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Review Article

Fabrication of Open-Channel Aluminum by Extraction of Templates Coated with Porous Layers

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Abstract

Open-channel aluminum with directional holes is fabricated by extraction of stainless steel wires coated with boron nitride and magnesium hydride, which are embedded in solidified aluminum. The extraction force decreases remarkably by adding magnesium hydride to boron nitride, which is attributed to formation of porous layers between the wires and aluminum. Besides, the extraction force decreases with decreasing diameter and length of the template wires, which is due to decrease in friction force of the wires to aluminum.

Introduction

Porous metals with directional long pores [1-3] have attracted extensive attention on applications to heat sinks[4] heat exchanger [5] For high performance of such devices, channel holes should possess small diameter and long size to obtain large contact area to the coolant. There are several perforation techniques for metals and alloys such as mechanical drilling, laser ablation and solidification techniques [6,7]. However, none of previous perforation techniques satisfy the requirements of production of open-channel aluminum for high performance devices with low production cost. Recently the present author fabricated open-channel aluminum with long elongated channel holes by extraction of lubricated template wires from solidified aluminum [6,7]. In order to perforate many holes in aluminum, a number of template wires should be extracted from aluminum by tensile force loaded to the template wires. Thus, smaller extraction force is desirable to fabricate open-channel aluminum with holes as many as possible. This paper reports that the addition of magnesium hydride to boron nitride reduced the extraction force of the stainless-steel template wires. Furthermore, it is shown that the small contact area of the wire to aluminum results in smaller extraction force, which is attributed to decrease in friction force of the wires to aluminum.

Materials and Process

Open-channel aluminum was fabricated by extracting lubricated metallic wires embedded in a solidified aluminum. High purity aluminum (99.99% pure) was used as samples. Hard stainless-steel wires, SUS304, were used as templates of open-channel holes. The thickness of the template wires was in the range from 0.28 mm and 4.0 mm in diameter. The length of the template wires was in the range from 20 mm to 100 mm. The inner dimensions of graphite crucibles were 50mm20mm150mm. Boron nitride (grain size is 2 in diameter) or/and magnesium hydride was diluted with cyclopentane, which was coated onto the wires as a release agent. Aluminum was melted at 953K in atmospheric air in an upper crucible for 900s. The solidified aluminumingot was taken out from the crucible. The embedded aligned wires were extracted by using a tensile test machine, and open-channel aluminum was fabricated. Force necessary to extract the template wires from aluminum was defined as the extraction force.

