Foaming Behavior of Aluminum Foam Precursor Using Only Friction Heat of Rotating Tool

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A friction heat foaming process (FHFP) was proposed for the foaming of an aluminum (Al) foam precursor that uses only friction heat. The precursors of the Al foam were also fabricated from Al plates by friction stir welding (FSW). It was shown that the precursor can be foamed using only the generated friction heat in only several tens of seconds. Consequently, Al foam can be fabricated using only friction based processes from the fabrication of the precursor to the foaming of the precursor.

Keywords: cellular materials, friction stir welding, precursor, foaming

1. Introduction

The precursor foaming process is one of the fabrication processes of aluminum (Al) foams¹,²). In this process, solid Al containing a uniformly distributed blowing agent powder called the precursor is first fabricated. Thereafter, by heat treatment of the precursor, the softened Al is expanded by gases released by the decomposition of the blowing agent to form Al foam.

Recently, the friction stir welding (FSW) precursor foaming process has been developed for fabricating the Al foam precursor³–⁵). In this process, a blowing agent powder is uniformly distributed in an Al plate by the intense stirring action of the rotating tool used in FSW. During FSW, the Al plate is softened by the heat generated by the friction between the rotating tool and the Al plate. The temperature during the FSW of Al is approximately 673–773 K⁶–⁷), which is lower than the foaming temperature of the Al foam precursor (approximately 832–973 K¹,²,⁸–¹⁰).

FSW was first developed for the welding of Al, although it is now used for the welding of copper (Cu) and steel⁶,¹¹,¹²). The temperature during the FSW of Cu and steel is much higher than that in the case of Al. Therefore, it is expected that an Al foam precursor can be simultaneously foamed during the FSW of Cu or steel, i.e., a composite material consisting of dense Cu or steel and Al foam can be easily fabricated only using friction heat.

In this study, the feasibility of a friction heat foaming process (FHFP), in which the foaming of an Al foam precursor is conducted using only friction heat, was investigated. The precursor was first fabricated by the FSW route. Thereafter, it was foamed by the friction heat between a Cu plate and a rotating tool. The foaming behavior of the precursor during the FHFP and the pore structures of the fabricated samples were investigated.

2. Experimental Procedure

2.1 Fabrication of precursor³–⁵)

Figure 1 shows a schematic illustration of the fabrication process of the Al foam precursor by the FSW precursor foaming process. As the starting material, Al-Si-Cu Al alloy ADC12 (equivalent to A383.0 Al alloy) high-pressure die casting plates of 3 mm thickness were used. First, as shown in Fig. 1(a), two die casting plates were stacked with TiH₂ powder (<45 μm) as the blowing agent and Al₂O₃ powder (≤1 μm) as the stabilization agent distributed between them along the path of the FSW tool. The amounts used were 0.9 mass% TiH₂ and 4.5 mass% Al₂O₃ relative to the mass of Al having dimensions of the area over which TiH₂ and Al₂O₃ were distributed and the length of the tool probe.

Second, as shown in Figs. 1(b)–(d), the TiH₂ and Al₂O₃ powders were mixed into the die casting plates via the intense stirring action of FSW by plunging and traversing the FSW tool through the plates. The FSW tool had a cylindrical shape with a screw probe. The diameter of the tool shoulder was 17 mm, and the diameter of the tool probe was 6 mm and its length was 5 mm. SKH51 high-speed tool steel was used as the tool material. The multipass FSW technique¹³–¹⁵), as shown in Figs. 1(c) and (d), was applied to obtain a large amount of precursor (the path of the tool comprised three lines to increase the size of the FSW region) and to thoroughly mix the powders in the Al plates (the same FSW region was stirred four times). The tool rotation speed was 1000 rpm and the welding speed was 100 mm/min. A tilt angle of 3° was
used.

Next, as shown in Fig. 1(e), the plates were turned over, and TiH₂ and Al₂O₃ were placed on the reverse side of the FSW surface along the path of the FSW tool. Then, as shown in Fig. 1(f), the FSW procedures shown in Figs. 1(c) and (d) were repeated to obtain a thicker precursor.

A precursor of 10.5 mm × 10.5 mm × 9 mm was machined from the region subjected to FSW.

