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The microstructure and tensile properties of Al_2O_3-coated $Al_{18}B_4O_{33}$ whisker reinforced AA2024 aluminum composite

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HIGHLIGHTS

- Al_2O_3 is coated on $Al_{18}B_4O_{33}$ whiskers by hydrothermal synthesis method.
- Hydrothermal temperature affects morphologies of coating and composite.
- Coating affects the precipitated state in matrix near the interface.
- Coating reduces interfacial reaction between whisker and matrix effectively.
- Coating enhances tensile property and effect of age strengthening of composite.

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ABSTRACT

The coating given to $Al_{18}B_4O_{33}$ whiskers is expected to improve the interface bonding between the whisker/matrix and then to prevent the interfacial reaction. Al_2O_3 was firstly coated on the surface of the $Al_{18}B_4O_{33}$ whiskers by a hydrothermal synthesis method. Al_2O_3-coated $Al_{18}B_4O_{33}$ whiskers reinforced AA2024 matrix composites were fabricated by squeeze casting. The effects of Al_2O_3 coating on the interfacial reaction between the whiskers and matrix, the precipitated phase near the interface and the tensile properties of the composites were investigated. The results presented that the surface treatment of the whiskers can reduce the interfacial reaction effectively and affect the precipitated state of the matrix near the interface. In addition, it can be found that the Al_2O_3 coating on the surface of the whiskers can obviously enhance the tensile properties and improve the effect of aging strengthening of the composite. The hydrothermal temperature to prepare the coated whiskers had an obvious effect on the coating morphologies on the surface of the whiskers and the microstructure of the corresponding composite. As the hydrothermal temperature increased, the tensile properties of the composites obviously increased. When the coated whiskers were prepared at 200 °C, the highest ultimate tensile strength and elongation to fracture can be obtained in the corresponding composite, while simultaneously the effect of aging strengthen of the composite was also greatly advanced.

1. Introduction

$Al_{18}B_4O_{33}$ whisker reinforced aluminum composites are attractive for a wide application because of their low density, improved mechanical properties and low cost [1–3]. An interfacial reaction between the whisker and the magnesium included in aluminum alloy is an obvious feature of the composites [4–8], thus it is difficult to reveal the true effect of the $Al_{18}B_4O_{33}$ whiskers given to the composites on the mechanical behavior.

As we know, the quality of the matrix-reinforcement interface has a crucial importance. Therefore, the final properties of metal matrix composites could be optimized by a good design of interface [9–12]. Moreover, $Al_{18}B_4O_{33}$ reacts with magnesium to produce brittle $MgAl_2O_4$ in the whisker-metal interface which can cause the damage of the whiskers and the consumption of Mg in aluminum matrix, thereby leading to the deterioration in reinforcement efficiency and the weakening of age strengthening of matrix [13]. The coating given to $Al_{18}B_4O_{33}$ whisker is expected to improve the interface bonding between the whisker/matrix and then to prevent the interfacial reaction.

Pan et al. [14] obtained an $MgAl_2O_4$ coating on $Al_{18}B_4O_{33}$ whiskers by magnesium deposition reacted with the whiskers. They found that the $MgAl_2O_4$ coating on the $Al_{18}B_4O_{33}$ whiskers

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played the role of barrier to prevent the interfacial reaction. Though the interfacial reaction was restrained and the effect of age strengthening of matrix was revealed, however, the ineluctable facts of the consumption of whiskers led to the true effect of the whisker on the mechanical properties being hard to achieve.

To avoid the consumption of $Al_{18}B_4O_{33}$ whiskers, some researchers prepared different coatings (such as ZnO, Cu and Al_2O_3) on the surfaces of $Al_{18}B_4O_{33}$ whiskers using various methods [15–17]. They found that the presence of these coatings prevented the interfacial reaction between the whisker and aluminum matrix (contained Mg). Not surprisingly, the coated, $Al_{18}B_4O_{33}$ whisker reinforced aluminum matrix composites exhibited much better mechanical properties (hardness and tensile properties) than the uncoated-$Al_{18}B_4O_{33}$w reinforced aluminum matrix composite.

However, the coatings on $Al_{18}B_4O_{33}$ whiskers are prepared at room temperature and normal atmosphere by the above methods (sol–gel method and electroless plating technique), thus the dynamical energy is low. It's certain that these methods have the disadvantages of slow reaction rate, easy clustering and difficult dispersion of coatings.

Synthesis under hydrothermal conditions offers some significant advantages over other chemical synthesis techniques [18,19]. The hydrothermal synthesis method had been used to advantage in oxide powder with nano-structured. Particularly, it is easy to control the particle size and morphology of powders by varying the synthesis conditions. But its application to reinforcement coating has not been reported up to now. There are no studies on the preparation and characterization of whiskers with coatings (prepared by hydrothermal synthesis). Particularly, the microstructure and tensile properties of the corresponding composites are lacking.

In the present work, an Al_2O_3 coating was firstly obtained on the surfaces of $Al_{18}B_4O_{33}$ whiskers using a hydrothermal synthesis method. The $Al_{18}B_4O_{33}$ whiskers (with and without Al_2O_3 coating) reinforced AA2024 composites were fabricated by squeeze casting. Subsequently, the characteristics of Al_2O_3 coating, the microstructure and mechanical properties of the composites were investigated and the strengthening mechanisms of $Al_{18}B_4O_{33}$ whiskers for the AA2024 matrix composite were also discussed.

