Science Press

Trans. Nonferrous Met. Soc. China 17(2007) s276−s279

Transactions of Nonferrous Metals Society of China

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Effect of particle size on mechanical properties of SiC_p/5210 Al metal matrix composite

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Received 15 July 2007; accepted 10 September 2007

Abstract: SiC_p/5210 Al metal matrix composites with a high volume fraction (50%) of SiC particles were fabricated by squeeze casting method. The effect of particle size on the mechanical properties of the composites was studied. The results show that with the decreasing of particle size, the bending strength of the composites increases, while the fracture toughness of the composites decreases. The bending strength and fracture toughness of 10 μm SiC_p/5210 Al metal matrix composite are 825 MPa, 10.0 MPa·m$^{1/2}$, and the fracture toughness of 63 μm SiC_p/5210 Al metal matrix composite reaches 12.8 MPa·m$^{1/2}$. The main fracture mechanism changes from particle crack to particle/matrix interface de-bonding with the decreasing of particle size.

Key words: metal matrix composite; SiC_p/5210 composite; squeeze casting; mechanical properties

1 Introduction

In particulate ceramic reinforced metals produced by infiltration, the ceramic particles are packed to volume fractions of around 50% or more. This is significantly above ceramic loadings in corresponding composites produced by stir-casting or powder metallurgy, which have been the main focus of research on particle reinforced metals for structural applications: these generally contain at most 30% ceramic[1−3]. Infiltrated particle reinforced metals are therefore qualitatively different from their lower-volume fraction ceramic counterparts[4−6]: with fully packed particles, there is ceramic particle contact throughout the composite and the ductile matrix cannot deform freely around each ceramic particle. Few data exist on the mechanical properties of such composites[1,3]: with their high ceramic content, they are seldom considered to be materials having promise in structural applications. As a consequence, trends and limits in their properties are little known or unclear. The present investigation is focused on the influence of particle size on the mechanical properties of the metal matrix composite.

2 Experimental

Commercial 5210 aluminum alloy was used as the matrix and particulate SiC as the reinforcement. The SiC particle was purchased from Beijing Huacheng Co., the average particle size was 10, 28, 40 and 63 μm, respectively.

SiC ceramic perform was cold pressed with pressure of 60 MPa, 5% (mass fraction) PVA was used as binder, and then the preform was treated at 1 100 ℃ for 4 h in air. The size of the preform was d 60 mm×8 mm. The composite was fabricated by direct squeeze casting method. The SiC preform was preheated to 590 ℃, the Al alloy was melted at 850 ℃, the infiltration pressure was 65 MPa and the holding time was 5 min.

The open porosity of the preform after oxidation was tested by the water immersion technique. The bending strength and fracture toughness of the composites were conducted on MTS test machine. Three specimens were tested to obtain an average value. The span for three-point bending strength tests was 30 mm. The test-pieces for three-point bending strength tests were 36 mm×4 mm×3 mm, and the cross-head speeds were 0.5 m/min. The fracture toughness of the composite was measured by single notch edged beam method. The span for fracture toughness tests was 25 mm. The test-pieces for fracture toughness tests were 30 mm×2.5 mm×5 mm, and the cross-head speed was 0.05 mm/min. The microstructure and fracture surfaces of the composites were observed by scanning electron microscopy (SEM, JSM-5600LV).

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3 Results and discussion

3.1 Microstructure

The microstructures of the as-cast SiC_p/5210 Al composites with different particle sizes are shown in Fig.1. The particles are tightly packed with a homogeneous spatial distribution in each composite. The distribution of particulate reinforcement is rather uniform. The infiltration of 5210 A1 alloy is quite complete. No significant pores were observed at the SiC_p/Al alloy interfaces.

3.2 Properties of composites

The volume fraction of SiC_p in all the composites was measured to be about 50%, as shown in Fig.2. The particle size has little effect on the volume fraction of SiC in the composite, and the effect of the volume fraction of ceramics particles on the mechanical properties of the metal matrix composite can be ignored.

The bending strength and fracture toughness of the as-cast SiC_p/5210 Al composites containing various particle sizes of reinforcement are compared in Fig.3. The bending strengths increase when the particle sizes are reduced. They are 616, 625, 747 and 825 MPa, respectively, for composites containing reinforcement with particles of 63, 40, 28 and 10 μm. The increase in strength of composites due to smaller reinforcement particle size has been reported by many authors[7−8]. Statistically, larger flaws and more defects are more likely to exist in larger particles and, therefore, will deteriorate the strength of composites when compared with the composites containing smaller particles. Aluminum metal matrix composites are the mixture of two phases: the ductile alloy and the rigid SiC particles. As a result, there exists elastic and plastic incompatibility between the phases especially at the interface regions. This leads to generation of interaction stress among the phase constituents either in elastic and plastic regions. This interaction stress leads to generation of geometrical dislocation along with the statistical dislocation in the matrix. Significantly, higher differences in thermal expansion coefficient between SiC (4.7×10^{-6} K^{-1}) and the virgin alloy (21×10^{-6} K^{-1}) lead to considerably higher amount of thermal residual stress in the matrix. This thermal residual stress leads to further generation of dislocation. The interaction stress and higher dislocation density cause higher elastic modulus, yield strength and fracture stress in composite as compared with the virgin alloy[9−12]. The smaller grain size in the composites containing smaller reinforcement particles can also contribute to the increase in strength. If the volume fraction of SiC_p remains the same, the smaller particle sizes will provide more interface area which serves as the nucleation sites of grain formation. Therefore, smaller grains will be observed in the matrix of composite containing smaller SiC_p. For the same volume fraction, the spacing between particles is reduced when the

