Selective Foaming Agents for Preparation of Foam Glass Ceramics as Insulation Materials from High-Titanium Blast Furnace Slag

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Abstract: Foam glass ceramics as insulation materials were fabricated using high-titanium blast furnace slag and waste glass through a one-step sintering. Notably, selecting a suitable foaming agent is crucial during preparation. In order to select a suitable foaming agent, foaming agents CaCO3, SiC, and AlN are mainly compared in terms of usage effectiveness and cost in this paper. Based on the results of Differential Thermal Analysis, the foaming temperatures of SiC and AlN are more suitable. Further experiments reveal that the foaming effects of 0.1 wt% SiC and 1 wt% AlN are similar. And the foam glass ceramics prepared with SiC have predominantly round, closed pores, leading to superior thermal insulation and compressive strength compared to those made with AlN. Therefore, SiC is relatively the most appropriate foaming agent.

Keywords: Foam glass ceramics; High titanium blast furnace slag; Foaming agent; Insulation material

1 Introduction

As urbanization progresses, the demand for energy-efficient building insulation is rising. Foam glass ceramics, made from industrial waste, offer a superior choice due to their light weight, high strength, and good thermal insulation properties [1]. High-titanium blast furnace slag (HTBFS) is a kind of solid waste produced by blast furnace smelting of vanadium-titanium magnetite [2]. Our research group has prepared foam glass ceramics by one-step sintering using HTBFS and waste glass (WG) as the main raw material successfully [3, 4]. In this preparation, the foaming and crystallization processes can be completed simultaneously, where the two processes would affect each other. Notably, a suitable foaming agent is significant for producing foam glass ceramics with good comprehensive properties. Selection on foaming agent mainly considers from two aspects: (1) Impurities cannot be brought to the existing glass system; (2) Lower cost while ensuring good foaming effect. Therefore, This study investigated common foaming agents $CaCO_3$, SiC, and AlN to select the more suitable one for fabricating foam glass ceramics as insulation materials via one-step sintering to utilize HTBFS and WG.

2 Experimental procedure

In search of the most suitable foaming agent, $CaCO_3$, SiC, and AlN were analyzed by using a Hitachi STA 7000 instrument to identify reaction temperature of foaming agents.

In this study, 42 wt% HTBFS and 58 wt% WG were used as the main raw materials, with 7 wt % $Na_2B_4O_7$ as a fluxing agent and 5 wt % H_3BO_3 as a stabilizer added according to previous exploration. Then the appropriate amount of selected foaming agent were to be added. These powders were ball milled and pressed into cylindrical samples with dimensions of Φ 18 mm × 13 mm and Φ 45 mm × 15 mm and sintered at 1050 ℃。

The sintered samples were etched with a 5 wt% HF solution and then observed for microstructure using SEM. The compressive strength was measured using a universal testing machine. Porosity was measured with a 3H-2000TD true density analyzer using the Archimedes principle. Thermal conductivity was measured with a DRE-2C meter on samples sized Φ40×13 mm.

3 Result and discussion

In this study, using software of Inorganic Glass Engineer System, the characteristic temperature of different mass ratios of HTBFS and WG were obtained in Table 1 (H: G means HTBFS: WG). It can be found that crystallization temperatures of these systems are range from 886 ℃ to 1061℃. For foaming agents, the foaming temperature should be similar to the crystallization temperature.

Table 1 Characteristic temperature of different combinations of HTBFS and WG

H:G	Softening Temperature (℃)	Melting Temperature (℃)	Crystallization Temperature (℃)
42:58	801	1390	886-1056
44:56	806	1384	890-1058
46:54	811	1378	895-1059
48:52	817	1372	899-1061

From the DTA-TG curve of $CaCO_3$ in Fig. 1(a), $CaCO_3$ decomposes between 680 ℃ and 814 ℃ (see reaction equation (1)).

$$CaCO_3 = CaO + CO_2 \quad (1)$$

The decomposition reaction of $CaCO_3$ is intense and gas production rate is fast. More importantly, the highest reaction temperature of $CaCO_3$, 814℃ is much lower than crystallization temperatures as shown in Table 1. Thus, it is not considered despite its low cost in this study.

