Materials Transactions, Vol. 46, No. 10 (2005) pp. 2156 to 2158

Effect of Ultrasonic Vibration on Infiltration of Nickel Porous Preform with Molten Aluminum Alloys

Yong Bum Choi[1,2], Gen Sasaki[1,2], Kazuhiro Matsugi[1,2] and Osamu Yanagisawa[1,2]

[1]*Graduate School of Engineering, Hiroshima University, Higashi-Hiroshima 739-8527, Japan*
[2]*Hiroshima Prefectural Institute of Industrial Science and Technology, Higashi-Hiroshima 739-0046, Japan*

In order to obtain the high-performance composites with high density, the influence of additional ultrasonic vibration on the infiltration of molten aluminum alloy (ASTM A336.0) into nickel porous preform by low-pressure and pressureless casting was investigated. There was no effect of ultrasonic vibration on infiltration distance under pressureless casting because of presence of surface oxide film on the molten alloy, even when the contact angle is reduced by ultrasonic vibration. However, infiltration distance increases upon applying ultrasonic vibration under low pressure. The infiltration distance appears to increase because of the decrease of the contact angle between the reinforcement and molten alloy upon applying ultrasonic vibration, as well as the reducing effect of oxide film on the surface of the molten alloy under low pressure. The improvement of infiltration by applying ultrasonic vibration under low pressure is applicable to the to infiltration of into nickel porous preform.

(Received April 26, 2005; Accepted August 4, 2005; Published October 15, 2005)

Keywords: *nickel porous preform, ultrasonic vibration, low pressure casting, pressureless casting, infiltration, contact angle, aluminum alloy, metal matrix composites*

1. Introduction

In order to fabricate metal matrix composites (MMCs) with high-performance properties by the infiltration casting technique, the squeeze casting process is generally used for the infiltration of into porous preform because of the low wettability between the molten aluminum alloy and preform. However, if it is possible to decrease the plunger pressure of the molten aluminum alloy into the mold, the composites can be fabricated by low pressure casting, die-casting and sand casting. These processes make it possible to fabricate large and complex-shaped composites. Furthermore, as these processes have high cost performance, MMCs will be used in many applications. Because the low wettability between the reinforcement and molten aluminum alloy causes defects such as porosity of the non-infiltrated parts around the reinforcement, it leads to degradation of the mechanical properties. Therefore, the improvement of the wettability between the reinforcement and matrix alloy is very important to enable high-performance composite fabrication.

In previous studies, the surface coating of the reinforcement,[1)] high-temperature treatment for the molten alloy,[2,3)] and the addition of a third metal element to the molten alloy[4)] have been attempted in order to improve the wettability. Unfortunately, these methods require complex process that will raise the cost factor in composites manufacture. Sometimes, the mechanical properties of the composites fabricated by these processes degrade because of chemical reaction and degradation of reinforcement. Recently, it has been found that ultrasonic vibration improves infiltration by increasing the wettability between molten aluminum alloy and reinforcement. Actually, many studies on the fabrication process of the composite by the ultrasonic infiltration technique have been attempted, for example, the improvement of wettability between molten aluminum alloy and SiO_2 particles in the in situ process based on melt stirring with ultrasonic vibration.[5–7)]

Unfortunately, the details of the effects of the ultrasonic vibration on the infiltration behavior into the preform have not yet been studied. Neither has any publication has been found on the influence of processing variables on the preform cell size. The goal of this study is to clarify the effect of ultrasonic vibration on the infiltration of porous nickel preform by molten aluminum alloy. In addition, the preform cell size is important to the strength of the composite.[8)] Therefore, the effect of preform cell size on the infiltration behavior is also investigated.

2. Experimental Procedure

To investigate the effects of ultrasonic vibration on the contact angle between the solid and liquid, liquid polyester resin was dropped onto a glass plate at 300 K and the time dependence of the ultrasonic vibration on the contact angle was estimated using a video camera system. Experiments on ultrasonic vibration were carried out with pressureless casting and low-pressure casting. The temperature of aluminum alloy (ASTM A336.0) was 1023 K in the experiment with the pressureless process and that of porous nickel preform was 673 K. Ultrasonic vibration time was 60 s. In the experiment with low-pressure casting, the temperatures of the matrix and reinforcement were the same as in the experimental with pressureless casting. The experiment of applying ultrasonic vibration to the mold was carried out after the infiltration of molten aluminum alloy into the porous nickel preform by the low-pressure process. The power and frequency of ultrasonic vibration were 1 kW and 18 kHz, respectively. Figure 1 shows the porous nickel preform (Sumitomo Electric Toyama Co., Ltd.) made by the metal plating method (MPM). This preform is made of a high-performance lightweight structural material. Cells of two sizes, 0.73–0.98 mm and 0.46–0.58 mm, were used. The effect of ultrasonic vibration on infiltration depending on preform cell size was investigated. The experimental conditions are listed in Table 1.

