FORMATION MECHANISM OF TiC IN Al/TiC COMPOSITES PREPARED BY DIRECT REACTION SYNTHESIS①

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ABSTRACT The mechanism of reaction synthesis TiC in Al/TiC composites prepared by direct reaction synthesis(DRS) has been investigated in detail using quenching experiment, XRD and SEM. The results have shown that the reaction mechanism is a solution-precipitation mechanism, in which titanium dissolves into melted aluminium and reacts with carbon to form TiC, and then TiC particles precipitates out of the melt. It has also been shown that the processing of reaction synthesis TiC can be divided into three stages: melting of aluminium powder in the preform, formation and resolution of Al_3Ti phase in the melted aluminium and the synthesis of TiC particles. Finally, a mechanism model of DRS to prepare Al/TiC has been established.

Key words reaction composites Al/TiC microstructure mechanism

1 INTRODUCTION

Direct reaction synthesis (DRS) was processed in Harbin Institute of Technology, and has been successfully used to prepare metal matrix composites (MMCs), such as Al/TiC, Al-Cu/TiC, Al-Si/TiC, Al-Cu/TiB_2. In the process, a preform consisting of several element powders was put into a aluminium melt. After complete reaction, a reinforcement has been formed and a composites has been obtained[1-3]. In the past several years, many researchers have been done on the optimizing process parameters, the microstructure and mechanical properties of the composites[4-6]. The mechanical properties such as yield strength, ultimate tensile strength increased markedly over that of matrix, at the same time, the ductility of the composites is still good enough[7,8]. So far, a few researches have been done on the reaction mechanism because of the fast reaction rate. However, it has been understood that the reaction happened in the preform, not in the aluminium melt[8], so it is necessary to study the preform to reveal the mechanism. In this paper, the reaction mechanism of DRS has been studied in detail.

2 EXPERIMENTAL

High purity (99.7%) titanium powder, 99.6% aluminium powder, and 99.3% carbon powder were used in these experiments. The three start powders were 325 mesh in size. The three start powders were mixed according to stoichimetrical molar ratio. The mixed powders were uniaxially pressed into d 10 mm × 5 mm green compacts or preforms, corresponding to a green density of approximate 50% ~ 60% of theoretical. In the experiment, the specimen was heated at a quick rate, at the same time, the temperature of the specimen was recorded by a function recorder and a thermocouple which put in the middle of the specimen. When the temperature of the specimen reached the preset tem-

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perature, the specimen was water quenched immediately. The microstructure of the quenched specimen have been observed by HITACHI S-570 scanning electron microscope (SEM). The phase analysis was conducted in a X-ray diffractometer. The DSC for Al-Ti-C preform and Al-Ti preform were preformed by heating at a rate of 20 ℃/min under an argon atmosphere.

3 RESULTS AND DISCUSSION

DSC analyses results for (a) Al-Ti preform and (b) Al-Ti-C preform are shown in Fig. 1. Significant endothermic or exothermic peaks are observed in Fig. 1(a) and (b). The endothermic peak in Fig. 1(a) and (b) is observed near 673 ℃ corresponding to Al melting point, indicating that the aluminium powder in the preform is melted firstly during the DRS processing. The peaks near 700 ℃ and 750 ℃ in Fig. 1(a) indicate that exothermic reactions between Al and Ti took place. There are three exothermic peaks in Fig. 1(b). The first and second exothermic peaks near 700 ℃ have the same positions and shapes as that in Fig. 1(a), displaying that the same exothermic reactions also took place in Al-Ti-C preform ——the reaction between titanium and aluminium. The third exothermic peak near 871 ℃ indicates that another exothermic reaction took place in Al-Ti-C preform, and it can also be founded that the released energy of the third reaction is more than that of the first and the second. Combined with the last reaction result it can be deduced that the third exothermic reaction corresponds to the synthesis reaction of TiC.

