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Novel thermal insulating and lightweight composites from metakaolin geopolymer and polystyrene particles

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ABSTRACT

In this work, new foamed thermal insulation geopolymer composite based on polystyrene particles (PP) and metakaolin was developed. Compressive strength, flexural strength, high temperature resistance and microstructure were evaluated. The experimental results show that compressivestrengthand flexural strength of the thermal insulation geopolymer composite decrease with increasing polystyrene particle content. However, it still exhibits considerable and sufficient strength. The dry density and thermal conductivityalso decrease as polystyrene particle content increases due to the contribution of polystyrene particles with low density. The floatation of the thermal insulation geopolymer composite on water surface indicates the relatively low density and a good quadratic function relationship can be found between thermal conductivity and dry density. Furthermore, the dense interfacial transition zone indicates the high compressive strength and flexural strength of thermal insulation geopolymer composites. The cumulative intrusion volume corresponding to the porosity decreases and the critical pore diametersshift to lower values with addition of polystyrene particles. Geopolymer composites gain strength after exposure around 400 °C, and it suffers dramatic strength loss after 800 °C temperature exposure especially for the 100% polystyrene particles addition specimen.

1. Introduction

Thermal insulation mortar is generally characterized by favorable thermal insulation and relatively high strength, it mainly consists of cementitious binder, water and lightweight aggregate such as expanded perlite, polystyrene particles and vitrified microsphere [1]. Traditionally, cement is used as the main cementitious material, however, the main drawbacks of cement including CO_2 emission and a vast amount of energy requirement, which result in environmental problems [2], prompt various researches in an attempt to search for alternative materials to produce a new kind of binder to combat these issues, especially for China, where large amounts of cement materials are required [3]. Geopolymer is such an alternative material, it is obtained from the alkali activation of reactive aluminosilicate solids, in particular metakaolin or fly ash [3,4]. Geopolymer is eco-friendly and is generally reported to be much more sustainable than ordinary Portland cement (OPC), in terms of reduced production energy requirement and lower CO_2 emission [5]. Geopolymer has several advantages when compared to OPC including higher compressive strength, faster setting time, lower CO_2 emissions and higher thermal resistance [5–9].

The previously reported findings mainly focused on cement based thermal insulation materials. Gong et al. [1] prepared thermal insulation mortar containing vitrified microsphere with improving waterproof performance and the thermal conductivity was evaluated. Liu et al. [10] successfully prepared a mortar with SiO_2 aerogel particles. The mortar based on SiO_2 aerogel particles shows a density of ~1.2 g/cm^3, a compressive strength and flexural tensile strength of ~2.15 MPa and ~0.45 MPa, a thermal conductivity of ~0.1524 W/m K. Wang et al. [11] developed practicable technology for recycling construction waste wood into formaldehyde-free cement-bonded particleboards that have value-added features of high strength, light weight, and thermal insulation for reuse in building and construction applications. Barreca et al. [12] proposed an original use of olive stone to improve the heat insulation performance of cement lime mortar and reduced its final density. Liu et al. [13] carried out experimental study on the bond property between thermal insulation concrete mixed with glazed hollow beads and rebar in freeze-thaw environment. However, after reviewing the previously published findings, there is a lack of experimental data on geopolymer based thermal insulating material with low density. The properties of thermal insulating material derived from geopolymer are not well-known, and little information is available about geopolymer based on metakaolin and polystyrene particles. Only

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Zhang et al. [4] reported the synthesis and characterization of geopolymer foamed concrete, which showed better thermal insulation properties than normal Portland cement foam concrete. Quantitative information on metakaolin geopolymer thermal insulating material with polystyrene particles still requires further investigation.

This work mainly aims to develop anew kind of thermal insulation composite material with low density by using metakaolin geopolymer combined with polystyrene particles. Compressive strength, flexural strength and microstructure were also evaluated.

2. Experimental procedure

2.1. Materials

MK, sourced from Yunnan, China by calcination of kaolinite at 800 °C was utilized as starting material to prepared geopolymer. The water glass was supplied by Zhongfa Water Glass Factory in Foshan, China. Alkali activator solution was prepared by dissolving solid sodium hydroxide (99.2% NaOH, analysis reagent purity) in the industrial water glass with a mix composition of 26.0% SiO_2, 8.2% Na_2O and 65.6% of H_2O.

