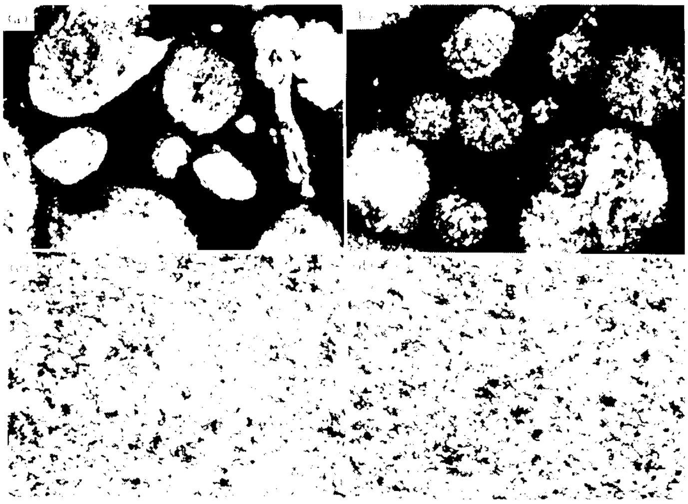

Fig. 4 Microstructure in different conditions (×1500)
(a)— as-received powders (b)—annealed powders (470 ℃, 2h)
(c)—1#; (d)—3#

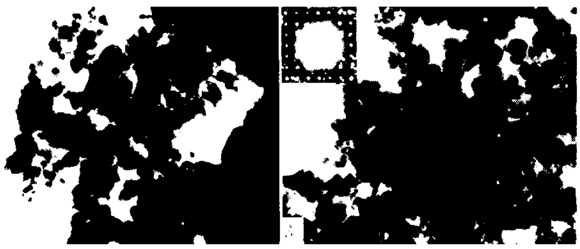

Fig. 5 Microstructure of sample 1# **and** 3# **(TEM)** (×40 000)

just as the present case. In present study, the **extruded sheet is long enough, so the temperature rise in different extrusion stages is** sure **to be different. During the initial stage, little** deformation and friction heat, thus small temperature rise, along with short heated time of the extruded section, lead to little difference

(*To page 146*)

EFFECT OF PARTICULATE SIZE AND CONTENT ON STRENGTH OF SiC_p/2024Al COMPOSITE AND ITS RELATIONSHIP WITH T6-TREATMENT①

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ABSTRACT Tensile tests and fracture surface observations on the SiCp/2024Al composites fabricated by powder metallurgy technigue were carried out. It is indicated that the SiC particulate size and content have a small effect on the strength of the as-extruded composites. After the T6-treatment, the effect increases obviously, and the strength of the composites increases obviously with decreasing SiC particulate size and increasing SiC particulate content. T6-treatment has no obvious effect on the fracture surface of small particulate composites. For the large particulate composites, the fractured SiC particulates on the fracture surfaces increase after T6-treatment. The experimental results were accounted for by the microstructural characteristics and strengthening mechanism of the composites.

Key words composite particulate aluminum T6-treatment strength

1 INTRODUCTION

Silicon carbide particulates are utilized to produce composites with higher strength and elastic modulus compared to the unreinforced matrix alloy. The composites are being increasingly considered for structural applications in the aerospace and automotive industry.

Generally, the modulus, fracture toughness, strength and ductility of the composites are determined by the particulate size and the volume fraction, the matrix flow stress and the interface bonding between particulate and matrix[1-3]. It was indicated that the strength of the composites increases with increasing particulate volume fraction and with decreasing particulate size[4]. It was reported that the particulates in the composite cracked typically for those size above 15—20 μm[3,5]. The present work aims to investigate the effect of the SiC particulate size and the volume fraction on the strength and fracture behavior of the extruded and T6-treated SiC_p/2024Al composites to understand the relationship between property and microstructure.

