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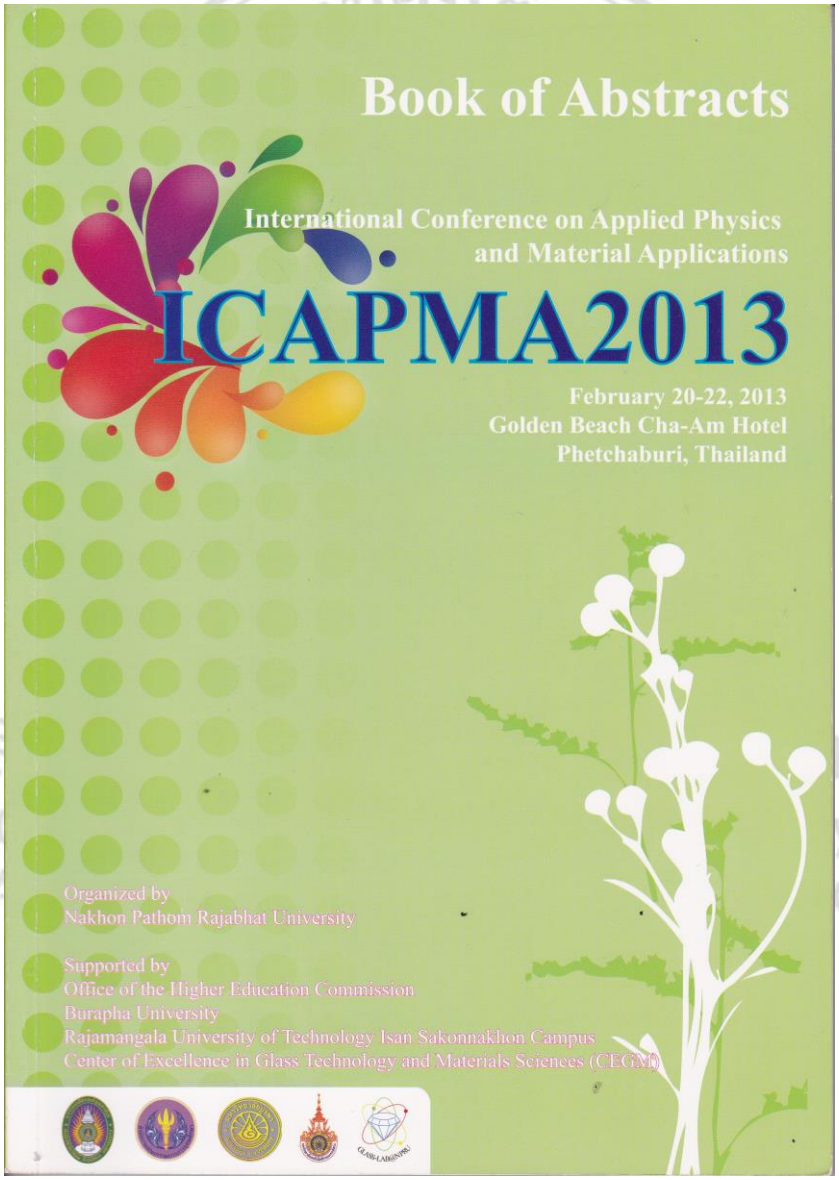

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Fabrication of Glass Foams from Industrial Wastes Used as Insulating Board

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Abstract. Insulating glass foam (IGF) was successfully fabricated by wet process. The starting proportion of 65 wt% waste glass, 12 wt% slag, 23 wt% commercial soap was added with 15 wt% Na_2SiO_3 and represented then was sintered at 725 °C. The IGF had cellular structure with the macro-pore size at 0.428 mm and thin cell walls. Density, thermal conductivity and compressive strength were 0.310 g/cm^3, 0.130 W/m.K and 0.78 MPa, respectively. The average pore diameter and porosity increased with increasing the Na_2SiO_3 concentration and the sintering temperature. On the other hand, the density, thermal conductivity and compressive strength were decreased.

Introduction

Microcellular materials including with glass foams are widely used in thermal/sound insulation, energy absorption and structural uses due to their unique properties such as light weight, low thermal conductivity, buoyancy and cushioning performance [1]. Glass foam is a heterophase system consisting of the solid phase (glass thin walls) and gaseous phase covered with the walls. Basically, glass foams is produced within two routes: (1) obtain by the action of a foaming agent, mostly carbon or carbonaceous substances (dry process) and (2) obtain from expansion of bubble gas which trapped in glass foam slip (wet process). During firing, the generating gas from the foaming agents and/or the expansion of bubble gas occur within a mass of the softened glass powders while viscous flow sintering. The properties of finished glass foams depend on the type and quantity of the added foaming agents, pore size/pore structures and heating profile [2].

