



HOKKAIDO UNIVERSITY

Title	Formation Behaviors of Microchannels in Reactive-Sintered Ni-Al Alloys by Sacrificial-Core Method
Author(s)	Teshirogi, Yuya; Ohmi, Tatsuya; Kumagai, Takehiko et al.
Citation	実験力学, 13(Special Issue), s209-s212 https://doi.org/10.11395/jjsem.13.s209
Issue Date	2013-07-15
Doc URL	https://hdl.handle.net/2115/74632
Rights	著作権は日本実験力学学会にある。利用は著作権の範囲内に限られる。
Type	journal article
File Information	J. JSEM 13. s209.pdf



Formation Behaviors of Microchannels in Reactive-Sintered Ni-Al Alloys by Sacrificial-Core Method

Yuya TESHIOGI¹, Tatsuya OHMI², Takehiko KUMAGAI and Manabu IGUCHI²

¹ Graduate School of Engineering, Hokkaido University, Sapporo, Hokkaido 060-8628, Japan

² Faculty of Engineering, Hokkaido University, Sapporo, Hokkaido 060-8628, Japan

(Received 15 January 2013; received in revised form 2 April 2013; accepted 20 April 2013)

Abstract

We investigate the effects of process conditions on the formation behavior of microchannels in reactive-sintered Ni-Al alloys as a part of a study to develop a powder-metallurgical process to produce a transpiration-cooling device including microchannel networks for a disaster preventing robot. The microchannel was successfully produced by a sacrificial-core method with a compact specimen composed of Ni and Al elemental powders when a moderate heating pattern was employed for sintering.

Key words

Microchannel, Powder Metallurgy, Transpiration Cooling, Nickel Aluminate, Porous Material, Reaction Sintering

1. Introduction

Continuing development of a disaster preventing robot has become quite important. [1, 2] This robot works in stand-alone mode in a high temperature environment like a fire disaster. Therefore, an advanced cooling technology is required for the robot to defend its internal electronic machines from heat damage. Some of the authors proposed a powder-metallurgical process to produce a transpiration-cooling device including microchannel networks based on a sacrificial-core method. [3]

Figure 1 presents the basic concept of the transpiration-cooling device including microchannel networks. The outer shell of the device consists of a thermally-resistant porous material and contains microchannel networks just as veins in plant leaves or blood vessels in animal bodies. The term “microchannel” means microscale flow passage. Cooling water is transported to every corner of the device through the microchannel networks, and then it seeps out to the surface through the porous material. The cooling water vaporizes absorbing the latent heat of evaporation, and the water vapor covers the surface of the device blocking the heat from the atmosphere.

Figure 2 illustrates the formation mechanism of the microchannel. In this process, two kinds of metals with different melting points are used: the body metal with a higher melting point is to compose the device body, and the sacrificial-core metal is to fuse and give the shape of the microchannel. A body-metal powder compact containing a shaped sacrificial-core metal is sintered at temperatures between the melting points of these metals. During sintering, molten sacrificial-core metal migrates to the body-metal region by infiltration and diffusion. As a result, a microchannel is formed at the site initially occupied by the sacrificial core. In addition, an alloy lining layer surrounding the microchannel often forms.

Ni-Al intermetallic compounds such as Ni₃Al and NiAl combine good thermal resistance, oxidation resistance and

corrosion resistance which are required for the outer shell materials of the robot. In addition, these intermetallic compounds can be produced from elemental powders by reactive sintering or combustion synthesis. The reaction products by these methods are porous in many cases. Some of authors examined Ni-Al mixed powder as the body metal and Al wire as the sacrificial core to produce a porous Ni₃Al device containing a microchannel. [3] According to their results, a porous Ni-Al alloy device containing a microchannel can be produced by reaction sintering. On the other hand, large shrinkage defects develop and damage the device when the combustion synthesis reaction occurs.

In this study, as a part of a study to develop a manufacturing process for the microchannel-type transpiration-cooling devices, we investigated the effects of the heating rate on the microchannel formation in various specimens with different molar ratios of Ni and Al.

