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Mechanical behaviors of ZL109/Al_2O_3·SiO_2 particle reinforced composites

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Abstract: The squeeze-casting method is utilized to synthesize ZL109/Al_2O_3·SiO_2 particle reinforced composites with 5%, 10%, 20%, 30% (volume fraction) Al_2O_3·SiO_2 particles, respectively. The microstructures and mechanical behaviors of ZL109/Al_2O_3·SiO_2 particle reinforced composites were studied, and the mechanical properties were tested. The results show that Al_2O_3·SiO_2 particles can be homogeneously distributed on the aluminum matrix in this process. The hardnesses of the composites are higher than that of the Al matrix, and increases with increasing the volume fraction of Al_2O_3·SiO_2 particles. The tensile strengths and elongations of the composites are lower than that of the Al matrix, and decrease with increasing the volume fraction of Al_2O_3·SiO_2 particles. The fracture characteristics of the composites has an obvious change with increasing the volume fraction of Al_2O_3·SiO_2 particles on the fracture section, the toughness dens become smaller and shallower, and the tearing ridges and “rivers” pattern appear. The fracture characteristics of the composites become fragile from ductile with the increase of the volume fraction of Al_2O_3·SiO_2 particles. Elastic moduli of the composites have little change compared with the Al matrix.

Key words: Al-matrix composites; Al_2O_3·SiO_2 particles; squeeze-casting method; mechanical behaviors; fracture mechanism

1 Introduction

The attractive physical and mechanical properties that can be obtained with metal matrix composites(MMCs), such as high specific modulus, strength, and thermal stability have been documented extensively[1−4]. Al-matrix composites have become the new materials prior developed as the result of the attractive physical and mechanical properties, such as low density, high specific strength, superior heat-conductivity and corrosion resistance. In recent years, materials investigators have manufactured some low-cost Al-matrix composites[5−8]. This makes the perspective of the extensive development and utilization of Al-matrix composites more certain.

The study of particulate reinforcement Al matrix MMCs mostly concentrates on using SiC, Al_2O_3 etc as reinforcement materials. But these reinforcement materials mostly have spiculate edges and corners. The condition of bearing stress easily causes stress concentration. So we commonly hope particle reinforcement materials being round[9−12]. ROHATGI et al[13−14] have studied Al/fly ash particulate reinforced composites. Their study has concentrated on investigating structure, properties, physical and chemical reaction during the preparation.

The fly ash particles are a kind of waste powder produced from burning coal of steam power plant. The shape of these fly ash particles is spheroidal and ellipsoidal. Because the basis of fly ash is Al_2O_3 and SiO_2, we also name it Al_2O_3·SiO_2 particles. Some of them possess porous and hollow structures and low density, high modulus. It can be a kind of perfect particle reinforcement[15−16]. The fly ash particles are cheap and easy to obtain. This makes the Al/Al_2O_3·SiO_2 particulate reinforced composites become a kind of cheap Al-matrix composite with very big economical and practical value. In this paper, the mechanical properties of ZL109/Al_2O_3·SiO_2 particle reinforced composites were studied. This is also a kind of useful exploration for new theory and exploiting new materials[13−16].

2 Experimental

The matrix materials used in this work were ZL109 Al alloy. Table 1 lists the chemical compositions of ZL109 Al-alloy. The reinforcement materials particles were pretreated Al_2O_3·SiO_2. Table 2 lists the composition of Al_2O_3·SiO_2 particles.

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Table 1 Chemical compositions of ZL109 (mass fraction, %)

Mg	Si	Cu	Mn	Fe	Zn	Ni	Ti	Others	Al
0.8−1.3	11.0−13.0	0.5−1.5	≤0.35	≤0.9	≤0.35	2.0−3.0	≤0.25	0.05−0.15	Bal.

