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Effect of fumed silica properties on the thermal insulation performance of fibrous compact

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Abstract

The particle properties play an important role in developing advanced thermal insulation board made by fumed silica. In this study, the effect of hydrophilic or hydrophobic on the thermal conductivity and fracture strength of the resultant insulation board was investigated. A higher thermal conductivity and higher strength were obtained in using hydrophilic particles. Very low thermal conductivity, below 0.02 W/m K, was achieved in using hydrophobic particles. The difference of thermal conductivity was mainly dominated by solid part. The decrease of thermal conductivity and increase of fracture strength were related to the bonding condition between particles in the boards.

Keywords: B. Composites; C. Thermal conductivity; E. Insulators; Fibers; Fumed silica

1. Introduction

The issues of saving energy and reduction of CO_2 emissions are very important nowadays. High performance thermal insulation material is one of the key issues to solve these problems. The silica aerogel prepared by supercritical drying is a very promising material. It exhibits nanoscale porous structure which leads to extremely low thermal conductivity. However, there are several problems of using this material for thermal insulation. The thermal insulation board made of silica aerogel is very fragile. Besides, the thermal insulation ability of silica aerogel decreases at high temperature [1].

The fumed silica has been used for thermal insulation board recently. The thermal conductivity of the compact made of fumed silica is close to that of silica aerogels. It is attributed to high porosity and its nanoscale porous structure in the compact. To improve its mechanical reliability, glass fibers were added to increase the strength of the compact. A dry processing method was also developed to fabricate fiber-reinforced fumed silica compact. The silica nanoparticles were first coated onto the glass fiber to form silica/fiber composite. Then, the powder mixtures were compacted to form the thermal insulation board [2,3]. By applying appropriate mechanical treatments, the nano scale pores remained. This method minimizes the fiber/fiber contacts through the fumed silica coating. Therefore, a highly uniform dispersion of glass fibers was achieved in the compact. To control its thermal conductivity at high temperature, SiC particles were added to decrease the radiation heat transfer of the compact. However, the effect of the particle properties on the performance remains unclear.

In this study, the fumed silica with hydrophilic or hydrophobic characteristics was used. The surface characteristics on the thermal conductivity and strength of the insulation board are investigated.

2. Experimental procedure

The starting materials used in this study were hydrophilic type fumed silica powder (AEROSIL300, Nippon Aerosil,

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Tokyo, Japan), hydrophobic type fumed silica powder (AEROSILR812, Nippon Aerosil, Tokyo, Japan), glass fibers (CS3J-888, Nittobo, Tokyo, Japan) and SiC powder (Silicar-Gl, Wacker Chemie, Munich, Germany). The specific surface area S_{BET} of the hydrophilic and hydrophobic type fumed silica, as determined by a BET method, was 300 m^2/g and 250 m^2/g, respectively. Through the use of surface area, the equivalent size, d_{SW}, of hydrophilic and hydrophobic fumed silica was respectively 10 nm and 12 nm. The fumed silica powder used in this study exhibited a three-dimensional nano-scale chain-like aggregated structure with spaces of several tens nanometers [2,3]. The glass fibers were added to reinforce the strength of the compact. The alkali content of the aluminum borosilicate glass fiber is less than 1 mass%. The diameter and length of the glass fibers were 10 μm and 3 mm, respectively, as shown in Fig. 1. The SiC powder was added to reduce the radiation heat transfer of the compact. The average diameter of SiC, as determined from a particle size analyzer (laser scattering method), was 3.3 μm, and its morphology was shown in Fig. 2.

