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Citation	実験力学, 11(Special Issue), s288-s291 https://doi.org/10.11395/jjsem.11.s288
Issue Date	2011
Doc URL	http://hdl.handle.net/2115/74644
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Type	article
File Information	J.JSEM 11. s288.pdf

Journal of JSEM, Vol.11, Special Issue (2011) SS288-SS291

Fabrication of Microchannels in Metallic Wire Bundles by a Sacrificial-Core Method

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(*Received 12 January 2011; received in revised form 15 April 2011; accepted 5 June 2011*)

Abstract
We examined a new method for producing a metallic thin rod or band in which a long microchannel ran through its entire length. A tin wire and about 140 copper wires were inserted in a nickel sheath. They were cold rolled to produce a band specimen. It was heated to 1173 K and then furnace-cooled. The band specimens before and after the heat treatment were cast-in inserted in aluminum. In either case, an open microchannel formed at the site initially occupied by the tin wire, and thus the aluminum casting containing the band had the long microchannel in its body.

Key words
Microchannel, Heat Exchanger, Metallic Wire, Sintering, Cast-in Insertion

1. Introduction

The tissue of plant stalks acts as a site for transportation of materials to maintain its vital activity as well as a constructional material to hold the structure of the plant. Such a living tissue can be a model of a future constructional material for mechatronics machines, in which a microchannel network acts as a pipeline for waste heat, materials, energy or information.

In this paper, we propose a new method to produce metallic thin rods or bands in which long microchannels run through their entire length. The concept of this process was drawn from studies on a powder-metallurgical microchanneling process [1-3]. Figure 1 illustrates the schematic of this microchanneling process. Two kinds of metals are used in this process: a body metal and a sacrificial-core metal. The former has a higher melting point and is to compose the device body, and the latter is to flow out and give the shape of the microchannel. A body-metal powder compact containing a sacrificial core, a shaped sacrificial-core metal, is sintered at temperatures between the melting points of these metals. The molten sacrificial-core metal migrates to the body-metal powder region by infiltration or diffusion and produces an alloy lining layer surrounding the cavity formed at the site initially occupied by the sacrificial core. Thus a microchannel can be produced directly in the body-metal sinter. However, this powder-metallurgical process is not suitable for large-size or low-melting-point products.

Figure 2 presents the concept of our new method. A sacrificial-core-metal wire is inserted in a bundle of body-metal wires. They are shaped by wire drawing, rolling or bending, and then the resulted rod or band is sintered to produce a long microchannel. The microchannel-containing members are cast-in inserted in a light metal such as aluminum or magnesium. In general, powder

