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Production of high porosity metal foams using EPS beads as space holders

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ABSTRACT

High porosity metal foams were produced using a SWS (Space holders & Whipped Slurry) process that uses EPS (Expanded polystyrene) beads as space holders and a whipped slurry of a metal powder and a water solution of PVA (Polyvinyl alcohol). First, the slurry is whipped and mixed with EPS beads, then molded, and finally frozen and left for 24 h to form a gel. After being thawed, the precursor thus obtained is desiccated, decomposed all binders and polystyrenes and sintered. The result is high porosity metal foam that maintains the molded shape. When stainless steel powder is used in this simple process, metal foams with a porosity ranging from 90% to 97%, plateau stress from 4 to 0.4 MPa and thermal conductivity from 0.5 to 0.1 W/mK are produced. Pore size can be controlled by using different sizes of EPS beads. This simple process can be used to produce metal foams of high porosity at high throughput. Also, this process can be used to reduce production costs using coarser and cheaper powder. Such coarse powder foam has lower thermal conductivity, and thus can be used as a thermal insulator. These low cost metal foams can expand these applications such as filters, thermal insulators, shock absorbers and acoustic insulators.

1. Introduction

High porosity metal foams are lightweight, have good thermal and acoustical insulation properties, and can be produced using one of several processes [1]. For example, one method produces aluminum foams from molten metal by using a foaming agent [2]. Another method coats metal onto a template material to produce nickel foams by CVD [3] or by galvanizing onto polyurethane foam [4]. Processes using metal powder have also been developed. Using a foaming agent and a gelatin of a metal powder slurry produces higher porosity metal foams compared to conventional metal powder processes [5,6]. A process for making metal foam using MHS (Metal Hollow Spheres) has been developed by the Fraunhofer Institute [7]. MHS is produced by coating metal powder onto EPS beads and then sintering. Also, aluminum-steel composite foam is produced using MHS [8,9]. Although all of these above-mentioned methods can produce metal foams with high porosity, each method has its own inherent problems. Some require expensive foaming agents or metal powders, some have limited applicable metals, and some are currently too complicated for mass production.

An easy, commonly used process involves metal powders with space holders. Numerous organic and inorganic materials can be used as the space holders, and are decomposed during the sintering process. Although this method can be used to produce porous titanium or micro stainless parts [10–13], it has difficulty producing a high porosity metal foam. We therefore developed a process that combines the space holder method and the whipped slurry method to produce metal foam. This process, which we call the SWS (Space holders and Whipped Slurry) process, can produce metal foams with porosity exceeding 95%. In this process, relatively coarse powder can be used, thus reducing the cost of foams to less than that for foams fabricated by processes that use powder alone to fabricate metal foams.

Here, we developed a new, low cost process to fabricate high porosity foams. Then, we used this SWS process to fabricate stainless steel foams, and evaluated their cell structure, mechanical properties, and thermal conductivity.

2. Experiment

2.1. SWS process to fabricate metal foam

Fig. 1 schematically illustrates a general outline of the SWS process to fabricate metal foam, and this process uses EPS (Expanded Polystyrene) as space holder. EPS is the polystyrene beads foamed using foaming agent and steam heating. It is commonly used as cushioning or buffer material. The SWS process involves the following five steps.

(1) Metal powder is mixed with a PVA (Poly Vinyl Alcohol) water solution binder and a surfactant to form slurry.

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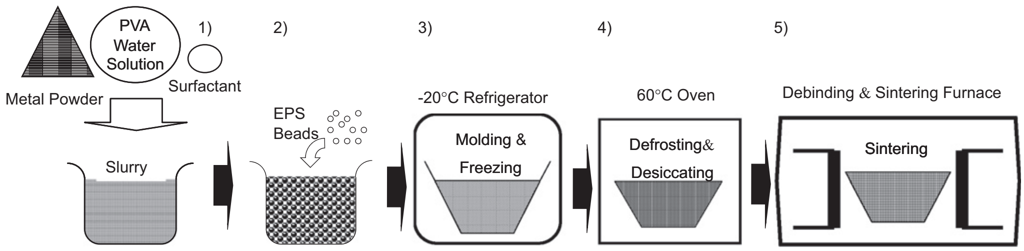

Fig. 1. SWS method for fabricating metal foam, (1) preparation of slurry, (2) mixing of the slurry and EPS beads and whipping, (3) molding and freezing, (4) gelation of slurry and desiccating, (5) debinding and sintering.