Table 1 shows the chemical composition of the powder mixtures used for experiments. The mass ratio of fumed silica (hydrophilic or hydrophobic): glass fibers: SiC in the powder mixtures (100 g) was 60:20:20. The mixture was mechanically processed by the attrition mill (Mechanofusion System, Hosokawa Micron Corp., Osaka, Japan) for 10 min. There was a certain clearance between the rotating rotor and chamber in the mill [4]. When the rotor rotating, powder mixture was compressed into the clearance through compressive and shear forces, despite no media ball was present. The clearance and the rotating speed were 3 mm and 1000 rpm in the experiment. After mechanical processing, the fumed silica/glass fiber powder mixture was obtained. To evaluate the surface characteristics of powder, the IR transmittance of the powder mixtures before and after mechanical processing was measured by a FTIR spectrometer.

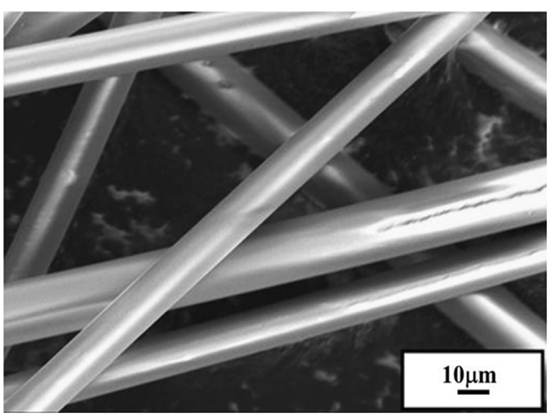

Fig. 1. SEM image of glass fibers.

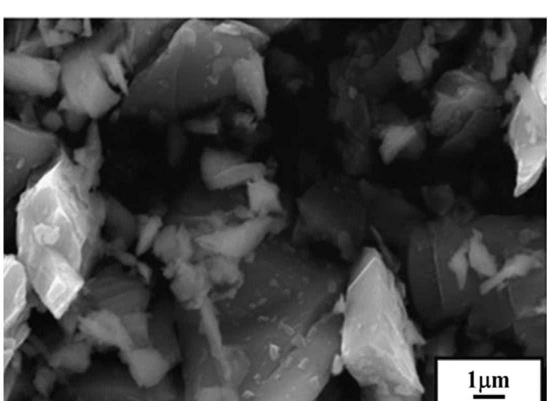

Fig. 2. SEM image of SiC particles.

Table 1
Composition of the thermal insulation board.

Material	Compounding ratio (mass %)	Average diameter
Fumed silica nanoparticle	60	10 nm (Hydrophilic)
(Hydrophilic or hydrophobic)		12 nm (Hydrophobic)
SiC particle	20	3.3 μm
Glass fiber	20	10 μm

The powder mixture was then uniaxially pressed to form the shape of board (100 mm × 150 mm × 10 mm) by applying the pressure of 2 MPa at room temperature. The approximate temperature and humidity during the mechanical processing and pressing were 25 °C and 50%, respectively. The microstructure was observed using scanning electron microscopy (SEM). The apparent density and porosity of the compact were determined by measuring its dimensions and the weight. Three samples were measured for each composition. Besides, the board made by using hydrophobic silica was heat treated at 400 °C for 12 h to evaluate the effect of hydrophobic surface group on the properties of the board. The FTIR analysis was applied to evaluate if CH_3 group on the surface of hydrophobic silica was decomposed at 400 °C.

Three-point fracture strength measurement using a universal testing machine was applied. The dimensions of the specimens were 10 mm in thickness, 30 mm in width and 100 mm in length. A crosshead speed of 1 mm/min with an inner span length of 80 mm was used in the measurement, at room temperature. Three specimens for each board were used for strength measurement. Thermal diffusivity of the compact was measured by a cyclic heat method [5]; and specific heat by a drop calorimeter method [5]. The thermal conductivity was calculated from thermal diffusivity, specific heat and density at the temperature range from 100 °C to 600 °C. The measurement was carried out three times for each board. In this study, the thermal conductivity under atmosphere was measured first, and then measured under vacuum. The thermal conductivity of a compact consists of nanostructure under atmosphere was evaluated by the following equation [6,7]:

$$\lambda = A\rho + B\,T^3/\rho + \lambda_g \quad (1)$$