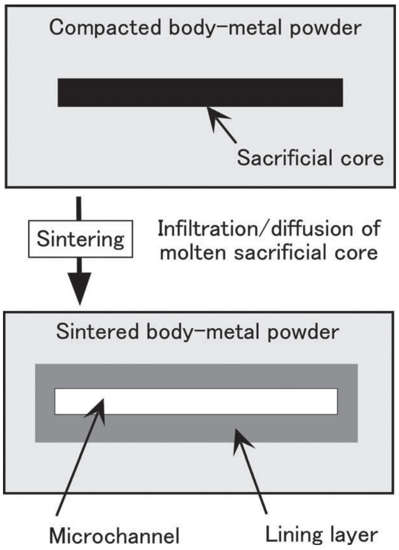

Fig. 1 Powder-metallurgical microchanneling process

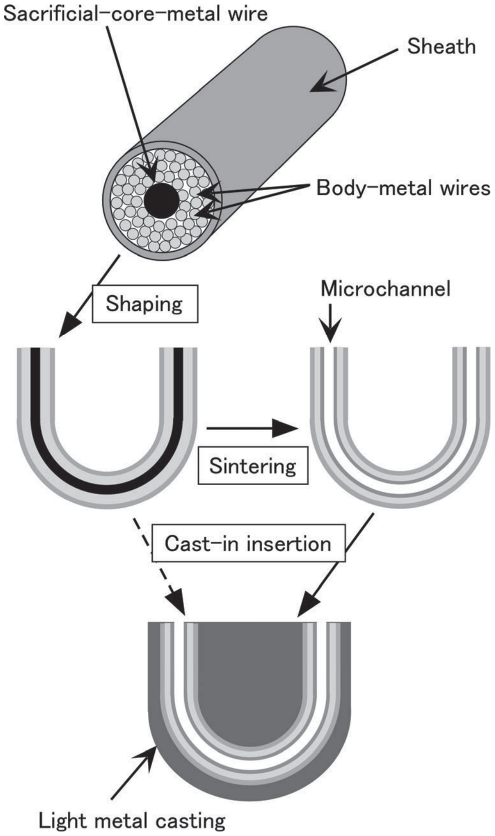

Fig. 2 Concept of the method for producing light metal members having long microchannels

metallurgy of these metals is not easy: the oxide film on the surface of the aluminum powder particles acts as a tight barrier against sintering, and magnesium powder is difficult to handle because it is extremely combustible. The cast-in insertion process can avoid such problems.

In the present study, we conducted cast-in insertion of a Cu-Sn band containing a microchannel into aluminum. We also examined a method to perform microchanneling heat treatment by using the enthalpy of the molten aluminum as described in Fig. 2.

2. Experimental Procedure

2.1 Verification of microchanneling in a wire bundle

In order to examine the microchannel formation in a wire bundle, a Ni-Al model specimen was prepared as depicted in Fig. 3. Thirty five grams of nickel powder containing 800 nickel wires 25 μm in diameter and an aluminum wire 200 μm in diameter was cold-pressed into a cylindrical green compact in a metal mold using a unidirectional pressure of 624 MPa. The average diameter of the nickel powder was 5 μm. The length of each metal wire was 10 mm. The compact specimen was sintered at temperatures between the melting points of aluminum and nickel. Line (a) in Fig. 4 shows the temperature history during the sintering of the Ni-Al green compact. The maximum temperature, 1473K, is 490 K higher than the melting point of aluminum, and within the range of the sintering temperature commonly used in the powder metallurgy of nickel. The sintering experiments were carried out in an argon gas atmosphere. A comparison experiment without nickel wires was also conducted.

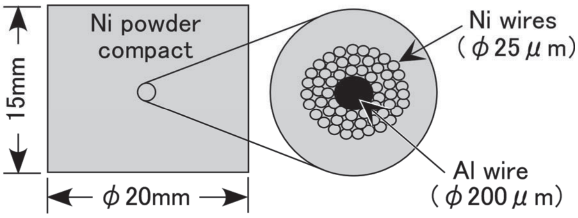

Fig. 3 Constitution of the Ni-Al model specimen

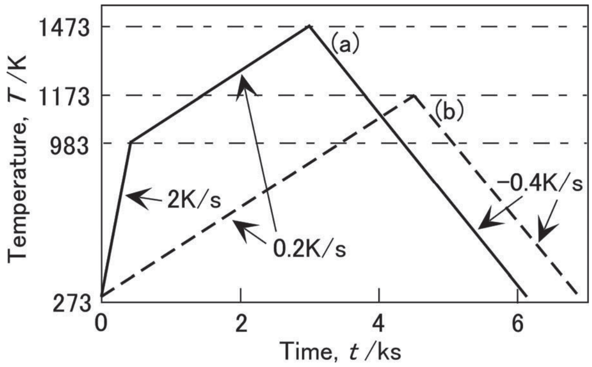

Fig. 4 Time-temperature patterns in the sintering heat treatments for the Ni-Al specimen (a) and the Cu-Sn specimen (b)

2.2 Cast-in insertion of the Cu-Sn band in aluminum

In the cast-in insertion experiments, a tin wire 500 μm in diameter and about 140 copper wires 170 μm in diameter were inserted in a nickel sheath having 3 mm outer diameter, 0.2 mm thickness and 70 mm length. The sheath containing the copper and tin wires was cold rolled to produce a band specimen. The thickness of the band specimen was 1.0 mm. The specimen was heated from room temperature to 1173 K, and then furnace-cooled. Line (b) in Fig. 4 shows the temperature history.