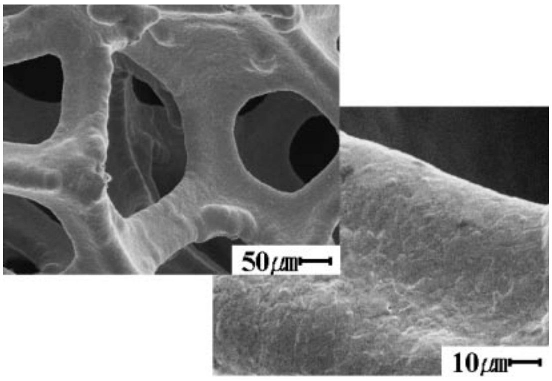

Fig. 1 SEM photograph of porous nickel.

Table 1 Experimental conditions of molten alloy infiltration into preform with ultrasonic vibration.

Matrix	ASTM A336.0 aluminum alloy Al–13 mass%Si–1.3 mass%Mg–1.3 mass% Cu–1.5 mass%Ni	
	Melting point 1024 K	
Reinforcement	Porous nickel preform Cell size	
	0.73–0.98 mm	0.46–0.58 mm
Ultrasonic vibration	1000 W, 18 kHz	
Applied pressure	Pressureless, low pressure of 0.2 MPa	

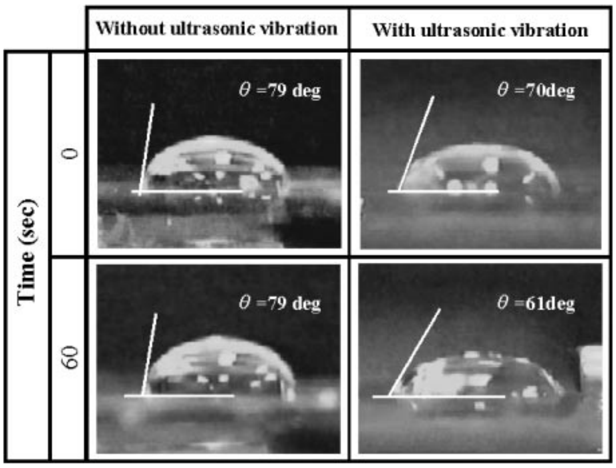

Fig. 2 The dependence of contact angle between the polyester resin and glass plate in air.

3. Results and Discussion

3.1 Influence of ultrasonic vibration on wettability

Wettability between molten alloy and reinforcement plays an important part in the infiltration process. It is necessary to investigate the effect of ultrasonic vibration on wettability. Figure 2 shows the time dependence of the contact angle of liquid polyester resin on a glass substrate with and without ultrasonic vibration. The contact angle under no ultrasonic vibration was constant (79°). In contrast, it was improved to 70° at the start of ultrasonic vibration but then degraded to 60° with increasing vibration time beyond 60 s. After stopping ultrasonic vibration, the contact angle increased to 67°, but did not return to the initial angle. The immediate degradation of the contact angle upon applying the ultrasonic vibration seems to be related to the rapid vibration acceleration, and the subsequent slow degradation is caused by the surface improvement. These results show that ultrasonic vibration improves of the wettability.

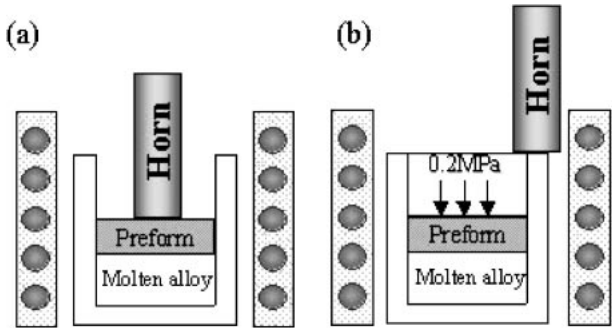

Fig. 3 Schematic diagram of the ultrasonic vibration apparatus; (a) without pressure, (b) with low pressure (0.2 MPa).

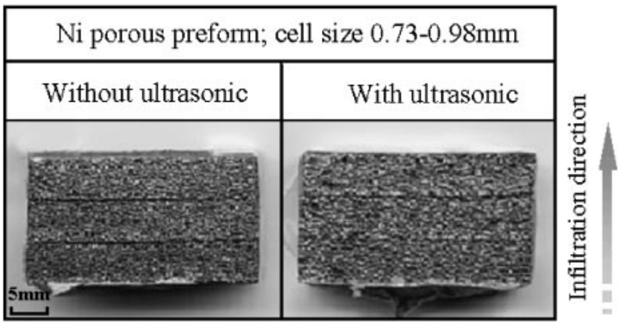

Fig. 4 Appearance of internal structure of nickel porous preform composed by pressureless.

