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Thermal conductivity of high porosity alumina refractory bricks made by a slurry gelation and foaming method[☆]

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Abstract

Alumina has high heat resistance and corrosion resistance compared to other ceramics such as silica or mullite. However, for its application to refractory bricks, its high thermal conductivity must be reduced. To reduce this thermal conductivity by increasing the porosity, a GS (gelation of slurry) method that can produce high porosity solid foam was applied here to produce the alumina refractory brick. This method was successfully applied to produce alumina foam with high porosity and thermal conductivity of the foam is evaluated. At room temperature, the thermal conductivity was about 0.12 W/mK when the foam density was 0.1 g/cm^3. At elevated temperature above 783 K, thermal conductivity of the foam was strongly affected by heat radiation and increased with increasing temperature, in contrast to the thermal conductivity of alumina itself, which decreased with increasing temperature. The alumina foams developed here achieved sufficient thermal insulating properties for use in refractory bricks.

Keywords: Alumina foam; High porosity; Refractory brick; Hydro-gel; Thermal conductivity

1. Introduction

Recent urgent demands for reduced energy consumption and efficient energy usage require high performance thermal insulation materials.[1] Such demands have been made in the field of refractory materials. Because conventional refractory bricks have good heat-resistance performance and can be produced at low cost,[2] they have relatively poor thermal insulation performance. Older thermal insulators in furnaces are now being replaced by high performance insulators such as mullite wool or alumina wool. When high heat resistance is not required, either “micro-therm”, which has very low thermal conductivity, or low-cost calcium silicate board can be used as such a replacement. However, if the porosity of conventional low-cost refractory bricks can be increased, both the insulation properties and performance at both room temperature and elevated temperature might be improved, and thus refractory bricks can become a viable replacement.

In our present study, a refractory brick whose main components are alumina and ceramic fiber was developed, because alumina has high thermal conductivity, although it requires high porosity to increase its thermal insulation performance. Traditionally, fugitive material or space holder material is used to give a refractory brick its porous structure, and polystyrene foam particles, sawdust and starch[3] are used as fugitive materials. However, the maximum porosity that can be achieved using fugitive or space holder material is only about 60–70%, and the resulting increase in insulation performance is therefore limited. Here, using the GS (gelation of slurry) method that was previously developed to produce high porosity metal foam,[4–6] we produced alumina refractory bricks. We then measured the porosity, mechanical properties (i.e., cell structure and compressive strength), and thermal conductivity of the foam. We also estimated thermal conductivity using modified kunii model. Our results show that this method can successfully produce ceramic foams with porosity from 94 to 98%, and can thus produce high porosity ceramic foams that have low thermal conductivity.

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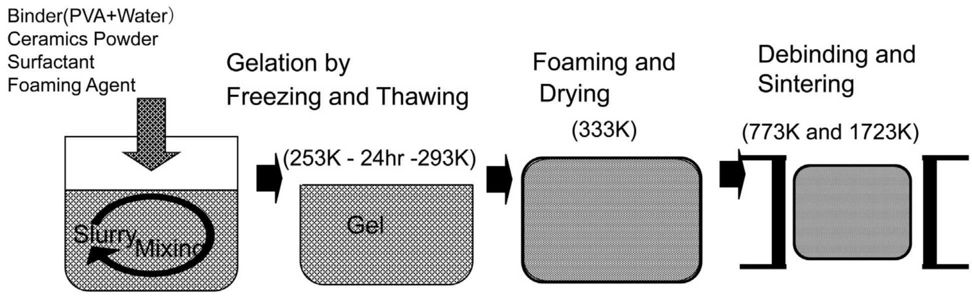

Fig. 1. GS method for producing high porosity ceramic foam.

Table 1
Ingredients for producing alumina refractory bricks.