Table 2 Compositions of fly ash particles (mass fraction, %)

State	Na_2O	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	Fe_2O_3
Before pretreatment	1.04	21.95	70.38	2.43	0.90	0.75	2.75
After pretreatment	0.02	24.31	74.16	0.03	0.37	0.75	0.36

First, sifted out fly ash particles with dimension *d* ≤45 μm from powder fly ash, and selected it as the reinforcements of ZL109/Al_2O_3·SiO_2 particle reinforced composites. Second, the fly ash particles were burned to remove organic substance and carbon particles. Third, the fly ash particles were pickled into 5%HCl to get rid of the harmful elements such as Fe. After the process of pretreatment, the composition of these fly ash particles was the mixed oxide chiefly composed of Al_2O_3 and SiO_2 (Table 2). So we also call them Al_2O_3·SiO_2 particles. The shape of these Al_2O_3·SiO_2 particles is spheroidal and ellipsoidal as shown in Fig.1. Some of them possess porous and hollow structures, low density (1.240 6 g/cm^3) and high modulus.

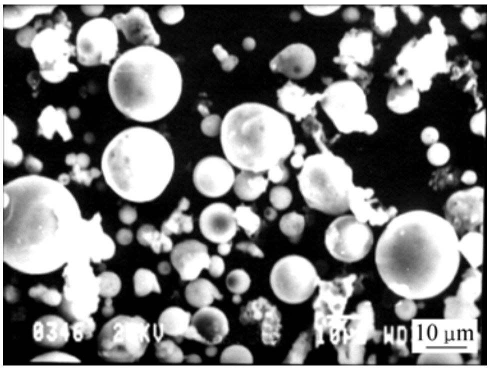

Fig.1 SEM micrograph of Al_2O_3·SiO_2 particles

The squeeze-casting method was utilized to synthesize ZL109/Al_2O_3·SiO_2 particle reinforced composites. The volume fraction of Al_2O_3·SiO_2 particles in the composites is 5%, 10%, 20% and 30% respectively. The ingot was extruded into stick with dimensions of *d* 30 mm×100 mm. The T6 heat treatment was performed for the composites. T6 heat treatment included a solid solution treatment at 515 ℃ for 6 h followed by water quenched. Afterwards, they were artificially aged at 170 ℃ for 14 h to reach the peak-aged condition.

The mechanical experimental were carried on the AG−10TA Electron Omnipotence Tester. The size of samples is shown as Fig.2. Tensile fracture surfaces of the composites were observed on the JXA−840 SEM.

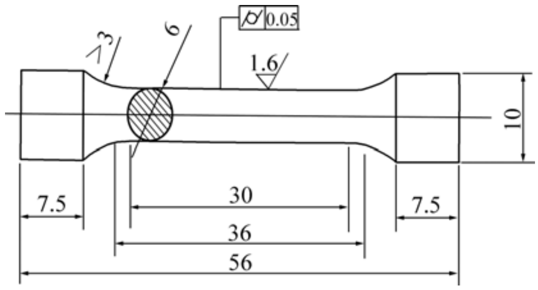

Fig.2 Scheme size of tensile sample (mm)

3 Results and discussion

3.1 Microstructure

The intrinsic properties of materials rest with its inner structure. The analysis for the microstructure of ZL109/Al_2O_3·SiO_2 particle reinforced composites (see Fig.3) shows that Al_2O_3·SiO_2 particles homogeneously distribute on the aluminum matrix in the process. Single Al_2O_3·SiO_2 particle prefers to distribute on the Al dendrite boundaries, the march of three crystals or in the aluminum matrix. Several Al_2O_3·SiO_2 particles prefer to distribute in-groups on the boundaries of the matrix. The segregation of Al_2O_3·SiO_2 particles is more serious with the Al_2O_3·SiO_2 particles content.