2 EXPERIMENTAL PROCEDURE

Atomized 2024Al consisted of (%): 4.20Cu, 1.47Mg, 0.56Mn, 0.02Zr, 0.40Si, 0.27Fe) powder with a mean size of 60 μm was employed as the matrix. α- SiC particulate with mean size of 3.5, 10 and 20 μm were used as the reinforcements. The composites containing 15, 20 and 30% (volume fraction) SiC particulates were fabricated by a P/M technique which involved mixing SiC particulate with aluminum alloy powder, hot compaction in vacuum, and then hot extrusion at 450 ℃ at an extrusion ratio of 20:1.

The specimens for tension and hardness tests were machined from extruded rods. A half of the specimens was T6-treated (500 ℃/1 h solutionized, water quenched, and 170 ℃/5 h aged). All the tensile specimens were tested at a strain rate of 8.33×10^{-4} s^{-1}. The tensile fracture surfaces were examined on a scanning

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electron microscope (SEM). The Rockwell hardness (HRB) of the polished specimens was measured. Data were obtained for each specimen by averaging five measurements.

3 RESULTS AND DISCUSSION

Fig. 1 shows the dependence of tensile strength of the composites on the SiC particulate size. The strength of the extruded composites decreases very slowly with increasing SiC particulate size, indicating that the particulate size has a marginal effect on the strength of the extruded composites. After the T6-treatment, the strength of the composites is significantly improved due to the precipitation strengthening, and increases by 100-150 MPa compared to the extruded composites. It can be noted that the effect of the SiC particulate size on the strength of the composites increases obviously after the T6-treatment, and the strength of the T6-treated composites is substantially raised with decreasing the SiC particulate size. The dependence of tensile strength of the extruded and T6-treated composites on SiC particulate volume fraction is shown in Fig. 2. With increasing SiC particulate volume fraction from 0%~15%, the strength of both extruded and T6-treated composites increases slowly in the approximately same way. With increasing SiC particulate volume fraction from 15%~30%, the strength of the extruded composites increases slowly, whereas the strength of the T6-treated composites increases obviously.

For the ceramic particulate reinforced aluminum matrix composites, the strengthening mechanism is mainly attributed to the particulate-dislocation interaction by means of the Orowan bowing mechanism[6], at the same time the particulate load-bearing by means of interfacial shearing also contributes to the increase in the strength of the composites. With decreasing the interparticle spacing of the reinforcing particulates in the composite, the effect of the Orowan strengthening mechanism increases[7], and the increase in the dislocation density of the composite matrix also makes the effect of the Orowan mechanism increase. The effect of the particulate load-bearing increases with the increasing particulate size and the aspect ratio of particulate. For the SiC particulate reinforced aluminum matrix composites, when the composites are rapidly cooled down from elevated temperature , the high density

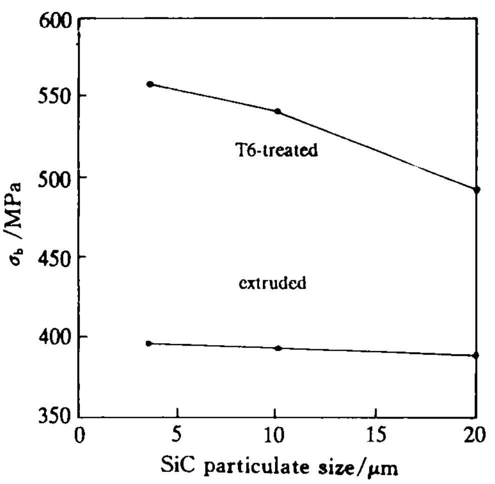

Fig. 1 Dependence of tensile strength on SiC particulate size for composites containing 15 Vol. %

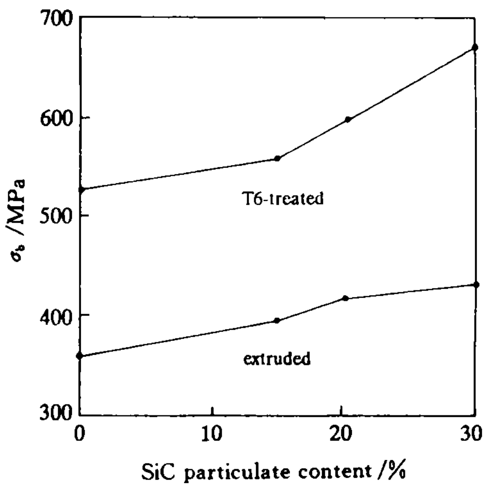

Fig. 2 Dependence of tensile strength on SiC particulate volume fraction for composites containing 3.5 μm SiC particulate

dislocation generates in the aluminum matrix adjacent to SiC particulate due to the great difference in the coefficients of thermal expansion of SiC and Al.