Ingredient	Specifications
Alumina powder	a-alumina, MM-22, Nippon lightweight Metal Co. Average particle diameter of powder = 0.3 μm, $A1_2O_3$ 99.6%
Ceramic fiber	CFP-50, ITM Co. Ceramics: $A1_2O_3$ 48%, SiO_2 52%, fiber length < 80 mm, average diameter = 2–4 μm
Polyvinyl alcohol (PVA)	N-300, Nippon GouseiKagaku Co., m.w. = 80,000
PVA binder	10 wt% water solution of N-300 PVA
Surfactant	Yashinomi Sennzai, Saraya Co. Ltd.
Foaming agent	Normal Pentane (n-Pentane)

2. Preparation and evaluation methods of alumina foams

2.1. GS (gelation of slurry) method

Fig. 1 shows a schematic of the GS (gelation of slurry) method for production of high porosity ceramic foam. First, a slurry containing ceramic powder, foaming agent, and surfactant in an aqueous polymer solution was prepared. The aqueous polymer solution was poly vinyl alcohol (PVA) solution because it forms a strong gel after being frozen and kept 10–20 K below the re-melting point of water.[7,8] The foaming agent was pentane because its boiling point is 319 K, which is about 30 K below the re-melting temperature of the aqueous PVA solution. Next, this slurry was frozen for 24 h, and then thawed to form a gel. Then, the slurry gel was heated to about 333 K, which is the temperature that pentane starts to foam. To achieve fine foaming condition, the slurry gel must be kept from 10 to 20 K lower than its re-melting temperature. This step in the GS method caused the slurry to take on a closed-cell structure. The slurry is then dried by heating to a set temperature, thus yielding a precursor of the ceramic foam. Finally, this precursor is sintered to form a ceramic foam.

2.2. Production of a high porosity alumina refractory brick

Table 1 shows the components of the alumina foam processed according to Fig. 1 as follows. First, a slurry was prepared by mixing the binder with the alumina powder and ceramic fiber. The ceramics fiber is mixed as solid skeleton for preventing cracks while the sintering. Table 2 shows the various concentrations of foaming agent used to determine the effect on porosity of the alumina foam and shows the corresponding surfactant concentrations. Next, a slurry gel was prepared by freezing the slurry at 253 K for 24 h and then thawing at 293 K. Then, a foam was prepared by first heating the slurry gel and then drying it in a constant-temperature oven at 333 K for several days. Finally, a high porosity alumina refractory brick was then formed by debinding this precursor at 773 K for 2 h, then sintering in a furnace under atmospheric conditions at 1773 K for 2 h using the protocol shown in Fig. 2. These alumina refractory bricks contain 92.2% Al_2O_3 and 7.8 wt% SiO_2

2.3. Evaluation of structure and strength of alumina foams

The structure of the alumina foams was observed using an electron microscope (Keyence VE-9800, Japan) in 0.5 kV electron accelerating voltage. The compressive strength σ of the foams was evaluated based on compression tests using an autograph (Shimadsu AGS-10kND, Japan). In the compression test,

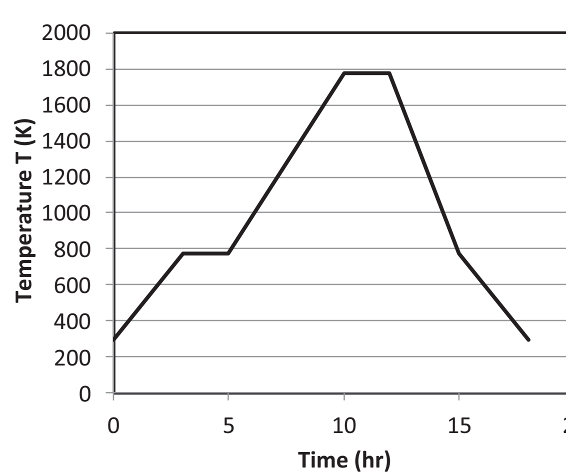

Fig. 2. Sintering protocol for producing high porosity alumina foams using GS method (Fig. 1).