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Core–shell structured al-matrix composite with enhanced mechanical properties

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ABSTRACT

Al-matrix composites with different contents of core–shell structured B_4C_p–Cu reinforcement were prepared by electrolessly coating Cu on B_4C_p and hot sintering the mixture of B_4C_p–Cu and Al powder. The influences of solution treatment on the microstructure and mechanical properties were investigated. The results showed that the initial Cu shell was changed into Al_2Cu shell, and part of Cu was dissolved into the Al matrix after solution treatment at 540 °C. With increasing solution dwelled time, the yield strength, ultimate compressive strength and ductility were improved gradually. As compared with the pure B_4C_p reinforcement, the introduction of core–shell structured B_4C_p-Cu and subsequent solution treatment improved the mechanical properties of Al-matrix composite. The improvement of mechanical properties is attributed to the fact that the Al_2Cu shell moderates the modulus mismatch and enhances the interface bonding between Al and B_4C_p, and that heat treatment introduces solution strengthening of Cu element into the Al matrix.

1. Introduction

Particle reinforced Al-matrix composite has attracted quite a lot of attentions because of its high strength and good abrasive resistance [1–3]. There are a lot of methods to incorporate the particles into Al matrix to form composites [4]. No matter what the method is, the interface bonding between the reinforcement and the matrix is a key issue to the strength and ductility of the final composite [5,6]. It has been reported that many a failure of composite is partially attributed to the debonding when the reinforcement is stiff and the matrix is soft [7,8]. Some researchers coated the particles with Ni by electroless plating to enhance the bonding of the Al alloy and the particles [9]. But the coating was very thin, in which way no effective element adding can be obtained at the same time.

B_4C particle (B_4C_p) has been widely used as reinforcement because of its high modulus, strength, hardness and low density [10–12]. It is known that the B_4C and Al have the modulus of ~450 GPa and ~70 GPa, respectively [13,14]. The tremendous difference in modulus brings negative effects to the bonding of the composite. In this work, the core–shell structured B_4C_p–Cu was proposed to reinforce Al matrix composite. This was realized by plating the B_4C particles with Cu (B_4C_p–Cu), hot sintering the mixture of B_4C_p–Cu and Al powder, and heat treating the B_4C_p–Cu/Al composite at high temperature. The introduction of Cu layer is intended for a couple of purposes: firstly to moderate the modulus mismatch and enhance the interface bonding between Al and B_4C via the formation of Al_2Cu layer (the elastic modulus is ~105 GPa) in subsequent heat treatment, and secondly to introduce solution strengthening of Cu element into the Al matrix [15]. The influences of content of core–shell B_4C_p–Cu, heat treatment on the microstructure, and compressive mechanical properties of Al matrix composite were studied.

2. Experimental procedure

The core–shell particle, i.e. the Cu-coated B_4C_p was firstly prepared by electroless plating. Commercial B_4C_p with an average particle size (APS) of 20 μm were used as the initial powder. The B_4C_p was boiled in aqueous sodium hydroxide solution of 40 g/l for 30 min to remove the oil that may exist on the surface, and then washed by deionized water till pH=7. The dried B_4C_p was put into an aqueous solution containing 10 g/l $SnCl_2$ and 30 ml/l concentrated HCl, sonicated for 10 min, and then washed by deionized water three times to get sensitized [9]. The sensitized powder was then put into an aqueous solution containing 0.5 g/l $PdCl_2$ and 3 ml/l concentrated HCl, stirred for 20 min, and washed by

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deionized water to get activated. The as-activated powder was put into aqueous solution consisting of 5.99 g/l cupric sulfate ($CuSO_4 \cdot 5H_2O$), 15.29 g/l trisodium citrate dehydrate ($Na_3C_6H_5O_7 \cdot 2H_2O$), 28.62 g/l sodium hypophosphite ($NaH_2PO_2 \cdot H_2O$), 30.91 g/l boric acid (H_3BO_3) and 0.52 g/l nickelous sulfate ($NiSO_4 \cdot 7H_2O$), with pH=9 at 65 °C to get copper-coated [16]. The plated powder was washed in alcohol and then dried at 60 °C.

The B_4C_p–Cu was added into pure Al powder of APS of 10 μm, and vibrated for 15 min to get blended. The as-blended powders with 5 wt%, 10 wt%, or 15 wt% B_4C_p–Cu were loaded in a mold having a diameter of 23 mm, and sintered under uniaxial stress of 300 MPa at 500 °C for 1 h. The vacuum level was higher than 0.01 Pa all through the sintering. The as-sintered B_4C_p–Cu/Al composite were then solution treated at 540 °C for 0, 30, 60 and 90 min and water quenched. For comparison, the B_4C_p/Al composites were also prepared.

The as-coated powder and the bulk composites were characterized by D/max2200PC X-ray diffraction (XRD) to determine the phase composition. Compressive mechanical testing was performed on SANS 5504 universal testing machine, with the strain rate of 0.2 mm/min on a cylinder sample having 3 mm in diameter and 6 mm in height. The microstructure of the sintered samples was observed on SCAM3400 scanning electron microscope (SEM) equipped with energy dispersive spectroscopy (EDS). Microhardness was tested on FUTURE-TECH FM-800 under 100 g force for 15 s.

