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ScienceDirect
Procedia Materials Science 4 (2014) 239 – 243
Procedia Materials Science
www.elsevier.com/locate/procedia

8th International Conference on Porous Metals and Metallic Foams, Metfoam 2013

Fabrication of nonporous layer on surface of ALPORAS by friction stir incremental forming

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Abstract

Porous metals having nonporous (skin) layer at the surface have a potential to improve the mechanical properties of the porous metals. To fabricate nonporous layer on surface of porous metals, friction stir incremental forming process is applied to form surface of a commercial closed-cell type aluminum foam (ALPORAS) in this study. In the process, the cell walls near the surface of the aluminum foam are plastically deformed by a rotating tool with a high rotation rate, fabricated the nonporous layer at the surface. The nonporous layer with thinner than 0.4 mm is fabricated at the surface without internal fracture of the aluminum foam under forming conditions of a tool rotation rate of 8000 rpm, a tool feed rate of 60 mm/min, and total forming depth of 7.0 mm.

Peer-review under responsibility of Scientific Committee of North Carolina State University

Keywords: Aluminum foam; Surface; Forming; Friction; Sandwich component.

1. Introduction

Due to environmental issue, the use of lightweight components has been mainly expanded in automobile structural components. Porous metals are one of promising materials for realizing lightweight components due to their low density (Nakajima 2013), however, they do not generally have enough strength for the components.

Control of porosity and pore distribution of porous metals is one of effective solutions to produce the porous metals with desired characteristics. The control of the porosity at the surface of porous metals has potentials to realize functionally graded properties and enhancement of the strength–weight relation. Sandwich components of aluminum foam (Seeliger 2002) and aluminum foam coated with resin (Kitazono et al. (2009)) have been proposed

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Peer-review under responsibility of Scientific Committee of North Carolina State University
doi:10.1016/j.mspro.2014.07.612

as surface treatment methods for enhancing the strength–weight relation of the porous metals. On the other hand, some forming processes have been applied to control the porosity at the surface of porous metals. For example, surface of lotus-type porous copper has been formed by wire-brushing or shot peening process for the purpose of improvement of the mechanical properties (Lobos et al. (2009), Koriyama et al. (2012)). In these processes, the cell walls near the surface were plastically deformed, and the nonporous (skin) layer was fabricated at the surface with fine grains.

In this study, for the purpose of enhancing the strength–weight relation of the porous metals, the friction stir incremental forming process (Otsu et al. (2009), Otsu et al. (2010), Otsu et al. (2011), Otsu et al. (2012)) is applied to form surface of closed-cell type aluminum foam for fabricating the nonporous layer.

2. Experimental

Friction stir incremental forming process for sheet metal forming was employed to fabricate nonporous layer on surface of porous metal. This process is combined single point incremental sheet forming and friction stir welding (Otsu et al. (2009), Otsu et al. (2010), Otsu et al. (2011), Otsu et al. (2012)). In this process, the sheets are heated and introduced severe plastic deformation involving dynamic recrystallization and grain refinement by friction as a result of rotation of a forming tool at very high speed. This process have been applied to form aluminum, magnesium and titanium sheets, and have resulted the improvements of the forming limit. The friction stir incremental forming process for porous metal is illustrated in Fig. 1. Forming was carried out using a commercial 3-axis NC milling machine. Porous metal used in this study was a commercial closed-cell type aluminum foam: ALPORAS (Miyoshi et al. (2000)) (Shinko Wire Company, Ltd., relative density of 0.1, mean pore diameter of ϕ4 mm, Fig. 2) and had a rectangular parallelepiped with 30 mm x 22 mm x 24 mm. The scatter of the pore size of the aluminum foam was considerably large as shown in Fig. 2. A tool was made of high speed tool steel and had a diameter of ϕ6 mm (diameter at end surface: ϕ4 mm). The diameter at the end surface of the tool was same with the mean pore diameter of the aluminum foam. The tool with a rotation rate of 8000 rpm was pushed against the surface of the aluminum foam for z direction of z_p = 0.5 mm under dry condition. The tool pass in x-y plane at i-th pass number for z direction is shown in Fig. 1c. The tool was moved with a feed rate of 60 mm/min for y direction in a pitch of x_p = 0.5 mm. The pass number for z direction was n = 1–20 (total forming depth nz_P = 0.5–10 mm).