The band specimens before and after the sintering heat treatment were cast-in inserted in aluminum as illustrated in Fig. 2. In each casting experiment, a U-shaped band specimen was set in a round-bottomed alumina mold 40 mm in inner diameter, and then molten aluminum was cast in the mold. The pouring temperature was 983K.

As a preliminary experiment in order to check the microchanneling behavior in the Cu-Sn band specimen, a shorter specimen was sintered. A copper sheath 25mm in length and a tin wire and 106 copper wires were used. The thickness of the band specimen after cold rolling was 1.7 mm. The other conditions were the same as the cast-in insertion experiments.

3. Results and Discussion

3.1 Microchanneling in the nickel wire bundle

Figure 5 presents optical micrographs of the microchannels produced in the nickel wire bundle (a) and in the nickel powder (b). Open microchannels were produced in both specimens. However, these specimens differed in the cross-sectional shape of the microchannel and the structure of the lining layer. In the powder-metallurgical microchanneling process, the microchannel often inherits the shape of the sacrificial core, which was distorted during powder compaction in our experiments. Thus the microchannel in Fig. 5(b) had a flat oblate figure. On the other hand, the as-received nickel wires had already been work hardened, and thus they beard the compression load and maintained their shape and array. Consequently, the sacrificial core in the case of Fig. 5(a) was not so much distorted as Fig. 5(b).

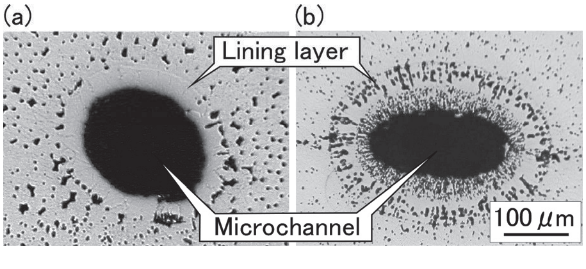

Fig. 5 Optical micrographs of the structures near the microchannels. (a) Microchannel in the Ni wire bundle, (b) Microchannel produced in the Ni powder

As for the structure of the Ni-Al lining layer, some of the authors reported that typical reactive infiltration occurred only in the case when the green-compact porosity, E, was high, for example, E=36.0%.[4] When the porosity was 31.5% or lower, a microporous lining layer formed and it controlled the migration of the sacrificial-core metal.[4] Formation of the dense lining layer in Fig. 5(a) corresponds to the former case because the nickel wire bundle maintained its porosity during the compaction of the specimen.

3.2 Formation of a long microchannel in the copper wire bundle

Figure 6 depicts a cross-sectional structure of the Cu-Sn band specimen with a copper sheath. The specimen was produced in the preliminary experiment. A microchannel was observed in the sintered copper wire bundle. The microchannel was open throughout the length of the sacrificial core.

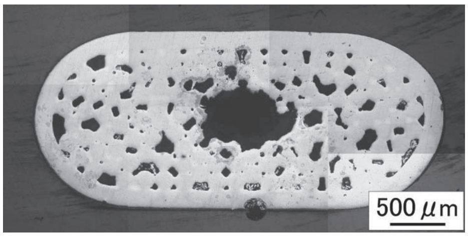

Fig. 6 Cross-sectional structure of the Cu-Sn band specimen with a Cu sheath

3.3 Fabrication of aluminum castings with long microchannels by cast-in insertion

Figure 7 shows a vertical section of the aluminum casting after cast-in insertion of the sintered Cu-Sn band specimen. A cross section of the band specimen was observed in Fig. 7. An optical micrograph of the structure of the Cu-Sn band is presented in Fig. 8(a). The microchannel formed in the band specimen. Figure 8(b) depicts a magnified image near the nickel sheath. Cast aluminum was closely contact with the nickel sheath.

