Energy and Buildings 81 (2014) 262–267

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

# Porous thermal insulation materials derived from fly ash using a foaming and slip casting method

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ARTICLE INFO

*Article history:*
Received 24 February 2014
Received in revised form 10 June 2014
Accepted 18 June 2014
Available online 24 June 2014

*Keywords:*
Thermal insulation material
Fly ash
Thermal conductivity
Environment friendly

ABSTRACT

The paper introduces a new kind of thermal insulation material using coal fly ash as main raw material by the method of foaming and slip casting process. The foaming ability of the suspensions with solid loading of 30, 35 and 40 wt% at different foaming agent additive levels were measured. The green bodies were then sintered under different sintering temperatures from 850 °C to 1000 °C for 2 h following the steps of foaming and drying. Effects of solid loading of suspensions and sintering temperature on the porosity, compressive strength and thermal conductivity were investigated. The sintered bodies, with porosity from 86.3 vol.% to 94.5 vol.% and compressive strength from 0.43 MPa to 1.01 MPa, contained spherical pores with no preferred orientation. The thermal conductivity of the sintered thermal insulation material, measured by the transient plane source (TPS) at room temperature, could reach as low as 0.0511 W/(m K). As an environmental friendly material, it is suitable for wall application to save energy.



## 1. Introductions

As is well known, buildings are large consumers of energy in all countries [1] and this is especially true in China, which is the second largest global energy consumer [2]. In the year 2004, building energy consumption alone constituted 20.7% of the total national energy consumption. At present, China has nearly 40 billion $m^2$ buildings, nearly 95% of which belongs to energy-intensive buildings because of the poor insulation performance. What is more, according to a survey, 16–20 billion $m^2$ buildings are erected and at that rate, the total building area will reach about 70 billion $m^2$ by 2020 and the situation will be critically severe [3,4]. As a result, thermal insulation has come into notice and has proven to be practical and logical first step toward achieving energy efficiency [1,5]. Not only can great energy savings be achieved by using thermal insulation materials with little capital expenditure (only about 5% of the building construction), but also the associated emitted pollutants are reduced [1].

However, the widely used organic thermal insulation materials at present are flammable and lots of hazards have been caused [6], especially when considering the fact that thermal insulation materials have side effects from the stage of their production until the end of their useful lifetime [5,7]. Therefore, developing new inorganic materials with good thermal performance, high durability and high security to substitute for the original flammable organic thermal insulation materials is significant [6]. Moreover, China is an energy superpower, relying mainly on coal to produce electricity, which generates millions of tons of coal fly ash every year [8]. A portion of fly ash is used by the cement and concrete industries but most of them is disposed in landfills or ash lagoons, which produces endangering consequences to the environment and people's health [8]. The objective of our research is to find out a new approach where the wastes can be used as potential resources for preparing higher-value added inorganic thermal insulation materials, which is an efficient way to enable the industrial by-product wastes to be beneficially reused [9].

In recent years, numbers of references have been reported on the synthesis of inorganic heat preservation materials using industrial by-product wastes. Though some advancement have been obtained, the proportion of wastes as raw materials was still insufficient and the thermal conductivity of prepared samples failed to meet the requirements of thermal insulation materials, which had confined the application of them. Besides, the high sintering temperature made the preparation process not cost-effective and energy intensive. Yang et al. [6] fabricated a kind of sintered thermal insulation wall material with 65 wt% fly ash added at 1050 °C. Lin and Chang [9] synthesized one kind of porous mullite ceramics with 20% fly ash, which were sintered from 1000 °C to 1270 °C

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http://dx.doi.org/10.1016/j.enbuild.2014.06.028
0378-7788/

**Table 1**
Chemical composition of FA and glass in weight percent.

| Oxides | FA | Glass |
|---|---|---|
| $SiO_2$ | 51.70 | 72.9 |
| $Al_2O_3$ | 26.24 | 0.95 |
| $Fe_2O_3$ | 3.28 | 0.14 |
| CaO | 11.10 | 11.36 |
| $SO_3$ | 3.54 | 0.49 |
| $TiO_2$ | 1.36 | – |
| $K_2O$ | 1.14 | 0.146 |
| MgO | 0.65 | 3.28 |
| $Na_2O$ | 0.57 | 10.54 |
| BaO | 0.09 | – |

and possessed a heat conductivity coefficient of 0.09 W/(m K). Figen Balo et al. [10] manufactured one type of insulation material with 60 wt% of fly ash added, the thermal conductivity of which was 0.315 W/(m K). Zhou et al. [4] and Valverde et al. [11] prepared insulation materials with pure fibers, which were not economic promising. Dmitar Zorić et al. [12] developed a kind of thermal-insulating lightweight aggregate at the sintering temperature of 1150 °C, with thermal conductivity of 0.0872 W/(m K). In our research, we tried to use high volume-added fly ash to synthesize a new kind of thermal insulation material with lower thermal conductivity at a relatively low sintering temperature.