AlN achieves foaming by reacting with O_2 to produce N_2, as shown in reaction equation (2). According to the curve in Fig. 1(b), AlN undergoes an oxidation reaction between 800 ℃ and 1200 ℃, close to the range of crystallization temperature. It is an appropriate foaming agent.

$$4AlN + 3O_2 = 2Al_2O_3 + 2N_2 \quad (2)$$

Fig. 1(c) shows the DTA-TG curve of SiC, which lacks significant exothermic or endothermic peaks. The mass first decreases and then increases due to the reaction of SiC with O_2 to form SiO_2 (see reaction equation (3)). According to this curve, as the temperature exceeds 850℃, the mass increases without notable exothermic peaks. This is because a dense SiO_2 layer forms on the SiC surface, requiring O_2 to diffuse inward for further reaction [5]. Thus, the oxidation of SiC is continuous and stable, with no distinct exothermic peaks in the DTA curve. So, SiC is also a suitable foaming agent as AlN.

$$SiC + 2O_2 = SiO_2 + CO_2 \quad (3)$$

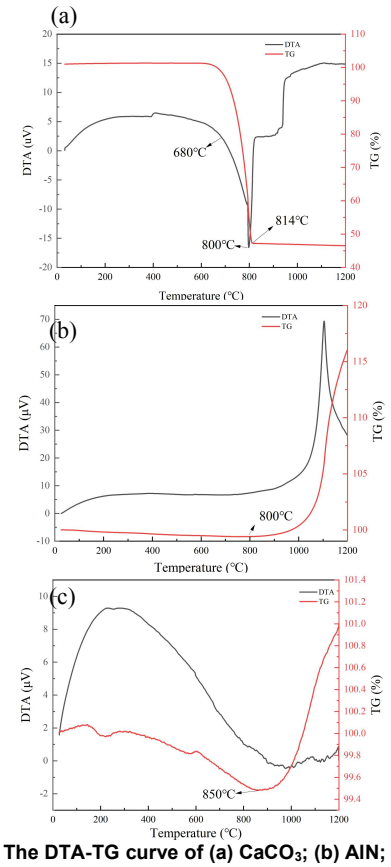

Fig. 1 The DTA-TG curve of (a) $CaCO_3$; (b) AlN; (c) SiC

To select the better foaming agent, 0.1 wt% SiC and 1 wt% AlN were separately added into basic components, and final foam glass ceramics were produced. Fig. 2. shows the microstructure of prepared foam glass ceramics.

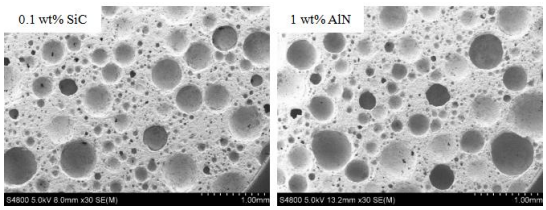

Fig. 2 Microstructure of foam glass ceramics

The foam glass ceramics prepared with SiC has more uniform and predominantly round, closed pores, with fewer interconnected structures. This can reduce air turbulence during heat transfer, inhibiting convective heat exchange and enhancing thermal insulation. Performance of foam glass ceramics with SiC and AlN are shown in Table 1. From a porosity difference of only 0.8%, SiC produces similar foaming effect as AlN at lower addition. Moreover, the foam glass ceramics prepared with SiC have a better compressive strength, 20 MPa and a lower thermal conductivity, 0.380 W/m·K. Additionally, SiC is more cost-effective than AlN. Therefore, the foaming agent SiC is more suitable for preparation of foam glass ceramics as insulation materials.

Table 2 Performance of foam glass ceramics with 0.1 wt SiC and 1 wt% AlN

	Bulk density (g/cm^3)	Porosity (%)	Compressive strength (MPa)	Thermal Conductivity (W/m·K)
SiC	1.42	54.2	20	0.380
AlN	1.40	55	15	0.415

4 Conclusion

Based on curves of DTA-TG, it is found that, compared with $CaCO_3$, SiC and AlN have more appropriate foaming temperature. Further experiments show that only 0.1 wt% SiC achieves the similar foaming effect of 1 wt% AlN, with a porosity difference of 0.8%. The foam glass ceramics prepared with SiC has more uniform and mainly round, closed pores. Moreover, its compressive strength increases, and the thermal conductivity decreases significantly. By adjusting the addition of SiC, the thermal insulation of foam glass ceramics can be further improved.

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