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Combustion Foaming Process of Porous Al/Al_3Ti Composite Made from Al Machined Chip

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Porous Al/Al_3Ti composites were fabricated by combustion foaming process of the blended powder precursors consisting of aluminum and titanium. Blended elemental powders consisting of Al (Al machined chip or atomized powder), Ti, B_4C were compacted or hot extruded, and then foamed by inducing the combustion reaction by high-frequency induction furnace. Ti and B_4C powders were added as exothermic agent, which generated large heat of reaction to promote foaming behavior. In this study, combustion foaming process of porous Al/Al_3Ti composite made from Al machined chip was investigated. The cell morphology of the specimen was compared with the porous specimen made from Al atomized powder. When the precursor was made by powder compaction at room temperature, the specimen made from Al atomized powder showed high porosity (>80%), but the specimen made from Al machined chip could not be foamed sufficiently. This was caused by low relative density of the precursor made from Al machined chip. When the precursor was made by hot extrusion, the specimen made from Al machined chip showed high porosity. However, the pore morphology tended to become large and irregular. The cell-wall microstructure of both specimens showed dispersions of Al_3Ti precipitates (30~200μm) in Al matrix. However, a number of small void (100μm or less) were observed in the cell-wall material made from Al machined chip.

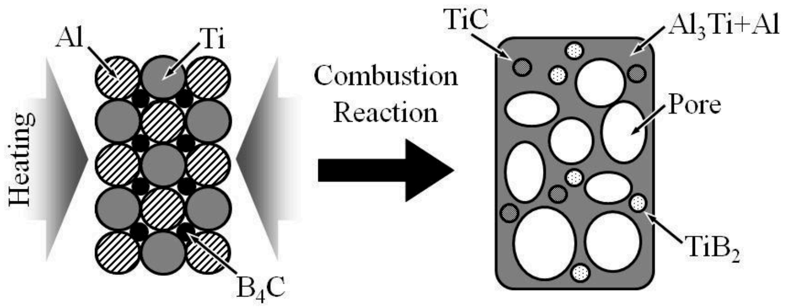
Keywords: *combustion foaming process, porous Al/Al_3Ti composite, Al machined chip, Al atomized powder.*

1. Introduction

Porous materials, which contain large amount of pores or cells, have unique features such as low density, high specific stiffness, high energy absorption, vibrational absorption. Therefore, they are regarded as structural materials for weight reduction of automobiles, and also for crash elements, damping materials and so on [1-3]. In this study, we focus on intermetallic foams. Intermetallics have features such as high melting point, lightweight, oxidation resistance, corrosion resistance [4]. Consequently, intermetallic foams, which have properties of both porous materials and intermetallics, can be applied to a severe application, such as high temperature situation or highly corrosive environments. Most of the manufacturing methods of porous materials require a large amount of energy such as the heating for a long time in the furnace, especially when high-melting point material is selected. In this study, intermetallic foams were fabricated by a simple and easy method called the combustion synthesis, and we have already reported the fabrication process of Al-Ni, Al-Ti foams [5,6]. However, the fabrication process of intermetallic foams use the atomized powder as the starting powder. When a mass-production is considered, the high material cost of the raw powder becomes a problem. In this study, machined powder which originally becomes waste were used as the raw powder which can substitute the atomized powder. We aimed at the development of the manufacturing process of intermetallic foams made from machined chip.

2. Experimental Procedure

Fig. 1 shows a brief outline of the combustion process for the synthesis of Al-Ti foam. The elemental powders used for synthesizing Al-Ti intermetallic foams were aluminum and titanium. In this method, a foaming agent consisting of titanium and boron carbide (B_4C) is used, which increases the enthalpy change (ΔH) of reaction system. The pores are foamed by gas components (mainly, H_2 gas) originally dissolved in or absorbed at metal powders.



$$3Al + Ti \rightarrow Al_3Ti + 146\ \text{kJ/mole Ti}$$

$$Ti + \frac{1}{3}B_4C \rightarrow \frac{2}{3}TiB_2 + \frac{1}{3}TiC + 254\ \text{kJ/mole Ti}$$

Fig. 1. Schematic illustration of the combustion synthesis of Al-Ti foams.

