MICROSTRUCTURES AND MECHANICAL PROPERTIES OF SEMI-SOLID EXTRUDED IN-SITU Al-4.5Cu-0.8Mg/TiC_p COMPOSITES①

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ABSTRACT A novel in-situ approach was used to prepare titanium carbide(TiC) reinforced Al based composites. The reacted, semi-solid extruded samples exhibited a homogeneous distribution of fine (0.1~1 um) TiC particles in a fine-grained Al-4.5Cu-0.8Mg matrix. The microstructures observed by TEM show that no reacted products were found in the interfaces between the matrix and the TiC particles, displaying that the interface cohesion strength is strong. The testing results have also shown that σ_y and σ_b of the composites have been improved greatly, which are about 439 MPa and 549 MPa, increasing by 55% and 29%, respectively, compared with those of unreinforced alloy. The fracture morphologies observed by SEM show that they belong to a micro-ductility fracture, and that existence of coarse Al_3Ti and segregation of TiC particles are also the causes of fracture.

Key words microstructure mechanical property Al/TiC_p fracture semi-solid extrusion

1 INTRODUCTION

Since the past decade, requirement for specific property material using in advanced aerospace field where conventional alloys are not suitable have escalated, attempts to enhance the performance characteristics of monolithic metallic materials by reinforcement with a high strength/high stiffness second phase are therefore required. So far, the research on the composites develops along the direction of low cost and good property so as to be used in commercial industry. However for conventional fabricating processes such as mechanical mixing, it is difficult for composite to arrive at the expectant mechanical properties, because the added particles are large in size and have oxides on the surface, which will inhibit the interface bonding between ceramic phase and matrix[1]. More recently, many researches have been done on a new in-situ process, including SHS(Self-propagating High-temperature Synthesis)[2], XD^{TM}[3,4] and VLS[5,6]. Because the ceramic particles are dispersed in-situ, the interface between ceramic and matrix is free from oxides, and the interfacial contact strength is high, in addition the particles are of submicron and the distribution is homogeneous, the composites are of better mechanical properties. The shaping of the composite is another important research aspects. Although the traditional casting method has advantage of low cost, its coarse grain usually results in low mechanical property. The semi-solid extrusion is a method to shape the metal by extrusion while the metal is still in the semi-solid condition, the fine grain

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obtained improves the mechanical properties greatly[7-9]. In this paper, the in-situ and semi-solid extrusion methods have been combined to produce composites, The relationship between the structure and mechanical properties of the composites and the effect of the percent of the reinforcer (TiC) on the mechanical properties have been studied in details.

2 EXPERIMENTAL PROCEDURE

Titanium powder (99.7%, less than 44 μm) and graphite powder (99.9%, less than 44 μm) were mixed with aluminum powder (99.5%, less than 44 μm) according to 50% (mole fraction) Al+ 50% (mole fraction) (Ti+C), then pressed into d 10 mm × 5 mm preforms with 50% theoretical density. Al-4.5Cu-0.8Mg was melted under air. Upon reaching the appropriate processing temperature (750 ~ 800 ℃), the preforms were put into the molten metal immediately, then the synthesis reaction was carried out in the melt immediately and intensely. After completion of the reaction, the melt was agitated and then shaped by semisolid extrusion. The processing has been described in Refs. [10, 11]. The extrusion temperature was 600 ~ 610 ℃ and the extruded ratio was 5∶1. The micrography analyses of final product were performed by HITACHI S-570 scanning electron microscope (SEM) and PHILPS EM420 transmission electron microscopy (TEM). The tensile specimens were machined to a gauge of 6.3 mm in width, 2.0 mm in length and 20 mm in height at first; and then heat-treated by a solution at 495 ℃ for 2 h, and artificial aging at 160 ℃ for 8 h (T_6) and natural aging (T_4). All samples were tested at room temperature in an Instron testing machine. The strain rate was selected at 0.008 (mm·s^{-1}). The datum is an average of five testing results.

3 RESULTS AND ANALYSES

3.1 Microstructures

Fig. 1 shows the longitudinal and transverse microstructure of the composites with different percent of TiC particles. In the longitudinal microstructure of the composites with 5% TiC, as shown in Fig. 1(a), there is a little tendency of TiC particles to line along the extruded direction; but in the transverse microstructure, as shown in Fig. 1(b), the distribution of TiC is homogeneous. In the microstructure of the composites with 10% ~ 15% TiC, as shown in Figs. 1(c) ~ (f), the TiC particles homogeneously distribute not only in the transverse direction but also in the longitudinal direction.

