FABRICATION OF ALUMINUM COMPOSITES REINFORCED WITH STAINLESS STEEL TRUSS STRUCTURE

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1 Introduction

Metal matrix composites(MMCs) have attracted much attention due to the attractive characteristics for a variety of applications, for example in the aerospace, military and automotive industries[1-2]. Especially, aluminum matrix composites(AMCs) reinforced with continuous metallic fibers have many attractive characteristics such as large flexibility with respect to the choice of fiber volume fraction, high specific strength, specific modulus, wear resistance and low thermal expansion coefficient properties[3-5]. These properties, however, are not proportionally increased because reinforcements are not dispersed uniformly in the matrix.

Recently, Kang et al.[6-8] have successfully fabricated a new type of periodic cellular metal named wire-woven bulk Kagome(WBK) structure using continuous helical wires. WBK structure has high specific strength and periodicity. Furthermore, the volume fraction of WBK can control to change the wire pitch and diameter.

In this study, WBK preforms fabricated by stainless steel 304 wires are used as a reinforcements to improve dispersibility known as a main problem of the composites. Microstructure, wettability and interfacial reaction between aluminum matrix and WBK preform are investigated as a basis for research.

2 Experimental procedures

2.1 Fabrication of WBK Truss Preform

The WBK preform is fabricated by using continuous herical wires. Stainless steel 304 wires of 0.78 ㎜ diameter are twisted until plastic deformation occurs in the wires and then methodically assembled in six different direction according to the procedure previously described in detail [6]. To shortly explain, the assembly process of WBK perform consists of wire plastic deformation, in-plane assembly, out-of-plane assembly and remove frame. Fig. 1 shows the assembly process of WBK preform. Assembled WBK preform are either preheated at 623K for 30min or not.

2.2 Fabrication of Composites

Pure aluminum(> 99.9%) was melted in the medium wave frequency induction melting furnace at 973K. At the same time, SS400 steel mold was preheated for dehydrating by gas torch. The WBK preforms were placed in the mold. Molten aluminum was poured into the mold to fabricate the composites in the air when the mold was preheated at 523K. After fabrication, the specimens were cut, polished initially with a grade 1200 grit SiC sand paper and finally using 1 ㎛ diamond suspension.

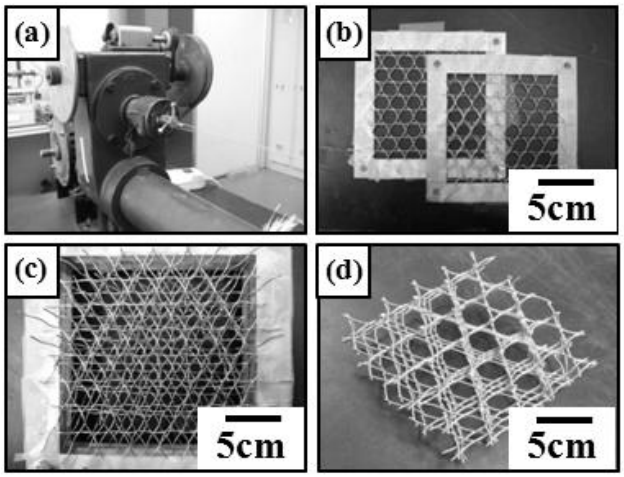

Fig.1. Assembly process of WBK preform: (a) fabrication of helical wires, (b) assembled WBK plane, (c) assembled multi-layered WBK and (d) accomplished WBK perform.

2.3 Interface Wettability and Reaction

The microstructure and wettability characteristic between aluminum matrix and stainless steel 304 WBK preforms were observed by optical microscope (VHX-200, KEYENCE CO., Japan). The microstructure and composition analysis were carried out the vicinity of interface between matrix and preform by scanning electron microscopy(JSM-5500, JEOL Co., Japan) and energy dispersive X-ray spectroscopy. Hardness measurements are performed using a micro-Vicker's hardness tester (HM-124, Akashi Co., Japan) under load of 25g for 10s.