Fernandes [3] and Mangutova [4] have prepared porous glass foams by dry process. The fly ash and waste glass are the main raw materials mixed with carbonate compounds as foaming agent. In this paper, insulating glass foam (IGF) is successfully fabricated from waste glass and slag cooperated with a commercial soap by wet process. The relation of sodium silicate (Na_2SiO_3) concentrations and sintering temperatures on the final properties of IGF are also investigated.

Experimental

Insulating glass foam (IGF) preparation

Waste glass (WG) from Thaitechnoglass Co., Ltd. and waste slag (WS) from smelting process were dry-milled, producing particle sizes smaller than 65μm and 100 μm, respectively. Commercial soap (CS) was cut and sized in order to obtain grains < 1 cm. The starting proportion (wt%) of 65%WG, 12% WS and 23% CS was prepared for total 1200 g. Commercial Na_2SiO_3 powder as deflocculant and sintering aid was added to the starting proportion in different concentrations, varying from 10 wt% to 15 wt% as noted IGF10 and IGF15, respectively. The mixtures were mixed with 570 cm^3 of water and 137 cm^3 carboxy-methylcellulose (CMC) in a high speed mixer for 15

min in order to produce a lot of small gas bubble. The density of slip was constant at 2.00 g/cm^3. The slip was poured into an acrylic mould (8 inch × 8 inch × 2 inch) and dried at 70 °C for 12 h. The dried samples were sintered at 700, 725 and 750 °C for 15 min with 3 °C/min and then were normal cooled to room temperature. Finally, the IGFs were cut (5 cm × 5 cm × 5 cm) and then polished in order to investigate their physical and thermal properties.

Measurement

Foam morphology and pore sizes were investigated using a digital microscope (Dino-lite AM-413ZT). After measuring and calculating more than 25 pores, the average pore sizes of the IGFs were determined. The density of the IGFs was evaluated according to the $\rho = m/V$ where ρ is density (g/cm^3), m is weight (g) and V is volume (cm^3) measured by the dimensions of the samples. Porosity in term of water absorption (%) was determined as following the procedure in the article [5]. The thermal conductivity (W/m.K) was recorded at room temperature with thermal conductivity sensor (v.3.0/revised 02-09). The compressive strength (MPa) was tested using a compression strength tester DTM (model no.DTMT556). Each result was the average of five measurements.

Results and discussion

Foam morphology

Primary observation, the foam morphology of IGF samples sintered at different temperatures was considered. The original pores were generated by CS during flicking with a high speed mixer. The foam structure obtained and still existed for sintering at 700 °C and 725 °C. The sample sintered at 750 °C, because of low softening temperature (<670 °C) and low viscosity of Na_2SiO_3, featured the dense and high compaction phenomena, so that the sintering and foaming temperatures could be investigated at 700 and 725 °C.

Pore size

Fig. 1 is the cellular structures of the four IGF samples. There existed homogeneously a lot of closed-pores with different diameters in all samples. The average pore diameters varied in the range of 0.379-0.428 mm which could be classified into macro-pores [2]. It was found that the average pore diameter increased with increasing the Na_2SiO_3 concentration and the sintering temperature. This could be explained by gas expansion. During sintering, the high Na_2SiO_3 concentration led to great gas expansion. According to foaming process, the samples begin to soften under the expansion pressure which brings large pore diameters. The IGF10 and IGF15 sintered at 725 °C led to lower high-temperature viscosity of cell walls and higher gas pressure, which stretch the cell wall as a result of the generation of largest pores at 0.428 mm and thin cell walls [6].

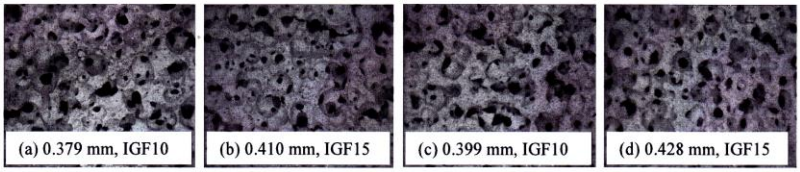

Fig. 1. Macro-cellular of IGFs (a) and (b) sintered 700 °C (c) and (d) sintered at 725 °C.

Density and porosity

The increases of the Na_2SiO_3 concentration and the sintering temperature resulted in a dramatic decrease of the density and increase of the porosity as shown in Fig. 2(a) and (b), respectively. The result of density is in good agreement with that of porosity. In this paper, the density varied in the range of 0.310-0.344 g/cm^3 which could be classified into medium foaming (0.10 g/cm^3 < ρ < 0.40 g/cm^3) [6]. It was found that either Na_2SiO_3 concentration or sintering temperature decreased the density of IGFs, however the density of IGFs sintered at 725 °C was much lower than sintered at 700 °C. The resulting of porosity was reverse. The changes of density and porosity related to the large pore diameters and thin cell walls as discussed above.