For the same volume fraction of the SiC particulate, the dispersity of the particulate inthe matrix increases significantly with decreasing particulate size from 20 to 3. 5 μm, and the interparticle spacing of the particulate decreases obviously. The high dislocation density generates in the composties after the T6-treatment, and higher dislocation density will generate for the small particulate composite. Therefore, the effect of the Orawn strengthening mechanism in the small particulate composite is larger than that in the large particulate composite, resulting in higher strength of the small particulate composite. With increasing SiC particulate size, the effect of Orawn mechanism is reduced, and the effect of the particulate load-bearing increases. For the composite containing the SiC particulate of 20 μm, the particulate have an aspect ratio of greater than one and are aligned along the extrusion direction (Fig. 3), which increases the effect of the particulate load-bearing. However, the strength of the large particulate composite is obviously lower than that of the small particulate composite due to the low fracture strength of the large SiC particulate in the composite[8]. The dislocation density in the matrix of the extruded composites is obviously lower than that of the T6-treated composite due to the slow cooling rate[9]. Even for the small particulate composite, the effect of the Orawn mechanism is not great due to the low dislocation density in the extruded composite, and the probability of SiC particulate fracture resulted from the particulate load-bearing in the extruded composite with the low matrix strength is lower than that in the T6-treated composite. Therefore, the effect of the SiC particulate size on the strength of the extruded composite is obviously lower than that of the T6-treated composite.

Above analyses are supported by the hardness of the composites (Table 1). For the extruded composites having the low dislocation density, the effect of the Orawn strengthening mechanism is not apparent. The hardness of the composites displays mainly as the resistance of the SiC particulate to the press-in of the steel ball, the large particulate can resist the press-in of the steel ball more effectively compared to the small particulate. Therefore, the hardness of the extruded composites increases slowly with increasing the SiC particulate size. The difference in the hardness between the composites and the unreinforced matrix alloy is 11. 58～13. 97. After the T6-treatment, the hardness of the composite matrix increases obviously due to the precipitation strengthening. The properties of the composite matrix contribute greatly to the increase in the hardness of the composites, and the composite as a whole can resist the press-in of the steel ball effectively, resulting in the obvious improvement in the hardness of the composites. It can be noted that the difference in the hardness between the T6-treated composites and unreinforced matrix alloy is only 7. 01～8. 88, and obviously lower than that between the extruded composites and unreinforced matrix alloy, demonstrating the important role of the matrix of the T6-treated composite in increasing the strength and hardness of the composite. For the T6-treated composite, the effect of the Orawn mechanism in the small particulate com-

Fig. 3 SEM image of composite containing 15% (volume fraction) 20 μm SiC particulate

posite is great due to small interparticle spacing and higher dislocation density. Therefore, the hardness of the T6-treated composites increases slowly with decreasing the SiC particulate size.

Table 1 Rockwell hardness (HRB) of composites and unreinforced matrix alloy

Condition	202Al	SiCp (3.5 μm) /2024Al	SiCp (10 μm) /2024Al	SiCp (20 μm) /2024Al
Extruded	58.14	69.72	69.73	72.11
T6-treated	80.2	89.08	88.37	87.21

For the composites containing the same size particulate of 3.5 μm, though the interparticle spacing of the SiC particulate decreases and the disloaction density in the composites increases with increasing the particulate volume fraction, the effect of the Orowan mechanism in the extruded composite is not great due to the low dislocation density in the matrix of the extruded composite, which results in that the strength of the extruded composite increases slowly with increasing the particulate volume fraction. After the T6-treatment, the disloaction density in the composite matrix is considerably raised, and increases with increasing the particulate volume fraction. So, the effect of the Orawn mechanism in the T6-treated composites increases with increasing the SiC particulate volume fraction, leading to the obvious increase in the strength of the T6-treated composites with increasing the particulate volume fraction.

