

Preparation and characterization of ultra-lightweight foamed geopolymer (UFG) based on fly ash-metakaolin blends

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HIGHLIGHTS

- Ultra-lightweight foamed geopolymer (UFG) with dry density 150–300 kg/m³ is prepared.
- UFG based on fly ash-metakaolin blends is prepared by the chemically foaming.
- The properties of UFG are investigated by designing and optimizing the components.
- UFG reveals lower thermal conductivity and desirable compressive strength.

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ABSTRACT

Ultra-lightweight foamed geopolymer (UFG) based on fly ash-metakaolin blends with its density of between 150 kg/m³ and 300 kg/m³ was successfully prepared by the mixed foaming method of chemical foaming. In the present study, the properties and characteristics of UFG were investigated by designing and optimizing the components of fly ash, metakaolin, alkaline activator, foam stabilizer and foaming agent (H₂O₂), as well as the curing temperature. The results showed that foamed geopolymer with curing age of 7 days presented its dry density between 150 kg/m³ and 300 kg/m³, the mean pore size between 0.57 mm and 1.13 mm, the porosity between 71.8% and 84.5%, the thermal conductivity between 0.0622 W/(m·K) and 0.0852 W/(m·K) and the compressive strength between 0.68 MPa and 2.23 MPa, showing better mechanical properties than the traditional portland cement foamed concrete with the same density. It is also found that curing temperature at 55 °C for 12 h seemed to substantially improve the compressive strength of UFG which is 1.91 MPa compared to curing at 25 °C for the same period of time.

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1. Introduction

Davidovits firstly proposed that geopolymer is an amorphous three-dimensional network structure aluminosilicate gel composed of silicon tetrahedron and aluminum oxide tetrahedral structural units [1]. It is generally believed that precursors used in geopolymer manufacture are produced by depolymerization-condensation reaction of an alkali-activation agent and rich silicon aluminum material (such as fly ash, metakaolin and slag, etc.) [2,3].

Porous concrete with independent closed air-voids structure is one of the typical representatives of inorganic thermal insulation materials. It is encouraging that the density of porous concrete is usually 10–50% of that of ordinary dense concrete, which reduces the energy consumption of the building, the load on the building

structure and labor costs in the construction or transportation [4–6]. In addition, many researchers have demonstrated that porous concrete has the advantages of fire-retardant, sound absorption, shock resistance, good long-term service and durability performance [7–9]. At present, large-scale lightweight building materials and components (such as prefabricated components, partition boards or the core of a lightweight sandwich plate, etc.) prepared from portland cement-based porous concretes have been widely used in many civil and structural engineering fields [10]. Compared with the portland cement-based porous concrete, foamed geopolymer prepared by introducing the bubbles into the geopolymer matrix is a new class of porous inorganic material. Most of the raw materials for the preparation of foamed geopolymer are solid waste, which produce more environmentally friendly building materials in the case of reducing production energy consumption and carbon dioxide emissions [11–13]. Furthermore, foamed geopolymer exhibits a wide variety of properties and characteristics, such as excellent mechanical properties, good durabil-

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ity, high temperature resistance and good ability to immobilize toxic metals [14], as well as improved the resistance to acids and the action of fire [15]. As a result, foamed geopolymer is considered to be more sustainable than conventional portland cement-based porous concrete.

In the process of preparing foamed geopolymer, some are prepared by introducing pre-formed bubbles into the geopolymer matrix by means of pre-foaming method with mechanical foaming [16,17], while others are prepared by the mixed foaming method of chemical foaming [18–20]. It is the key to ensure that the foaming process and the hardening process of the slurry match each other in foamed geopolymer. Therefore, the selection of proper foaming method, foaming agent and matrix composition have significant influence on the preparation of foamed geopolymer. There are many research studies on the composition, physical properties and applications of foamed geopolymer, which have focused mostly on the densities of 600–1800 kg/m³ [21–23]. It is generally considered that the lower density in foamed geopolymer, the lower thermal conductivity and the better insulation effect in foamed geopolymer. Therefore, in order to obtain a better insulation effect, special attention should be paid to the preparation of low density foamed geopolymer when designing insulation materials. However, few researchers have studied the composition and properties of ultra-lightweight foamed geopolymer (<300 kg/m³), which effectively improve the thermal insulation properties.

In this study, the ultra-lightweight foamed geopolymer (UFG) with its density of <300 kg/m³ is prepared by incorporating hydrogen peroxide as air-entraining agents into matrix composed of fly ash, metakaolin, alkaline activator and foam stabilizer. Hydrogen peroxide decomposes and releases gases under alkaline conditions, which are fixed during the hardening of the geopolymer slurry to form honeycomb pores. The purpose of this study is to investigate the effect of different components on the properties and characteristics of UFG. The relationship between dry density, compressive strength, air-voids structure, thermal conductivity and curing temperature of UFG is also investigated. The effects of the air-entraining agent and foam stabilizer are evaluated based on the observed development of the air-voids structure (porosity, pore size and pore size distribution) by stereomicroscopy and Image-Pro Plus (IPP) software. The composition of UFG is characterized by X-ray diffraction (XRD) at different curing temperatures.