Fig. 2 shows the TEM microstructure of the composites. It can be found from Fig. 2(a) that the synthesized TiC particles are 0.1~ 1 μm with smooth surface and spherical shape. But the particles in the composites which were not in-situ processed are of sharp angles and the stress is easy to concentrate at the interface between the particles and the matrix during the tensile processing, which reduces the mechanical properties[12].

Fig. 2(b) shows the TEM microstructure of the interface between the matrix and the TiC particles. It has been clearly shown that no reaction products have been found, displaying the interface contact is strong.

3.2 Mechanical properties

The mechanical properties of the composites with different percent of TiC particles at T_4 heat treatment condition have been shown in Fig. 3. The yield strength (σ_y) and the ultimate tensile strength (σ_b) of the composites have been improved greatly over the unreinforced alloy, and increase with TiC percent increasing, e. g. at 15% TiC, the σ_y and σ_b are up to 387 MPa and 476 MPa, increasing 75% and 30%, respectively. As expected, the elongation of the composites are inversely related to the percent of TiC particles, but it is still more than 5% at 15% TiC.

Fig. 4 shows the change of the mechanical properties of the composites with the percent of TiC as T_6 heat treatment condition. The results have shown that the mechanical properties have the same change tendency with that at T_4 condition. At 15% TiC, the σ_y and σ_b are up to 439 MPa and 549 MPa, the elongation is still as high as 4.3%, indicating that the composite has enough ductility. Combined with the microstructure of the composites as shown in Fig. 1, the reason may be due to the smooth surface and spherical shape of TiC particles and homogeneous distribution of TiC, which results in less separate function of TiC to the matrix and great improvement in strengthes, especially in yield strength.

3.3 Fracture analyses

Fig. 5(a) is a typical fracture morphology of Al-4.5Cu-0.8Mg/15-TiC semi-solid extruded composites. It can be found that there are many fine dimples in the fracture surface. No titanium atom has been found in the dimples surface by use of EDA, indicating that the fracture is due to decohesion of the particle and matrix. It is thought that when particles are well bonded to the matrix, as is usually the case, aluminum adheres to them at the fracture surface hiding them from view. These results are quite different from that of large SiC(15~20 μm) reinforced metal composites, which is caused by the fracture of SiC particles[12, 13].

Unfortunately, there exists some large fracture plane and cluster of particles, which has been confirmed by EDA to be Al_3Ti and TiC, respectively. The existence of Al_3Ti is due to the

