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Fresh properties, compressive strength and microstructure of fly ash geopolymer paste blended with iron ore tailing under thermal cycle

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HIGHLIGHTS

- A geopolymer is proposed based on fly ash blended with iron ore tailing.
- IOT decreases fluidity and prolongs setting time of geopolymer.
- 20% IOT leads to denser microstructure and higher surface hardness after thermal cycle.
- Less than 30% IOT improves the thermal resistance of geopolymer.

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ABSTRACT

This study aims to broaden the application of iron ore tailing (IOT) in geopolymer. Fresh properties, residual strength, mass loss and microstructure evolution of geopolymer prepared by using fly ash as starting material blended with IOT and activated by sodium silicate and sodium hydroxide solutions were investigated after exposure to 3 and 7 heat-cooling thermal cycles at different target heating temperatures of 200 °C, 400 °C and 800 °C when fly ash was partially replaced by IOT at levels ranging from 0% to 30% with an interval of 10%, by weight. The experimental results uncover that IOT addition influences the workability and setting time of geopolymer especially when more than 20% of IOT is added. Under the effects of thermal cycles, the compressive strength decreases significantly especially after 7 thermal cycles. The loss in compressive strength increases as the cycle target temperature increases from 200 °C to 800 °C. The presence of IOT evidently improves the thermal resistance of geopolymer with the replacement level of IOT less than 30%. The reduced $Ca(OH)_2$ and the associated formation of additional C-S-H evidences the role of IOT in the formation of C-S-H and supports the results of the increasing compressive strength. Replacing of fly ash with 20% IOT leads to a reduction of the porosity and microcrackings which results in much denser microstructure. Surface Vickers-hardness of geopolymer has also been optimized by IOT addition regardless of exposure target temperature.

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1. Introduction

Fly ash, as industrial by-product with pozzolanic properties, is collected by mechanical and electrostatic separators from fuel gases of power plants before discharged into the atmosphere, it mainly consists of unburned carbon particles and aluminosilicate particles [1] and the mineral constituents of fly ash include glassy phase and minor crystalline phases (quartz, mullite, hematite and magnetite) [2]. Fly ash is known as one of the wastes causing environmental impacts in the form of air and water pollution. In particular, it is currently found that the amount of fly ash production increases up to 600 million tons per year [3]. In the past, the most common method to manage fly ash was to dispose in landfills [4]. The disposal of fly ash is one of the major environmental issues as dumping of fly ash as waste material may cause severe environmental hazards [5]. Utilization of fly ash efficiently will reduce the amount of coal combustion by-products that must be disposed in landfills, which produces endangering consequences to the environment and people's health.

It is generally considered that fly ash is a resource that has been put in the wrong position, and has tremendous potential in various

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new areas in recent years. One of the best ways for treatment of fly ash is to synthesize fly ash-based geopolymers by alkali-activated reaction because of its low-cost, environment-friendly, energy-saving and resource-recycling benefits [6–8].

Iron ore tailing (IOT) is a mining and mineral waste obtained from the iron ore mining industry. The ores are dark grey in colour, fine-grained, non-plastic and rich in silica aluminum and iron [9].

The proper disposal of tailings has become crucial for environmental preservation. In the case of iron ore tailings, they are fine materials containing silica, together with iron oxides, alumina and other minor minerals. This constitution puts the tailings in the civil construction industry [10] and makes it an excellent alternative to produce geopolymer.

Iron ore tailing is a common type of hazardous solid waste in China and has caused serious environmental problems [11]. The value of using some byproducts such as slag, which is used to produce blended cements and concrete, has already been widely recognized, but most of hazardous materials like iron ore tailings have been discarded. This has led to serious environmental deterioration. These untreated tailings not only occupy large amounts of land but also pollute water resources and the air. In order to alleviate environmental pressures and attain sustainability, one feasible solution is to reuse iron ore tailing as secondary resource such as precursors in producing geopolymer since it is rich in silica and alumina.

These solid wastes mentioned above, generated from various mining and industrial activities, continue to be a major environmental concern. Fast deterioration of the environment due to rapid industrialization leads the environmental agencies to formulate several quantitative measures in respect of generation, treatment, transport, handling, disposal and recycling of solid/liquid wastes over the period [12]. As a result, there is an increasing interest in search of possible alternative uses of solid wastes as the starting materials to produce high value added products such as geopolymer before their final discharge [13–17].

Recent years have seen a great development in new type of inorganic cementitious materials, i.e. geopolymer around the world. Geopolymer was firstly introduced into the inorganic cementitious world by Davidovits in the later 1970s [18]. It can be synthesized by mixing aluminosilicate reactive materials such as fly ash or iron ore tailings mention above and strong alkaline solutions (such as NaOH or KOH) at room temperature.