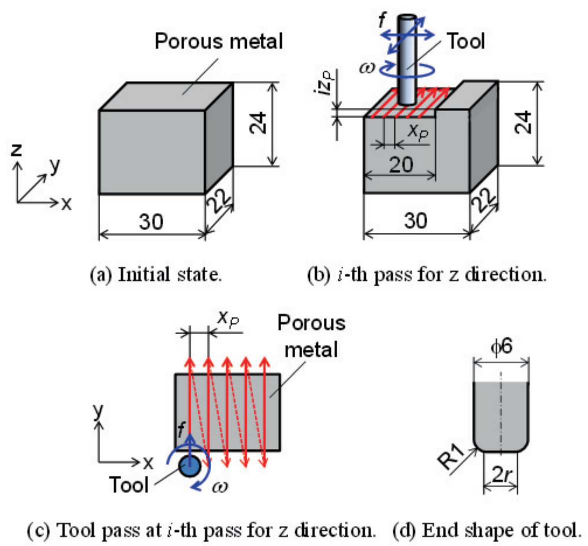


Fig. 1. Friction stir incremental forming process for porous metal (ω: tool rotation rate, f: tool feed rate, x_P: forming pitch for x direction, z_P: forming pitch for z direction, i: pass number for z direction).

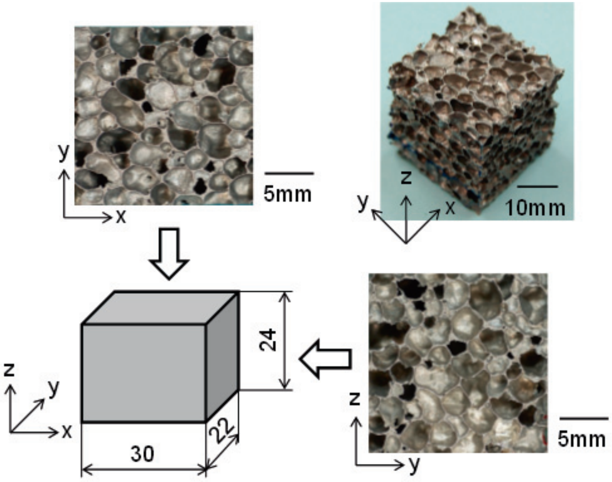
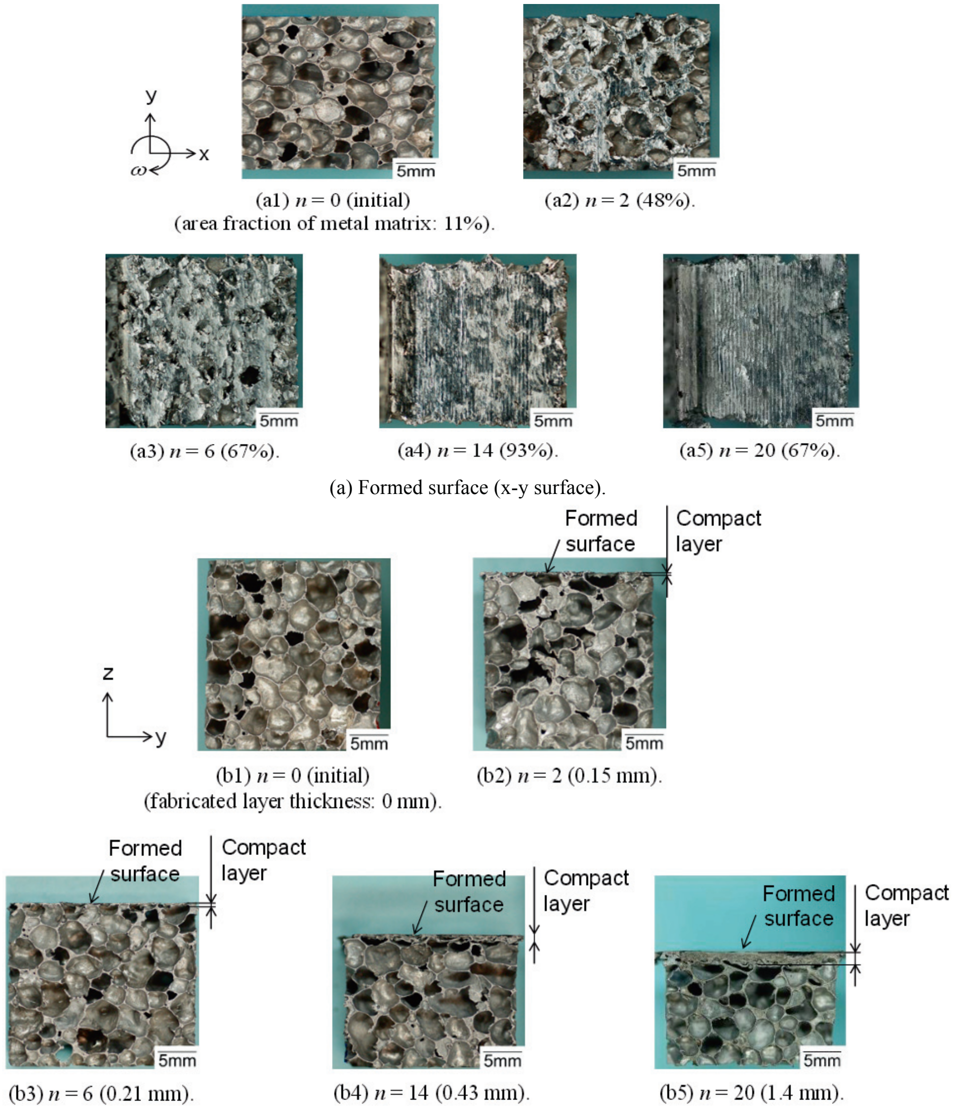