3.2 Hardness

The hardness tests of ZL109/Al_2O_3·SiO_2 particle reinforced composites were carried out. The results show that the hardness of the MMCs is higher than that of Al matrix, and increases with increasing volume fraction of the Al_2O_3·SiO_2 particles. In the following solid solution treatment and artificial ageing, the hardness of both ZL109 Al matrix and ZL109/Al_2O_3·SiO_2 particle reinforced composites is increased (see Fig.4).

From the microstructure of the MMCs, we can see that Al_2O_3·SiO_2 particles distribute homogeneously on the aluminum matrix. These hardness particles distributing homogeneously can strengthen the matrix. Within a definite range, the more the particles are dispersed, the more obvious this strengthening effect

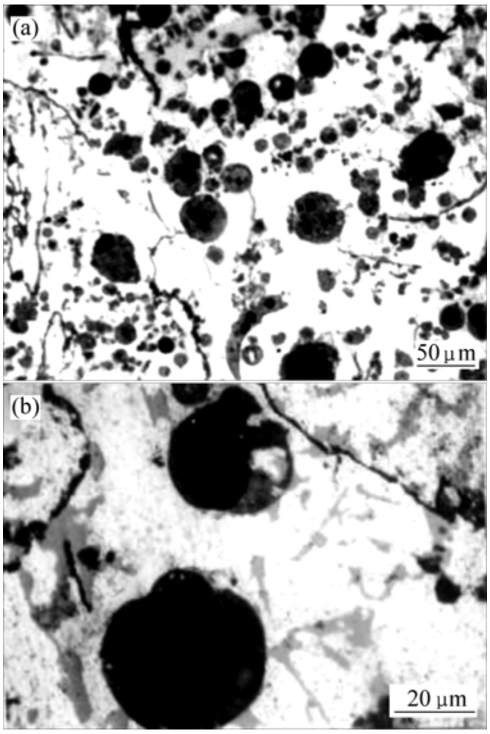

Fig.3 Microstructures of ZL109/$Al_2O_3 \cdot SiO_2$ particle reinforced composites: (a) ZL109/10% $Al_2O_3 \cdot SiO_2$ particle reinforced composites; (b) single $Al_2O_3 \cdot SiO_2$ particles

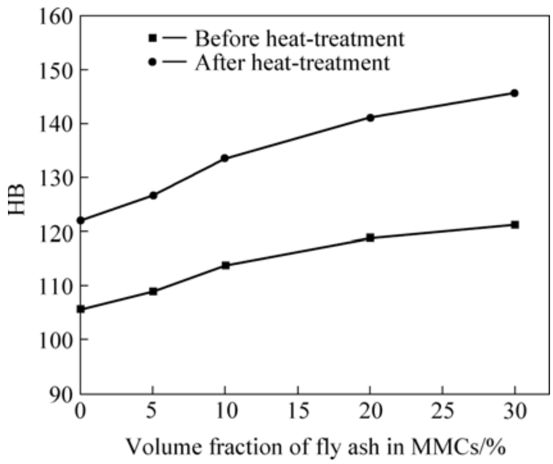

Fig.4 Hardness of Al matrix and composites

will be.

3.3 Mechanical properties

The mechanical property tests of ZL109 $Al_2O_3 \cdot SiO_2$ particle reinforced composites were also carried out. The tensile strength and elongation of the composites are lower than those of the Al matrix (see Figs.5 and 6). And the tensile strength and elongation decrease with increasing volume fraction of $Al_2O_3 \cdot SiO_2$ particles. The elastic modulus is the intrinsic property of the metal materials determined by the metal and its crystal structure. Then the elastic modulus of the composites has no big change compared with that of the Al matrix (see Fig.7).

