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Fabrication of Porous Aluminum by Friction Stir Processing Route Precursor Method and its Mechanical Properties

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In the automotive industry, closed-cell porous aluminum is expected to be used as a new functional material because of its light weight, high energy absorption and high sound-insulating property. Recently, a new processing route for fabricating the precursor, which utilizes friction stir processing (FSP), has been developed. In the FSP route, a precursor is fabricated by mixing blowing agent powder and stabilization agent powder into aluminum alloy plates by the significant stirring action of FSP. It is expected that, by applying the FSP route precursor method, the cost-effective fabrication of porous aluminum with high productivity can be realized. In this study, A1050 aluminum porous aluminum was fabricated by using rolled plates. Pore structures of fabricated porous aluminum were nondestructively observed by X-ray computed tomography (X-ray CT). The mechanical properties of fabricate porous aluminum were evaluated by compression tests.

Keywords: *porous metals, friction stir processing, aluminum alloy, porosity, foam*

1. Introduction

In the automotive industry, porous aluminum is expected to be used as a new functional material because of its many advantages such as weight reduction enabling low fuel consumption, high crash energy absorption properties for increased safety, and high sound absorption reducing the acoustic emissions from cars and improving their comfort[1]. There are various processes used for producing porous aluminum[1]. A foamable precursor is often used for fabricating closed-cell porous aluminum[2-8]. In the precursor method, aluminum alloy (as a starting material) and a blowing agent powder are first mixed. This foamable mixture is called the “precursor”. Next, the precursor is heat-treated to decompose the blowing agent powder and to release gases. Finally, these gases expand the softened aluminum alloy to form porous aluminum. There are several routes for fabricating the precursor, such as the powder metallurgical route[2-4], the ARB process route[5, 6] and the compressive torsion processing route[7, 8]. However, various factors prevent their practical application[1], such as the use of expensive aluminum alloy powder for the starting material and the need for many time-consuming and complicated fabrication processes.

Recently, a precursor method based on friction stir processing (FSP) has been developed to improve the cost-effectiveness and productivity of fabricating porous aluminum[9, 10]. In the FSP route, the precursor is fabricated by mixing a blowing agent powder and a stabilization agent powder into aluminum plates using the stirring action of FSP. It is expected that, by applying the FSP route precursor method, the cost-effective fabrication of porous aluminum with high productivity can be realized.

In this study, A1050 aluminum porous aluminum was fabricated by using rolled plates. Pore structures of fabricated porous aluminum were nondestructively observed by X-ray computed tomography (X-ray CT). The mechanical properties of fabricate porous aluminum were evaluated by compression tests.

2. Experimental Procedure

2.1 FSP procedure

Figure 1 shows a schematic illustration of the FSP route used in this study. Commercially available pure aluminum A1050 plates of 3.5 mm in thickness were used. Two aluminum plates were stacked with the blowing agent powder and stabilization agent powder distributed between them. FSP was carried out using an SHH204-720 FSW machine (Hitachi Setsubi Engineering Co., Ltd.). The FSP tool has a columnar shape with a screw probe. The diameter of the tool shoulder is 17 mm, the diameter of the tool probe is 6 mm and its length is 5 mm. SKH51 high-speed tool steel was used as the tool material. The traversing speed of the tool was 100 mm/min and a tilt angle of 3° was used throughout the experiments.

Titanium(II) hydride (TiH_2, <45 μm) powder and alumina (α-Al_2O_3, ~1 μm) powder were used as the blowing agent and stabilization agent, respectively. The stabilization agent was used to stabilize the pore structure and to prevent the release of gases from porous aluminum by improving its viscosity during the foaming process. The powders were placed along the path of the FSP tool, as shown in Figure 1(a). The amounts used were 1 mass% TiH_2 and 5 mass% Al_2O_3, relative to the mass