The SEM image of tensile fracture surfaces of the composites is shown in Fig. 4. The fracture surfaces of the small particulate composites were consisted of the fine dimples, and no fractured SiC particulate was found (Fig. 4 (a-b)), indicating that the main strengthening mechanism for the small particulate composites is Orawn mechanism, and the effect of the particulate load-bearing is small. The fractured SiC particulate appeared on the fracture surfaces with increasing the particulate size (Fig. 4(c-d)), indicating that the effect of the particulate load-bearing mechanism increases with increasing the particulate size. When the SiC particulate size is raised to 20 μm, a great amount of the fractured partculates are exposed on the fracture surfaces (Fig. 4(e-f)), indicating that the particulate load-bearing has become the main strengthening mechansm. It can be noted that there was some difference in the fracture surfaces of the extruded and T6-treated composites. For the small particulate composites, the fracture surfaces of the extruded and T6-treated composites were analogous, the plastic deformation on the fracture surface of the extruded composite was somewhat larger than that of the T6-treated composite. For the large particulate composites, the fractured SiC particulates on the fracture surface of the T6--treated composite were more than that of the extruded composite, which can be accounted for by the obvious increase in flow strength of the matrix of the T6-treated composite. The stress transferred to the SiC particulates by means of interfacial shearing increase obviously due to the increase in flow strength of the matrix, resulting in the increase in probability of the SiC particulate fracture.

4 CONCLUSION

(1) The tensile strength of the SiC particulate composites decreases with increasing particulate size. The SiC particulate size has a marginal effect on the strength of the extruded composite, and the effect increases obviously after the T6-treatment.

(2) The tensile strength of the SiC particulate composites increases with increasing particulate volume fraction. The effect of particulate volume fraction on the strength of the composites increases after the T6-treatment.

(3) The amount of the fractured SiC particulates on the fracture surfaces of the composites increases with increasing particulate size. After the T6-treatment, more SiC particulates were tensile fractured.

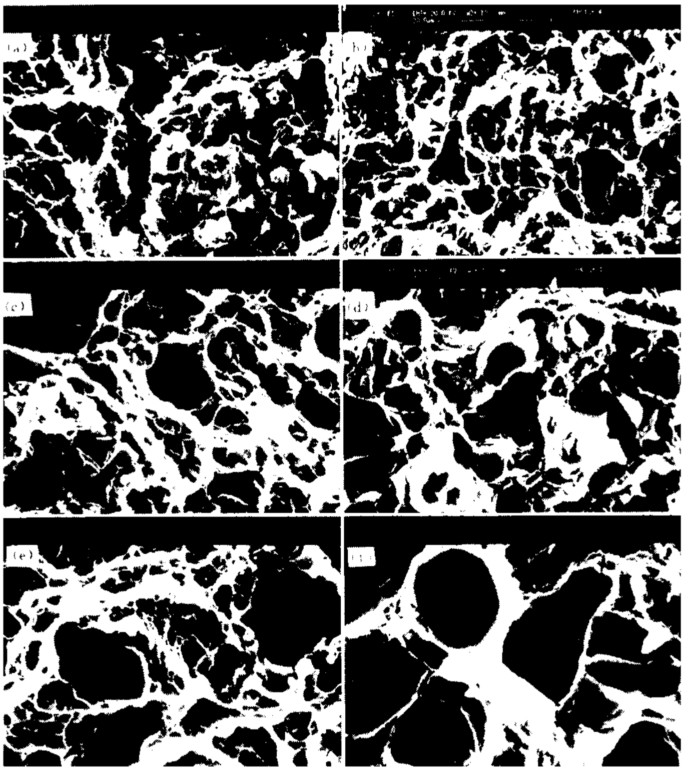

Fig. 4 SEM image of tensile fracture of 15%(volume fraction) SiCp/2024Al composites:
(a), (b) 3.5μm; (c), (d) 10μm; (e), (f) 20μm; (a), (c), (e)—extruded; (b), (d), (f)—T6-treated

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