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Improvement of the tensile strength of $Al_{18}B_4O_{33}$w/Al composite at elevated temperatures by change of interfacial state

H.Y. Yue, L.D. Wang, W.D. Fei *

School of Materials Science and Engineering, Harbin Institute of Technology, Harbin 150001, People's Republic of China

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Abstract

In general, it is very difficult to obtain obviously reinforced effect in discontinuously reinforced aluminum matrix composites at the temperature above 400 °C. In the present study, we report an effective method to improve the high-temperature tensile strength of $Al_{18}B_4O_{33}$w/Al composite by change of interfacial state. The pure aluminum matrix composites reinforced by $Al_{18}B_4O_{33}$w with different $ZnAl_2O_4$ coating contents were fabricated by squeeze casting. The results indicate that $ZnAl_2O_4$ coating of the whiskers can effectively improve the high-temperature tensile strength of $Al_{18}B_4O_{33}$w/Al composite, although the tensile strength of the composite decreases with increasing the tensile temperature. On the basis of fractograph analysis, the fracture mechanism of the composites at elevated temperatures was investigated.

Keywords: Composites; Interface; High-temperature properties

1. Introduction

Discontinuously reinforced aluminum matrix composites (DRAMCs) have a number of advantages over monolithic aluminum alloys, such as high-specific strength, stiffness and excellent high-temperature properties [1–3]. Researches on the properties of DRAMCs at elevated temperatures are not only to investigate the high-temperature deformation behaviors and fracture mechanisms but to promote the wider applications in many fields, such as pistons for internal combustion engines and automobile brake shaft, some parts in aeronautic fields and astronautic fields and so on [4,5].

However, extensive researches have indicated that for various DRAMCs, whatever the strengths of composites at room temperature are, they begin to converge at the temperature above 300 °C and they are all nearly identical at above 400 °C [6–8]. Even in some composites, the strengths of the composites are lower than those of the matrix alloys. The reason is generally believed that the shear strength of the matrix rapidly declines and almost no load transfer from the matrix to the reinforcement exists at higher temperatures.

Matrix alloy and reinforcement kinds, orientation and volume fraction of the reinforcement in composites, preparation and heat-treatment processes do not have too much influence on the tensile strength of DRAMCs at temperatures above 400 °C [7,9–11]. Even for SiCw/Al composites with high-interfacial bonding strength, the similar results can be obtained [11]. Therefore, it is difficult to improve high-temperature tensile properties of DRAMCs according to the routine methods, although it is very important for the wider applications of DRAMCs. Up to now, little information can be available to improve the high-temperature strength of DRAMCs.

In the present study, discontinuous $ZnAl_2O_4$ particles were coated on the surface of aluminum borate whisker ($Al_{18}B_4O_{33}$w) by a sol–gel route. The effect of $ZnAl_2O_4$ coating of the whiskers on the tensile strength and fracture mechanism of the composites were investigated at elevated temperatures.

2. Experimental

The reinforcement used was $Al_{18}B_4O_{33}$w with a diameter of 0.5–1.5 μm and a length of 10–30 μm. In order to obtain $ZnAl_2O_4$ coating of the whiskers, ZnO was firstly coated on the surface of $Al_{18}B_4O_{33}$w by a sol–gel route, and then the ZnO-

* Corresponding author at: School of Materials Science and Engineering, Harbin Institute of Technology, P.O. Box 405, Harbin 150001, People's Republic of China.

E-mail address: wdfei@hit.edu.cn (W.D. Fei).

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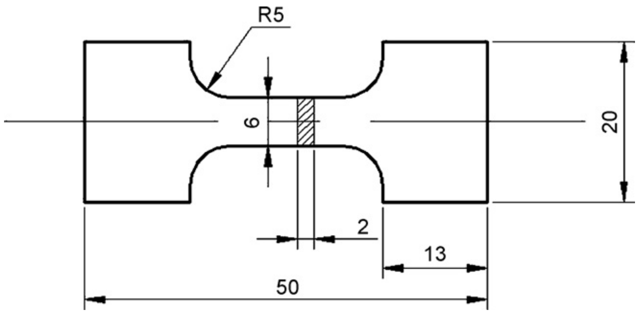

Fig. 1. Dimensions of tensile specimens.

coated whiskers were sintered at 1000 °C for 1 h. During the sintering process, the reaction between the whiskers and ZnO coating took place, so $ZnAl_2O_4$ coating was introduced. The detailed coating process and reaction mechanism can be found in our previous study [12].

The pure aluminum matrix composites reinforced by $Al_{18}B_4O_{33}$w with different $ZnAl_2O_4$ coating contents were fabricated by squeeze casting. The volume fraction of $Al_{18}B_4O_{33}$w in the composite was 20%. In order to investigate the effect of coating content on tensile properties of the composites at elevated temperatures, the initial massive ratio of ZnO to ABOw selected was 0, 1:30 and 1:10, that is, the volume fraction of $ZnAl_2O_4$ coating in the composites was 0%, 0.96% and 2.88%, respectively. The corresponding abbreviation separately is $Al_{18}B_4O_{33}$w/Al, $Al_{18}B_4O_{33}$w/$ZnAl_2O_4$/Al and $Al_{18}B_4O_{33}$w/3$ZnAl_2O_4$/Al.

