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Forming of aluminum foam using steel mesh as die during foaming of precursor by optical heating

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ABSTRACT

Ultralightweight aluminum foam (Al foam) is expected to be used for the components of vehicles and construction materials. To apply Al foam in these industrial fields, the fabrication of Al foam with complex shapes is an important requirement. In this study, a steel mesh was used as a die for fabricating Al foam with a complex shape during the foaming of a precursor by employing optical heating. From the free foaming of the ADC12 precursor, it was shown that the precursor can be foamed by passing light through the steel mesh similarly to the foaming without the steel mesh. In addition, it was shown that ADC12 foams with similar porosity and pore structures were obtained both with and without the steel mesh. From the foaming of the ADC12 precursor while restricting its upward expansion by the steel mesh, it was shown that ADC12 foam with plane surface can be obtained. No protrusion of ADC12 foam through the mesh openings was observed. The steel mesh was easily peeled off from the ADC12 foam after the foam had solidified. Similar pore structures to those in the case of free foaming were obtained and no collapse of the pores at the surface in contact with the steel mesh was observed. From the foaming of the ADC12 precursor in steel mesh dies with triangular and square cross sections, it was shown that ADC12 foam with similar shapes to the steel mesh die and similar pore structures to those in the case of free foaming can be obtained. Consequently, it was demonstrated that a steel mesh can be used as a die for the forming of ADC12 foam with little effect on the pore structures of the obtained foam.

1. Introduction

Ultralightweight aluminum foam (Al foam) is expected to be used for the components of vehicles and construction materials [1,2]. To apply Al foam in these industrial fields, the fabrication of Al foam with complex shapes is an important requirement. There are several papers on the fabrication of Al foam with complex shapes. Using a casting route, Ito and Kobayashi demonstrated that Al foam with a complex shape can be fabricated by pouring foaming molten Al in a mold [3]. Wiehler et al. and Hartmann et al. demonstrated integral foam molding, which is a modified die-casting process, where Al melt mixed with blowing agent is injected into a mold cavity to produce a three-dimensional light metal foam [4,5]. Using a precursor foaming route, Schäffler and Reglero et al. demonstrated that Al foam three-dimensional parts can be produced by heating a foamable precursor in a mold [6,7]. Cambronero et al. foamed a precursor in a closed mold using concentrated solar energy [8]. Banhart reported that Al foam with a complex shape can be fabricated by heating a precursor and squeezing the foam into a mold [9]. In these fabrication processes, a dense steel mold was generally used.

In our preliminary study, we attempted to foam a precursor using optical heating. The precursor was solid Al containing blowing agent powder. By heat treatment of the precursor, gases produced by the decomposition of the blowing agent expanded the precursor, resulting in Al foam. It was shown that the precursor can be foamed by passing light through light-transmitting materials, such as sapphire. In addition, sapphire can be used as a die to fabricate Al foam with plane surface during the foaming of the precursor. No bonding between sapphire and Al foam occurred. This indicates that materials that can both transmit light and not bond with Al can be used as a die to fabricate Al foam with complex shapes by using optical heating to foam the precursor.

In this study, a steel mesh was used as a die to fabricate Al foam with complex shapes. There are several advantages of using a steel

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mesh as a die. First, it can transmit light; therefore, the precursor in the steel mesh die can be directly heated by the light. Second, the volume of the steel mesh die is relatively small compared with that of a dense steel mold or a sapphire die; therefore, it is expected that the energy loss because of the endothermic property of the die will be small. Third, a steel mesh can be easily deformed to obtain the desired shape of the die. Therefore, the cost of the die is expected to be low. Fourth, the contact area between the foamed Al and the die is small. Therefore, the foamed Al and die may be easily separated, i.e., a release agent is not necessary.

The aim of this study is to conduct fundamental studies to obtain Al foam with complex shapes using a steel mesh die with optical heating. First, free foaming of the precursor with and without a steel mesh was conducted to confirm that the precursor can be foamed by passing light through the steel mesh. Next, Al foam with plane surface was fabricated by using the steel mesh to restrict the expansion of the precursor to confirm that the steel mesh can retain its shape when subjected to the foaming force of the precursor and that no protrusion of the foaming Al through the mesh openings occurs. In addition, Al foams with triangular and square cross sections were fabricated by foaming the precursor in a deformed steel mesh. The pore structures of the obtained Al foams were observed by X-ray computed tomography (X-ray CT) to confirm that Al foam obtained using the steel mesh had similar pore structures to those of Al foam obtained without using the steel mesh and that no collapse of the pores occurred at the surface in contact with the steel mesh during the foaming process.

