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Effect of Bi_2O_3 coating on interfacial wettability and tensile properties of $Al_{18}B_4O_{33}w$/Al composite

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Abstract A pure aluminum matrix composite reinforced by Bi_2O_3-coated $Al_{18}B_4O_{33}$ whisker was fabricated by squeeze casting method. The effects of Bi_2O_3 coating on the whisker/matrix wettability and the ultimate tensile strength and elongation to fracture of the composite are investigated. The results show that Bi_2O_3 coating can react with aluminum matrix during casting process, which improves the whisker/matrix wettability. Moreover, the ultimate tensile strength and elongation to fracture of the composite attain the maximum values at the mass ratio of 40:1 between whisker and Bi_2O_3 coating.

Introduction

Aluminum borate whisker ($Al_{18}B_4O_{33}$ whisker, denoted as ABOw) reinforced aluminum matrix composite (ABOw/Al) has been investigated extensively because of not only its good properties, but also the lower price of ABOw [1–3].

Because of the importance of the interface in ABOw/Al composite, many researches about the interface in the composite have been done, including the interfacial reaction and its effect on the properties of the composite [3–6].

In most cases, the matrix/reinforcement wettability is one of the most important interfacial properties and influences directly the properties of the composites. Unfortunately, the matrix/reinforcement wettability is generally poor in the ceramic reinforced metal matrix composite, which decreases the mechanical properties of the composite. So many efforts have been made to improve the matrix/reinforcement wettability, such as increasing the liquid metal temperature for casting composite [7], coating metal or oxide on the surface of reinforcement [8, 9], and adding some surface-active element into matrix [10, 11]. Among these, the method based on the interfacial reaction between the coating of reinforcement and the matrix has shown success in improving the matrix/reinforcement wettability. However, few studies have been concerned with the increase of the mechanical properties of ABOw/Al composite by improving the ABOw/liquid aluminum wettability.

In our previous research, ABOw/Al composite with Bi_2O_3 coating had the good plastics formability [12]. In this study, Bi_2O_3 was coated on the surface of ABOw using a simply chemical method [3]. The effect of Bi_2O_3 coating of whisker on ABOw/liquid aluminum wettability was investigated by squeeze casting method. In addition, the effects of Bi_2O_3 coating content on the tensile properties of ABOw/Al composites were investigated and discussed.

Experimental

The materials used in the present study were pure aluminum and ABOw with a diameter of 0.5–1.5 μm and length of 10–30 μm. The volume fraction of ABOw in the composite was 20%. Bi_2O_3 was coated on the surface of whisker using a chemical method [3]. Then, the whisker preform was sintered at 830 °C for 0.5 h (higher than the melting point of Bi_2O_3 coating, 821 °C [13] to obtain a high strength preform). The Bi_2O_3-coated ABOw reinforced aluminum composite (denoted as ABOw/BO/Al) and ABOw reinforced aluminum composite (ABOw/Al) were fabricated using squeeze casting method. The mass

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Table 1 Specification for ABOw/Al composites with different Bi_2O_3 coating contents

Mass ratio between coating and whisker	Bi_2O_3 coating content in composite (mass %)	Abbreviation
1:10	2.2	10ABOw/BO/Al
1:20	1.1	20ABOw/BO/Al
1:40	0.55	40ABOw/BO/Al

ratios between Bi_2O_3 and ABOw were 1:10, 1:20, and 1:40, respectively in ABOw/BO/Al composites. And the corresponding abbreviations of these composites are listed in Table 1.

To study the effect of Bi_2O_3 coating on the infiltration process of molten aluminum into the whisker preform during squeeze casting, the infiltration experiment was carried out on a CSSC4400 tensile (compression) machine under the same conditions with the preparation of composite ingot. The dimension of the infiltrated preform was 20 mm in diameter and 30 mm in length.

The interfacial structure of ABOw/BO/Al composite was observed on a CM12 type transmission electronic microscope (TEM), and the specimens for TEM observation were thinned by ion milling. The microstructures and tensile fractographs of the composites were examined using an OLYMPAS PMG3 type optical microscope (OM) and an S3000 type scanning electronic microscope (SEM). Tensile test was performed on an Instron 5590 tensile machine. The dimension of tensile specimen is shown in Fig. 1.

