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Effect of particle size of fly ash on the properties of lightweight insulation materials

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HIGHLIGHTS

- Effect of fly ash on the properties of lightweight insulation materials was studied.
- The polymerization state of fly ash was depolymerize when grinding time increased.
- The size and structure of pores were influenced by the particles size of fly ash.
- The $\leq$ 60 μm fly ash particles had positive effect on the properties of specimens.

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ABSTRACT

The paper reports the effects of fly ash particle size on the properties of the lightweight insulation materials. The microstructure and mechanical properties of lightweight insulation materials are separately investigated by SEM (scanning electron micrograph) and tabulate thermal conductivity apparatus methods. In addition, the effects of particle size distribution of fly ash on the properties of lightweight insulation materials is studied by grey incidence analysis. The results show that when the ball milling time increases, the particle size of fly ash decreases and the distribution becomes narrow. At the same time, the polymerization state of fly ash would be depolymerize from high poly structure to low polymeric structure. Moreover, the linear shrinkage, bulk density, compressive strength, acid resistance and thermal conductivity of lightweight insulation materials have also increased, but the apparent porosity decreases. And the studies highlight that when the content of fine fly ash particles increases, the nucleation and growth of mullite is accelerated and the sintering driving force is improved at high temperature, which have a positive effect on improving the physicochemical properties of materials. The particles ranging from 20 to 30 μm has a great influence on the linear shrinkage, bulk density, compressive strength, acid resistance rate and thermal conductivity of lightweight insulation materials.

1. Introduction

Preparation of lightweight insulation material from industrial waste has been paid much more attentions due to its low price and environment-friendly features [1–3], which will relieve pressure from industrial waste pollution to the environment and improve the comprehensive utilization of resources. For instance it is estimated that the world production of fly ash in the year 2000 was about 600 Mt (million tonnes) and was once regarded as the environment pollutants. But fly ash is identified as important raw material of industrial with the development of science and technology now [4,5].

In addition to unburnt carbon, crystalline mullite, quartz and hematite, fly ash is mainly comprised of amorphous fine spherical particles [6]. Therefore, fly ash is considered as suitable candidate material to prepare the lightweight insulation materials which has been widely used in thermal insulation material, refractory material and other application fields [7–9]. And in recent years considerable progress has been made in the development of new wall insulation materials from wastes. However, very little research has focused on the ways to improve the properties of lightweight insulation materials by using fly ash. And the suitability particle size of fly ash for use in the lightweight insulation materials manufacturing industry is difficult to estimate because that physical and chemical properties of fly ash are affected by the particle size and the size distribution is much wider which increase the difficulty of the analysis. Therefore some scholars [10,11] just make a simple per-process of fly ash before using it

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to prepare ceramic tile and insulation materials. But to the best of author's knowledge, no reports have detailed studied the effect of particle size distribution of fly ash on the properties of lightweight insulation materials by grey incidence analysis.

In this work, fly ash of different particle size is obtained by the use of mechanical ball milling with different duration. And then the prepared fly ash is mixed with flint clay, kyanite, clay and pore creating materials to prepare lightweight insulation refractory materials. At last, grey incidence analysis is used to study the effect of particle size distribution on the properties of lightweight insulation materials.

2. Experimental procedures

2.1. Raw materials

In this study, fly ash was obtained from Wuhan, flint clay, kyanite, clay, saw dust and organic binder PVA20-99(H) (2 wt% solution) are adopted as raw materials. The chemical compositions of raw materials and formulations of specimens are respectively shown in Tables 1 and 2.

2.2. Methods

Fly ash was firstly ground with a ball-to powder weight ratio of about 5:1 at a milling speed of 35 rpm. Steel balls with diameter of 20 mm, 15 mm and 10 mm were used as the milling medium with different grinding time (0 h (untreated), 3 h and 6 h). The various materials were weighted according to Table 2 and homogenized by ball milling for 3–6 h, moreover the mixture was crushed in case of agglomeration followed by the commixture with 7–10 wt% organic binder PVA20-99(H) (2 wt% solution). Cylindrical compacts with 50 mm in diameter and 40 mm in thickness were obtained at a uniaxial pressure of 2.5 MPa. The compacts were dried at 110 °C for 12 h and sintered at 1300, 1350 and 1400 °C for 3 h.