3. Results and discussion

The morphology of the initial and the as-coated B_4C_p is presented in Fig. 1. As can be seen, before the plating, the edge of B_4C_p is very sharp, and the surface is smooth. After plating, the edge become blunt, and the surface become coarse. It can be seen that something was well plated onto the surface of particles.

XRD pattern of the as-coated B_4C_p is presented in Fig. 2. Besides B_4C peaks, the ones emerged from Cu were also detected. It is therefore inferred that the Cu was plated on the surface of B_4C_p after the electroless plating.

The typical microstructures of the as-sintered samples subsequently underwent different solution dwelling time are shown in Fig. 3. As can be seen from the image, the coating on the B_4C_p becomes more and more apparent as the solution dwelling time increased. When the dwelling time was 0, i.e. without solution treatment, the coating on the B_4C_p is almost invisible, leaving pits around the core B_4C_p (Fig. 3a). This may be attributed to the Cu

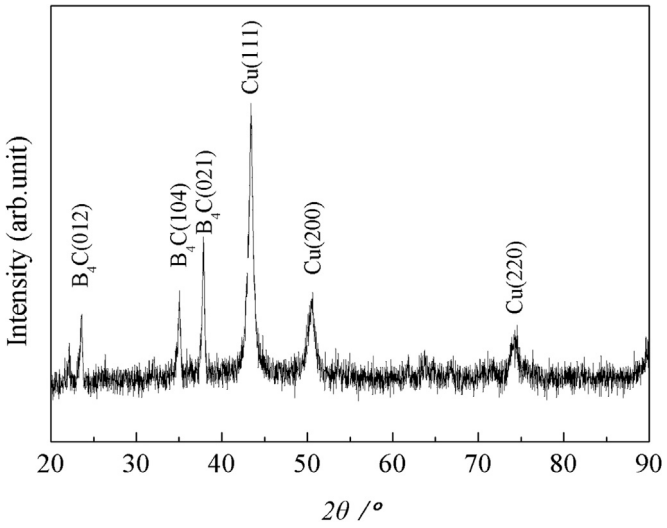

Fig. 2. XRD pattern of the as-coated B_4C_p.

layer being polished due to weak bonding between Cu and B_4C_p. When dwelled for 90 min, the coating, i.e. the shell remained integrated (Fig. 3d). EDS line scan mapping across one particle of this sample proves that the shell is a Cu-rich layer, as shown from the inset of Fig. 3d. EDS spotting on the shell presents an approximate Al/Cu atomic ratio of 2:1.

To further reveal the phases in the composites, XRD test on the as-sintered and solution treated samples was conducted. Fig. 4 presents the XRD patterns of the 15 wt% B_4C_p–Cu/Al composites after solution treatment for different time. It can be seen that when there is no solution treatment, peaks of Cu is clearly observed, and no Al_2Cu peaks is visible, which indicates that the initial shell of the as-sintered sample is composed of Cu. And after heat treatment, the peaks of Cu are weakened and the peaks of Al_2Cu appear, as shown in patterns of 30, 60 and 90 min. As a combination of the above analysis, it is quite likely that the inter diffusion of Al and Cu resulted in the formation of Al_2Cu, and simultaneously enhanced the bonding between Al and the Cu/Al_2Cu shell [17]. This may be the reason that the shell on the 90 min dwelled sample kept its integrality (Fig. 3d). No inter reaction between B_4C_p and Al/Cu was found in the samples during the whole processing, since the temperature was not high enough to activate the reaction between them [18,19].

Compressive mechanical properties of the core–shell structured Al matrix composites were evaluated. The typical

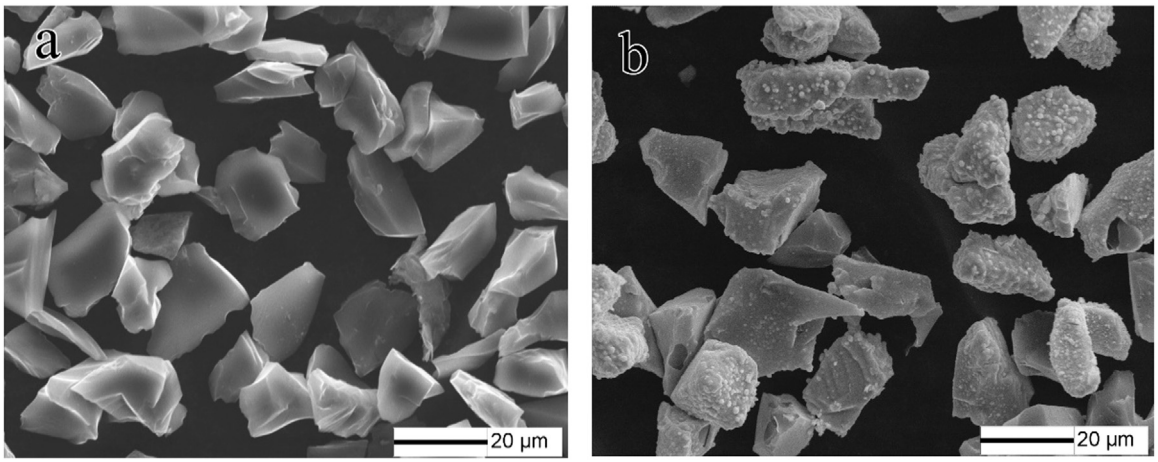

Fig. 1. SEM images showing the morphology of (a) initial B_4C_p and (b) as-coated B_4C_p.