The sizes of elemental powders (aluminum, titanium,boron carbide powders) are shown in Table 1. Photos of Al particle and frequency distribution (number criterion) of particle size are shown in Fig. 2. As a foaming agent powder, titanium and boron carbide (B_4C, ave.10μm) powders were used. The Al/Ti powder blending ratios (mole ratio) were 4.0, 7.0 and the amount of foaming agent ($Ti+1/3B_4C$) was 10 vol%. After titanium, aluminum and foaming agent powder was blended, the blended powder was compacted at room temperature under the pressure of 150MPa in a cylindrical shape (ϕ=15mm, h=15mm) or extruded at 673K to make a precursor. The precursor was inserted into a silica tube under Ar gas atmosphere and heated by an induction coil to induce the combustion reaction. The porosity of the foamed specimen was measured by Archimedes method. Pore size (diameter of equivalent area circle) and circularity were evaluated by image analyzing software. Circularity was calculated by the following equation:

$$\text{Circularity} = 4\pi \times (\text{pore area}) / (\text{peripheral length})^2 \quad (1)$$

The circularity is calculated as 1.0 when the pore morphology is completely spherical, whereas it is close to 0 when pore morphology becomes complex. The cross section of the precursor was observed by an optical microscope, that of the foamed specimen was observed by a scanning electron microscope (SEM) and analyzed by an energy dispersive X-ray spectrometer (EDX).

Table 1. The size of elemental powders.

	Al machined chip	Al atomized powder	Ti powder	B_4C powder
size	modal diameter:0.6~0.7mm	<45μm	<45μm	10μm

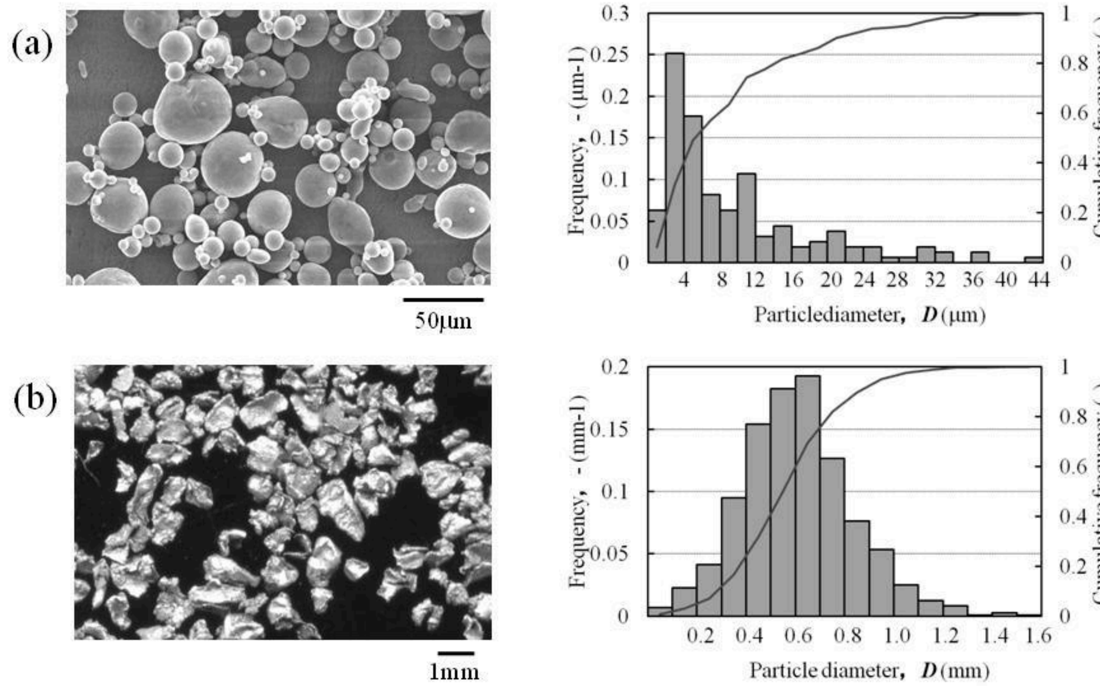


Fig. 2. Photos of Al powder and frequency distribution (number criterion) of particle.
(a)Al atomized powder and (b)Al machined chip

3. Result and Discussion

Fig. 3 shows cross section of Al-Ti foams made by compaction of Al atomized powder and Al machined chip. When the precursor was made by powder compaction, the specimen made from Al atomized powder showed high porosity and foamed homogeneously, but the specimen made from Al machined chip could not be foamed sufficiently and its pore morphology was inhomogeneous. Fig. 4 shows cross section and pore morphology of Al-Ti foams made by hot extrusion of Al atomized powder and Al machined chip. When the precursor was made by hot extrusion, even though the specimen was made from Al machined chip, it could be foamed sufficiently and show high porosity. However, it was found that its pore morphology tended to become large and irregular. Fig. 5 shows optical micrograph of cross section of precursors made by compaction and hot extrusion with Al atomized powder and Al machined chip.