Results and discussion

Interface of ABOw/BO/Al composite

The typical OM photograph of ABOw/BO/Al composite is shown in Fig. 2a. It can be found that the distribution of whiskers in the composite is homogeneous and random, and no crack or hole can be found. Figure 2b is the back-scattering electronic (BSE) image of 10ABOw/BO/Al composite which shows that the Bi-rich phases (bright regions due to larger atomic number of element Bi) distribute mainly on the surface of whiskers in 10ABOw/BO/Al composite.

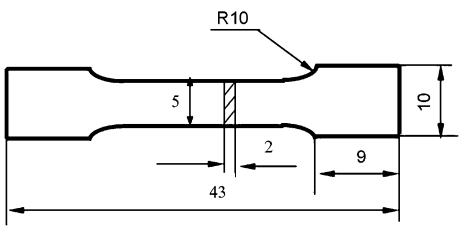

Fig. 1 Dimension of tensile specimen (in mm)

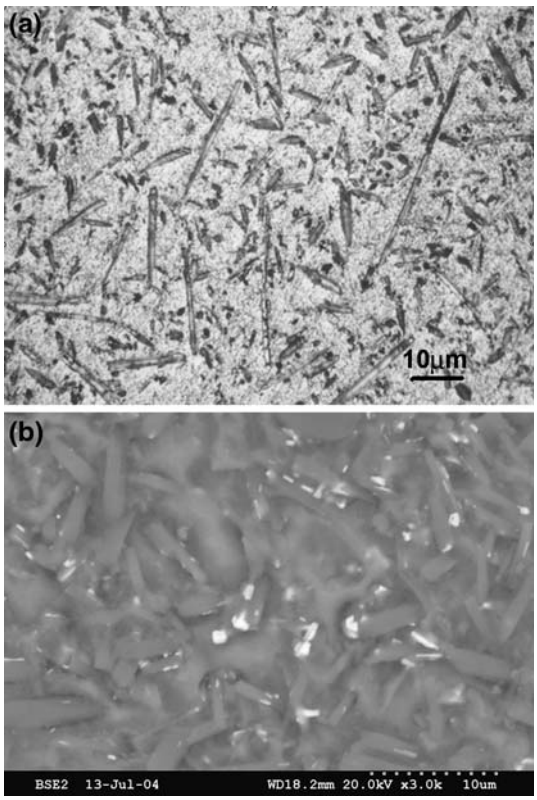

Fig. 2 Micrographs of 10ABOw/BO/Al composite: (**a**) OM image, (**b**) BSE image

Figure 3 is the TEM micrographs of 10ABOw/BO/Al composite. The black regions on the interface may be Bi-rich phases due to larger atomic number of element bismuth, and distribute clearly on the surface of whiskers and the inter-whisker regions in which liquid Al is difficult to fill during casting process (Fig. 3a, b). According to the analysis of the selected area electron diffraction pattern (SADP) corresponding to region A in Fig. 3b, the material in region A is indexed as Bi. Because the whisker coating is Bi_2O_3 after whisker preform sintered, it can be inferred that the pure Bi on the interface resulted from the interfacial reaction between Bi_2O_3 coating and Al matrix during squeeze casting process. In this way, liquid Al is prone to fill in the inter-whisker regions by the interfacial reaction during casting process.

Infiltration pressure of squeeze casting

Figure 4 shows the variation of the infiltration pressure (IP) with the ram displacement for ABOw/Al and 10ABOw/BO/Al composites. The value of the IP is dependent mainly on the whisker/liquid aluminum surface tension, the better the whisker/liquid aluminum wettability, the lower the

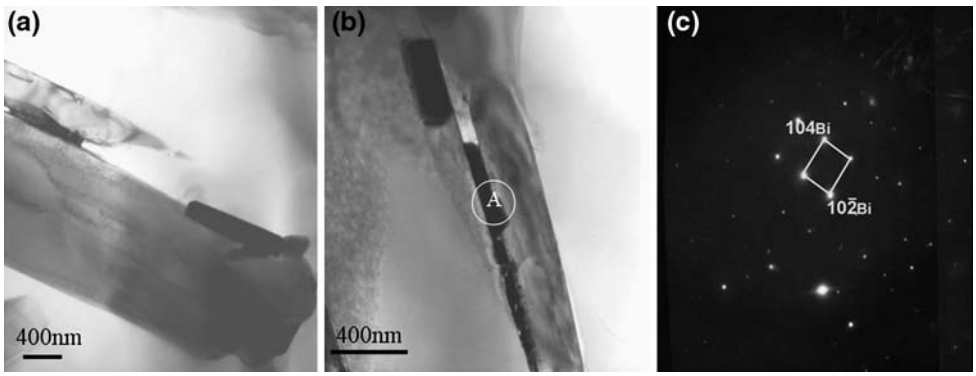

Fig. 3 TEM photographs of 10ABOw/BO/Al composite: (**a**) and (**b**) morphologies, (**c**) SADP corresponding to the region "A" in (**b**)

