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Short communication

# The interfacial structure and mechanical properties of $Ti_5Si_3$-coated $SiC_P$/Al2014 composites fabricated by powder metallurgy with hot pressing

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ABSTRACT

The composites reinforced with $Ti_5Si_3$-coated $SiC_P$ showed higher relative densities and mechanical properties than those of uncoated ones. It is mainly due to the translation of $Ti_5Si_3$ coating layer into $Al_3Ti$ interfacial layer during the sintering process, increasing the interfacial bonding strength between α-Al and $SiC_P$.



## 1. Introduction

The high-density $SiC_P$/Al composites fabricated by powder metallurgy have been the goal that researchers have made great efforts to pursue all the time [1–3]. Lower relative density indicates higher quantity of micropores which could act as crack course during deformation, weakening the mechanical properties of composites. Moreover, interfacial debonding resulted from the weak bonding interface also limits its further application and development [4,5].

The decrease in the melting point of Al alloy or the increase in wetting between $SiC_P$ and molten Al alloy could improve the relative density of composites fabricated by powder metallurgy technology with the semi-solid sintering process [6–8]. Addition of Mg or Si element was the most common way to improve the relative density of composites, mainly because the addition of Si or Mg element could decrease the melting point of Al alloy [9–12]. However, mechanical properties of composites would be weakened with the addition of excessive amount of alloy element [10]. Moreover, the electroless Ni, Ni-P and Cu coating layers could not only enhance the relative density of composites but also increase the matrix strength, but these layers could not improve interface strength because the coating layer had reacted with or diffused into Al alloy matrix [13,14]. Therefore, it will be a great progress to develop a new coating layer with improved effects on the wetting and interfacial bonding strength between SiC and Al matrix.

In our previous work, a $Ti_5Si_3$ coating layer had been prepared by salt-bath plating. It had greatly promoted the wetting of SiC by the molten Al and dispersal uniformity of $SiC_P$ in the cast Al2014 composite [15]. However, the effects of the $Ti_5Si_3$ coating layer on the mechanical properties and interfacial structure of the composite by powder metallurgy have not been investigated. In the present work, the $Ti_5Si_3$ layer translated into an $Al_3Ti$ interfacial layer, improving the relative density mechanical properties of composites.

## 2. Experimental materials and methods

### 2.1. Surface modification of $SiC_P$

The $SiC_P$ with an average size of 10 μm, Ti and salt-mixture ($BaCl_2$, NaCl) were sufficiently mixed by ball milling at 50 rpm for 24 h with a powder weight ratio of 10:1. The mixed powder was pressed into compacts and then putted into a high vacuum furnace at 1173 K for 1.5 h. Finally, the coated $SiC_P$ were isolated from the mixture by deionized water.

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### 2.2. Preparation of the $SiC_P$/Al2014 composites

Al2014 powders (93.04Al-4.5Cu-0.65Mn-0.53Fe) and $Ti_5Si_3$-coated $SiC_P$ were ball-mixed at 190 rpm for 7 h with a weight ratio of 10:1. The mixed powders were die-pressed into compacts, then were heated in a vacuum furnace at 853 K for 1 h, and subsequently decreased to 773 K with a pressure of 80 MPa for 30 min. Finally, the composites were extruded at 783 K with an extrusion ratio of 18:1, and the extruded samples were solution-treated at 783 K for 2 h, and then artificially aged at 433 K for 18 h.

### 2.3. Characterization

The density measurements of composites were carried out by the Archimedes method. The phase compositions were identified by X-ray diffraction (XRD, Rigaku D/Max 2500PC, Japan) with Cu-Kα radiation using a scanning speed of $4^{\circ}\,min^{-1}$. The microstructures were detected by optical microscope (OM, Axio. Image. A2m, Carl Zeiss, Germany), scanning electron microscopy (SEM, Evo18, Carl Zeiss, Germany) equipped with an energy dispersive spectrometer (Model Link-ISIS, Oxford, Britain) and high-resolution transmission electron microscopy (HRTEM, JEM-2100F, Japan). The tensile tests referring to the National Standards of People's Republic of China (GB/T228-2002) [16] were carried out under a materials testing system (MTS, MTS810, USA) with the strain rate of $3\times10^{-4}\,s^{-1}$. The TEM specimens were slowly thinned to 30 μm in thickness by 600, 1000 and 2000 grit abrasive papers, followed by punching 3 mm diameter discs. Finally, the discs were ion beam thinned.

## 3. Results and discussion

Fig. 1(a)–1(d) shows the SEM images and corresponding EDS spectrums of uncoated and $Ti_5Si_3$-coated $SiC_P$. Compared with uncoated $SiC_P$ shown in Fig. 1(a), angles of coated $SiC_P$ become smoother. Besides, the corresponding EDS spectrum of coated $SiC_P$ showed that Ti element is observed besides Si and C elements, indicating that the surface composition of $SiC_P$ is changed. Considering the XRD pattern of surface-modified and uncoated $SiC_P$ shown in Fig. 1(e), it could be concluded that a $Ti_5Si_3$ coating layer was generated on the surface of $SiC_P$.