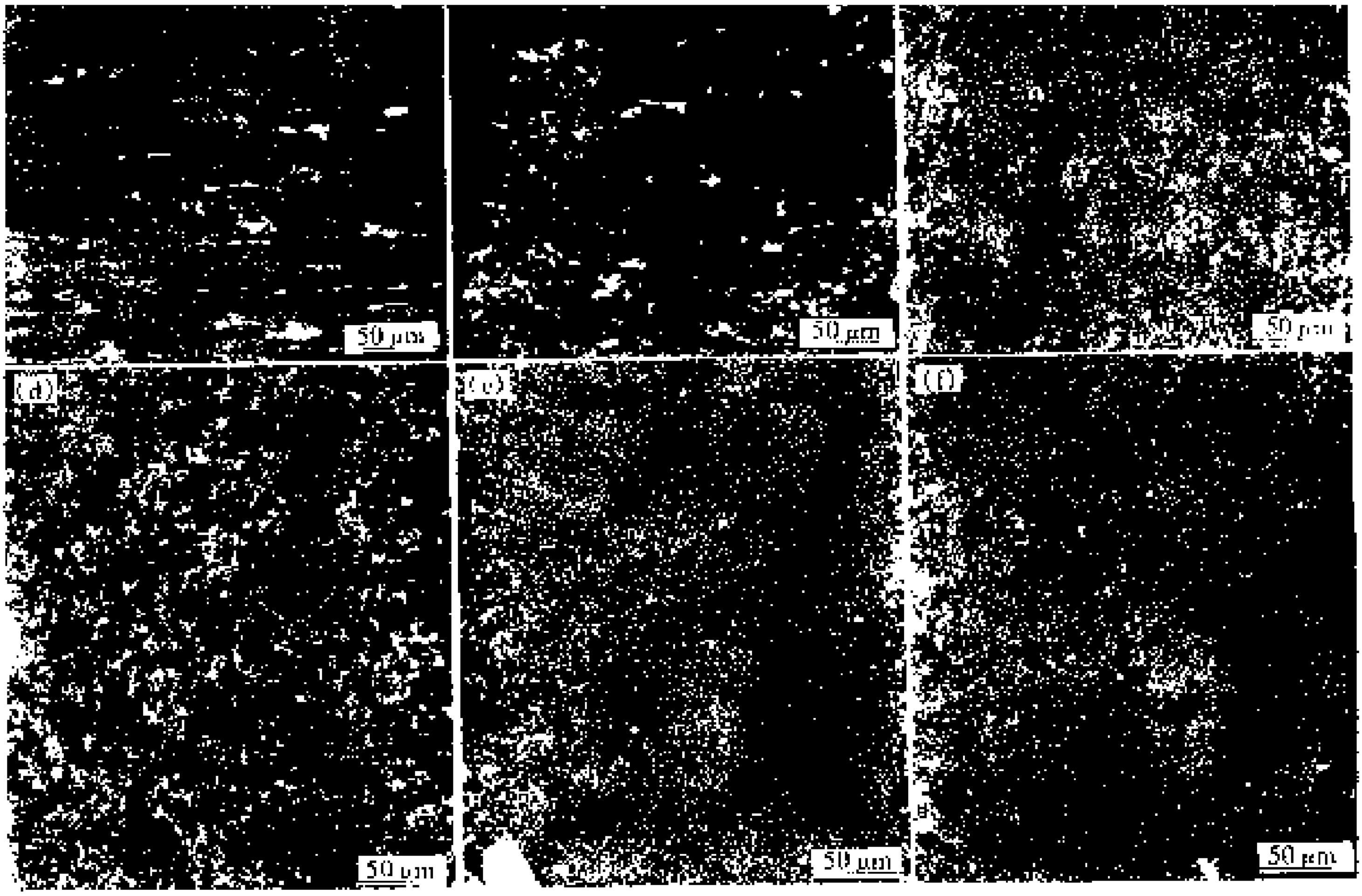

Fig. 1 Microstructures of extruded Al-4.5Cu-0.8Mg/TiC_p composites with different percents of TiC

(a), (c), (e) —Showing microstructures of longitudinal direction; (b), (d), (f) —Showing transverse microstructures; (a), (b) —5% TiC; (c), (d) —10% TiC; (e), (f) —15% TiC