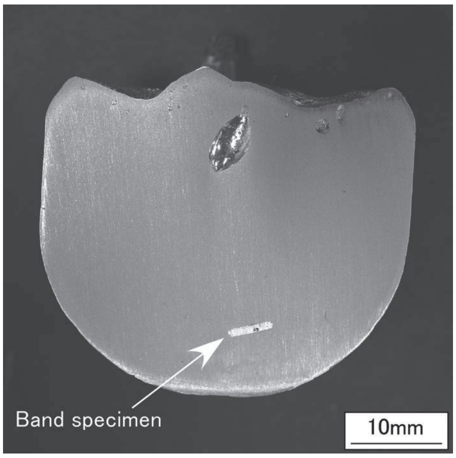

Fig.7 Vertical section of the aluminum casting containing the sintered Cu-Sn band specimen

Figure 9 shows the result of the method to perform the microchanneling heat treatment by using the enthalpy of the molten aluminum. The raw band specimen was cast-in inserted just after rolling and shaping. Just as we intended, a microchannel was produced in the specimen. This result indicates that the enthalpy of the cast aluminum was sufficient to produce the microchannel. However, the copper wires were not sintered in this case. During cast-in insertion, the temperature exceeded the melting point of tin for 1.2ks (see Fig. 10). This thermal condition was sufficient for microchanneling but not for the sintering of copper wires.

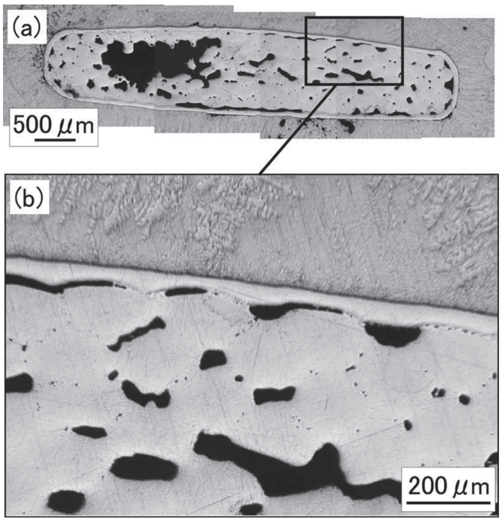

Fig. 8 Cross-sectional structure of the Cu-Sn band specimen cast-in inserted in the aluminum casting (a) and magnified image near the Ni sheath (b)

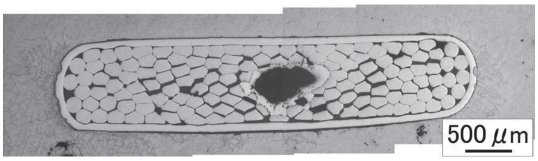

Fig. 9 Cross-sectional structure of the Cu-Sn band specimen cast-in inserted just after rolling and shaping

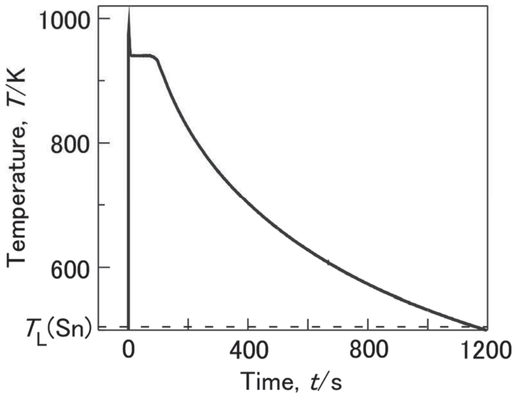

Fig. 10 Cooling curve during cast-in insertion in the case of Fig. 9

4. Conclusions

(1) A metal band containing a long microchannel was fabricated by a sacrificial-core method using body-metal and sacrificial-core-metal wires.

(2) Aluminum castings containing microchannels were produced by the cast-in insertion technique with the microchanneled bands produced from copper (body metal) wires and a tin (sacrificial-core metal) wire.

(3) Similar microchannel was produced in the raw band composed of copper wires and a tin wire during cast-in insertion. The enthalpy of the cast aluminum was sufficient to produce the microchannel. However, the copper wires were not sintered in this condition.

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