The $SiC_P$ distributed uniformly in 5 vol%–20 vol% $Ti_5Si_3$-coated $SiC_P$/Al2014 composites, as shown in Fig. 2(a)–2(d). The Fig. 2(f) illustrates no apparent porosity or other micro defects. However, lots of micropores around uncoated $SiC_P$ could be clearly observed in Fig. 2(e). Fig. 2(g) shows the X-ray diffraction analysis for the phase compositions of composites. According to the result, no other phases are detected besides α-Al and SiC phases in uncoated $SiC_P$/Al2014 composite, indicating that no interface reaction has occurred. However, $Ti_5Si_3$-coated $SiC_P$ have reacted with Al matrix because new reaction products of $Al_3Ti$ phase instead of $Ti_5Si_3$ phase have been detected, suggesting that the following reaction should take place at 853 K:

$$15Al + Ti_5Si_3 = 5Al_3Ti + 3Si,\ \ \Delta G_1^{\circ} = -46.512\ \text{KJ/mol} \tag{1}$$

Fig. 3 shows the TEM images of the interface between $Ti_5Si_3$-coated $SiC_P$ and α-Al in the composite. It can be clearly seen that the interface is thin, smooth and tightly bonded. An interfacial layer with 50–60 nm in thickness exists between $SiC_P$ and α-Al. The electronic diffraction pattern showed that the product of interface is $Al_3Ti$ phase, which is consistent with the XRD result of composites, indicating a tight chemical bonding between Al matrix and $SiC_P$. As it was reported that no reaction between Al matrix and $SiC_P$ occurred below 893 K [8], the uncoated $SiC_P$ would form a weak interface with Al matrix by physical combination, which would result in lower mechanical properties.

Fig. 4(a)–(c) shows the relative density, ultimate tensile strength and facture strain of composites reinforced with different volume fraction of $Ti_5Si_3$-coated and uncoated $SiC_P$, respectively. The relative densities of composites reinforced with both $Ti_5Si_3$-coated and uncoated $SiC_P$ decreased with the increase in the volume fraction of $SiC_P$, but the $Ti_5Si_3$-coated ones are invariably higher than the uncoated ones with the same content of $SiC_P$. As the solidus and liquidus temperatures of Al2014 alloy are 823 K and 920 K, respectively [17], alloy powders in this work would partly melt in the sintering process. Compared with uncoated $SiC_P$, the wetting of molten Al alloy on the $Ti_5Si_3$-coated SiC was significantly promoted [15], the molten Al could effectively spread on the surface of $Ti_5Si_3$-coated $SiC_P$, thus most micropores and possibility of crack initiations resulted from micropores could be reduced.

According to the results, shown in Fig. 4(c) and (d), ultimate tensile strength of the composites reinforced with both $Ti_5Si_3$-coated and uncoated $SiC_P$ increased first and then decreased with

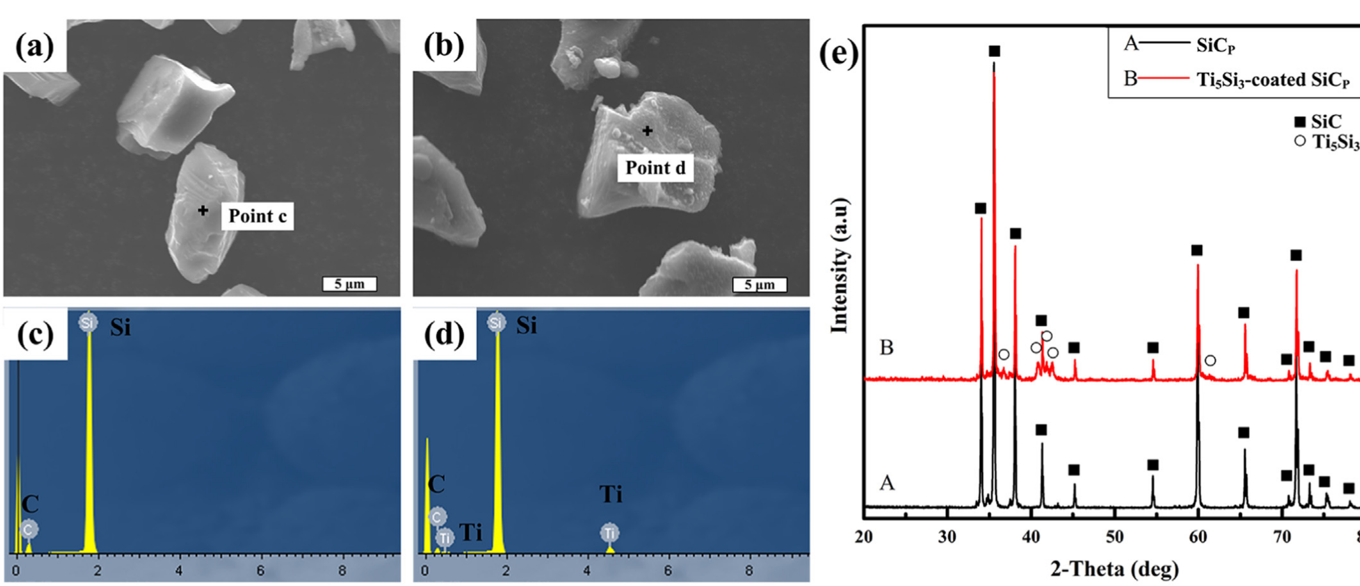


**Fig. 1.** The SEM micrographs of (a) original $SiC_P$ and (b) $Ti_5Si_3$-coated $SiC_P$; (c–d) corresponding EDS analyses; (e) the XRD patterns of $Ti_5Si_3$-coated and uncoated $SiC_P$.