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Sulfuric acid resistance of fly ash based geopolymer concrete

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HIGHLIGHTS

- Effect of OPC replacement on compressive strength of geopolymer concrete.
- Effect of OPC replacement on sulphuric acid resistance of geopolymer concrete.
- SEM and EDS analysis of unexposed and sulphuric acid exposed fly ash based geopolymer concrete.
- XRD analysis of unexposed and sulphuric acid exposed fly ash based geopolymer concrete.

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ABSTRACT

The sulfuric acid resistance of fly ash based geopolymer concrete blended with an additional calcium source is presented in this paper. Ordinary Portland cement (OPC) was added as additional calcium in the geopolymer system as fly ash replacement (0, 10, 20 & 30%). The specimens were exposed to 2% sulfuric acid solution up to the age of 365 days, and the deterioration was identified in terms of mass loss and compressive strength retained. Microstructural analysis; SEM, XRD, and EDS was also carried out.

The results indicate that the inclusion of OPC (as fly ash replacement) improves the compressive strength of fly ash based geopolymer concrete specimens significantly whereas it did not have a similar effect on its resistance to sulfuric acid. The increase in compressive strength for the unexposed geopolymer concrete specimens was due to the additional calcium hydrated products which co-existed with alumina-silicate polymer structures. On the other hand, for the specimens exposed to sulfuric acid for 365 days, the inclusion of OPC at 10% showed the maximum retained compressive strength of around 52% of the strength value achieved for unexposed specimens at the same age. However, OPC inclusion beyond 10% decreases the ability of geopolymer concrete specimens to retain compressive strength. Maximum deterioration was observed when fly ash was replaced by OPC at 30%. This was due to the formation of additional calcium sulfate which increased with the increase in calcium products in the mixture. Microstructural changes were also observed for the exposed specimens at 365 days and confirmed the presence of sulfur compounds as a major cause for the deterioration.

1. Introduction

A lot of waste products are released from the industrial sector which is creating disposal problems and the most challenging environmental hazard global warming. The cement industry is another energy intensive sector which enhances this problem by releasing greenhouse gas like carbon dioxide [1]. As a result, for the sustainable development, various authors are focusing on the utilization of industrial waste products as an alternative to ordinary Portland cement (OPC) to solve problems like disposal as well as global warming. The use of waste products such as silica fume, fly ash, metakaolin, etc. in concrete applications have found to be beneficial; however, these wastes can only be used as partial replacement of OPC [2–4] and cannot totally replace it. In this regard, Davidovits [5] introduced the concept of geopolymers which can be produced by the reaction of silica and alumina with the alkali-activating solutions. Out of various materials that are rich in alumina and silica like fly ash, metakaolin, rice husk ash, etc. fly ash is most popular due to its easy availability all across the globe [6]. The mechanism of geopolymers involves the reaction of silica and alumina, liberated by hydroxides and silicates of sodium or potassium as the alkali-activating solution, and results in the formation of strong alumina-silicate polymeric structures. Due to the slow reactivity of the source materials, the alkali-activating solution often requires additional heat [7] to accelerate the dissolution process which can improve the properties of geopolymers

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considerably. Previous studies [8–10] have reported various factors that influence the mechanical and durability properties of geopolymers momentously such as choice of source materials, their finenesses, the concentration of alkali-activating solutions and the curing parameters. Since the structural integrity of geopolymer binder depends on alumina-silicate and not on calcium silicate hydrate, they have been found to have higher early age strength, low creep and shrinkage [11] and also better durability properties in terms of resistance against aggressive acids and sulfates [12,13]. Fly ash is an abundantly available waste product and because of a fair amount of silica and alumina, it has been used in geopolymers quite effectively. However, the only limitation that is resisting its use in the actual construction cast-in-situ applications is the requirement of high temperature curing in achieving better or comparable properties to that of conventional OPC concrete.

Studies have shown the significant improvement in microstructure and strength development by adding calcium source in the geopolymer system at considerably lower curing temperatures [14,15]. In this study, fly ash based geopolymer concrete specimens are prepared and their resistance to sulfuric acid has been examined. The reason for choosing sulfuric acid over any other acid is due to its practical utilization as concrete members are often subjected to sulfuric acid in various applications like mining, sewage, and food processing industries. OPC has been included (as an additional calcium source) in the geopolymer system as the partial replacement of fly ash (0, 10, 20 & 30%) and its effect on sulfuric acid resistance has been examined up at 28, 90 and 365 days. The parameters such as mass loss and retained compressive strength are used to observe the deterioration. In addition, to examine the microstructure, scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDS) & X-ray diffraction (XRD) analysis have also been carried out on the unexposed as well as sulfuric acid exposed geopolymer concrete specimens.