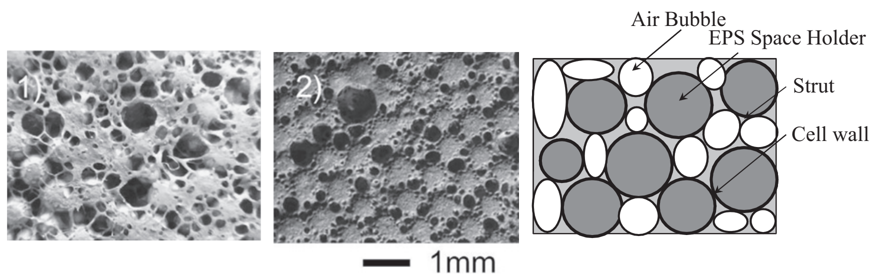

Fig. 2. Photographs of precursor and sintered metal foam. (1) Precursor and (2) sintered metal foam (3) schematic of foam structure.

(2) The slurry is whipped and mixed with EPS space holders to trap air bubbles and prevent these bubbles from bursting.
(3) The mixture of slurry and space holders is molded, and then frozen and left for 24 h to allow the PVA binder to become a gel [14].
(4) The obtained precursor is defrosted and the molded shape is retained due to the PVA binder gel. Then the precursor is heated at 333 K for 48 h for solidification by desiccation.
(5) The precursor is heated at 773 K for 2 h to decompose the space holders and binder. The precursor is then sintered.

Fig. 2 shows (1) photograph of the precursor, (2) photograph of sintered foam and (3) schematic of the foam structure. The foam becomes the structure composed of the pore made by air bubble and the EPS space holder. The pores made by air bubble become the structure composed by struts. The pores made by ESP are coated surface by metal powder and they have cell walls.

2.2. Fabrication of stainless steel foam using the SWS process

The SWS process was applied to fabricate stainless steel foam as follows. Two SUS 316L stainless steel powders were used; PF3F and PF20F (Epson Atmix Co.) with an average particle diameter of about 3 and 10 μm, respectively. The PVA binder was an 8 wt% water solution of HA-26PVA (Nippon Gohsei Co.), which has a polymerization degree of about 2600. This PVA binder becomes a gel as a result of the freezing and thawing operations in the SWS process. The surfactant was a neutral detergent (Saraya Kagaku Co.). The EPS space holder has particle size distribution from 0.6 to 1.0 mm, average diameter about 0.85 mm, and a tap density of 30 kg/m^3. The metal powder, PVA binder, surfactant and EPS beads were mixed at different concentrations as shown in Table 1. Debinding, decomposing of EPS and sintering were continuously processed by heating the precursors in vacuum as shown in Fig. 3. The precursors were sintered in a vacuum. The binder and EPS beads were decomposed by slowly heating from room temperature to 773 K over a period of 4 h, and then kept at that temperature for 2 h. The temperature was then increased to sintering temperatures 1323 K (PF3F) and 1423 K (PF20F) for 2 h and kept at that temperature for 30 min to bond the powder. The two stainless steel foams are hereafter called PF3F and PF20F foams. They have a skin on the sample surface. A skin is a slurry film composed on a mold surface, and this part has high density compare to inner part of the foam. Therefore, skin part is avoided for evaluation of foam properties.

Table 1
Concentrations of prepared slurries.

No.	SUS316 powder (g)	Powder weight/ EPS weight	PVA binder (8 wt%) (ml)	Surfactant (ml)	EPS beads (ϕ0.8 mm)
1	400	20	90	10	20 g (670 ml)
2	200	10	90	10	20 g (670 ml)
3	120	6.0	90	10	20 g (670 ml

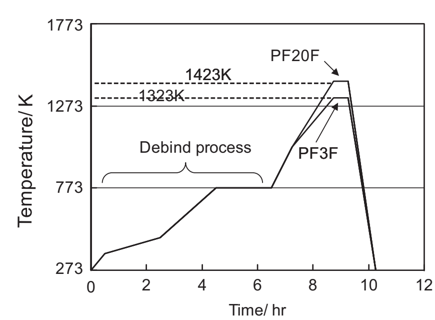

Fig. 3. Debinding and sintering temperature diagrams of the furnace.

2.3. Evaluation of stainless steel foams

The cell structures of the SST foams were observed using an optical microscope (Olympus BX60M, Japan). To prepare the cross-sections for photography, the pores in foams were infiltrated with resin.