3 Results and Discussion

3.1 Interface Wettability

Fig. 2 shows interface wettability between aluminum matrix and stainless steel 304 WBK preform observed by optical microscope. When the wires were crossed in nonpreheated preform, exterior part of its joint has good wetting condition but interior part had bad wetting condition as shown in Fig. 2(a). For the case of preheated preform, both exterior and interior parts of joint had good wetting condition as shown in Fig. 2(b). These features may be attributing to the lower solidification rate around the joint of preform compared to the nonpreheated preform.

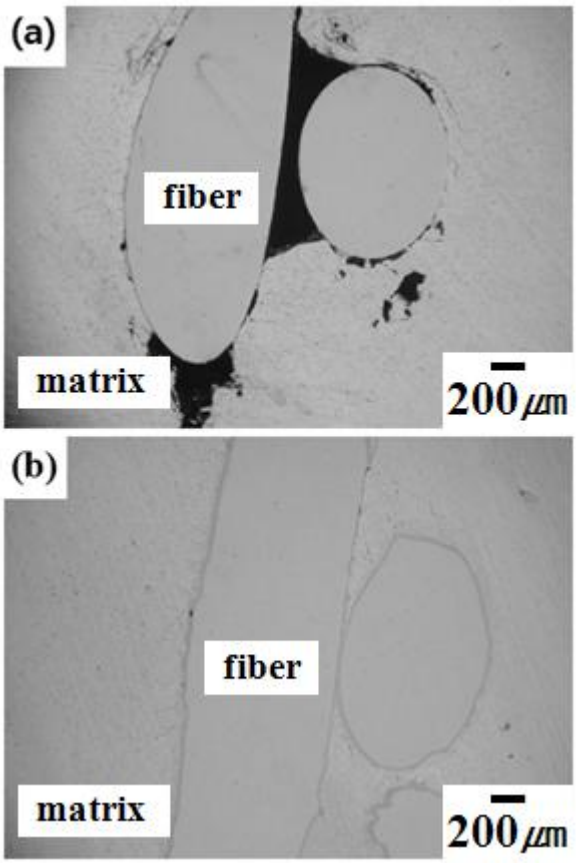

Fig.2. Surface wettability of aluminum matrix and stainless steel 304 WBK: (a) Non-preheated and (b) Preheated composites at 624K for 30minutes.

Fig. 3 shows the schematic representation of wetting. Young[9], from a mechanistic approach, expressed the relationship among the horizontal components of the three interfacial tension of such a system at the three-phase contact as

$$\gamma_{SV} = \gamma_{SA} + \gamma_{AV} \cos\theta \qquad (1)$$

$$\theta = \cos^{-1}\frac{\gamma_{SV} - \gamma_{SA}}{\gamma_{AV}} \qquad (2)$$

where γ is the interfacial tension between stainless steel-vapor($_{SV}$), stainless steel-molten aluminum($_{SA}$), molten aluminum-vapor($_{AV}$) phases and θ is the contact angle measured through the molten aluminum phase as shown in Fig. 3.

Wettability is increased with decreasing contact angle θ which is decreased with increasing γ_{SV} and decreasing γ_{SA}, γ_{AV}. γ_{SA} is dominantly dependant of temperature. Wettability could be controlled by reducing γ_{SA} from temperature increase. Therefore, the wettability of preheated WBK-Al composites is better than that of nonpreheated WBK-Al composites. Consequently, preheated preform showed good wettability because of low γ_{SA} from preheating. Also, low solidification rate owing to low temperature gradient between matrix and preform affected wettability.