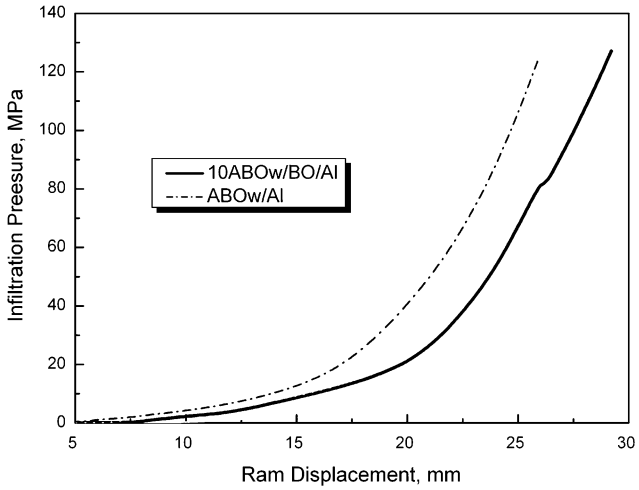

Fig. 4 Variation in the infiltration pressure with the ram displacement during casting process

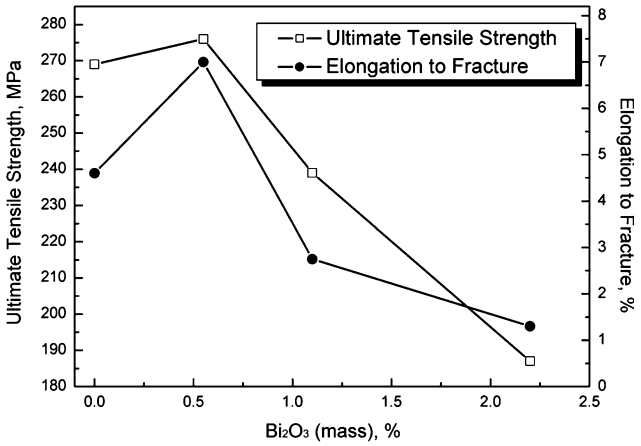

Fig. 5 Variation in the tensile properties of ABOw/Al composites with the Bi_2O_3 coating content

value of the IP. According to previous studies [8, 9], the interfacial reaction contributed to achieving the good reinforcement/matrix wetteability. It is clear that the IP of 10ABOw/BO/Al composite is lower than that of ABOw/Al composite, which means the whisker/liquid aluminum wettability in 10ABOw/BO/Al composite is better than that in ABOw/Al composite. In addition, this similar result can be also found in 20ABOw/BO/Al and 40ABOw/BO/Al composites. Therefore, we can conclude that the addition of Bi_2O_3 coating enhances efficiently the whisker/matrix wettability.

Tensile properties

Figure 5 shows the variation of the ultimate tensile strength (UTS) and elongation to fracture (δ) of the composites with the Bi_2O_3 coating contents. The UTS and δ of the composite increase firstly and then decrease with the Bi_2O_3 coating content increasing. 40ABOw/BO/Al composite, corresponding to 0.55% of Bi_2O_3 coating content, attains the maximum values of the UTS and δ. It should be noted that the δ of 40ABOw/BO/Al composite is almost as one and a half as that of ABOw/Al composite. Therefore, a proper Bi_2O_3 coating content is crucial for optimizing the tensile properties of ABOw/BO/Al composite.

Figure 6 shows the tensile fractographs of the composites with different Bi_2O_3 coating contents. It can be seen in Fig. 6 that those fractographs of the composites are quite different. In the fractograph of ABOw/Al composite, many holes and grooves with the shape of whisker can be found (as showed by arrows in Fig. 6a). Those holes may result from the pull-out of whisker or the unfilled regions in the composite.

For 40ABOw/BO/Al composite, many dimples rather than holes can be seen in the fractograph as shown in Fig. 6b because of the good whisker/matrix wettability, which corresponds to the highest UTS and δ of the composite. The fracture behavior of 40ABOw/BO/Al composite becomes ductile fracture.