3.2 Effect of infiltration behavior with ultrasonic vibration

Figure 3 shows the experimental setup for the application of ultrasonic vibration without pressureless (a) and with a low pressure of 0.2 MPa (b). Figure 4 shows the results of the infiltration behavior with ultrasonic vibration under the pressure-less process. Infiltration of the molten alloy into preforms is not observed. Although the ultrasonic vibration improves the wettability between reinforcement and molten alloy to below 90°, infiltration is prevented by oxide film that exists on the surface of molten alloy. Figure 5 shows the results of infiltration in the case of low-pressure casting with two cell sizes, 0.73–0.98 mm and 0.46–0.58 mm. The effect of the infiltration of molten alloy into the preform under low pressure was observed. It seems infiltration distance is increased due to the reduction of oxide film on the surface of the molten alloy on applying low pressure. Infiltration distance increases by applying ultrasonic vibration with low pressure. The infiltration distance seems to increase because of the decrease of the contact angle between the reinforcement and molten alloy upon applying ultrasonic vibration. The maximum infiltration distance under low pressure without ultrasonic vibration is 3.2 mm in a cell size

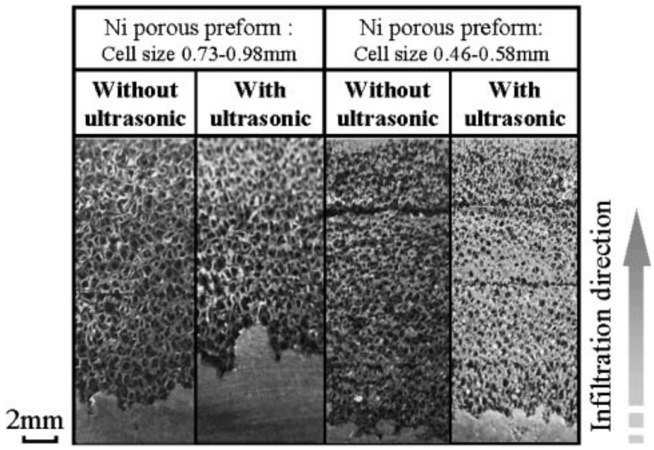

Fig. 5 Appearance of internal structure of nickel porous preform composed by low pressure (0.2 MPa).

of 0.73–0.98 mm, but increases to 7 mm with ultrasonic vibration. For a cell size of 0.46–0.58 mm, maximum infiltration distance under low pressure is 1.5 mm without ultrasonic vibration but increases to 2 mm with ultrasonic vibration. The infiltration under low pressure with ultrasonic vibration is greater in the cell of 0.73–0.58 mm than in the cell size of 0.46–0.58 mm. The effect of oxide film on the molten aluminum alloy surface seems to be weaker for the preform with cell size of 0.73–0.98 mm than for the preform with cell size of 0.46–0.58 mm. The results of this study revealed that the effect of ultrasonic vibration on infiltration differs according to cell size under low pressure. However, ultrasonic vibration was confirmed to improve infiltration.

4. Conclusion

This study examined the effect of ultrasonic vibration on the infiltration of molten alloy into preform. Ultrasonic vibration was confirmed to improve the wettability between the reinforcement and molten alloy. In addition, this study devised a new preparation method of the composite that involved the application of ultrasonic vibration and low pressure. Also, the decrease of the contact angle upon applying ultrasonic vibration confirmed its influence on the infiltration of molten aluminum alloy into preform. However, infiltration was not observed when applying only ultrasonic vibration. The contact angle is reduced by applying ultrasonic vibration, but it is considered that infiltration is inhibited by oxide film on the molten alloy surface. However, with ultrasonic vibration and low pressure, infiltration was enhanced because oxide film on the molten aluminum alloy was decreased by low pressure. Furthermore, the ultrasonic vibration effect on infiltration differs according to cell size with low pressure. However, ultrasonic vibration was confirmed to improve infiltration.

Acknowledgements

We would like to thank the Hiroshima Prefectural Institute of Industrial Science and Technology for financial support of this study. The coauthor thanks Mr. Y. Sugimoto and N. Oda of Mazda Motor Co., Ltd.

REFERENCES

1) J. P. Rocher, L. M. Quenissert and R. Naslain: J. Mater. Sci. **24** (1989) 2697.
2) J. Hashim. L. Looney and M. S. J. Hashimi: J. Mater. Pro. Tech. **119** (2001) 324.
3) V. Laurent, D. Chatillon and C. Chatillon: Acta Metall. **36** (1988) 1979.
4) S. Y. Oh, J. A. Cornie and K. C. Russel: Metal. Trans **20A** (1989) 553.
5) Y. Nakanishi, Y. Tunekawa, M. Okumiya, N. Mohri, I. Niimi and S. Sato: J. Jpn. Inst. Metal. **57** (1993) 81.
6) Y. Nakanishi, Y. Tunekawa, M. Okumiya, N. Mohri and I. Niimi: J. Japan Inst. Light Metal. **43** (1993) 8.
7) Y. Nakanishi, Y. Tunekawa, M. Okumiya, N. Mohri and I. Niimi: J. Japan Inst. Light Metal. **43** (1993) 14.
8) P. R. Onck, E. W. Andrews and L. J. Gibson: Int. J. Mech. Sci. **43** (2000) 681.