Up to now, scores of processing routes for preparing porous material with low thermal conductivity have been carried out, including gelcasting [13], reaction-bonding technique [14], starch consolidation method [15], leaching method [16] and freeze drying [17]. All the methods are more or less costly and impractical to realize industrial-scale production. In our present work, we combined foaming method and slip casting process, which could not only prepare highly porous material but also be practical and cost-effective. In our experiments, thermal insulation materials, with porosity varying from 86.3 vol.% to 94.5 vol.%, were prepared by using coal fly ash as raw materials, which were environmentally friendly and no hazardous substances were released in the process of fabrication.

## 2. Experimental

### 2.1. Materials

Coal fly ash (100 meshes), obtained from the coal fired power station at Hefei, China, was used as raw material. Waste glass (100 meshes) was used as additional material which provided sufficient amorphous phase necessary for good thermal insulating properties [12]. The native clay (100 meshes) was added to enhance the strength of the green bodies because of its plasticity. Table 1 gives the main chemical compositions of the as-received fly ash and waste glass. X-ray diffraction (XRD, Philips X' Pert Pro Super, Philips, Netherlands) of ground fly ash (200 meshes, 38 μm) showed that the major crystalline phase was quartz and the minor crystalline phases were calcite and anhydrite (as shown in Fig. 1). Sodium dodecyl sulfate (K12, chemically pure, Shanghai Chemical Regent Co., China) was employed as foaming agent and a certain amount of sodium polyacrylate (PAAS, Chemically pure, 80 meshes) was selected to stabilize the foams [18].

### 2.2. Sample preparation

As shown in Fig. 2, the foaming and slip casting process consists of the preparation of suspension, foaming, slip casting, drying and sintering. In our preliminary study, we found that the suspensions with solid loading of lower than 30 wt% are difficult to shape up while the suspensions with solid loading of above 40 wt% are

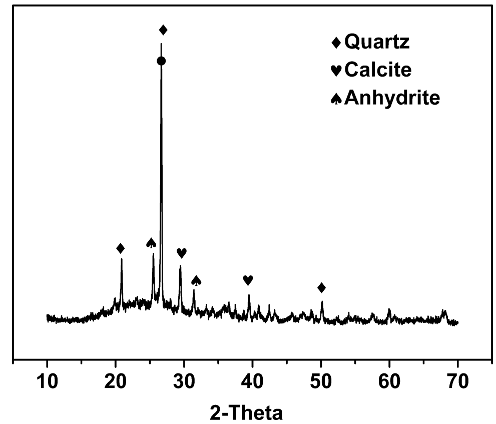


**Fig. 1.** XRD pattern of as-received fly ash.

difficult to foam. As a result, the prepared suspensions with 30, 35, 40 wt% solid loading, adding 0.5 wt% (compared with bulk particles) amount of PAAS as foam stabilizer, were homogenized with a planetary mill (SFM-1, China) for appropriately 20 h at room temperature using corundum spheres. After adding different amounts of foaming agent K12, the foaming process was realized through a high stirrer with the speed of 1200 rpm around for appropriately 2–3 min (as shown in Fig. 3). Thereafter, the foamed slurries were poured into plaster molds. After total drying, the green bodies were sintered to 650 °C with a heating rate of 2 °C/min and maintained 1 h to remove crystal water and organic additives. Subsequently, the bodies were sintered to different temperatures from 850 °C to 1000 °C and held for 2 h (heating rate: 5 °C/min) in air.

### 2.3. Characterization

#### 2.3.1. Crystalline phase and microstructure

The crystalline phase of the as-received fly ash was confirmed by XRD to confirm the major phase of it. Microstructure was observed by a scanning electron microscope (SEM, XL30, Philips, Netherlands) on fracture surfaces of sintered specimens.

#### 2.3.2. TG and DTA

TG (thermal gravity analysis) is the mass loss rate of samples with the temperature rise and DTA (differential thermal analysis) is the comparison of temperature change between material under

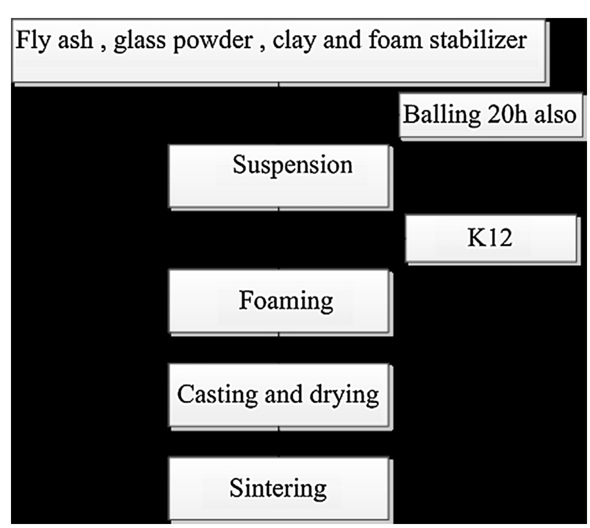


**Fig. 2.** Flowing-chart of process of experiment.