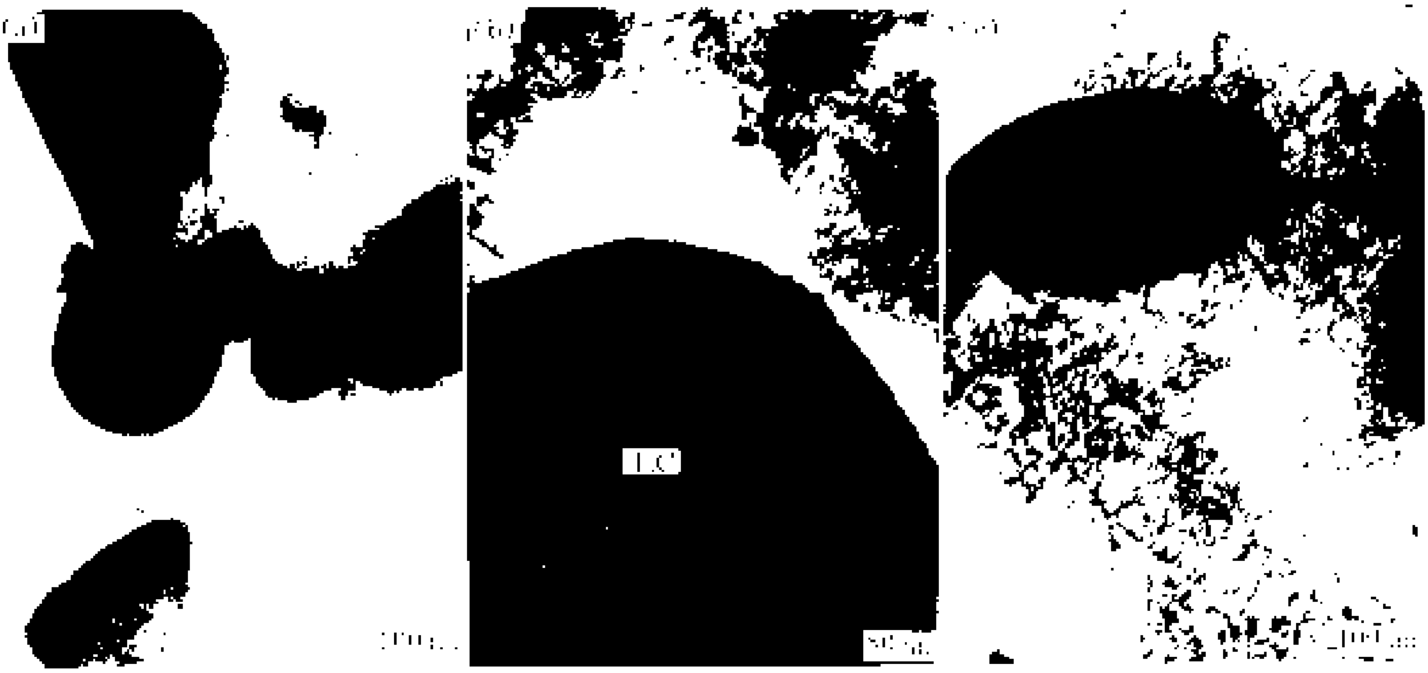

Fig. 2 TEM microstructures of Al-4. 5Cu-0. 8Mg/ TiC_p composites

(a) —Morphology of TiC particles; (b) —Interface between TiC particles and matrix

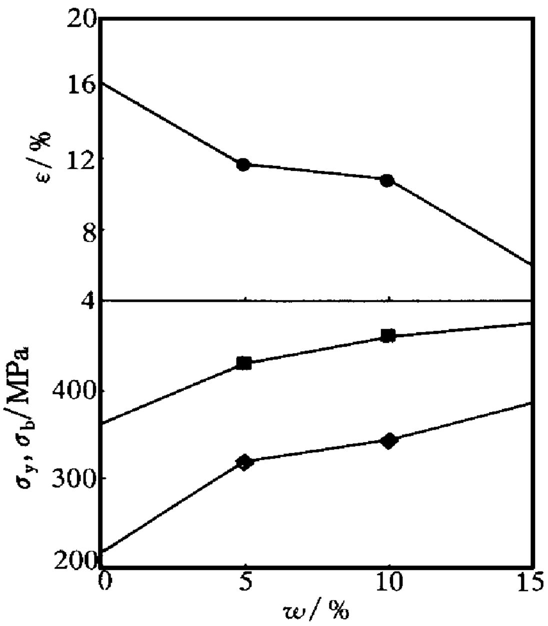

Fig. 3 Mechanical properties of Al-4. 5Cu-0. 8Mg/ $TiC_p(w)$ composites (T_4)

● —ε; ■ —σ_b; ◆ —σ_y

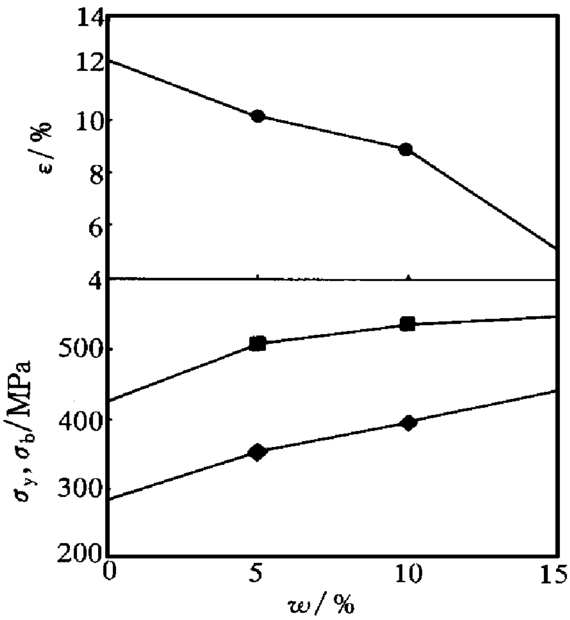

Fig. 4 Mechanical properties and elongation of Al-4. 5Cu-0. 8Mg/ TiC_p composites(T_6)

● —ε; ■ —σ_b; ◆ —σ_y

incomplete reaction between titanium and carbon. It is analyzed that crack initiation in the tensile specimens is preferred at large particle and regions where particles cluster. It is suggested that the reduction or elimination of those Al_3Ti and TiC particles cluster will improve the strength and ductility.