Fig. 2. Initial state of closed-cell type aluminum foam, ALPORAS specimen (relative density of 0.1, mean pore diameter of ϕ4 mm).

3. Results

Figure 3 shows photographs of the initial and formed aluminum foams. The surface of the aluminum foam was plastically deformed and stirred by the rotating tool, and the cell wall near the surface were gradually closed with increasing pass number for z direction. However, the scratch marks by the rotating tool were appeared along a forming pass direction at the formed surface at n > 14 (nz_P > 7.0 mm) because the aluminum adhered to the end surface of the rotating tool during the forming with increasing total pass number. The maximum area fraction of metal matrix (surface area of metal matrix/nominal surface area of aluminum foam) was obtained over 90% at n = 14 (nz_P = 7.0 mm), however, the area fraction of metal matrix decreased at n = 20 (nz_P = 10 mm) due to the scratch marks by the rotating tool.

As well as the area fraction of metal matrix at the formed surface, the thickness of the fabricated compact layer increased with increasing total pass number. The nonporous layer with a thickness of about 0.4 mm was fabricated on the surface without internal fracture of the aluminum foam at n = 14 (nz_P = 7.0 mm). On the other hand, thick compact layer with a thickness of over 1.0 mm was obtained at n = 20 (nz_P = 10 mm), however, folding of the cell wall (cell walls were not joined) was observed at lower part of the fabricated layer, and the fabricated layer was not nonporous layer at the lower part as shown in Fig. 3b. From this thing, the tool rotation is found to be effective to stir the cell walls only near surface of the formed surface. The maximum thickness of the fabricated nonporous layer is found to be about 0.4 mm under this forming condition.



(b) y-z cross-section.

Fig. 3. Photographs of initial and formed aluminum foam (n: total pass number for z direction).

4. Conclusion

Friction stir incremental forming process was applied to form surface of a closed-cell type aluminum foam. The nonporous (skin) layer with thinner than 0.4 mm was successfully fabricated on the surface without internal fracture of the aluminum foam under forming conditions of a tool rotation rate of 8000 rpm, a tool feed rate of 60 mm/min, and total forming depth of 7.0 mm.

Acknowledgement

This study was financially supported in part by the Light Metal Educational Foundation, Inc.

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