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Interfacial reaction and tensile properties of 6061Al matrix composite reinforced with copper-coated $Al_{18}B_4O_{33}$ whiskers

H.Q. Gao, W.D. Fei *

School of Materials Science and Engineering, Harbin Institute of Technology, P. O. Box 405, Harbin 150001, PR China

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Abstract

Copper was deposited onto the surfaces of aluminum borate whiskers through electroless plating. The microstructure and tensile strength of aluminum alloy 6061(AA6061) matrix composite reinforced by the copper-coated whisker were studied. The composite with a whisker volume fraction of 20% was fabricated by the squeeze casting method. The results show the interfacial reaction takes place only between the coating and matrix, and the ultimate tensile strength (UTS) of the composite is enhanced greatly by the whisker coating. When the composite was subjected to solution treatment at 490 °C, the UTS of composite increases with the solution time increasing, and the UTS of the composite is 357 MPa when the solution time is 4 h. The mechanism of the effect of solution treatment on the tensile properties of the composite was discussed.

Keywords: Aluminum borate whisker; Aluminum matrix composite; Copper coating; Interfacial reactions; Mechanical properties

1. Introduction

In the field of metal matrix composites (MMCs), much attention has been paid to the interfacial reactions between reinforcement and matrices [1–3]. Many methods have been proposed to overcome the problem of poor wettability between ceramic reinforcement and aluminum alloy for squeeze casting method. Some of these methods are expensive and complex, and a cheap and simple technique is still to be found. As one of the ways of surface treatment of reinforcements, the electroless plating technology has been progressed constantly and paid much attention [4–6].

Aluminum matrix composites reinforced by aluminum borate whiskers ($Al_{18}B_4O_{33}w$, denoted by ABO_W) have been extensively studied not only because of their desirable properties, but also because of low cost [7–10]. As it is well known, during the fabrication and second processing at high temperature for ABO_W-reinforced aluminum composite (ABO_W/Al), ABO_W can react with magnesium in aluminum alloys to produce crisp spinel $MgAl_2O_4$ [11]. This reaction usually degrades the properties of the composite [12–14]. So, one of important issues for ABO_W/Al composite is to control interfacial reaction. Chen et al. [15] showed that copper can be coated on the surface of SiC particle by electroless plating, and the properties of SiC particle reinforced aluminum composite could be improved.

In the present study, copper was deposited onto surfaces of aluminum borate whiskers by electroless plating to minimize the spinel reaction. The interfacial reaction and the mechanism of the effect of solution treatment on the tensile properties of the composite were investigated.

2. Experimental

ABO_W with a diameter of 0.5–1 μm and a length of 10–30 μm, made in Shikoku Chemical Company of Japan, was coated with copper by an electroless plating copper technique. The whisker surfaces were sensitized and activated before coating by Solution I and Solution II,

* Corresponding author. Fax: +86 451 86413922.
E-mail address: wdfei@hit.edu.cn (W.D. Fei).

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Table 1
Chemical composition of the solutions for whisker surface sensitization and activation

Solution I	10 ml/l HCl, 5 g/l $SnCl_2 \cdot 2H_2O$, balance H_2O
Solution II	1.67 g/l $AgNO_3$, 10 ml/l $NH_3 \cdot H_2O$, balance H_2O

respectively. The chemical compositions of these solutions are given in Table 1.

Chemical composition of the electroless bath was as follows: 16 g $CuSO_4 \cdot 5H_2O$, 15 g NaOH, 15 ml 36% HCHO, 20 g $C_{10}H_{14}N_2O_8Na_2 \cdot 2H_2O$, 14 g $C_4H_4O_6KNa \cdot 4H_2O$, 0.03 g $K_4Fe(CN)_6 \cdot 3H_2O$ and balanced with water in one liter of capacity. The $K_4Fe(CN)_6 \cdot 3H_2O$ acts as a stabilizer. Stirring during electroless plating is required to eliminate the gas bubbles from the surfaces of aluminum borate whiskers to receive uniform coating. The phase composition of the coated whisker was characterized on a Philips X′ Pert X-ray diffractometer with the radiation of Cu Kα, the tube voltage of 40 kV and the current of 35 mA. The X-ray diffraction (XRD) result of as-coated whisker is shown in Fig. 1, in which Cu phase can be found clearly. The copper-coated whiskers were made into preform with a shape size of $\varphi 90 \times 20$ mm. The whisker preform was dried at the room temperature for 48 h, then dried at 60–120 °C for 24 h, respectively, and finally sintered at 835 °C to obtain higher preform strength. The XRD spectrum of whisker preform is shown in Fig. 2, in which CuO phase can be found clearly, that is to say, Cu coating on the whisker surface was oxidated during the sintering process of whisker preform. Finally, ABO_W/6061Al composites were fabricated by squeeze casting method, with the die preheating temperature of 520 °C and casting temperature of 820 °C. The solution treatment was carried out at 490 °C for various times. Tensile experiment was carried out on an Instron 1186 testing machine. The dimension of tensile specimen is shown in Fig. 3.