2. Experimental procedure

Al_2O_3 was coated on the surface of $Al_{18}B_4O_{33}$ whiskers (ABOw) using a hydrothermal synthesis method. Firstly, the whiskers were put into aluminum nitrate solution. The mass ratio between ABOw and $Al(NO_3)_3$ was set as 3:1. Secondly, dilute NH_4OH water solution was dribbled into the aluminum nitrate solution with the whiskers under stirring. Subsequently the mixed solution was transferred into an autoclave and a pressure of 80 MPa was applied on it. Thirdly, the autoclave was maintained at 140, 160, 180 and 200 °C for 4 h respectively, and then cooled to room temperature naturally. A boehmite (AlO(OH)) was coated on the surface of whiskers. At last, filtrating and sintering the whiskers with AlO(OH) coatings, Al_2O_3 can be obtained on the surface of whiskers due to the decomposition of boehmite. Moreover, the whisker preform was sintered at 900 °C for 1 h to obtain a high strength.

The ABOw (20% volume fraction) reinforced AA2024 composite was fabricated by squeeze casting. AA2024 has chemical compositions of Cu, 4.4; Mg, 1.5; Mn, 0.6; Si, 0.5; Fe, 0.08 in wt. %. The composites with and without the Al_2O_3 coating on the whiskers are refereed as ABOw/AlO/Al and ABOw/Al, respectively.

Solution treatment of the composite was carried out for 30 min at 495 °C in a salt bath furnace followed by quenching in cold water. The samples were artificially aged at 185 °C with various holding times and Vicker's hardness of aged specimens was measured. The measurement of hardness showed that the peak aging time was 8 h for the composite.

Tensile tests were performed on an Insrton 5590 test machine. The dimension of tensile specimen is shown in Fig. 1. The specimens selected for tensile test were as-cast and peak-aged composites (T6 state). All the tests were carried out at a strain rate of 0.5 mm per minute. Three specimens were tested for each composite at room temperature.

The morphologies of the coated whiskers and the tensile fractographs were examined by a **Hitachi** S-4700N scanning electron microscope (SEM). The microstructures of the composites were investigated using a FEI G2F30 transmission electron microscopy (TEM).

3. Results and discussions

3.1. Characterization of coated whiskers

Fig. 2 is the surface morphologies of ABOw without and with Al_2O_3 coating prepared at the different hydrothermal temperature. From Fig. 2a, it can be seen that the surface of whiskers is smooth. After coating, it can be observed that the Al_2O_3 particles on the surface of whiskers increased with the increase of the hydrothermal temperature, as shown in Fig. 2b–e. When the hydrothermal temperature is 200 °C, the size of the Al_2O_3 particles becomes more and larger.

3.2. Tensile properties of the composites

Fig. 3 is the ultimate tensile strength (UTS) and elongation to fracture (δ) of the composites in the as-cast and T6 states. It is noted that the UTS (Fig. 3a) and δ (Fig. 3b) of the composites can be improved by the reinforcement coating, and the UTS and δ of the composites increased with the hydrothermal temperature increasing. After T6 treatment, the δ value of the composites was faintly decreased, but the UTS of the composites was further enhanced. Moreover, it can be noted that the ABOw/AA2024 composite had about 12% strength enhancement after T6 treatment, and yet the ABOw/AlO/AA2024 composite (the Al_2O_3 coating was prepared at 200 °C) had about 24% strength enhancement after T6 treatment. This means that the effect of aging strengthen is greatly advanced by the whisker coating. In order to simplification, the ABOw/AA2024 and ABOw/AlO/AA2024 (the Al_2O_3 coating was prepared at 200 °C) composites before and after T6 treatment are refereed as C1, C1-T6, C2 and C2-T6, respectively. Fig. 4 presents the typical tensile stress–strain curves of the C1, C1-T6, C2 and C2-T6 composites. Clearly, the C1 and C2 exhibits almost similar stress–strain curves. Similarly, the C1-T6 and C2-T6 also exhibits almost similar curves. It is obvious that shape of the curve is different between C1 (C2) and C1-T6 (C2-T6).

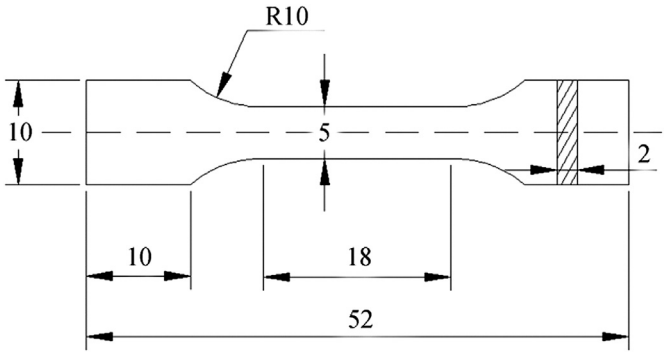

Fig. 1. Dimension of the tensile specimen (mm).