Figs. 2(a) ~ (f) show the XRD results of the specimen quenched at 648 ℃, 670 ℃, 740 ℃, 770 ℃, 1 260 ℃ and 1 500 ℃, respectively. In Fig. 2(a), except the diffraction peaks of aluminium, titanium and carbon, no other diffraction peaks of new phase have been found, indicating that no new phases have been formed or no reaction happened at this temperature. When the temperature reached 670 ℃, in Fig. 2(b), beside the diffraction peaks of aluminium, titanium and carbon, diffraction peaks of Al_3Ti have been found, but no diffraction peaks of TiC has been found, displaying that only the reaction between titanium and aluminium happened at this temperature. When the temperature of the preform was up to 770 ℃, in Fig. 2(d), the diffraction peaks of TiC have also been found besides that of Al_3Ti, and no evidence of residual titanium. It shows that at this temperature while progressing of the reaction between aluminum and titanium, the synthesis reaction of TiC between titanium and carbon also happened. It can also be found from Figs. 2(b) ~ (e) that with the increasing of the temperature, the diffraction strength of TiC increased rapidly and the diffraction strength of Al_3Ti decreased

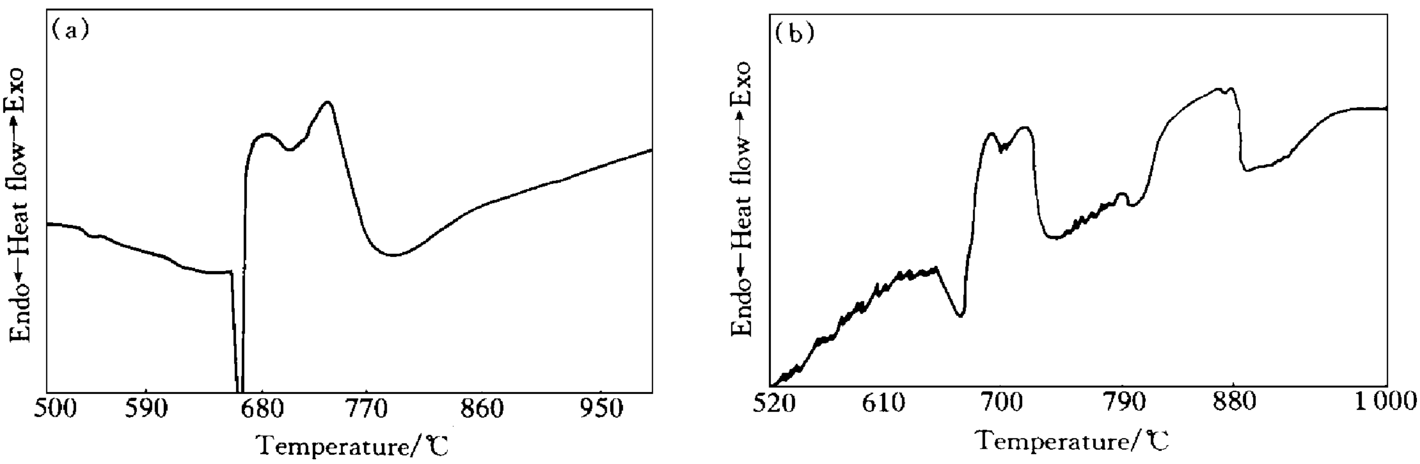

Fig. 1 The DSC results

(a) —Al-Ti preform; (b) —Al-Ti-C preform

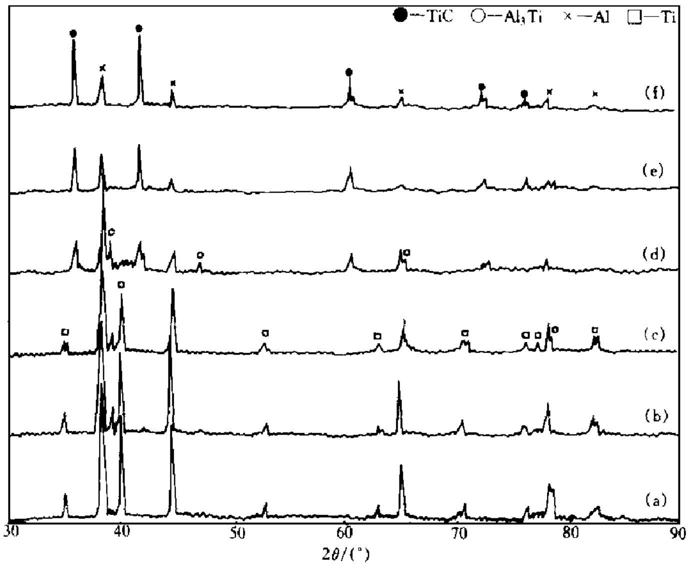

Fig. 2 The XRD patterns of specimen quenched at different temperature

(a) —648 ℃; (b) —670 ℃;
(c) —740 ℃; (d) —770 ℃;
(e) —1 260 ℃; (f) —1 500 ℃

markedly, showing that the content of TiC in the specimem increased and that of Al_3Ti decreased with the increasing of the temperature. At 1 500 ℃, only TiC and aluminium phase have been found in Fig. 2(f).

Fig. 3 shows the microstructure of the specimen quenched at different temperature. In Fig. 3(a), it had been shown that the aluminium powder has been melted, and diffused all over the specimen and surrounded the titanium and carbon powders. But titanium and carbon powders still kept original surface and shape. The EDXA result shows that no new phase has been found. In the specimen quenched at 685 ℃, Fig. 3(b), a fine gray spherical phase is observed beside titanium powder, the EDXA result shows that its composition is 74% Al and 26% Ti, corresponding to Al_3Ti phase, indicating Al_3Ti phase formed near titanium powder. The reason for this may due to that: titanium powder is surrounded