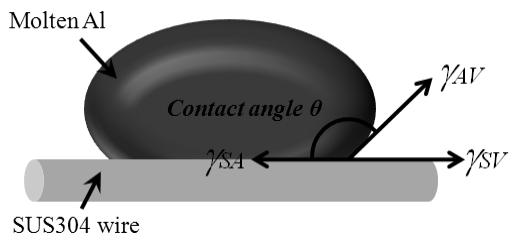

Fig.3. Schematic representation of wetting

3.2 Interface reaction

3.2.1 EDS analysis in the vicinity of interface

EDS analysis carried out vicinity of interface and the results are given in Fig 4. Reaction zone(R.Z.) was not formed when preform was not preheated, and each composition was inherent in Fig 4(a). However, interface reaction was confirmed when preform was preheated in Fig. 4(b). It is supposed that the layer is a mixture of Fe_2Al_5 and $FeAl_3$[10]. Further study is required to determine the percentage of the individual intermetallic compounds at various position of the R.Z..

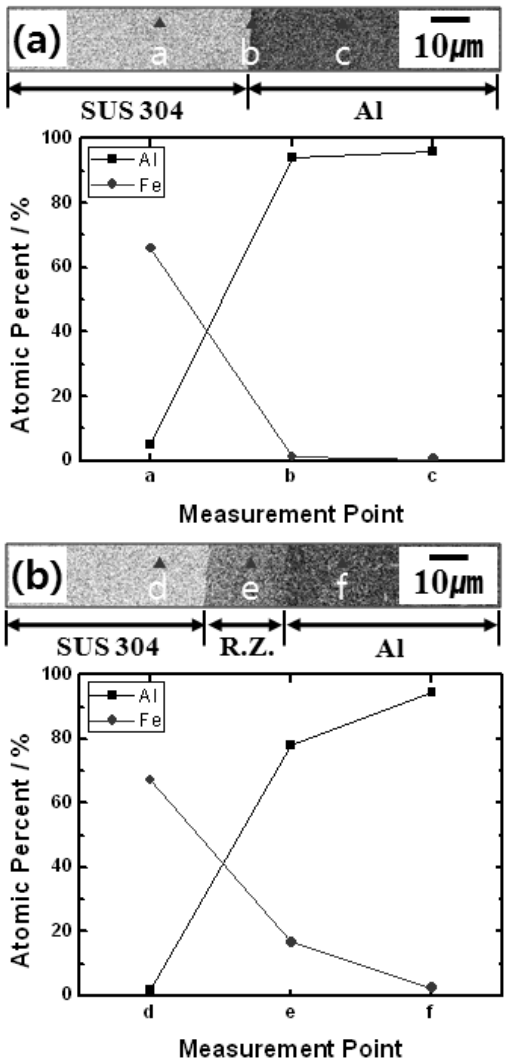

Fig.4. Composition analysis from WBK preform to aluminum matrix: (a) Non-preheated, (b) Preheated composites at 624K for 30minutes

3.2.2 Hardness profile in the vicinity of reaction

Fig. 5 is a micro-hardness value of vicinity of interface was measured by micro-Vicker's Hardness tester. When preform was not preheated, matrix and WBK preform exhibit identical hardness value of materials. However, the change in hardness from reinforcement to matrix is shown in Fig. 5(b). The hardness at the R.Z. is much higher than that in the reinforcement and matrix. Hardness distribution from the inner to the outer zone of R.Z. indicates that multiple phase exist and percentage difference in the R.Z.. From EDS analysis and hardness value, intermetallic compounds formation was confirmed.