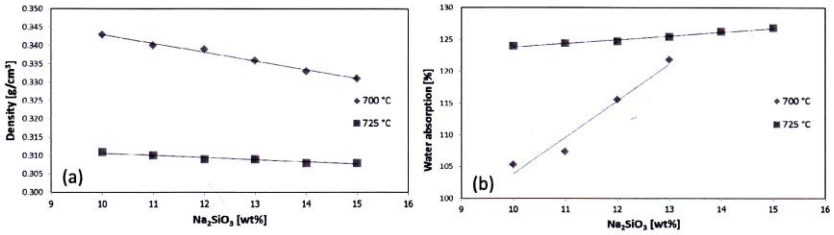

Fig. 2. The effects of Na_2SiO_3 content and sintering temperature on (a) density (b) porosity.

Thermal conductivity

Fig. 3(a) illustrates thermal conductivity of IGFs. The thermal conductivity values of IGFs, in this paper, were 0.130-0.157 W/m.K which enhanced thermal insulation capability after compared with other materials [6,7]. It could be seen that the thermal conductivity decreased with higher Na_2SiO_3 concentration, due to lower density and higher porosity of the IGFs which were mainly responsible for thermal insulation property. Thus, the thermal conductivity of IGF15 (0.150 W/m.K) was lower than IGF10 (0.157 W/m.K) after sintered at 700 °C. In the other hand, for given concentration of Na_2SiO_3, the thermal conductivity decreased after sintered at 725 °C as 0.144 W/m.K and 0.130 W/m.K for IGF10 and IGF15, respectively. This statement could be substantiated by density results and macro-cellular of different pore diameters (Fig. 1).

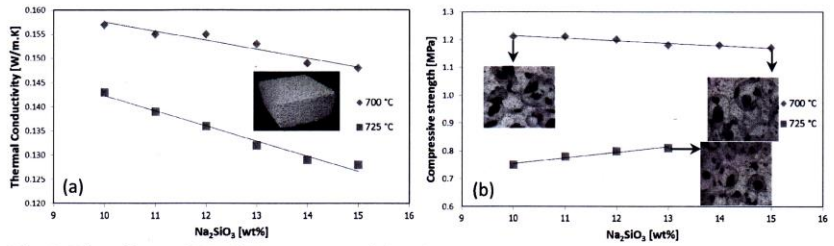

Fig. 3. The effects of Na_2SiO_3 content and sintering temperature on (a) thermal conductivity (b) compressive strength.

Compressive strength

Generally, compressive strength is reasonably correlated with density and cellular structure of the foamed materials. Fig. 3(b) illustrates connectivity between macro-cellular features and compressive strength for IGFs sintered at 700 °C and 725 °C. It could be seen that the compressive strength decreased with higher Na_2SiO_3 concentration and sintering temperature. The larger pore diameters and thin cell walls in IGF15 resulted in compressive strength 1.18 MPa that is lower than that for IGF10 at 1.22 MPa. In the other hand, for given concentration of Na_2SiO_3, the compressive strength decreased after sintered at 725 °C. There is insignificantly changed for different Na_2SiO_3 concentrations as 0.75 MPa and 0.78 MPa for IGF10 and IGF13, respectively. Although the compressive strength values of IGFs, in this paper, were lower than other materials [8]. However, the IGF15 sintered at 725 °C could primarily be applied for interior thermal insulating board as shown in Fig. 4(a) similarly with other works [9, 10].

Conclusion

In this paper, insulating glass foam (IGF) was successfully fabricated from the starting proportion of 65 wt% waste glass, 12 wt% slag, 23 wt% commercial soap and was added with 15 wt% Na_2SiO_3 by wet process. The insulating broad was sintered at 725 °C which represented the cellular

structure with the macro-pore size at 0.428 mm and represented thin cell walls. Density, thermal conductivity and compressive strength were 0.310 g/cm^3, 0.130 W/m.K and 0.78 MPa, respectively. The average pore diameter increased with increasing the Na_2SiO_3 concentration up to 15 wt% and the sintering temperature at 725 °C. The decrease of density and the increase of porosity related to the large pore diameters and thin cell walls. The thermal conductivity reached to the lowest value due to the lowest density and the highest porosity of the IGF containing 15 wt% Na_2SiO_3 sintered at 725 °C. Again, the compressive strength decreased after sintered at 725 °C which was insignificantly changed for different Na_2SiO_3 concentrations.

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