The alkali activation of waste materials, which were first introduced in 1940s and formed the origins of the research into geopolymer [19], is a chemical process transforming glassy structures (partially or totally amorphous and/or metastable) into very compact well-cemented composites. Nowadays, the knowledge concerning the mechanisms controlling the alkali activation process is considerably advanced, however, there are still many things to investigate. A very well-known example of the alkali activated material is represented by the activation of blast furnace slag with a mild alkaline solution corresponds to a complex process that is composed of the initial destruction of the slag and a later polycondensation of the reaction products and that the knowledge of the nature of these products has been the objective of many investigations, although some controversy still persists. In any case, most of authors agree in considering C-S-H gel as the main reaction product [20–22]. Furthermore, the alkaline activation of metakaolin and fly ash has also been widely investigated recently [23].

Davidovits was the pioneer in introducing binders other than cement that could be produced by the reaction between alkaline liquids and source materials that are rich in silica and alumina, commonly known as geopolymerization. Geopolymer exhibits a wide variety of properties and characteristics, including high compressive strength, low shrinkage, high temperature resistance [24] and permeability resistance [25,26], and seems to be a desirable alternative to ordinary Portland cement and environmentally sustainable characteristics [27]. Besides, the CO_2 emission is at least 80% less compared to manufacture of ordinary Portland cement [27,28].

Analysis of published literatures indicates that fly ash based geopolymer receives more attention and interest from researchers due to sustainable high mechanical strength, high temperature resistance, higher durability when compared with ordinary Portland cement. Duan et al. [29] recently investigated durability and microstructure of fly ash and metakaolin based geopolymer exposed to elevated temperatures and acid attack and concluded that geopolymer presented better durability and denser microstructure compared to ordinary Portland cement when exposed to elevated temperatures and acid attack. Also fly ash paste activated by multi-compound activator had higher relative slump and compressive strength with reference to the NaOH-activated fly ash paste [30]. Ranjbar et al. [31] found higher early compressive strength in fly ash based geopolymer compared to palm oil fuel ash added geopolymer. After the fire exposures up to 1000 °C, the geopolymer concrete specimens were found to suffer less damage in terms of cracking than the OPC concrete specimens. The geopolymer concrete specimens generally retained higher strength and showed continued densification of the microstructure with the increase of fire temperature than the OPC concrete specimens [32]. Furthermore, Deb et al. [33] added ground granulated blast-furnace slag into fly ash geopolymer concrete and observed significant increase in strength and some decrease in the workability.

Generally, fly ash based geopolymer was cured at temperatures higher than room temperature. Ambient-cured FA-based geopolymers received less attention from researchers. Somna et al. [34] investigated NaOH-activated fly ash geopolymer cured at room temperature. Ground fly ash could be used as a source material for making geopolymers cured at room temperature and the compressive strengths at 28 days of 20.0–23.0 MPa were obtained. Ogundiran et al. [35] studied immobilization of lead smelting slag within fly ash based geopolymer cured at room temperature. Zhang et al. [36] reported that geopolymers were successfully synthesized at the ambient condition of 23 °C and 40–50% relative humidity (RH) with the 28-day compressive strength ranging from 11.3 to 21.3 MPa, and concluded that the ambient condition is also confirmed to be a practically feasible scheme for curing geopolymers. Xie et al. [14] presented the results of the behavior of fly ash-, bottom ash- and blended fly and bottom ash-based geopolymer concrete cured at ambient temperature. It indicated that bottom ash-based GPCs exhibited significantly lower geopolymerization than that of the fly ash-based GPCs. Nath et al. [37] presented a study on low calcium fly ash based geopolymer concrete cured in ambient temperature (23 °C) without additional heat and the results suggested that suitable geopolymer mixtures can be designed for ambient curing. They [38] also concluded that fly ash-based geopolymer concrete for curing in ambient condition can be proportioned for desirable workability, setting time, and compressive strength using ground granulated blast-furnace slag (GGBFS) as a small part of the binder. Xie et al. [39] improved the ambient-cured (20 °C) geopolymer achieved by controlling the moisture condition of the specimens after hardening.

However, on reviewing the previously published findings, very few researchers have studied the geopolymerization of iron ore tailings, the utilization of iron ore tailings as precursor of geopolymer are even not well known, little information was available about iron ore tailings based geopolymer. Furthermore, no research has been conducted on utilizing industrial waste such as fly ash and IOT to produce geopolymer. Information of effects of iron ore tailings addition on fly ash geopolymer still required further investigation.

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