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Regular Article

Mechanical, thermal and fire performance of an inorganic-organic insulation material composed of hollow glass microspheres and phenolic resin

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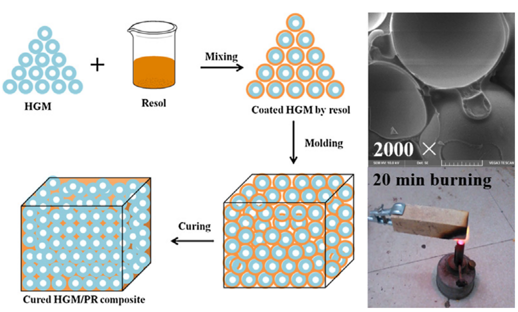
GRAPHICAL ABSTRACT

An inorganic-organic porous insulation material composed of hollow glass microspheres and phenolic resin is successfully fabricated and possess excellent flame retardant property and fire safety.



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ABSTRACT

Hypothesis: Organic foamy materials possess good thermal insulation properties and inorganic materials are non-combustible. Hence, it is possible to develop a kind of organic-inorganic lightweight thermal insulation materials with excellent fire safety.

Experiments: Hollow glass microsphere (HGM), as one kind of lightweight noncombustible inorganic material, was chosen as the filling material. Phenolic resin (PR), as the flame retardant polymeric material, was used as binding material. A series of HGM/PR composites with various PR/HGM mass ratio were prepared. Properties, such as apparent density, microstructure, mechanical strength, thermal conductivity, burning behavior and flame retardancy of the specimens were determined, respectively.

Findings: The results show that the surface of HGM particles is coated by a layer of cured PR and the HGM powder is glued together firmly from the scanning electron microscope (SEM) images. With the increase of PR/HGM mass ratio, both of apparent density and mechanical strength of HGM/PR composites increase, but thermal conductivity and limiting oxygen index (LOI) values decrease, all of the specimens still possess high LOI value (>50%). What's more, no flaming combustion (merely partial carbonization) and hardly any smoke can be observed during the burning process, which indicates the HGM/PR composites possess excellent flame retardant property and fire safety.

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1. Introduction

Organic foams have been widely utilized as building external wall insulation material due to their lightweight and low thermal conductivity [1–5]. The typical organic insulation materials include rigid polyurethane foam [6–10], expanded polystyrene foam [11–13], extruded polystyrene foam [14–16] and phenolic foam [17–20]. Nevertheless, such organic insulation materials often possess a huge fire hazard due to the inherent flammability. Therefore, the development of building external wall insulation materials, with higher flame retardant performance, is of great significance.

The existing inorganic insulation materials including inorganic fiber [21], inorganic mortar insulation materials [22], foamed glass [23], foamed concrete [24] etc. are non-combustible, but they have some obvious deficiencies in insulating properties, density and workability comparing to the organic materials. Inorganic insulation material possesses higher thermal coefficient of conduction. The thickness of material should be increased for the same insulation effect, which may increase the weight of the entire insulation systems and cause wall-cracking, and bring large area of insulation materials to fall off. In addition, the temperature of organic foam production is lower than 200 °C, but the temperatures of rock wool production are higher than 1000 °C, which requires a large quantity of energy and goes against energy conservation and emission reduction. Some new kind of inorganic insulation materials, such as aerogel [25–27] and vacuum insulated panel [28,29], appeared successively. Aerogel has lower thermal coefficient and lower density, but its production process is complicated. Moreover, aerogel possesses low strength, high brittleness and high cost, which has been greatly restricted for the application in building insulation field. For the vacuum insulated panel, it also has very low thermal coefficient due to the lack of convection. Nevertheless, the insulation performance of vacuum insulated panel will be affected when use for a long time with the gradually decreasing vacuum degree.

Based on the above analyses, organic foamy materials exhibit good thermal insulation properties, but, highly flammable. Inorganic materials are non-combustible, but worse thermal insulation properties than the organic ones. Consequently, exploitation of a kind of lightweight organic-inorganic composites with fireproofing function seems increasingly necessary and urgent.

