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Fresh properties, mechanical strength and microstructure of fly ash geopolymer paste reinforced with sawdust

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HIGHLIGHTS

- A geopolymer is proposed based on fly ash blended with sawdust.
- Relationships between flow, setting time, density and sawdust content are observed.
- Sawdust is beneficial for the resistance to cracking and drying shrinkage.
- Sawdust exhibits positive effect on compressive and flexural strength after 28 days.
- Sawdust addition leads to the formation of an optimal microstructure.

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ABSTRACT

This work aims to verify the feasibility of utilizing sawdust in geopolymer to make reinforced composites and broaden application of sawdust in geopolymer. Fresh properties including workability and setting time, density, nailing ability, drying shrinkage, mechanical strength and microstructure of fly ash geopolymer activated by sodium silicate and sodium hydroxide solutions blended with 0–20% of sawdust by mass with an interval of 5% were investigated.

The experimental results uncover that sawdust addition influences the workability of geopolymer. The sawdust content is inversely proportional to the setting time and a good linear relation is found between density and sawdust content. Sawdust is beneficial for the resistance to cracking and drying shrinkage especially the later ages. Sawdust exhibits little effect on compressive strength before 14 days of curing and it possesses positive effect after 28 days. 5% of sawdust addition exhibits little effect on flexural strength regardless of days of curing. The flexural strength increases with increasing content of sawdust. With the increasing addition levels of sawdust, the porosity decreases and compact matrix can be observed. Sawdust addition leads to the formation of an optimal microstructure. The results from mechanical properties and microstructure observation are compatible.

1. Introduction

Relatively low flexural strength and poor resistance to crack opening and propagation are the main disadvantages of conventional cement concrete [1,2]. Generally, replacement of ordinary Portland cement (OPC) by mineral admixtures in concrete can decrease porosity, especially in the long-term [1]. On the other hand, mineral admixtures such as silica fume can also increase the brittleness of concrete and lead to the high probability of cracks formation. The cracks weaken waterproofing capabilities of concrete, exposing the concrete to destructive substances such as moisture, chloride, sulfates etc.

Furthermore, the annual worldwide production of Portland cement is expected to grow to 4.38 billion tonnes in 2050 based on 5% growth per year [3]. It is estimated that up to 0.54 tonne of CO_2 per tonne of clinker is released during calcinations and 0.46 tonne of the CO_2 emitted is the result of burning fuel to provide the thermal energy necessary for calcination [4]. Hence, a small reduction of Portland cement production could result in significant environmental benefits in terms of CO_2 emission. This has encouraged research into environmental-friendly cementitious

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materials producing high strength and good durability while maintaining an acceptable level of energy consumption for production.

The aforementioned issues about the drawbacks of cement prompt various researches in an attempt to develop a new cementless binder, and geopolymer is such an emerging alternative binder, which was first developed by Davidovits [5]. Geopolymers are three-dimensional aluminum silicate inorganic polymers composed by [AlO_4] and [SiO_4] tetrahedra that are mainly prepared from aluminum silicates or industrial waste [6] such as fly ash [7,8], slag [9–11], metakaolin [12,13] etc. and mixed with an alkali silicate solution under highly alkaline conditions.

Geopolymer represents an alternative to Portland cement due to similar or even better binding properties [14,15]. In recent years, geopolymer has attracted considerable attention due to its early compressive strength, low permeability, good chemical resistance and excellent fire resistance behaviour [16–22].

Although different source materials can be used to prepare geopolymer binders, fly ash, represents industrial waste that can be found all over the world, it is particularly attractive for the synthesis of geopolymers. Fly ash is a by-product of thermal power plant that produces electricity, it contains an ample quantity of amorphous alumina and silica. Therefore, it is a suitable and a good source material for producing geopolymeric binder owing to its chemical compositions.

The properties of fly ash-based geopolymer concrete have been studied in the last decades [23–28]. Fly ash-based geopolymer concrete has properties favourable for its potential use as a cementitious material due to excellent durability aspects. Some authors [29–32] have reported similar engineering properties of geopolymer concrete that were favourable for its use as a construction material.

Despite the fact that research in this area is intense and there are a large number of publications that suggest a wide range of applications of these materials, FA-based geopolymers are still far from practical applications on a large scale and many problems are still need to be further investigated [33].