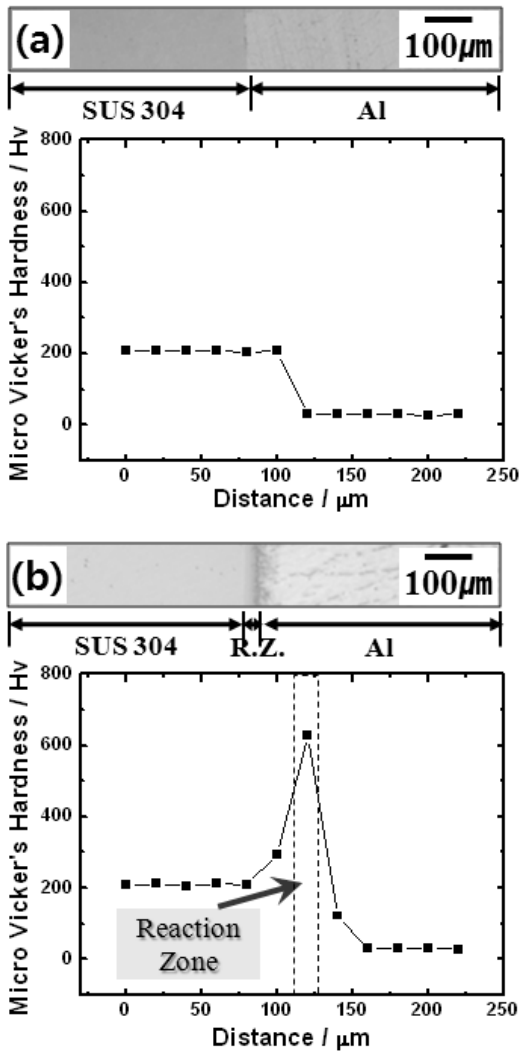

Fig.5. Cross-sectional micro-hardness profile in vicinity of reaction zone: (a) Non-preheated, (b) Preheated composites at 624K for 30minutes

4. Conclusion

The WBK preforms fabricated by herical stainless steel 304 wires are used as a reinforcement to improve dispersibility of composites. Preheated preform shows a good wettability rather than non-preheated preform and also interfacial reaction between aluminum matrix and prefrom was observed. Also, from EDS analysis and micro-Vickers hardness value, Intermetallic compounds mixture of Fe_2Al_5 and $FeAl_3$ formation was confirmed.

Acknowledgment

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References

[1] J. H. Son, W. J. Lee, Y. H. Park, Y. H. Park and I. M. Park "Analysis of Effective Elastic Modulus and Interfacial Bond Strength of Aluminum Borate Whisker Reinforced Mg Matrix Composites by Using Three Dimensional Unit Cell Model". *Kor. J. Met. Mater*., Vol. 48, Issue 5, pp469-475, 2010.

[2] B. J. Choi and Y. J. Kim "Microstructure and Tensile Property of In-Situ (TiB+TiC) Particulate Reinforced Titanium Matrix Composites". *Kor. J. Met. Mater*., Vol. 48, Issue 8, pp780-789, 2010.

[3] W. Zhang, D. Chai, G. Ran and J. Zhou "Study on microstructure and tensile properties of in situ fiber reinforced aluminum matrix composites". *Materials Science and Engineering A*, Vol. 476, Issues 1-2, pp157-161, 2008.

[4] Z. H. Melgarejo, O. M. Suarez and K. Sridharan "Wear resistance of a functionally-graded aluminum matrix composite". *Scripta Materialia*, Vol. 55, Issue 1, pp95-98, 2006.

[5] H. Wang, G. Li, Y. Zhao and G. Chen "In situ fabrication and microstructure of Al_2O_3 particles reinforced aluminum matrix composites". *Materials Science and Engineering A*, Vol. 527, Issue 12, pp2881-2885, 2010.

[6] Y. H. Lee, B. K. Lee, I. Jeon and K. J. Kang "Wire-woven bulk Kagome truss cores". *Acta Materialia*, Vol. 55, Issue 18, pp6084-6094, 2007.

[7] K. J. Kang "A wire-woven cellular metal of ultrahigh strength". *Acta Materialia*, Vol. 57, Issue 6, pp1865-1874, 2009.

[8] B. K. Lee and K. J. Kang "Compressive strength of tube-woven Kagome truss cores". *Scripta Materialia*, Vol. 60, Issue 6, pp391-394, 2009.

[9] Young T. "An essay on the cohesion of fluids". *Philosophical Transactions of the Royal Society London*, Vol. 95, pp65-87, 1805.

[10] R. B. Bhagat "High pressure squeeze casting of stainless steel wire reinforced aluminum matrix composites". *Composites*, Vol. 19, Issue 5, pp393-399, 1988.