2.3. Characterization techniques

Bulk density and apparent porosity was measured by Archimedes method using distilled water as liquid media. The compressive strength was measured on a hydraulic universal testing machine (HT-9051; Hung Ta Instrument, Taichung Taiwan). And thermal conductivity measurements were performed on the disk shape (20 mm in thickness and 180 mm in diameter), at 300 °C, 600 °C and 900 °C respectively using water flow plate thermal conductivity apparatus (PBDR-02, Precondar, PR China). Since the green specimens are expected to shrink when exposed heat treatment, diameters of specimens were measured before and after sintering to characterize the linear shrinkage rate dimensionally using the following equation.

$$L(\%) = 1 - \frac{d_0}{d_1}$$

where d_0 refers to a average value for a green specimens through six diameters measured at the top, middle and bottom, and d_1 is obtained in the same way for the same specimens after sintering.

And the weight of specimens were expected to decrease when exposed immersion in HCl acid solution at room temperature for 30 min. Weight of specimens were measured before and after immersion to characterize the acid solubility rate determined by the following equation.

Table 1
Chemical composition of raw materials (wt%).

Chemical composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	TiO_2	IL
Fly ash	31.87	13.98	1.60	0.87	0.57	50.00
Flint clay	47.26	47.76	0.95	0.36	0.82	0.06
Kyanite	36.34	58.90	0.91	0.02	0.02	0.23
Clay	28.85	51.39	1.80	0.21	0.57	16.12

$$C(\%) = 1 - \frac{w_0}{w_1}$$

where w_0 refers to weight for the specimens, and w_1 refers the weight for the same specimens after immersion in HCl acid solution at room temperature for 30 min.

And particle size of fly ash was measured by Laser Particle Size Analyzer (Mastersizer 2000; Malvern Instruments Ltd., Worcestershire, UK). The microstructure of the specimens were characterized by field emission scanning electron microscopy (Quanta 400; FEI Company, Hillsboro, OR, USA).

3. Results and discussion

3.1. Effect of ball milling on particle size and microstructure of fly ash

Fig. 1 represents the smaller particle size and narrower particle-size distribution of fly ash with the increase of ball milling time. It can be observed that, after a 6-h milling the amount of particles with a size larger than 30 μm. As the grinding time is prolonged, the rate of size reduction decreases gradually. Therefore we set the milling time at 0, 3 and 6 h. The d_{50} value (the middle level diameter of the particles) of prepared fly ash are 134.639, 84.093 and 79.762 μm respectively. Meanwhile, the structure of fly ash would be destroyed by mechanical force in the ball milling process [12]. And the polymerization state of fly ash would be depolymerize from high poly structure to low polymeric structure.

Fig. 2 shows scanning electron micrograph of fly ash particles with different ball milling time. It manifests that ball milling destroys a lot of the spherical morphology of fly ash particles, at the same time the specific area and high surface energy of fly ash increases, which can promote sintering of the specimens and so the specimens can obtained enough strength at low temperature.

3.2. Properties of specimens containing different particle size of fly ash

Physical properties of the specimens sintered at 1300, 1350 and 1400 °C are shown in Fig. 3. The specimens for ball milling 0, 3 and 6 h of fly ash are coded as A, B and C respectively. From 1300 °C to

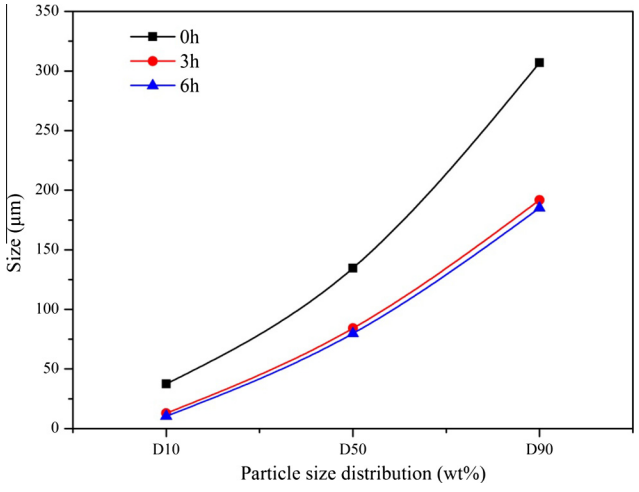

Fig. 1. Particle size distribution of fly ash after ball-milling for 0, 3 and 6 h.

Table 2
Formulations of samples (wt%).

Samples	Fly ash			Flint clay	Kyanite	Clay	Saw dust	PVA (1 wt%)
	0 h (grinding time)	3 h (grinding time)	6 h (grinding time)					
A	20			20	40	20	±40	±7–10
B		20		20	40	20	±40	±7–10
C			20	20	40	20	±40	±7–10