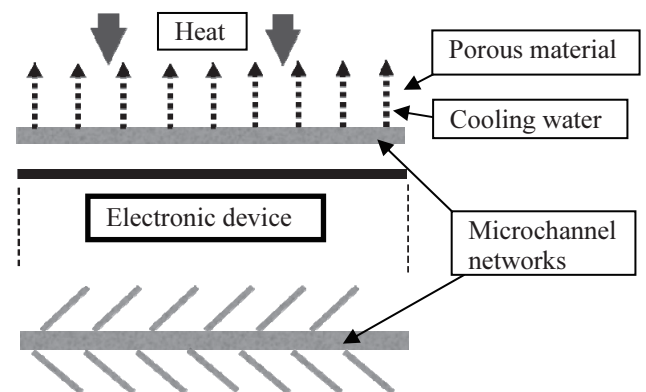


Fig. 1 Concept of the transpiration-cooling device including microchannel networks [3]

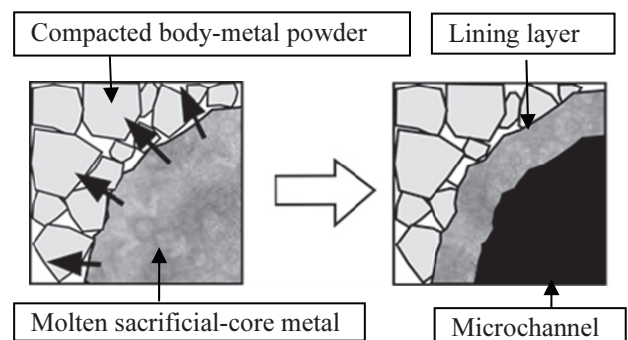


Fig. 2 Schematic illustration of the microchannel formation mechanism in the sacrificial-core method [3]

2. Experimental Procedure

A cylindrical Ni-Al mixed powder compact containing Al wire was prepared by unidirectional pressing at room temperature. The average diameter of the Ni powder was 5 μm and that of the Al powder was 100 μm . Molar ratios of Ni and Al, $M_{\text{Ni}}/M_{\text{Al}}$, was 3, 2 or 1. A straight Al wire 500 μm in diameter and 10 mm in length was used as the sacrificial core. The compacting pressure, P_c , was 500 MPa (for the cases of $M_{\text{Ni}}/M_{\text{Al}} = 3$ or $M_{\text{Ni}}/M_{\text{Al}} = 2$) or 100 MPa (for $M_{\text{Ni}}/M_{\text{Al}} = 1$). Figure 3 schematically illustrates typical temperature histories during the heat treatments. The specimen was heated at a constant rate, R_h , of 0.3, 0.2 or 0.1 K/s from room temperature to 1173 K, and then it was kept at 1173 K for 10.8 ks before furnace-cooled at about 0.1 K/s. In case when abrupt temperature rise up to 1173 K was observed during heating, which was an indication of the combustion synthesis reaction, energizing to the furnace was stopped and the specimen was naturally cooled in the furnace. In any other case, the sintering behavior was viewed as ordinary reaction sintering.

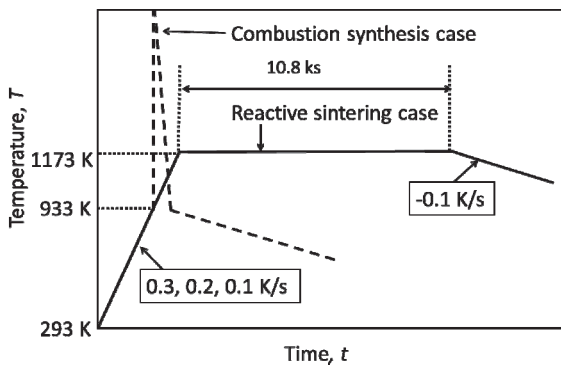


Fig. 3 Schematic time-temperature curves during the heat treatments

3. Results and Discussion

3.1 Effects of the heating rate on the microchannel formation and the sintering behavior

Figure 4 shows a typical macrostructure of a vertical section of the reactive-sintered specimen. The specimen maintained the original shape of the green compact, and a vertical section of the microchannel was observed near the center. Additionally, a porous structure can be observed in the body metal region. Figure 5 depicts an external appearance of a combustion-synthesized specimen. This specimen was completely melted and thus the microchannel was not formed. On the other hand, the microchannel was successfully produced in a combustion-synthesized specimen when the reaction was not so hard that the specimen was distorted. Its structure was similar to the reactive-sintered specimen shown in Fig. 4.

Table 1 summarizes the experimental results regarding the effects of the heating rate on the reaction behavior and the formation behavior of microchannels for different body-metal compositions. This indicates that the microchannel can be formed when the heating rate is low. It is also suggested in Table 1 that the exothermic reaction becomes harder as the aluminum content in the body metal becomes higher.

Figure 6 shows a back-scattered electron image of a typical structure near the microchannel. As shown in this figure, the microchannel and the pores are encompassed by NiAl intermetallic compound (the gray phase), and Ni solid solution is also observed around them. This result suggests that the size and distribution of the Al powder particles can control those of the pores. [4]

In general, the combustion synthesis reaction is ignited at the contact interface between solid Ni and liquid Al. In the case of low heating rate, however, Al diffuses into Ni region before the temperature reaches the melting point of Al. As a result, some intermetallic compounds with high melting points are formed at the interface between solid Ni and solid Al. The intermetallic compounds prevent the direct contact between liquid Al and solid Ni at temperatures above the melting point of Al.