2. Materials and methods

2.1. Materials

Fly ash, metakaolin, alkaline activator (sodium hydroxide pellets + sodium water glass + distilled water) and calcium stearate (as foam stabilizers) were selected to prepare ultra-lightweight foamed geopolymer (UFG) by adding air-entraining agent (H₂O₂). Fly ash (FA, class F) with a BET specific surface of 3.23 m²/g was sourced from a coal-burning electric power plant at Nanjing, China. Metakaolin (MK) with a BET specific surface of 14.04 m²/g was obtained from BASF SE (Badische Anilin-und-Soda-Fabrik). Table 1 lists the results of X-ray Fluorescence (XRF) analysis of FA and MK. The corresponding particle size distribution (Fig. 1) was determined by using a Mastersizer 2000 (Malvern, England). The sodium water glass with SiO₂/Na₂O modulus of 3.24 was supplied by

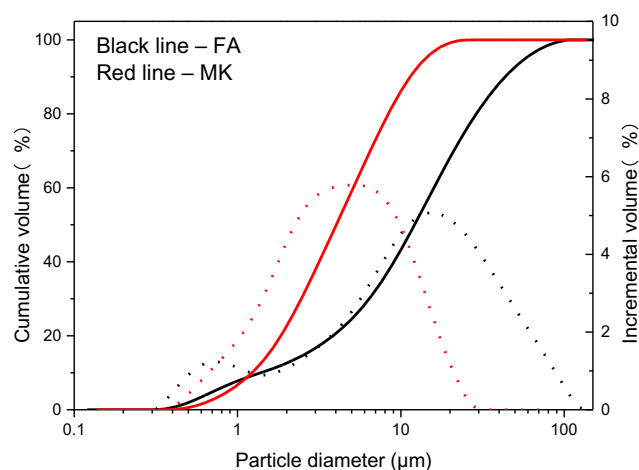


Fig. 1. Particle size distribution of FA and MK.

Dewang Chemical Co., Jinan, China. Sodium hydroxide pellets (NaOH, purity ≥96%) and distilled water were added to sodium water glass to constitute the alkali-activator (AA), where the SiO₂/Na₂O moduli were equal to 1.0, 1.2, 1.4, 1.6, 1.8, respectively. Hydrogen peroxide (H₂O₂, 30 wt%, Wokai Biotechnology Co., Shanghai, China), which provides a more homogeneous air-voids structure network, was selected as air-entraining agent for the geopolymer slurry. Calcium stearate (CS, Aladdin Biochemical Technology Co., Shanghai, China) was incorporated to improve the stability of bubbles and paste.

2.2. Specimen preparation

The molding process has a significant effect on the properties of UFG. Therefore, a suitable specimen preparation procedure is crucial. In this study, UFG was prepared in the laboratory. The mixture proportion of all mixtures is given in Table 2. The process was specified as follows: Firstly, the binder materials and the calcium stearate were mixed into the vertical mixer for 180 s to obtain a homogeneous mixture. The predetermined amount of alkaline activator was prepared at least 24 h prior to its use [24], and then it was poured into the dry materials in the vertical mixer. The mixture was first stirred with a lower speed of about 140 ± 5 rpm for 150 s, then stopped for 15 s, and then stirred with a higher speed of about 285 ± 10 rpm for another 150 s until a homogeneous mortar without lumps of undispersed geopolymer was obtained. A certain amount of H₂O₂ was then introduced into the fluid mixture stirring for another 18 s and the fluid geopolymer paste was immediately casted into the PVC moulds (100 mm × 100 mm × 100 mm and 300 mm × 300 mm × 60 mm). Subsequently, the surface of the test specimens was covered with a polyethylene film. Finally, the curing temperatures of specimens from No.1 to 25 groups were 25 ± 2 °C. However, No. 26–29 group of specimens were first cured at 25 ± 2 °C for 2 h, followed by cured at 40 °C, 55 °C, 70 °C, 85 °C for 12 h, respectively. And then all the specimens were continued curing at 25 ± 2 °C to the specified age.

Table 1
Chemical compositions of cementitious materials (% by weight).

Material	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	TiO ₂	MgO	Na ₂ O	K ₂ O	Ignition Loss
FA	46.75	37.76	3.96	3.29	1.52	0.725	0.20	0.794	3.15
MK	50.93	44.97	0.417	0.064	1.48	0.091	0.203	0.181	1.32

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