HGM is one kind of hollow, spherical and lightweight inorganic functional powder [30–32]. Due to its excellent performances, such as low density, low thermal conductivity, excellent dispersion, good fluidity and chemical stability, it has been widely used in many fields such as aerospace [33], coatings [34], plastics [35], building materials [36], oil gas exploitation [37] and so on. In particular, the hollow structure endows HGM low density and low thermal conductivity, which makes HGM quite attractive in insulation fields. Li et al. [38] used HGM as the hybrid core materials in vacuum insulation panel. Hu et al. [39] investigated the mechanical and thermal insulation properties of silicon rubber and HGM composites. Zhang et al. [40] studied the effect of particle size of HGM on heat insulation performance of water-borne coatings. Wang et al. [41] fabricated a sort of thermal insulation material by using HGM as aggregate and aluminum-chrome-phosphate solution and tetraethyl orthosilicate as binders. Zhang et al. [42] studied the effect of HGM on the thermal insulation of polysiloxane foam and found the addition of HGM yielded a minimum thermal conductivity and improved the thermal stability and mechanical properties. However, the addition of HGM in insulation materials is very small in most cases, which limits the application of it. Therefore, considering HGM as host materials and using some binders to make the powdery HGM forming porous block material is a feasible technical route for the development of new insulation materials.

Compared to other organic materials, PR is more difficult to burn. Even after burning, PR has the least smokes and toxic gases generated [43]. PR also has been used as a flame retardant and insulation material. Liu et al. [44] prepared PR microspheres with a closed structure, and it showed high thermal performance. Zhang et al. [45] combined hollow carbon spheres with PR to prepare syntactic foams, and found that the compressive and flexural strength decreased with decreasing PR content, which indicated that PR could binding powders together and provide a higher strength for foams.

In this study, PR was used as a binder for bonding the HGM particles to form an inorganic-organic insulation material. A series of HGM/PR composites with different PR/HGM mass ratios were prepared. The mechanical, thermal and fire performances of the HGM/PR composites were investigated.

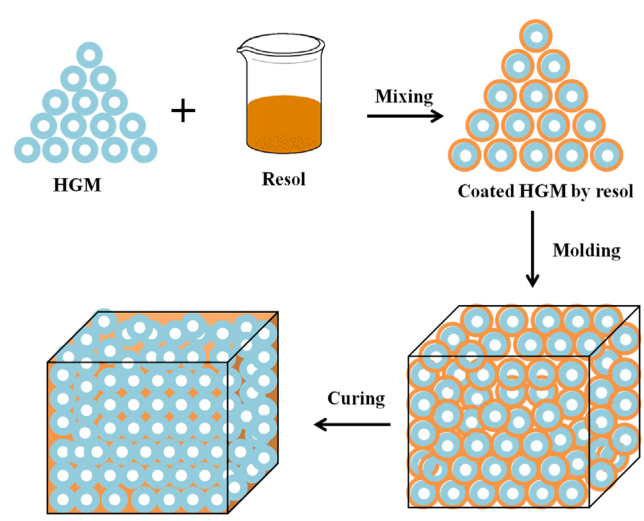
2. Experimental

2.1. Materials

HGM was purchased from Sino Steel MaAnshan Institute of Mining Research Co., Ltd. (MaAnshan, China). The commercial code of HGM is H32, which is a kind of white powder and possesses good fluidity. The particle size range is D50 $\leq$ 55 ìm. The target crush strength (90% survival) is 14 MPa. The true density and tap density of HGM are 0.33 g/m^3 and 0.20 g/m^3, respectively. Resol-type PR (2130, reddish brown liquid, solid content: 85%) used as a binder was purchased from Xinxiang Rongxin Refractory Materials Co., Ltd. (Xinxiang, China).

2.2. Preparation of HGM/PR composites

The HGM/PR composites were prepared by uniform mechanical mixing of HGM and PR with different PR/HGM mass ratios (0.7–1.3). After mechanical mixing of HGM and PR, the obtained mixture was put into a mold. Afterwards, the molded samples were cured in an air-circulating oven at 100 °C for 2 h and 150 °C for 2 h, and the solid HGM/PR composites were prepared. The detailed preparation process is illustrated in Scheme 1.



Scheme 1. Preparation process of HGM/PR composites.