Interfacial microstructures of the composites were observed using a Philips CM-12 transmission electron microscope (TEM) with an operating voltage of 120 kV. Specimens used for TEM observations were abraded to a thickness of 30 μm and finally thinned by ion-milling.

Tensile experiments were carried out using an Instron-1186 testing machine at a constant strain rate of 1 mm/min in the temperature range from 200 to 500 °C, and specimens were heated in an Instron-SF375D resistance furnace. A thermocouple was attached to the specimen and the specimen was held at the desired temperatures for 15 min to ensure a uniform temperature distribution before testing. The dimensions of tensile specimens used are given in Fig. 1. Tensile fracture surfaces of the composites were examined by an S-3000 scanning electron microscope (SEM).

3. Results

Fig. 2 shows TEM morphologies of the interface in as-cast composites reinforced by $Al_{18}B_4O_{33}$w with different $ZnAl_2O_4$ coating contents. It can be seen that, in $Al_{18}B_4O_{33}$w/Al composite, the interface is smooth and no interphase exists. However, interphase particles can be clearly found in $ZnAl_2O_4$-coated $Al_{18}B_4O_{33}$w reinforced aluminum composites, as shown in Fig. 2b and c, which are verified as $ZnAl_2O_4$ according to our previous study [12]. With the increase of the coating content, the sizes of interphase particles become larger and they discontinuously distribute on the whisker surface with an average size of about 30–100 nm. Because $ZnAl_2O_4$ particles are the reaction products between the whiskers and ZnO coating, and $ZnAl_2O_4$ do not react with aluminum during squeeze casting, thus, $ZnAl_2O_4$ particles at the interface embed in both the whisker and aluminum matrix and form many steps on the surface of $Al_{18}B_4O_{33}$w at the interface.

Tensile strengths of the composites reinforced by $Al_{18}B_4O_{33}$w with different $ZnAl_2O_4$ coating contents at elevated temperatures are shown in Fig. 3. It can be seen that the ultimate tensile strength (UTS) of the composites decreases with increasing the tensile temperature and increases with increasing $ZnAl_2O_4$ coating content. At the tensile temperature of 200 °C, the UTS of $Al_{18}B_4O_{33}$w/Al and $Al_{18}B_4O_{33}$w/3$ZnAl_2O_4$/Al composite is 164 MPa and 261 MPa, respectively. However, at the tensile temperature of 500 °C, the UTS of $Al_{18}B_4O_{33}$w/Al and $Al_{18}B_4O_{33}$w/3$ZnAl_2O_4$/Al composite rapidly reduces to 41 MPa and 73 MPa, respectively. The UTS of $ZnAl_2O_4$-coated $Al_{18}B_4O_{33}$w reinforced aluminum composite is obviously higher than that of uncoated $Al_{18}B_4O_{33}$w reinforced aluminum composite. Even at the tensile temperature of 500 °C, the increase ratio of the UTS of $Al_{18}B_4O_{33}$w/3$ZnAl_2O_4$/Al composite can reach 78% compared with that of $Al_{18}B_4O_{33}$w/Al composite. So, $ZnAl_2O_4$ coating of $Al_{18}B_4O_{33}$w provides a very effective method to

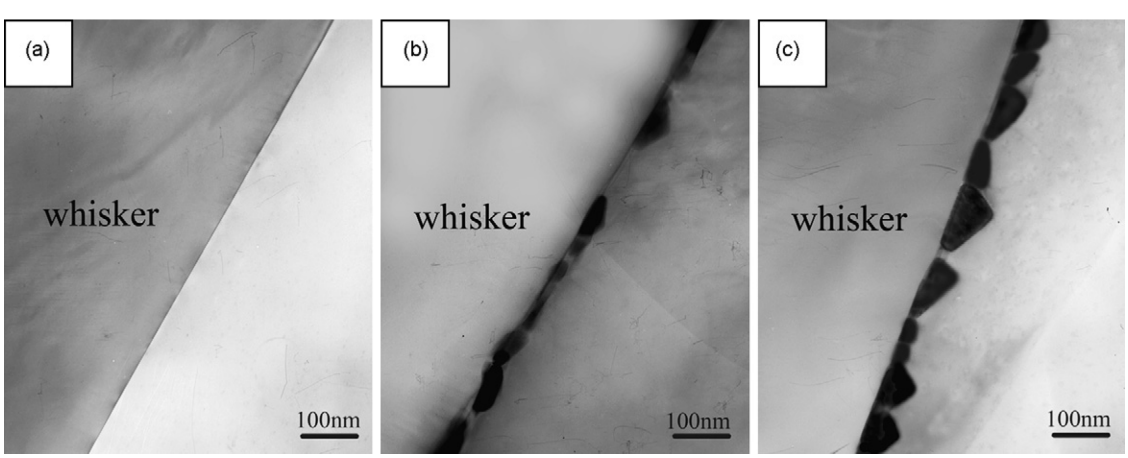

Fig. 2. TEM micrographs of the interface in as-cast composites reinforced by $Al_{18}B_4O_{33}$w with different $ZnAl_2O_4$ coating contents: (a) 0%, (b) 0.96%, (c) 2.88%.