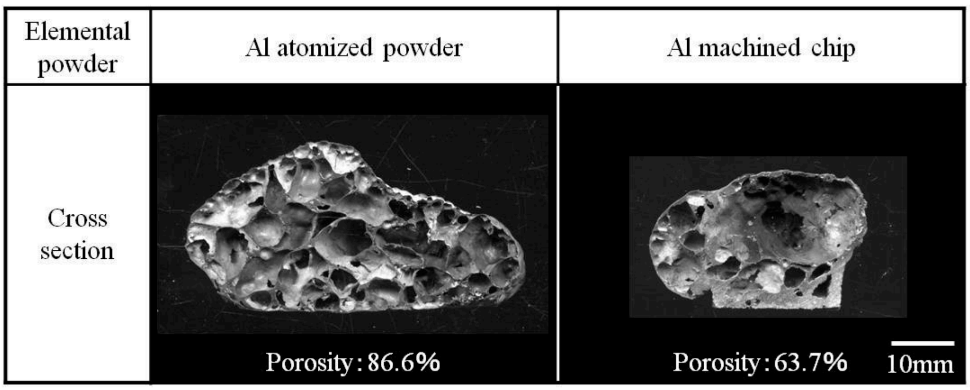


Fig. 3. Cross section and porosity of Al-Ti foams made by compaction of Al atomized powder and Al machined chip.

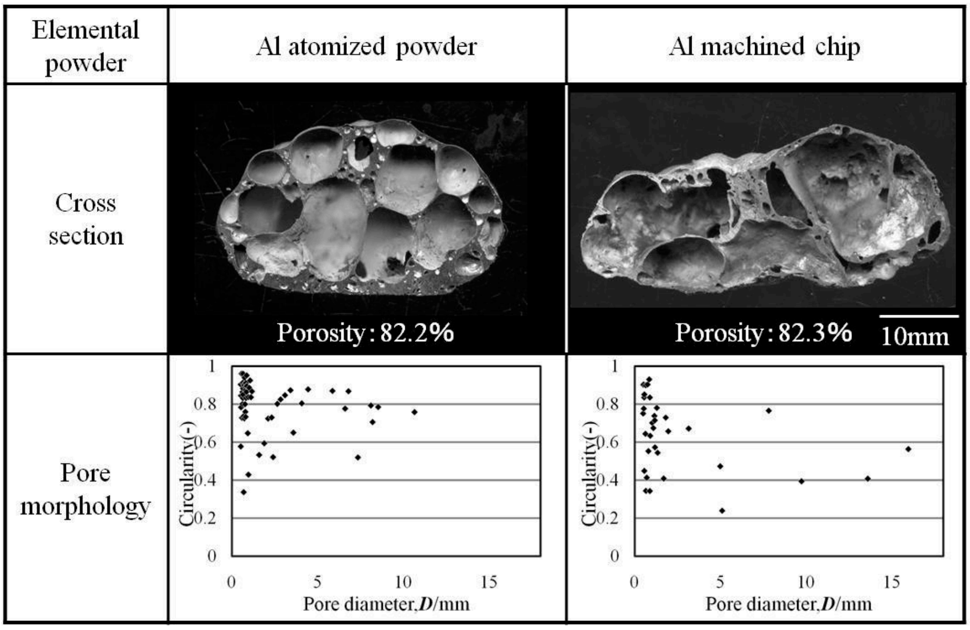


Fig. 4. Cross section and pore morphology of Al-Ti foams made by hot extrusion of Al atomized powder and Al machined chip.