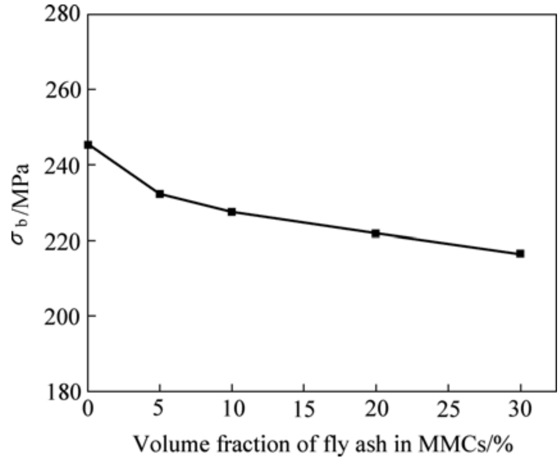

Fig.5 Curve of tensile strength vs content of fly ash for Al matrix and composites

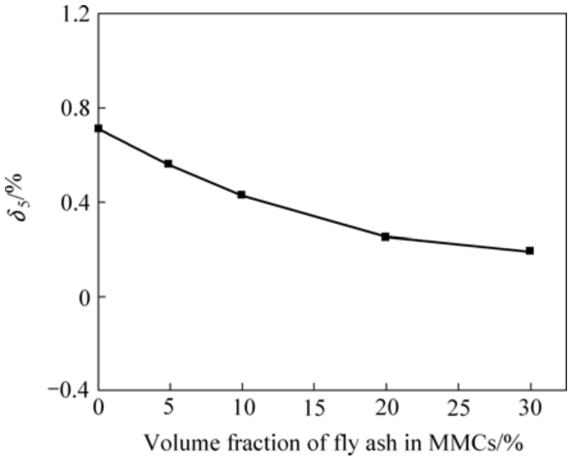

Fig.6 Curve of elongation vs content of fly ash for Al matrix and composites

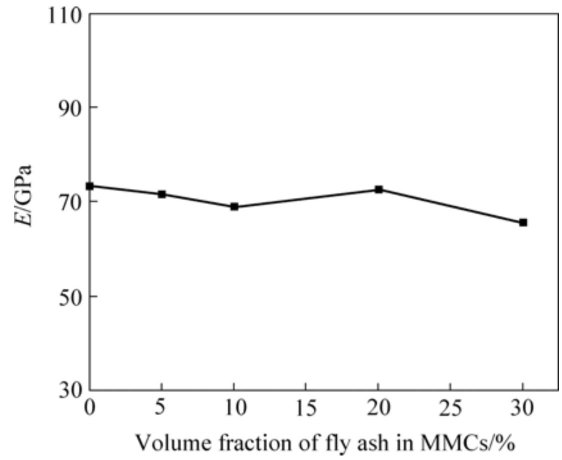

Fig.7 Elastic modulus of Al matrix and composites

With increasing volume fraction of $Al_2O_3 \cdot SiO_2$ particles, the content of air hole increases gradually in the composites. Air hole can reduce effective area

