperatures ranging from 30 °C to 85 °C and a relative humidity of about 95% [6,10]. It is investigated that the amount of calcium content in geopolymer mix has a significant effect on the resulting hardened geopolymer because it was found that calcium oxide form calcium silicate hydrate (CSH) along with the aluminosilicate geopolymer gel.

Moreover, several previous studies reported availability of mixing fly ash based geopolymers with silica fume, metakaolin and blast furnace slag [11,12]. Temuujin et al. [13] confirmed that the addition of calcium compounds CaO and $Ca(OH)_2$ improves mechanical properties of the fly ash-based geopolymers cured at ambient temperature. In addition, the geopolymerization process is also influenced by other factors such as, the type and properties of aluminosilicate sources and composition of alkaline solution [14,15].

Sulfate attack is an important durability and serviceability concern for geopolymer materials used in construction. Previous experience with portland cement and blended cement concretes showed cases of concrete deterioration when exposed to sulfate attack in the environment [16,17]. Because of reactions involve CH, C–S–H and the aluminate component of hardened cement paste which occur due to sulfate attack on OPC concrete [18,19]. Expansion and cracking are caused, directly or indirectly, by ettringite and gypsum formation, while softening and disintegration are caused by destruction of C–S–H [18,20]. Bakharev, Sanjayan and Chen [21] carried out durability tests on alkali activated slag and found that they perform better than ordinary portland cements. The performance of geopolymer concretes in aggressive environments was studied using tests on absorption and acid resistance [22].

Wallah and Rangan [23] reported that geopolymers have excellent durability properties as it exhibits extremely small changes in length and also showed little increase in mass after one year of exposure in sulfate solution. In another study, Bakharev [24] used geopolymer materials prepared by activation using different types of alkali solutions to be immersed in sulfate solution with various concentrations.

Studying the durability of geopolymers against magnesium sulfate attack especially that contain granulated blast furnace slag is a topic needing more investigations because the researches in this field are limited. The main objective of this research is to determine the effect of curing temperature, sodium hydroxide solution molarity, alkaline solution to binder ratio and binder type on the performance of geopolymer mortar exposed to magnesium sulfate attack up to one year and compare between geopolymer mortar and portland cement mortar. Magnesium sulfate resistance was evaluated in the terms of weight change, residual compressive and flexural strength, expansion strain percent, visual inspection of specimens and microstructure evaluating using scanning electron microscope (SEM), X ray diffraction (XRD) and thermogravimetric analysis (TGA). Voids ratio and water absorption tests were also performed.

2. Experimental program

2.1. Materials

In this study, class F fly ash according to ASTM C618, ground granulated blast furnace slag (GGBFS) and silica fume were used as the main silicon-alumina source materials for geopolymer mortar. Ordinary portland cement Type I according to ASTM C 150 was used to compare the sulfate resistance of geopolymer mortar with portland cement mortar. The chemical compositions of the used fly ash, GGBFS, silica fume and portland cement are presented in Table 1. Natural siliceous sand with fineness modulus of 2.76 and specific gravity of 2.62 was used as natural aggregate.

A combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) solutions were used as alkali activators of binders. Sodium hydroxide (NaOH) in pellet form with 98% purity was dissolved in potable water to make the solution of the desired concentration. Sodium silicate solution was obtained from a local commercial producer. It was colorless and had a chemical composition of 14.7% Na_2O 29.4% SiO_2 and 55.9% H_2O. The specific gravity of sodium silicate was 1.52

High range water reducer naphthalene-based admixture (Type F) according to ASTM C494/C494M with specific gravity of 1.2 was used to improve workability of the fresh mortar.

2.2. Test parameters

Four parameters were considered in this study. These parameters included curing temperature, sodium hydroxide solution molarity, alkaline solution to binder ratio and binder type. Three types of binders were used. These types were fly ash (ASTM Class F), ground granulated blast furnace slag (GGBS) and silica fume. Three curing temperature degrees of 30°, 60° and 90 °C were considered. For sodium hydroxide solution molarity, four concentrations of 10 M, 12 M, 14 M and 16 M were considered. The considered alkaline solution to binder ratios were 0.35, 0.40, 0.45 and 0.50. For all mixtures, the ratio of sodium silicate solution-to-sodium hydroxide solution of 2, ratio of sand-to-binder of 3, extra water and admixture of 6% and 3% by weight of binder respectively were kept constant. Portland cement mix with water cement ratio of 0.35 is used as control mix in order to compare between OPC mortars and geopolymer mortars exposed to magnesium sulfate attack. To study the previous parameters, twenty-seven geopolymer mixes (9 for

Table 1
Chemical composition of Fly ash, GGBS, Silica fume and Portland cement.

Chemical composition	Fly ash (%)	GGBS (%)	Silica fume (%)	Cement (%)
Silicon dioxide (SiO_2)	60	36.74	96.81	19.6
Iron oxide (Fe_2O_3)	2.50	0.40	0.45	3.42
Aluminum oxide (Al_2O_3)	28	10.78	0.25	5.30
Calcium oxide (CaO)	2.50	43.34	0.16	61.6
Magnesium oxide (MgO)	1.00	3.21	0.26	3.40
Sulfur trioxide (SO_3)	0.40	0.50	0.14	2.30
Na_2O	0.50	0.18	0.14	–
K_2O	1.00	0.17	0.28	–
Loss on ignition (LOI)	2.50	0.60	1.30	2.60