Results and Discussion

In order to investigate quantitatively whether coating of boron nitride is effective for extracting stainless steel (SUS) wires, first of all the SUS wires without coating of boron nitride were tried to be extracted. Figure 1(a) shows a plot of the extraction force versus extraction length of the uncoated SUS wires embedded in aluminum. The SUS wire was not able to be extracted and was fractured at the force of about 880 N, which is equivalent to the tensile strength of the stainless steel [8]. The upper curve in Figure 1(b) shows a plot of the extraction force versus extraction length of the SUS wires whose surface were coated with boron nitride of 50 in thickness. The extraction force was in the range of elastic tensile deformation. The lower curve in Figure 1(b) shows a plot of the extraction force versus extraction length of the SUS wires whose surface were coated with a mixture of boron nitride and magnesium hydride of 50 in thickness. The extraction force of the SUS wire coated with the mixture of boron nitride and magnesium hydride is much smaller than that with boron nitride. The extraction force is shown as a function of the weight ratio of , where and are the weight of MgH_2 and BN, respectively, as depicted in Figure 2. The thickness and length of SUS wires are 1.0 mm in diameter and 40.0 mm, respectively. The extraction force decreases drastically in the range of from 0 to 0.4 with increasing MgH_2, and then, decreases slightly until about 1.5. This result indicated that even if more MgH_2 was added, the extraction force kept almost constant. Since it is known that gas pores are formed by hydrogen decomposed with the reaction of $MgH_2 \rightarrow Mg + H_2$ in the temperature range higher than 670K [9,10] it is surmised that the porous layers may be formed to decrease the extraction force. Figure 3(a) shows the sectional view of stainless steel wire before extraction. The average diameter of the SUS wire was 1.08mm, while the average diameters of channel holes of open-channel aluminum were 1.16 mm for coating with boron nitride and 1.45 mm for the mixture with boron nitride and magnesium hydride as shown in Figure 3(b) and (c) respectively. Therefore, the increase in diameter is (1.16/1.18=0.98) nearly zero before and after extraction of SUS wire coated with boron nitride. However, further increase of (1.45/1.18=1.23) 23% in diameter due to the addition of magnesium hydride was found, that is, the volume expansion of $(1.45/1.18)^2 = 1.51$) 51% was observed. Thus, it is considered that this expansion is attributed to formation of the porous structure as illustrated in Figure 3(e).The extraction force was measured as functions of the diameter and the length of SUS wires in open-channel aluminum. 50 in thickness of the mixture of MgH_2 and BN whose weight ratio =1.5 was coated onto SUS wires uniformly. Figure 4(a) shows a plot of the extraction force against the length of the SUS wires. The thickness of the SUS wires was 1.0 mm in diameter. The extraction force is directly proportional to the length of the wires. Figure 4(b) exhibits a plot of the extraction force versus the diameter of the SUS wires. The length of the SUS wires was constant to be 40.0 mm. The extraction force increases linearly with increasing the diameter of the wires. When the SUS wires are embedded in the solidified aluminum, a contact area *S* of the SUS wire to surrounding aluminum is shown as

$$S = \pi d L \quad (1)$$

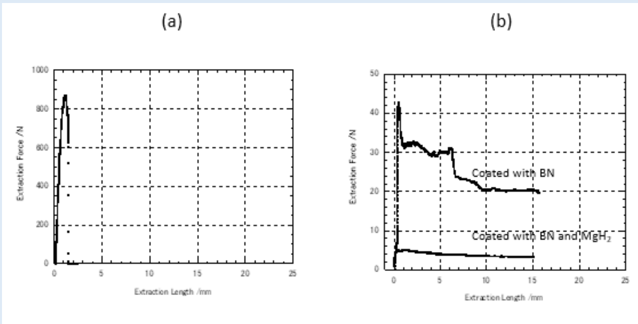

Figure 1: (a) Extraction force-extraction length curve of template stainless steel wire of 1mm in diameter embedded in aluminum, (b) extraction force-extraction length curve of template wire coated with BN, and extraction force-extraction length curve of template wire with the mixture of BN and MgH_2 [11].

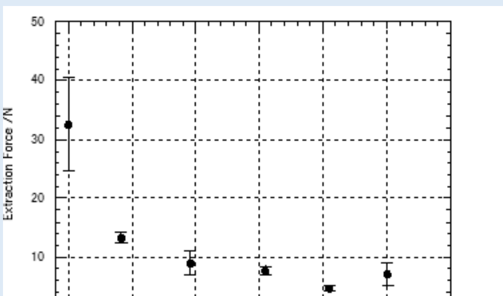

Figure 2: Dependence of extraction force on with weight ratio of W_{MgH2}/W_{BN} in open-channel aluminum [11].