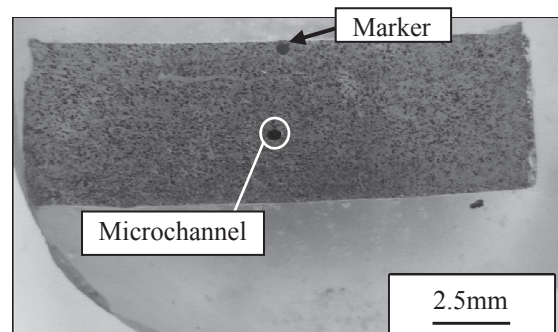


Fig. 4 Typical macrostructure of the reactive-sintered specimen ($M_{\text{Ni}}/M_{\text{Al}} = 2$, $P_c = 500$ MPa, $R_h = 0.2$ K/s)

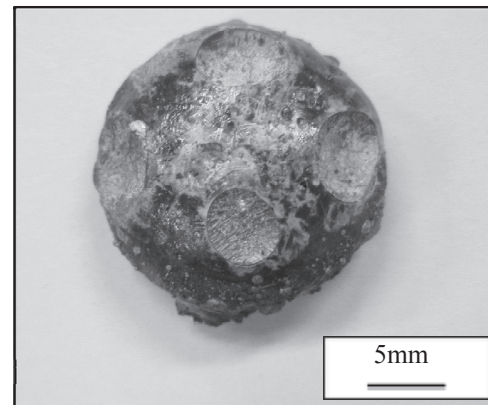


Fig. 5 External appearance of a combustion-synthesized specimen in which microchannel formation was failed ($M_{\text{Ni}}/M_{\text{Al}} = 2$, $P_c = 500$ MPa, $R_h = 0.3$ K/s)

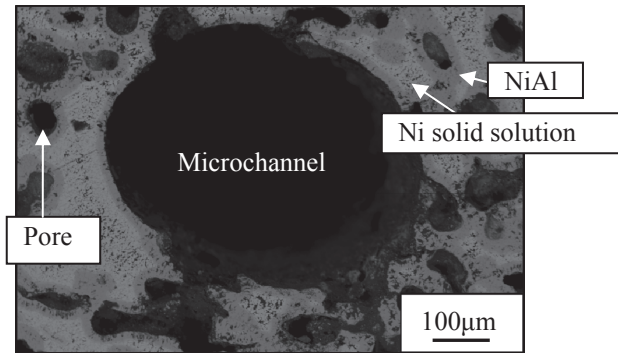


Fig. 6 Back-scattered electron image of a typical structure near the microchannel ($M_{Ni}/M_{Al}=2$, $P_c=500$ MPa, $R_h=0.2$ K/s)

Table 1 Influence of the heating rate on the reaction and microchannel formation for each composition

R_h / Ks^{-1}	M_{Ni}/M_{Al} [P_c/MPa]		
	3 [500]	2 [500]	1 [100]
0.3	●	×	×
0.2	○	●	×
0.1	○	○	×

Mark	Reaction	Microchanneling
○	Reactive sintering	Success
●	Combustion synthesis	Success
×	Combustion synthesis	Failure

3.2 Microchanneling heat treatment for the case of $M_{Ni}/M_{Al}=1$

In general, a hard combustion synthesis reaction does not occur when the apparent thermal conductivity of the compact specimen is not sufficiently high for self-propagation of the exothermic reaction. Therefore, low compacting pressure for the preparation of the compact specimen is favorable for inhibition of the hard reaction. However, the combustion synthesis was occurred in the case of $M_{Ni}/M_{Al}=1$ even when the compacting pressure was 100 MPa (see Table 1). This result indicates that it is difficult to produce a microchannel under the constant heating-rate condition. We thus explored the microchanneling heating treatment for the case of $M_{Ni}/M_{Al}=1$.