4 CONCLUSIONS

(1) When the mass percent of TiC particles in reinforced matrix materials is more than 5%,

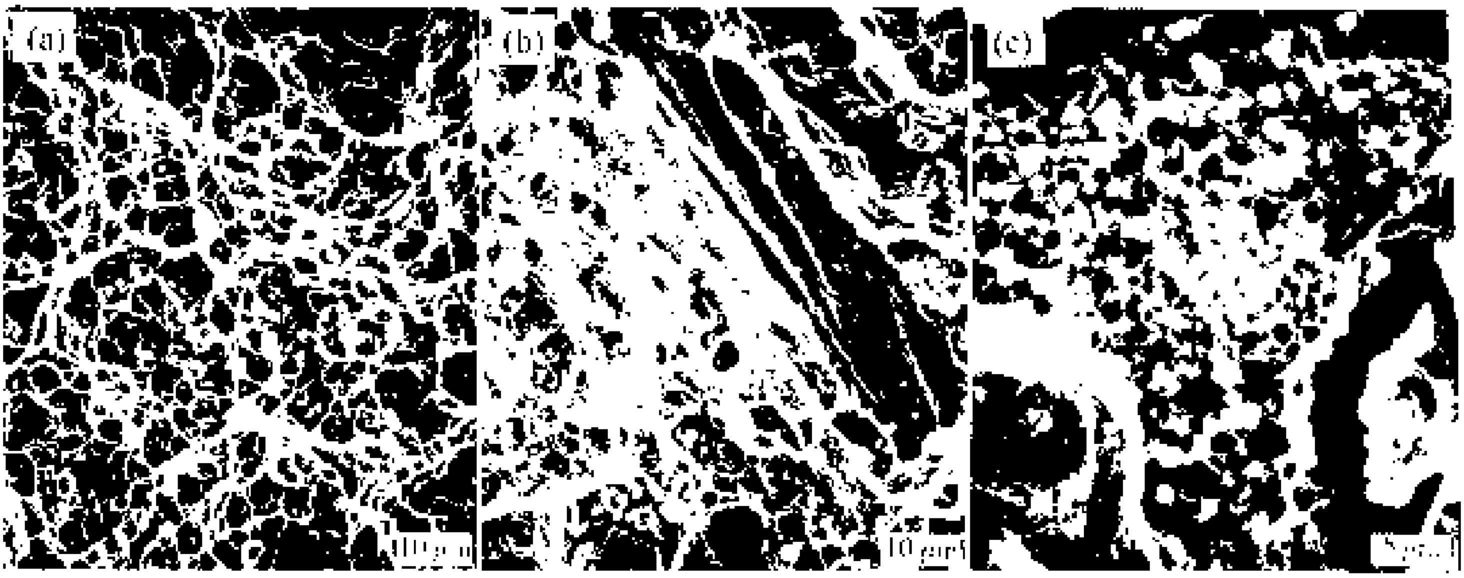

Fig. 5 Fracture morphologies of composites

(a) —Al-4.5Cu-0.8Mg/10%TiC; (b) —Tensile sample including Al_3Ti;
(c) —Tensile sample showing many TiC particles in dimple

the distribution of TiC is homogeneous not only in the transverse microstructure but also in the longitudinal microstructure. When the mass percent of TiC is low as 5%, the TiC particles have tendency to line along the extrusion direction in the longitudinal microstructure, but the distribution in the transverse direction is homogeneous. It is thought that it can be improved by appropriately selecting the processing parameters.

(2) The synthesized TiC particles are fine in size and of smooth surface and spherical shape. No reacted product is found in the interface between TiC particle and matrix material.

(3) The strengthes of the composites have been greatly improved over that of the unreinforced matrix materials. Under T_6 heat treatment condition, the σ_y and σ_u of the composites with 15% TiC are up to 440 MPa and 549 MPa, respectively, and the elongation is still more than 4.3%. The fracture morphology analysis has shown that it belongs to micro-ductility fracture.

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