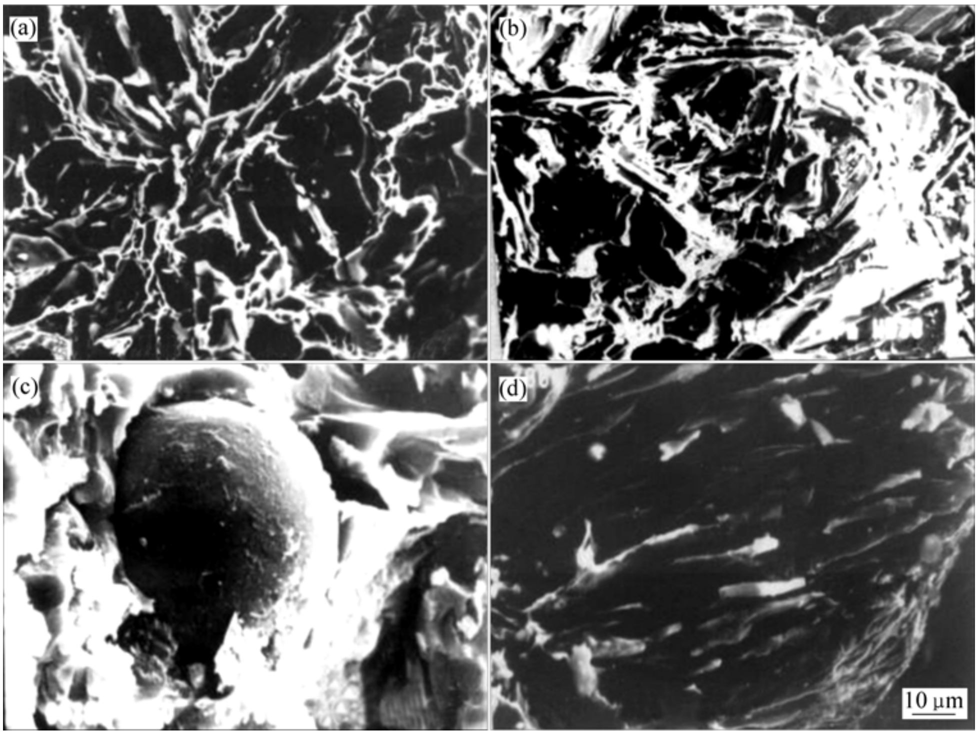

Fig.8 Fractographs of composites: (a) 10% particles; (b) 20% particles; (c) $Al_2O_3{\cdot}SiO_2$ particle; (d) “river” pattern

bearing load of the composites and lead to stress concentration. Thereby it can make the tensile strength and elongation of the composites reduce compared with the Al matrix. Otherwise, $Al_2O_3{\cdot}SiO_2$ particles prefer to distribute in-groups on the boundaries of the matrix, and with increasing volume fraction of $Al_2O_3{\cdot}SiO_2$ particles, this phenomenon become more seriously. It will enhance the extent of stress concentration. From the view of interface reaction, the interface between Al matrix and $Al_2O_3{\cdot}SiO_2$ particles belongs to a kind of weak combining interface. The combining strength of the interface is relatively low. It can make the results that with increasing volume fraction of $Al_2O_3{\cdot}SiO_2$ particles, the weak region in the composites enlarges. So it cause the tensile strength and elongation of the composites reduce with the volume fraction of $Al_2O_3{\cdot}SiO_2$ particles.

3.4 Fractograph

The fracture nature of the composites has an obvious change(see Fig.8(a), (b)) with increasing volume fraction of $Al_2O_3{\cdot}SiO_2$ particles that on the fracture section, the toughness dens are becoming smaller and shallower, the tearing ridge and “river” pattern (see Fig.8(d)) appear in the fracture section. The fracture nature of the composites becomes fragile from ductile with increasing volume fraction of $Al_2O_3{\cdot}SiO_2$ particles. The fracture happens easily near the interface between the $Al_2O_3{\cdot}SiO_2$ particles and Al matrix (see Fig.8(c)).

4 Conclusion

1) $Al_2O_3{\cdot}SiO_2$ particles homogeneously distribute on the aluminum matrix, and prefer to distribute among the Al dendrite boundaries, on the march with three crystals or in the aluminum matrix.

2) The hardness of the composites is higher than that of the Al matrix, and increases with increasing volume fraction of the $Al_2O_3{\cdot}SiO_2$ particles.

3) The tensile strength and elongation of the composites are lower than Al matrix, and decrease with increasing volume fraction of $Al_2O_3{\cdot}SiO_2$ particles. The elastic modulus of the composites has little change compared with that of the Al matrix.

4) The fracture nature of the composites has an obvious change with increasing volume fraction of $Al_2O_3{\cdot}SiO_2$ particles that on the fracture section, the toughness dens become smaller and shallower, and the tearing ridge and “river” pattern appear. The fracture nature of the composites becomes fragile from ductile with increasing volume fraction of $Al_2O_3{\cdot}SiO_2$ particles.

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