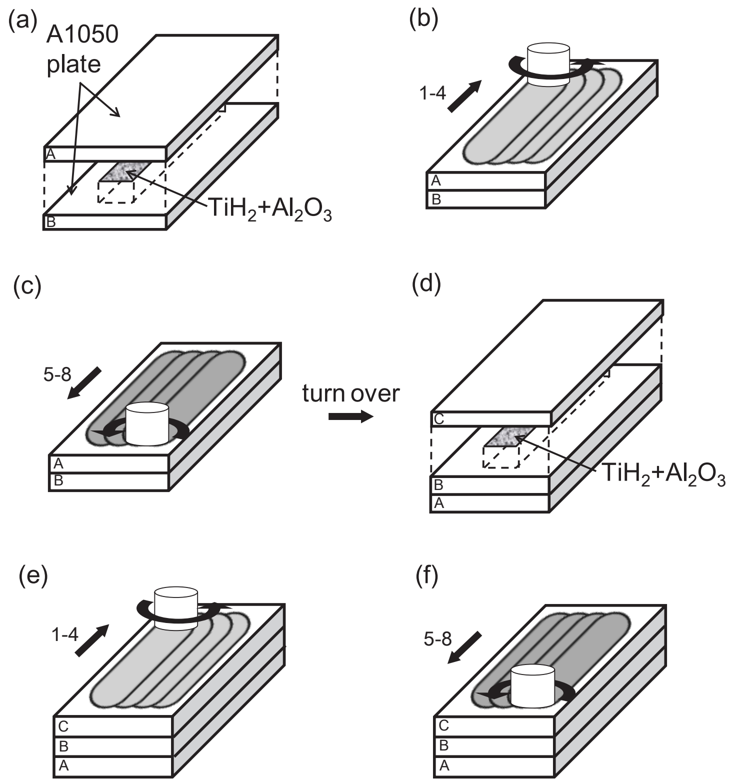

Fig. 1 Schematic illustration of the manufacturing process of a precursor of porous aluminum by friction stir processing.

of aluminum with the dimensions of the area over which TiH_2 and Al_2O_3 were distributed and the length of the tool probe. Multipass FSP[11, 12] was applied to thoroughly mix TiH_2 and Al_2O_3 by traversing the same FSP region more than once and to obtain a larger area of precursor by traversing different regions. First, as shown in Figure 1(b), FSP was carried out four times in the region where TiH_2 and Al_2O_3 were placed by shifting the FSP tool by approximately the diameter of the tool probe in the direction perpendicular to the FSP direction for each FSP. Second, as shown in Figure 1(c), the traversing direction was reversed and FSP was carried out four times in exactly the same region as before. Third, as shown in Figure 1(d), the plate was turned over, and TiH_2 and Al_2O_3 powders were placed on the reverse side of the FSP surface along the path of the FSP tool. Finally, as shown in Figures 1(e) and (f), the same FSP procedures as those shown in Figures 1(b) and (c) were carried out once again to obtain a thicker precursor. The tool rotating rate during the traversing of the tool was 2200 rpm throughout the fabrication of each precursor of porous aluminum.

2.2 Foaming procedure

The precursors were heat-treated in a preheated electric furnace to induce foaming. The holding temperature (equal to the preheated temperature) and the holding time were 1003 K and 14 min, respectively. The sample was then cooled to room temperature under ambient conditions. Then, the compression test specimen of 25×25×25 mm^3 was cut out from the foamed sampel by electro-discharge machining.

2.3 X-ray CT inspection

The pores in the compression test specimen were observed nondestructively by X-ray CT using an SMX-225CT microfocus X-ray CT system (SHIMADZU Corporation) at room temperature. The X-ray source was tungsten. A cone-type CT, which has a three-dimensional image construction system, was employed. In this system, a single rotation of the specimen was sufficient to obtain a three-dimensional volume image, which consists of a set of X-ray CT images with a slice pitch equal to the length of one pixel in the X-ray CT image. The X-ray tube voltage and current were 80 kV and 30 μA, respectively.

3. Results and Discussion

Figure 2 shows cross-sectional X-ray CT images of samples of obtained porous aluminum. Gray regions indicate the aluminum alloy and black regions indicate pores. Although there were some large pores, roughly good circularity of pores were obtained. However, it is essential to optimize the heating condition further to fabricate porous aluminum with small pores and higher circularity.

Figure 3 shows the compression stress-strain curve obtained from porous aluminum fabricated by

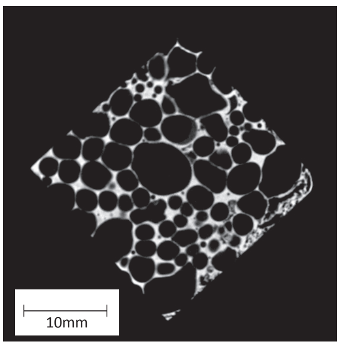

Fig.2 Cross-sectional X-ray CT images of samples of obtained porous aluminum.

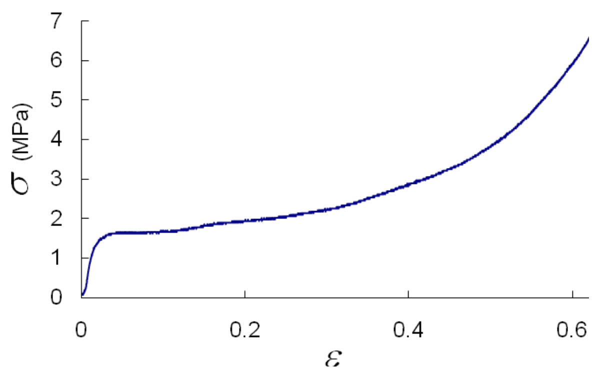

Fig.3 Compress stress-strain curve obtained from porous aluminum fabricated by friction stir processing route.

FSP route. It was shown that almost same stress-strain curve was obtained compared with conventional ALPORAS[13] for static compression tests.

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