2. Experimental procedures

2.1. Fabrication of precursor

Fig. 1 shows a schematic illustration of the fabrication of the precursor. A friction stir welding (FSW) route [10,11], was applied to fabricate the precursor. First, as shown in Fig. 1(a), two Al-Si-Cu alloy ADC12 (equivalent to A383.0 Al alloy) high-pressure die-casting plates of 3 mm thickness were prepared [12]. ADC12 has a relatively low melting point (solidus temperature of 788 K and liquidus temperature of 853 K; as in Ref. [13]). Therefore, it is expected that the ADC12 precursor can be easily foamed by optical heating even through the steel mesh. In our preliminary tests, the foaming of the ADC12 precursor began around the solidus temperature, then high-porosity ADC12 foam with round pores was obtained above the liquidus temperature. Next, a blowing agent powder (TiH_2, <45 μm, 1 mass%) and a stabilization agent powder (α-Al_2O_3, ~1 μm, 5 mass%) were thoroughly mixed and placed between two ADC12 plates. Next, as shown in Fig. 1(b), laminated ADC12 plates were subjected to FSW by traversing the rotating tool along the area where the powder mixture was placed. The intense stirring action of FSW thoroughly mixed the powder mixture into the ADC12 plates during the welding of the laminated plates. The tool rotating rate, traversing rate and tilt angle during the FSW were 1000 rpm, 100 mm/min and 3°, respectively, in accordance with Ref. [14,15]. The tool was made of tool steel with a shoulder diameter, probe diameter and probe length of 17 mm, 5 mm and 4.8 mm, respectively.

Next, as shown in Fig. 1(c), multiple-line multipass FSW, as demonstrated by Sato et al. [16], was performed to fabricate a large area of precursor by shifting each traversing line by a length equal to the probe diameter (5 mm) perpendicular to the tool traversing direction. Moreover, as shown in Fig. 1(d), overlapping FSW, as demonstrated by El-Rayes and El-Danaf [17], was performed to thoroughly mix the powder mixture into the ADC12 plates by traversing the tool on the same traversing lines as those in the previous multiple-line FSW shown in Fig. 1(c). In this study, four lines × four overlapping FSW was conducted in accordance with Ref. [14,15]. Finally, as shown in Fig. 1(e), precursors of 15 mm × 15 mm with 6 mm thickness were machined from the region where FSW was conducted.

2.2. Free foaming of precursor

Fig. 2 shows the setup for the free foaming of the precursor by optical heating through the steel mesh. The precursor was set on a ceramic honeycomb. The steel mesh was placed on square steel pipe spacers to prevent the foamed Al from coming in contact with the steel mesh. The distance between the steel mesh and the surface of the ceramic honeycomb was 25 mm. A K-type thermocouple was placed in a previously drilled hole in the precursor at a distance of 3 mm from its bottom surface to obtain the temperature of the precursor during the foaming process. The foaming behavior of the precursor was recorded with a video camera.

2.3. Foaming of precursor to fabricate ADC12 foam with plane surface using steel mesh

Fig. 3 shows the setup for the foaming of the precursor to fabricate ADC12 foam with plane surface by optical heating through the steel mesh while restricting the upward expansion of the precursor using the steel mesh. The precursor was set on a ceramic honeycomb and the steel mesh was placed on two square steel spacers. The distance between the steel mesh and the surface of the ceramic honeycomb was 10 mm so that the foamed precursor

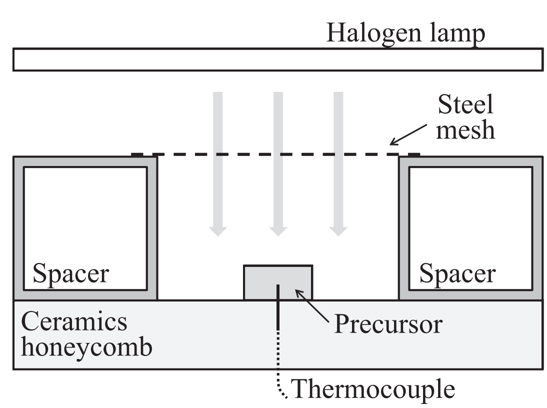

Fig. 2. Schematic illustration of free foaming of ADC12 precursor by optical heating through a steel mesh.

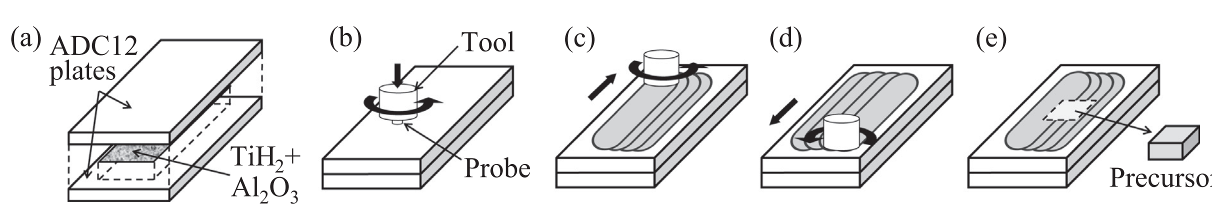

Fig. 1. Schematic illustration of fabrication of ADC12 precursor by FSW route.