The thinned foils of composites were prepared by ion milling for transmission electron microscope (TEM) observation of the interface region, and TEM observation was done on a Philips CM-12 TEM. Tensile fractographs of the composites were investigated by scanning electron microscope (SEM) observation on a S-570 SEM.

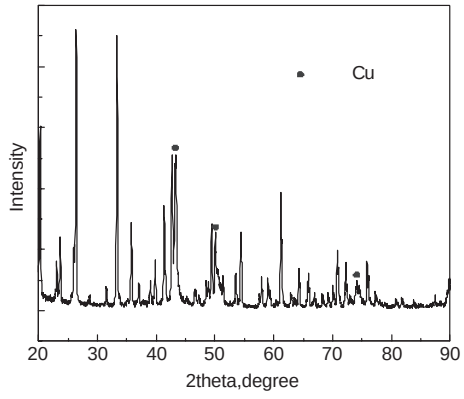

Fig. 1. XRD spectrum of the whisker with Cu coating.

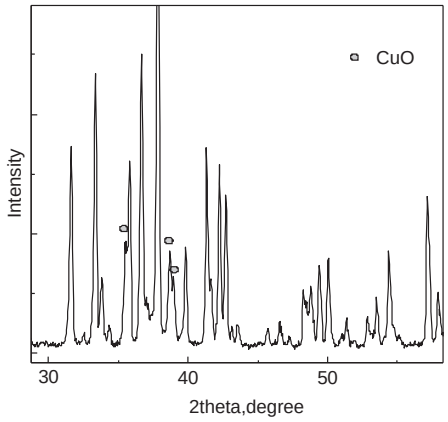

Fig. 2. XRD spectrum of the perform with Cu coating after sintering at 1100 °C.

3. Results and discussion

3.1. Interfacial reactions

TEM photographs of as-cast composite are given in Fig. 4. The interphase shown in Fig. 4a distributes on the surface of whiskers discontinuously. The corresponding selected area electron diffraction pattern (SADP) indicates that the interphase is $AlCu_3$.

As shown in Fig. 2, Cu-coating on the whisker surface was oxidated into CuO during whisker perform sintering, therefore, the formation $AlCu_3$ may result from the reaction between CuO and Al during squeeze casting process. At first, the following reaction may take place,

$$3CuO + 2Al \rightarrow Al_2O_3 + 3Cu \quad (1)$$

Because the time of squeeze casting is short, Cu, the interfacial reaction product of Eq. (1), cannot diffuse enough from interfacial region to the matrix far from interface. In this case, the content of Cu in the region nearby interface may be very high, and Cu can react with Al to form $AlCu_3$.

Fig. 5 shows the TEM photographs of the composites subjected to solution treatment at 490 °C for 2 h. As arrowed in Fig. 5a, some particles can be found near the interface between the whisker and matrix; the analysis of corresponding SADP shown in Fig. 5b indicates that the particles are Al_2O_3. It is clear

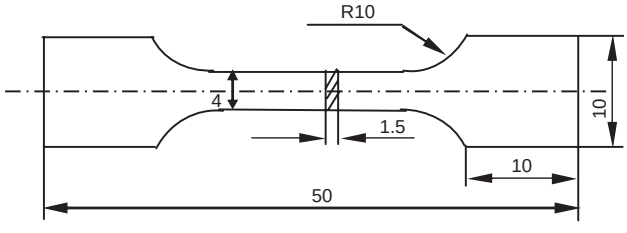

Fig. 3. Dimension of tensile specimen.