Traditionally, several methods have been used to strengthen cementitious materials. The most commonly used method was to add fibers to reinforce cementitious materials [34]. Fibers are incorporated into concrete to overcome this weakness, producing materials with increased flexural strength, ductility, toughness and improved durability properties [35–37]. Adding fibers into plain concrete has been proved to be an effective method to eliminate its inherent brittleness. The fibers bridge the cracks in the matrix and transfer the applied load to the matrix, thus fiber reinforced concrete has better post-crack behavior than plain concrete [38]. The presence of fibers also leads to higher impact resistance and greater flexural and tensile strengths [39]. These property enhancements depend on a number of factors including matrix strength, fiber volume and fiber surface bonding characteristics [40,41].

However, high cost and health hazard of fibers preparation hinder its application. As one of lignocellulosic biomasses, sawdust is the by-product from the mechanical milling or processing of timber (wood) into various useable sizes. The production of this waste is up to 24.15 million m^3 per year [42]. The sawdust mainly consists of lignin, cellulose, and hemicellulose. Large amounts of these wastes were either burnt or land filled. These approaches cause various environmental problems like air pollution, emission of greenhouse gases, and occupation of useful land. Therefore, the disposal of sawdust is getting more and more attentions in recent years. The abundance and availability of sawdust together with its relatively low cost guarantee its continued utilization.

Among these disposals of sawdust, mineral-bonded sawdust composites which combine sawdust with Portland cement [43], magnesite cement [44] and gypsum [45] have long history, and the earliest commercial mineral-bonded (cement) sawdust composite dates back to 1930 s [46].

As mentioned above, sawdust is either disposed of burning or land filling. But in recent days, land filling is becoming limited due to scarcity of waste land and increasing environmental concerns, furthermore, burning also leads to environmental contamination. In this regard, many researches and studies are being carried out to use sawdust, especially in construction materials to develop a sustainable way of its disposal. The increasing demand of cement leads to higher rate of environmental degradation and more exploitation of natural resources for raw material. The use of sawdust as partial cement replacement in concrete can reduce the requirement of cement to a large extent [47].

Researchers [47–49] had conducted tests which showed promising results for sawdust being suitably used to replace cement partially in concrete. Chowdhury et al. [50] evaluated the suitability of burnt sawdust as partial cement replacement in conventional concrete. It was concluded that the strength properties of concrete mixture decreased marginally with an increase in burnt sawdust contents, but strength increased at later ages. Elinwa et al. [51] assessed the properties of fresh self-compacting concrete containing sawdust, they found that the compressive strength development showed a tremendous improvement over the control. Aigbomian et al. [52,53] developed a new wood-crete building material using sawdust. It was able to withstand considerable amount of impact load and the most suitable for wall paneling or other non- and semi-structural application with good thermal insulating properties. Sales et al. [54,55] evaluated the potential application of lightweight concrete produced with lightweight coarse aggregate made of the water treatment sludge and sawdust, by determining the thermal properties, mechanical properties and possible environmental impact of future residue of this concrete. Also, Zhou and Li [56] made light-weight wood-magnesium oxychloride cement composite building products with sawdust as aggregate by extrusion. They reported that the composite exhibited less die swell and better performance in resisting high temperature.

However, after reviewing the previously published findings, the effects of sawdust on geopolymer are even not well known, little information is available about microstructure changes of geopolymer and fly ash was not mentioned. Information of effects of sawdust addition on fly ash geopolymer still requires further investigation.

Therefore, this present study is devoted to determine the fresh properties, density, nailing ability, drying shrinkage, mechanical strength, microstructure evolution and pore structure of geopolymer prepared using fly ash as resource material and activated by liquid alkaline activator when fly ash was partially replaced by sawdust at levels ranging from 0% to 20% with an interval of 5%, by weight.

2. Experimental

2.1. Materials

Fly ash utilized in this study was provided by Shenhua Junggar Energy Corporation in Junggar, Inner Mongolia, China. The micrographs of fly ash were shown in Fig. 1. Sawdust, which was obtained from a wood workshop as residuals when cutting natural wood, was used as reinforcement component for geopolymer. There were some wood fibers in the sawdust as observed from naked eyes. The sawdust with density of 0.79 g/cm^3 was incorporated into the geopolymer composites without any special pretreatment. This wood, which is used in both the civil construction and furniture sectors, is highly water absorbent with the water absorption of 67% after immersed in water for 24 h and very light with a regular fiber length due to its anatomical structure as shown in Fig. 2.

The chemical analysis of starting material mentioned above was listed in Table 1, the properties of sawdust was given in Table 2.