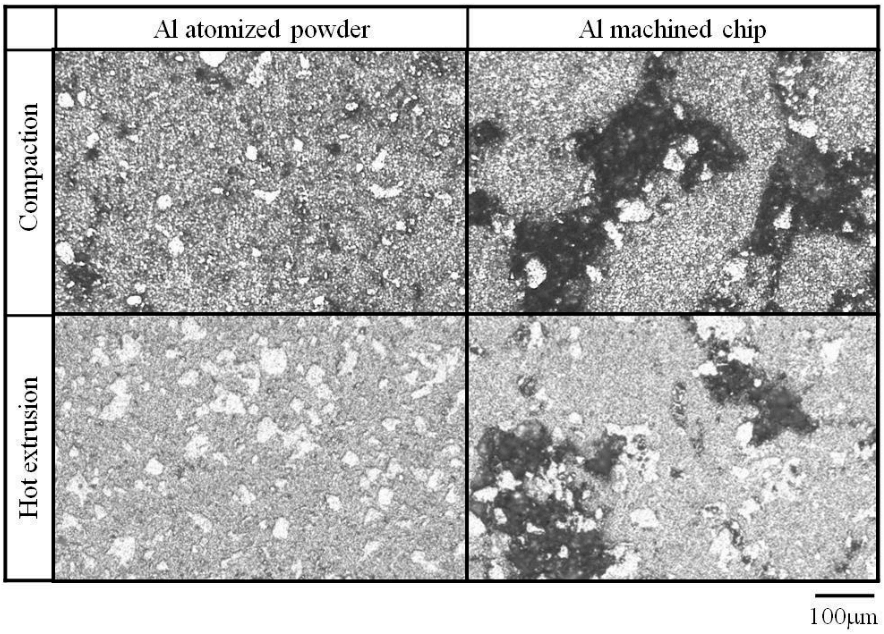


Fig. 5. Optical micrograph of cross section of precursors made by compaction and hot extrusion with Al atomized powder and Al machined chip.

Fig. 6 shows the cell-wall microstructure of the specimens (Al/Ti powder blending mole ratio: 4.0 and 7.0) made by hot extrusion from various elemental Al powders. The cell-wall microstructure of specimens made from both elemental powder showed a distribution of platelet Al_3Ti (30~200μm) in Al matrix. In addition, it was found that the proportion of Al in reactive product increased as Al/Ti powder blending mole ratio increased. Many small voids of 100μm or less were observed in the cell-wall material made from Al machined chip.

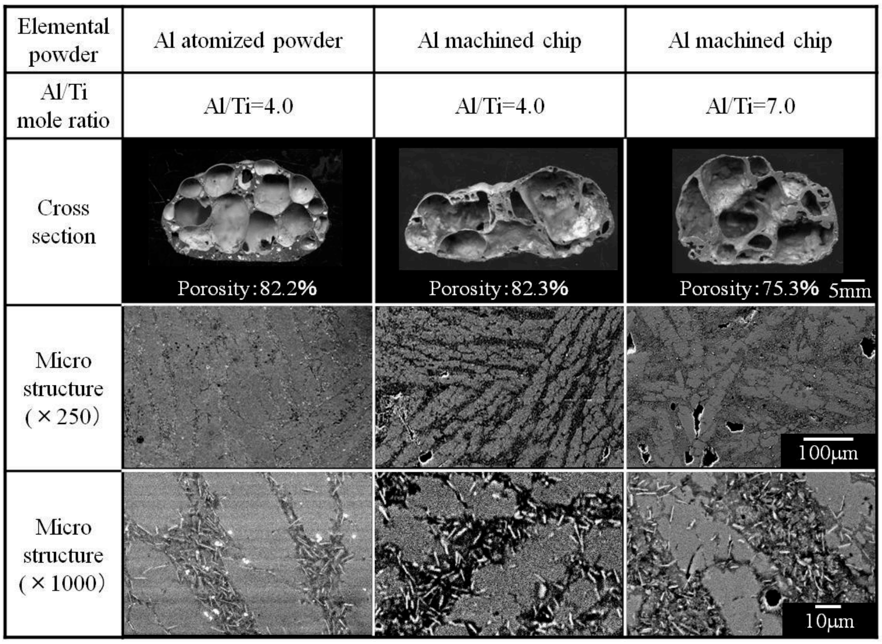


Fig. 6. Cell-wall microstructure of specimen (Al/Ti powder blending mole ratio: 4.0 and 7.0) made by hot extrusion of Al atomized powder or Al machined chip.

4. Conclusions

The possibility of the manufacturing process of porous Al/Al_3Ti composite made from machined chip was examined. The pore morphology of Al-Ti foams was compared with the specimens made from Al atomized powder and following results were obtained.

(1) When the precursor was made by powder compaction, the specimen made from Al atomized powder showed high porosity (>80%), but the specimen made from Al machined chip could not be foamed sufficiently.
(2) When the precursor was made by hot extrusion, the specimen made from Al machined chip showed high porosity. However, its pore morphology tended to become large and irregular.
(3) The cell-wall microstructure of both specimens showed a distribution of Al_3Ti (30~200μm) in Al matrix. However, many small voids of 100μm or less were observed in the cell-wall material made from Al machined chip.

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