Table 1
Physical properties of OPC.

Physical properties	OPC
Standard consistency	33%
Initial setting time	78 min
Final setting time	410 min
Specific gravity	3.12
Fineness (m^2/kg)	307

2. Materials and methods

2.1. Materials

Fly ash obtained from Rajiv Gandhi power plant, Northern India was used as source material with specific gravity 2.36, specific surface area 272 m^2/kg. OPC was used as calcium source with the physical properties as shown in Table 1. For observing the microstructure and phase determination, SEM, EDS, and XRD analysis were performed on fly ash and OPC particles as shown in Figs. 1–3. Also, X-ray fluorescence (XRF) analysis was carried out to evaluate their chemical composition, as shown in Table 2. As a requirement for geo-polymeric reactions, the results showed a high amount of alumina and silica for fly ash whereas OPC confirmed the presence of high calcium content. Fly ash particles were observed to be spherical whereas OPC particles were found to be irregular in shape. XRD analysis showed the presence of quartz and mullite for fly ash whereas calcite, portlandite, and ettringite were found to be major constituents for OPC. The alkali-

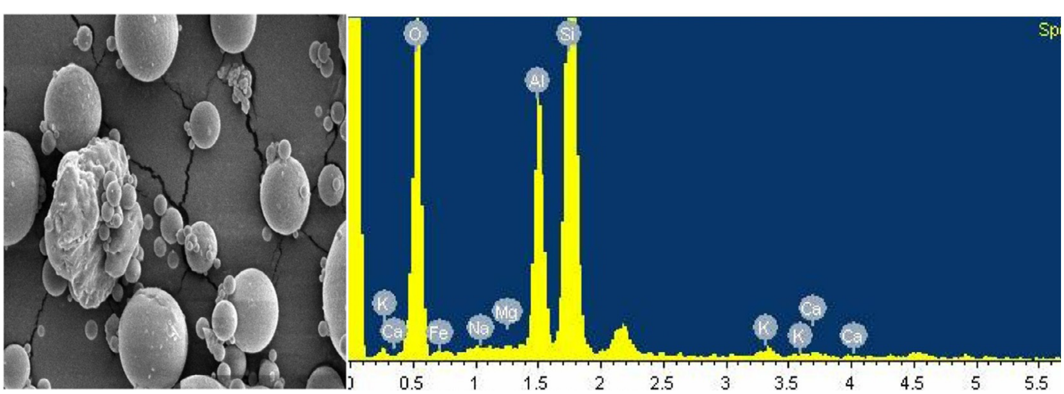

Fig. 1. SEM/EDS analysis of fly ash particles.

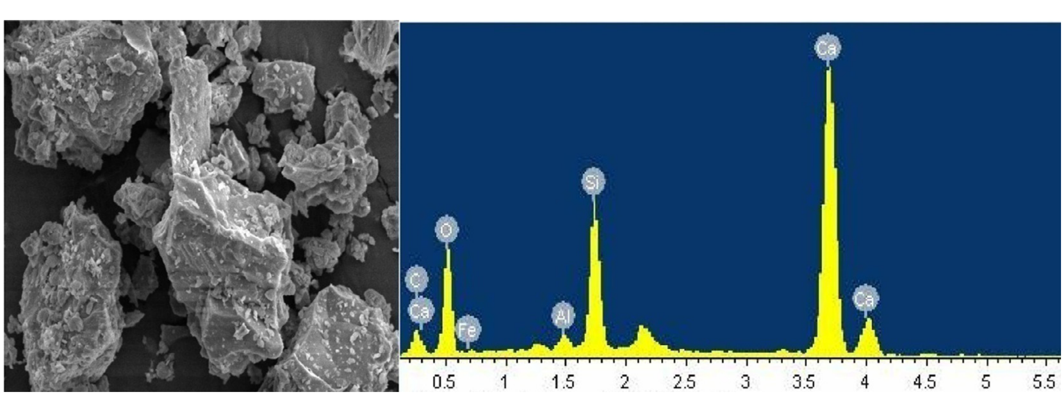

Fig. 2. SEM/EDS analysis of OPC.