Figure 7 gives the time-temperature curves in the heat treatment experiments. Curve (1) in Fig. 7 indicates the constant heating-rate experiment referred in Table 1. In the case of Curve (a), the external heating was stopped immediately after ignition of the combustion synthesis

reaction. Further self-propagation of the reaction was prevented by this procedure. Figure 8 depicts the macrostructure of a transverse section of the specimen heat-treated with Curve (a). In this case, the peak temperature, 995 K, was not so high that the specimen was deformed. However, the sacrificial-core metal still remained at the original site, and the reaction seemed to be not completed. In the case of Curve (2), the specimen after the incomplete combustion synthesis reaction was held at 953 K for 5.4 ks and then heated at 0.1 K/s. As a result, the specimen reflashed and melted completely. Figure 9 presents the macrostructure of the specimen heat-treated as Curve (3). In this case, the microchannel was successfully produced. This result indicates that the long-time temperature holding at relatively low temperature is a key for microchanneling in a high-Al specimen. It also suggests that the main mechanism of microchannel formation in Ni-Al system is Al diffusion into solid Ni region.

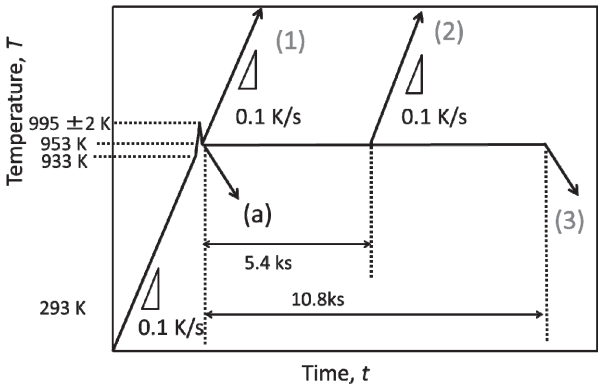


Fig. 7 Schematic time-temperature curves during heat treatments for the case of $M_{Ni}/M_{Al}=1$

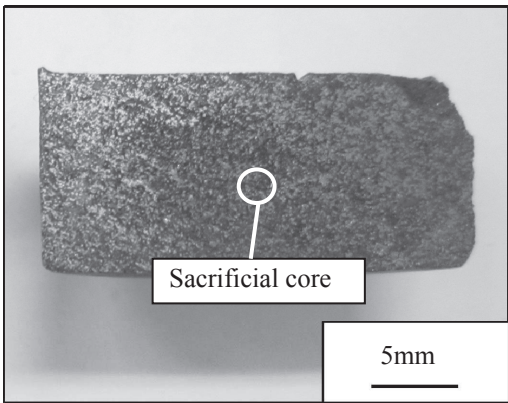


Fig. 8 Macrostructure of a transverse section of the specimen in the case of Curve (a) in Fig. 7 ($M_{Ni}/M_{Al}=1$, $P_c=100$ MPa)

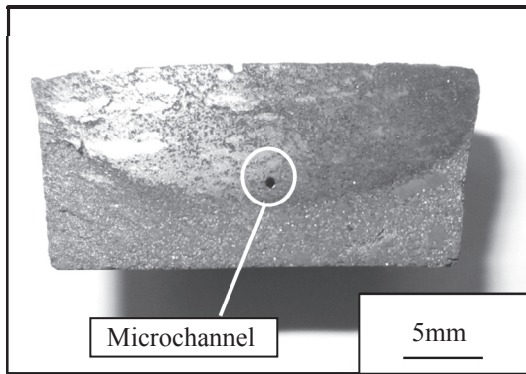


Fig. 9 Macrostructure of a transverse section of the specimen in the case of Curve (3)
($M_{\text{Ni}}/M_{\text{Al}}=1$, $P_c=100$ MPa)

4. Conclusions

(1) The microchannel was produced in the reactive-sintered specimen, which maintained the original shape of the green compact.

(2) The microchannel was not formed when the specimen was distorted or completely melted by the hard combustion synthesis reaction.

(3) Even in the case of the high-Al specimen, $M_{\text{Ni}}/M_{\text{Al}}=1$, the microchannel was successfully produced by long-time temperature holding at 953 K.

References

- [1] Oka, T., Yano, T., Ochi, M., Tanaka, I. and Fukuchi, H.: Development of Thermal Protection System with Transpiration Cooling, *Ishikawajima-Harima engineering review*, **36** (1996), 364-367.
- [2] Yano, T., Imai, R. and Isomura, K.: Thermal-hydraulics in Micro-channel, *Journal of Japan Society of Fluid Mechanics*, **21** (2002), 55-61.
- [3] Omura, M., Ohmi, T., Kumagai, T. and Iguchi, M.: Fabrication of Ni-Al alloy Transpiration-Cooling Device by Powder-Metallurgical Microchanneling Process, *Journal of JSEM*, **11** Special Issue (2010), SS272-SS275.
- [4] Ohmi, T., Matsuura, K. and Kudoh, M.: Formation of intermetallic-lined microchannel in sintered metals by local reactive infiltration, *Journal of Self-Propagating High-Temperature Synthesis*, **13** (2004), 121-129.