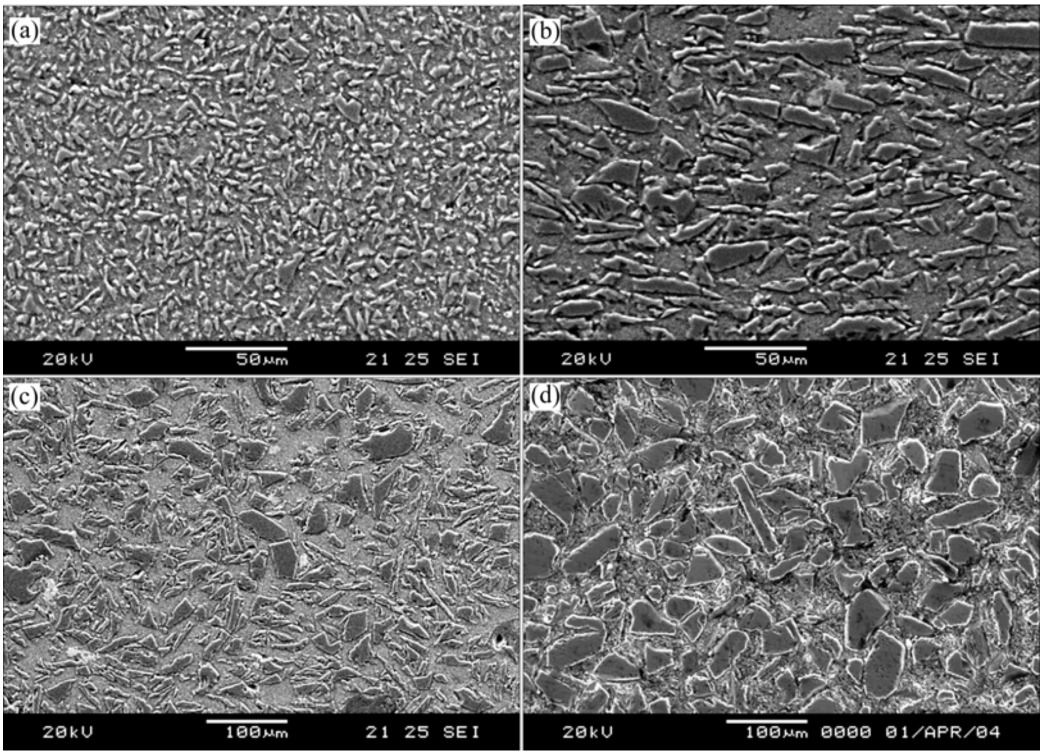

Fig.1 Microstructures of SiC_p/5210 Al composite with different particle sizes: (a) 10 μm; (b) 28 μm; (c) 40 μm; (d) 63 μm

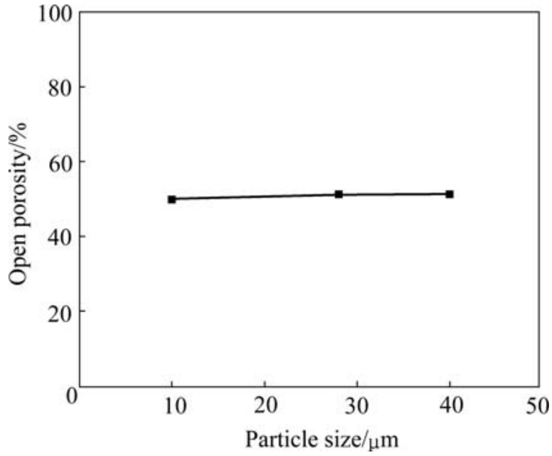

Fig.2 Open porosity of preform with different particle sizes

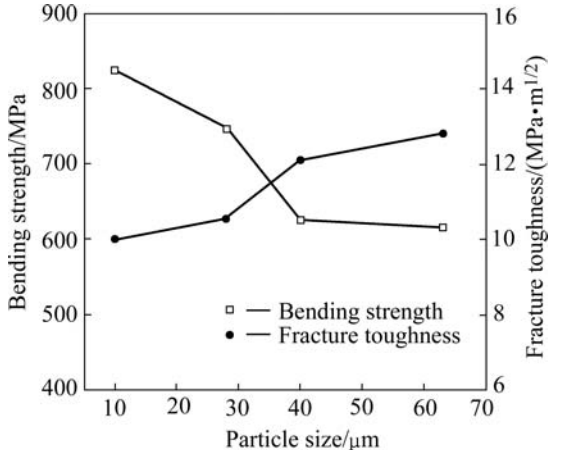

Fig.3 Bending strength and fracture toughness of composite with different particle sizes

particle size is smaller. Therefore, smaller particles will exert more constraint on grain growth during cooling and more restriction on plastic flow during deformation which can also contribute to the increase in strength.