2.2. Sample preparation

The alkali activator solution was prepared prior to the preparation of geopolymer for 24 h at ambient environment. A 30% wt/wt hydrogen peroxide (H_2O_2) solution was used as blowing agent [14] according to the research work conducted previously. Polystyrene particles with average diameter and bulk density of 2.5 mm and 13.6 kg/m^3, respectively, were used as lightweight aggregate. Geopolymer were synthesized by mechanically mixing metakaolin with the liquid alkali activator mentioned above (modulus of alkaline activator Ms=1.5, the mass ratio of sodium silicate and sodium hydroxide=8:1). The liquid alkali activator/metakaolin mass ratio equals to 0.5. The weighed metakaolin and alkali activator were premixed for 2 min to give complete homogenization. Afterwards, H_2O_2 solution, at the ratio of 3.0 wt% with respect to the weight of metakaolin, was added to the mixture and mixed for another 1 min. Polystyrene particles (polystyrene particles-metakaolin mass ratio varies from 25% to 100% by mass with an interval of 25%) were added to the mixture for another 2 min. Finally, the pastes were poured into plastic molds. The detailed preparation process of polystyrene particles-foamed geopolymer composite was illustrated in Fig. 1.

2.3. Test procedure

Fresh foamed geopolymer composites were cast into cubes molds with size of 40×40×40 mm for compressive strength test, prism specimen with size of 40×40×160 mm was cast for flexural strength test. Prisms specimens of 200×200×40 mm were cast for thermal conductivity test. The measurement of thermal conductivity of foamed specimen was carried out using the method proposed in [15]. All the specimens were vibrated to remove entrained air bubbles. After hardening, the samples were released from the molds and were subjected to curing in standard condition of 20 °C and 95% RH up to acquired days for tests. Compressive strength and flexural strength were tested using a universal testing machine with loading capacity of 2000 kN and loading rate of 0.6 MPa/s at 28 days of curing, respectively. For each testing age, six specimens were tested and the average values were reported.

For high temperature resistant performance test, cubes of 40×40×40 mm were casted and were removed from the moulds 24 h after casting, and were subjected to curing in standard condition of 20 °C and 95% RH up to 28 days. At the end of the curing period, all the specimens were exposed to high temperatures at 400 °C and 800 °C, respectively, installed inside the refractory furnace for heating to evaluate the fireproof characteristics. The samples were kept for 2 h under the target temperature. The heating rate of the oven was selected as 3.0 °C/min [16]. After that, all the specimens were allowed to cool naturally to ambient temperature for residual compressive strength test.

Microstructure observation including foamed geopolymer matrix and interfacial transition zone (ITZ) between geopolymer matrix and polystyrene particles at 28 days of curing was performed using a Japanese Hitachi FESEM electron microscope (SU8010), operating at an accelerating voltage of 15 kV for photomicrographs.

3. Results and discussion

3.1. Mechanical properties

The mass ratio of polystyrene particles to metakaolin was kept as 0,

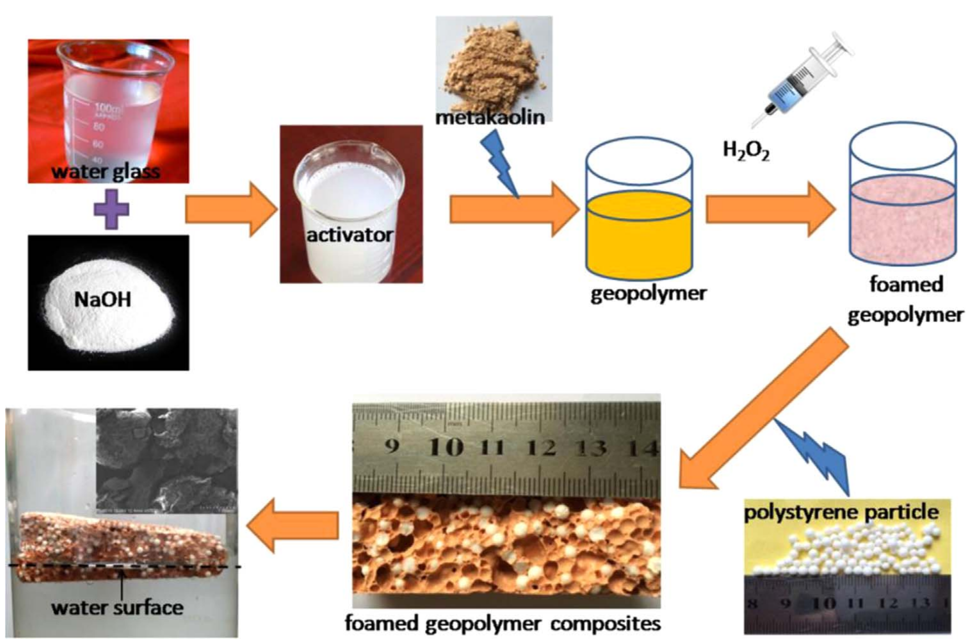

Fig. 1. The preparation of polystyrene particles-foamed geopolymer composites.