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Effect of CuO particle size on synthesis temperature and microstructure of Al_2O_{3p}−Al composites from Al−CuO system

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Abstract: Al_2O_{3p}−Al composites were synthesized using an in-situ reaction in the 80%Al−20%CuO (mass fraction) system. The effects of the CuO particle size on the synthesis temperature and microstructure of the composites were investigated by various methods. The results indicate that the CuO particle size has a significant effect on the temperature at which the complete reaction in the Al−CuO system occurs: the temperature is 200 °C lower in the Al−CuO system containing CuO particles with sizes less than 6 μm than that containing CuO particles with sizes less than 100 μm. The interfacial bonding between Al_2O_3 particles and Al is not complete when the temperature is below a critical value. The morphology of the Al_2O_3 particles varies from ribbon-like shape to near spherical shape when the temperature is above a critical value. These two critical temperatures are affected by the particle size of CuO, and the critical temperature of the sample containing CuO particles with sizes less than 6 μm is 100 °C lower than that of the sample containing CuO particles with sizes less than 100 μm.

Key words: CuO; particle size; synthesis temperature; Al_2O_{3p}−Al composite

1 Introduction

Particle-reinforced aluminum matrix composites are of interest because of their highly desirable properties, such as high specific strength and stiffness, good wear resistance, low thermal expansion coefficient and traditional preparation process, for various applications in the aerospace, military, electronic devices and automobile industries [1−3]. Traditionally, composites are produced directly by adding reinforcement particles to the aluminum matrix using ex-situ techniques. In contrast, the in-situ technique is extensively utilized to produce particle-reinforced composites with contaminant-free reinforcement/matrix interfaces because the reinforcement particles are formed by the nucleation and growth from the parent matrix phase [4]. The in-situ formation of particles also provides effective control of the particle size and the level of the reinforcement, yielding better tailorability of properties [5].

The chemical reactions between the reactants, which are keys to the production of in-situ metal matrix composites, are extremely important. The displacement reactions between Al and metal oxides, such as CuO [6], SiO_2 [7], ZnO [8] and TiO_2 [9], used to produce Al_2O_{3p}−Al composites have been widely discussed due to the low cost of raw materials. CuO is one of the most widely used metal oxides because it easily reacts with aluminum. An Al_2O_3−Al(Cu) composite was synthesized in the CuO−Al system at 1173 K by inserting the samples into the molten aluminium [10]. Some Cu_2O phase still existed in the CuO−Al system after being sintered at 950 °C for 30 min [11]. An increase in the sintering time accelerated the formation of submicron in-situ α-Al_2O_3 particles and decreased the quantity of the Al_2Cu intermetallic phase [12]. The Al_2O_3 particle size was observed to increase with increasing temperature and oxidation time [13]. Below 700 °C, amorphous alumina formed, which transformed to crystalline alumina at higher temperatures [14]. The initial reaction temperatures increased with an increase in the heating rate [15]. The eutectic network in the oil-quenched sample was distributed more uniformly and was finer in size than that of the furnace-cooled sample when the sintered sample was cooled down from 1000 °C [16]. These studies indicate that the microstructure of the composite is controlled by the process parameters in the Al−CuO system.

However, the effect of the CuO particle size on the microstructure of the composite has not been extensively

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investigated. A change in the size of low melting component is found to have a limited influence on the synthesis conditions. However, a change in the size of high melting component size influences the combustion temperature and propagation velocity [17]. Therefore, in this study the effects of the CuO particle size on the composite microstructure, specifically on the morphology of in-situ Al_2O_3 particles and the interface bonding between Al_2O_3 particles and Al at different synthesized temperatures, were investigated, which is beneficial to obtaining a strong interface bonding between the in-situ Al_2O_3 particles and Al and to obtaining a high performance Al_2O_{3p}−Al composite.

2 Experimental

The powder mixture containing 80% Al and 20% CuO (mass fraction) were used to prepare the in-situ composite. Two different kinds of CuO (referred to as samples 1 and 2, AR) and one kind of Al powder (< 20 μm, AR) were used as the raw materials. The particle sizes of CuO powders were less than 100 μm and 6 μm for samples 1 and 2, respectively. Each powder mixture was blended and cold-pressed under 400 MPa to form a compact with a diameter of 10 mm.