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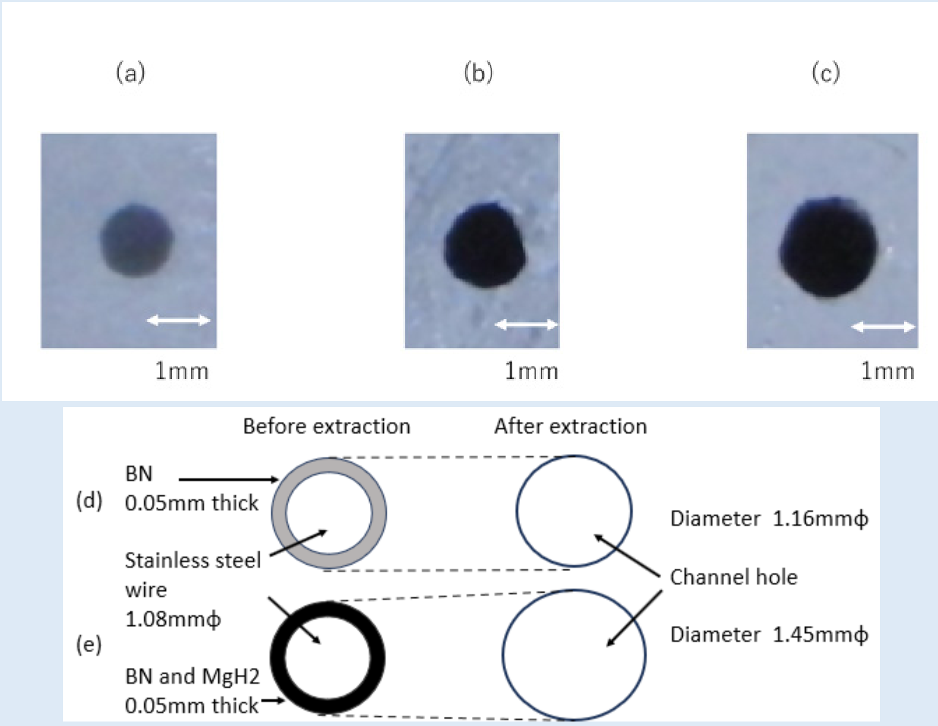

Figure 3 (a): Sectional view of stainless steel wire embedded in aluminum, (b) sectional view of channel hole extracted by stainless steel wire coated with boron nitride, (c) sectional view of channel hole by stainless steel wire coated boron nitride and magnesium hydride, (d)schematic drawing of section of channel hole extracted by stainless steel wire coated with boron nitride, and (e) schematic drawing of section of channel hole extracted by stainless steel wire coated with boron nitride and magnesium hydride [11].

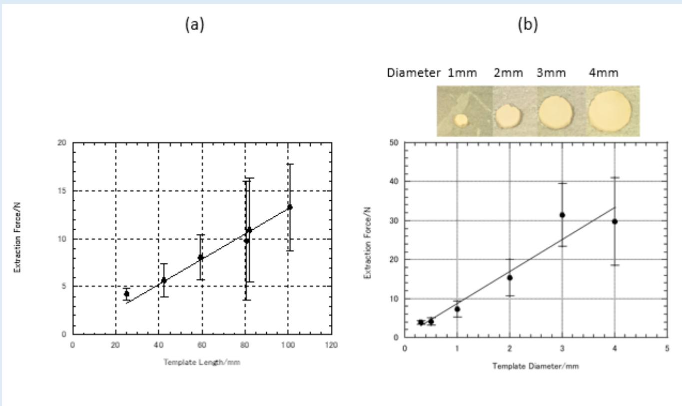

Figure 4(a): Variation of extraction force with template length of open-channel aluminum. (b) Variation of extraction force with template diameter of open-channel aluminum [11].

where d and L are the diameter and the length of the SUS wire embedded in aluminum, respectively. From the results of Figure 4(a) and (b) the extraction force F is proportional to d and L, and thus,

Therefore, the following are obtained.

$$F \propto S \quad (2)$$

It is concluded that the extraction force F is directly proportional to the contact area. Therefore, the decrease in the contact area of the wires to aluminum reduces the extraction force of the wires.

Conclusion

The open-channel aluminum with directional holes is fabricated by extraction of stainless-steel wires coated with boron nitride and magnesium hydride embedded in solidified aluminum. The results obtained are as follows.

a) The addition of magnesium hydride to boron nitride significantly facilitates the extraction, which is attributed to the formation of porous layers between the stainless-steel wires and aluminum.

The extraction force is directly proportional to the contact area of the stainless-steel wires to aluminum. The contact area of the stainless-steel wires to aluminum controls the extraction force of the stainless-steel wires from aluminum.

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