The failure mechanisms of ceramic particle reinforced metal matrix composite were mainly crack of ceramic particles, debonding at the ceramic/metal interface and fracture of the metal matrix. The fracture surfaces of SiC_p/5210 Al composites are shown in Fig.4. With the increase of the particle size, the fracture surface of the composite was smooth. When the particle size was 10 μm, the failure mainly occurred at the ceramic/ matrix interface, and the fraction of ceramic particle cracking was little (Figs.4(a) and (b)). With the increasing of particle size, the fraction of ceramic particle crack increased, while the fraction of interface debonding decreased.

With the introducing of ceramic particles, the fracture toughness of the composite was greatly decreased compared with the virgin alloy. When the particle size increased from 10 to 63 μm, the fracture toughness increased from 10.0 to 12.8 MPa·$m^{1/2}$. According to the definition of fracture toughness, the fracture toughness of composite was proportional to fracture surface energy. Among the main failure mechanisms of particle reinforced metal matrix composite, deformation of metal matrix contributes the most fraction to the surface fracture energy, the next is debonding at the ceramic/matrix interface, and the crack of ceramic particle is the third. In this study, the process

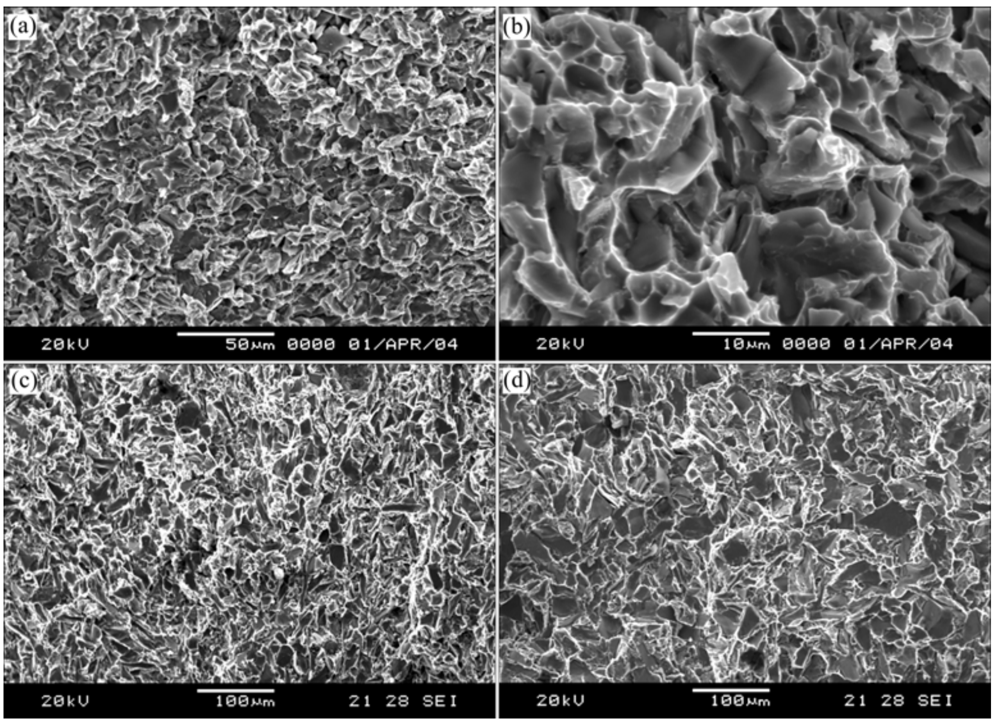

Fig.4 Fracture surfaces of SiC_p/5210 Al composite with different particle sizes: (a), (b) 10 μm; (c) 28 μm; (d) 40 μm

parameter and the volume fraction of SiC_p was the same for composites, so the change of fracture toughness was associated with the change of particle size. On one hand, with the increase of particle size, the spacing between particles is increased, the constraint of the ceramic particles is small, and the matrix can easily deform, which will contribute more to the fracture toughness. On the other hand, with the increasing of the particle size, the fraction of ceramic cracking is increased, the contribution to the toughness is greatly decreased, which leads to the decreasing of the toughness. The fracture toughness of the composite is a couple effect of the two mechanisms, so with the increasing of particle size, the fracture toughness of the composite increases.

4 Conclusions

1) The bending strength of SiC_p/5210 Al composite with a high volume fraction (50%) increases with decreasing particle size. The bending strength of SiC_p/5210 Al composite reaches 825 MPa, when the particle size is 10 μm.

2) The fracture toughness of SiC_p/5210Al composite with a high volume fraction (50%) increases with the increasing of particle size. When the particle size changes from 10 to 63 μm, the fracture toughness of the composite increases from 10.0 to 12.8 $MPa\cdot m^{1/2}$.

3) The main failure mechanism changes from interface debonding to crack of ceramic particle, when the ceramic particle size changes from 10 to 63 μm.

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(Edited by PENG Chao-qun)