Differential scanning calorimetry (DSC, Netzsch STA409 PC) measurement was conducted to determine the reaction temperatures between Al and CuO. During the analysis, two samples (*d* 4.0 mm×1.0 mm) obtained from two different (CuO+Al) green compacts (corresponding to two different CuO powders) were used. These two samples were heated in argon atmosphere in the differential scanning calorimeter where the temperature increased from ambient to 900 °C at a heating rate of 20 °C/min.

The reactions of these two different (CuO+Al) green compacts were performed by directly placing them into a tube furnace at 600, 700, 800 and 900 °C and sintered for 1 h in argon atmosphere. To further analyze the effect of the particle size of CuO on the microstructure of products, two other different green compacts were sintered at 1000 °C. All samples were allowed to cool down to room temperature inside the furnace with the power turned off. The main phase analysis of the composite and the compact was identified by X-ray diffraction (XRD, D/MAX−2500/PC, 40 kV, 20 mA) techniques using Cu K_α radiation. The microstructures of all the samples were studied by optical microscopy and scanning electron microscopy (SEM). Elemental chemical analysis was performed by using an energy dispersive spectrometer (EDS) attached to the SEM.

3 Results and discussion

3.1 DSC results

Figure 1 shows the DSC curves of samples 1 and 2. The DSC curve of sample 1 is observed to exhibit three peaks, one endothermic peak at approximately 680 °C due to the melting of Al and two exothermic peaks between 570 °C and 760 °C, which are located on the left and right sides of the endothermic peak and are overlapping the endothermic peak. The DSC curve of sample 2 is similar to that of sample 1 when the temperature is below 760 °C, but the Al melts at a relatively low temperature in sample 1 compared with that in sample 2. However, another independent exothermic peak was observed at 810−870 °C for DSC curve of sample 2. According to Refs. [5,12,14,16,18,19], the peak is explained by Reactions (1)−(4) in Ref. [16]:

$$2Al(s,l)+6CuO(s)\rightarrow Al_2O_3(amorphous)+3Cu_2O(s) \quad (1)$$

$$2Al(s,l)+2Cu_2O(s)\rightarrow Al_2O_3(amorphous)+6Cu(s) \quad (2)$$

$$Al(l)+Cu(s)\rightarrow (Al,Cu)(l) \quad (3)$$

$$Al_2O_3(amorphous)\rightarrow \alpha\text{-}Al_2O_3(s) \quad (4)$$

According to the above analysis, it is reasonable to postulate that the CuO particle size can influence the heat release during the reaction between Al and CuO. Fine CuO particles have larger available reacting surface areas, which leads to the violent reaction. BISWAS et al [20] reported a similar effect of the particle size of Ni on the thermal response of an Al/Ni system. The violent reaction corresponds to a higher heat release rate. This can explain the relatively low melting temperature of Al and the appearance of the third exothermic peak in the DSC curve of sample 2.

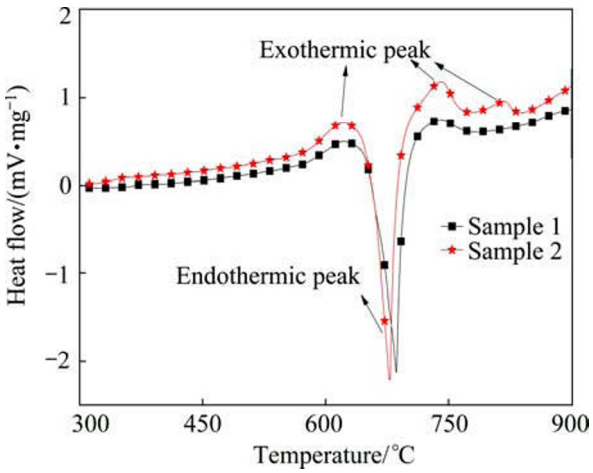

Fig. 1 DSC curves of Al−20%CuO samples obtained under flowing argon at heating rate of 20 °C/min