When Bi_2O_3 coating content is more, many grooves with the shape of whisker and the bare whiskers can be seen as shown in Fig. 6c (as showed by arrows in Fig. 6c), which may result from the interfacial debonding because of

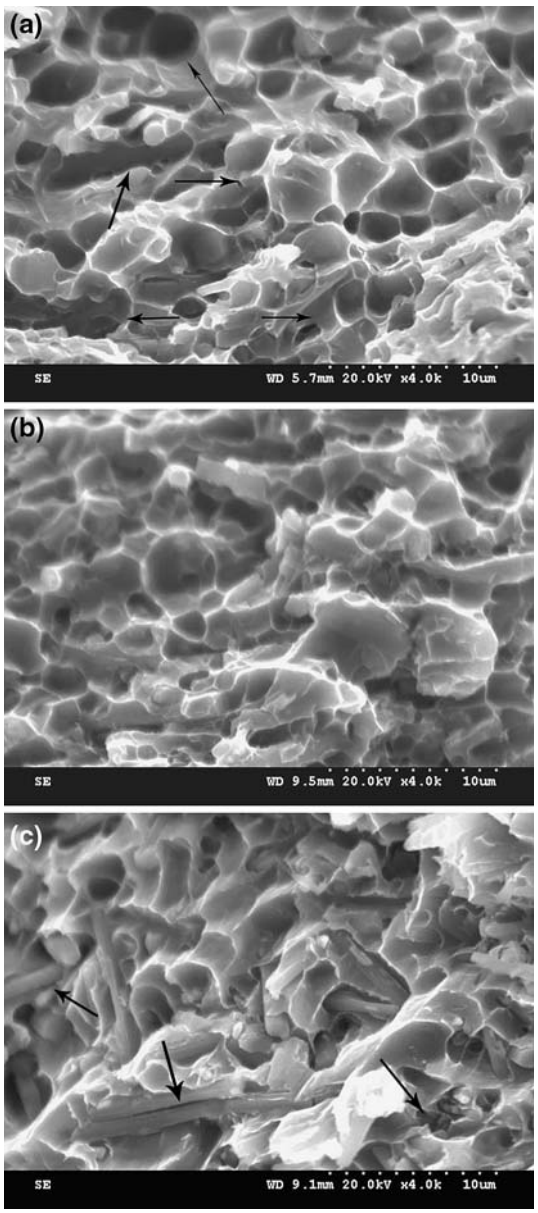

Fig. 6 Tensile fractographs of the composites (**a**) ABOw/Al, (**b**) 40ABOw/BO/Al, (**c**) 10ABO/BO/Al

the fracture of low strength phase Bi or brittle phase Bi_2O_3 on the interface.

Discussion

The UTS and δ of the composite increasing firstly and then decreasing with Bi_2O_3 coating content increasing may be primarily attributed as following. On one hand, based on the results of the infiltration experiment, the Bi_2O_3 coating improves the whisker/matrix wettability, and liquid Al is very easy to fill in the inter-whisker regions during casting process where the cracks propagate easily during tensile deformation. Therefore, the addition of Bi_2O_3 coating decreases the quantity of the microvoids existing in the composite and the coating/matrix interfacial reaction enhances also the interfacial bonding strength of the composite [3], both which help to increase the UTS and δ of the composite. On the other hand, the contents of the low strength phase Bi [13] and the unreacted brittle phase Bi_2O_3 on the interface also increase with Bi_2O_3 coating content increasing. Unfortunately, the early fracture of the coating during tensile deformation leads directly to the decrease in the UTS and δ of the composite. Therefore, a suitable Bi_2O_3 coating content is helpful for the improvement of the tensile properties of the composite, and in the present study, the suitable Bi_2O_3 coating content is about 0.55%.

Conclusions

1. Bi_2O_3 coating of whisker can react with aluminum in the squeeze casting process of ABOw/BO/Al composite.
2. The addition of Bi_2O_3 coating decreases the infiltration pressure of the composite during casting process, which suggests the improvement of the whisker/liquid aluminum wettability.
3. The Bi_2O_3 coating content affects the UTS and δ of the composites, and the composite with a suitable Bi_2O_3 coating content (0.55%, i.e. 40ABOw/BO/Al composite) can attain the highest values of the UTS and δ.

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