2.2 Foaming procedure of precursor

Figure 2 shows a schematic of the foaming process of the precursor during the FHFP. First, as shown in Fig. 2(a), the precursor was placed in a hole (φ = 15 mm) previously drilled in a commercially available oxygen-free Cu plate of 10 mm thickness. Another oxygen-free Cu plate of 3 mm thickness was placed under the 10-mm-thick Cu plate as a back plate. Next, as shown in Fig. 2(b), a rotating tool (φ = 25 mm) was pressed onto the Cu plate at a distance of 1.5 mm from the hole. The tool used was made of tungsten carbide (WC) and had a cylindrical shape with a flat bottom. Note that a tungsten-based alloy is conventionally used as the tool material in the FSW of Cu. The diameter of the tool was determined in accordance with Ref. 16) to generate a large amount of friction heat. A rotation speed of 3000 rpm, a tool indentation rate of 1 mm/min, a tool indentation depth of 1.5 mm (i.e., a tool indentation time of 90 s), and a tilt angle of 3° were used. With the indentation of the rotating tool, friction heat was generated between the Cu plate and the rotating tool, resulting in the foaming of the precursor. In this study, three precursors were foamed (samples I–III). The foaming behavior of each precursor during the FHFP was recorded on a digital video camera.

3. Experimental Results and Discussion

Figure 3 shows the foaming behavior of one of the precursors during the FHFP (sample I), where t is the tool indentation time elapsed from when the rotating tool first came in contact with the surface of the Cu plate, as shown in Fig. 3(a). Note that at t = 0 s, only the back of the tool is in contact with the surface of the Cu plate because the tool was tilted by 3°. As shown in Fig. 3(b), with increasing indentation of the rotating tool, the tool became red-hot owing to the generated friction heat and foaming started. Thereafter, as shown in Figs. 3(c)–(f), the precursor continuously expanded by foaming until the tool was unloaded. Note that most of the foaming occurred the first 20 s (t = 54–74 s), and thereafter only a small amount of foaming occurred. Consequently, it was shown that the precursor can be foamed by the FHFP.

Figure 4(a) shows the relationship between the tool indentation time t and the temperature T during the indentation of the rotating tool for each of the samples. a–f in the figure correspond to the foaming behavior shown in Figs. 3(a)–(f),
respectively. The temperature was measured by a thermocouple placed at the bottom of the hole of the Cu plate, as shown in Fig. 4(b). The indentation of the tool generated friction heat in the vicinity of the rotating tool, which transferred to the high-heat-conductivity Cu plate, causing a gradual increase in the temperature at the thermocouple. The rate of temperature increase decreased with increasing temperature, which is considered to be due to the increased amount of heat released from the Cu plate. The temperature increased until the unloading of the tool, reaching a maximum at $t = 90$ s. Thereafter, the tool was unloaded and moved upward, causing the temperature to decrease. This tendency was the same regardless of the sample, except for a small difference in the maximum temperature. However, the foaming started when the temperature reached approximately 700 K for all samples in this study. Therefore, the foaming behavior is expected to be controlled by varying the time during which the temperature exceeds 700 K. Clearly, realizing the accurate control of the temperature during the FHFP is necessary in a future study.

Figure 5 shows a cross section of foamed sample 1. The sample was cut from the front to the back in Fig. 3 at the center of the sample and the observed surface corresponded to Fig. 4(b). The rotating tool was indented onto the Cu plate surface on the right side of the precursor. The pores in the upper part where foaming first occurred, as shown by arrow (a), were very small. This is because the upper part of the precursor was pushed upward by the lower part of the precursor that foamed afterwards; therefore, the upper part rapidly cooled immediately after foaming. In contrast, the lower part, as shown by arrow (b), had a large pore size. This part subjected to friction heat for almost the entire tool indentation time; therefore, the foaming time was longer at this part and the pores coalesced. There were some dense parts with few pores, as shown by arrow (c). Such parts were away from the rotating tool and were pushed upward before foaming by the lower foamed part. According to these results, it is necessary to control the temperature so that it simultaneously exceeds the foaming temperature (700 K in this study) over the entire region of the Cu plate where the precursor exists.

In this study, the indentation rate of the tool was 1 mm/min and a tilt angle of 3° was used to reduce the load during the tool indentation owing to the capacity of the machine used. It is expected that increasing the indentation rate and using a tilt angle of 0° will result in rapid foaming due to the rapid increase in temperature in the entire Cu plate in the vicinity of the precursor; therefore, finer pores throughout the foam can be expected.

4. Conclusion

In this study, a friction heat foaming process (FHFP) was proposed for the foaming of an Al foam precursor. In this process, a rotating WC tool was indented next to a hole in a Cu plate in which the precursor was placed. It was shown that the precursor can be foamed using only the generated friction heat in only several tens of seconds.

In the FHFP, no external heat source, such as an electric furnace, was used to foam the Al foam precursor. In this study, Al foam precursors were also fabricated from Al plates by friction stir welding (FSW). Consequently, Al foam can be fabricated using only friction based processes from the fabrication of the precursor to the foaming of the precursor.

REFERENCES


![Fig. 5 Pore structures of Al foam fabricated by FHFP.](image-url)