by melted aluminium, and titanium must dissolve in the melted aluminium. When the concentration of titanium in aluminium melt is more than 0.15% (peritectic point), a peritectic reaction happens and Al_3Ti phase is formed. Because the Al_3Ti phase is a solid, it precipitates from aluminium melt and diffuse outside. It can also be found from Fig. 3(c) and (d) that the carbon powder is surrounded by a white layer proved to be a titanium rich layer through EDXA result, due to a kind of mechanism, e.g. the absorption function of carbon. When the temperature arrived at 770 ℃, a fine spherical particle proved to be TiC by EDXA which is found around carbon powder in Fig. 3(e). The reason for this may be that at the region around carbon powder, the carbon is around by titanium rich layer, the reaction between titanium atom and carbon atom will happen, and TiC particle will form, and precipitate from the aluminium melt and diffuses outside. With the increasing of temperature, the content of TiC increases markedly and the content of Al_3Ti decreases, At 1 500 ℃, only TiC particles have been formed and no Al_3Ti phase has been found any longer in the specimen in Fig. 3(f).

From above results and analyses, a model of the mechanism of reaction synthesis TiC can be summarized as shown in Fig. 4. Heated by the aluminium melt, the aluminium powders in the specimen are melted, and diffuse all over specimen including the titanium and carbon powders, as shown in Fig. 4(b). At the same time, titanium dissolve into the melted aluminium. When the concentration of the titanium in the melted aluminium is more than the peritectic point (0.15%), a peritectic reaction happens and Al_3Ti phase is formed around titanium powder, as shown in Fig. 4(c). On the other hand, the Al_3Ti phase in the melted aluminium away from titanium powder will decompose into Ti and Al because of the high temperature and the low concentration of Ti in the melted aluminium. The titanium atoms diffuse through melted aluminum, and the carbon powder is surrounded by a Ti rich layer because of its absorption function, as shown in Fig. 4(c).

With the increasing of the temperature, the reaction between titanium atom and carbon atom happens preferably because the formation free energy of TiC is less than that of Al_3Ti, and TiC phase is formed and precipitates from the melt, diffuses outside. Likewise, the Al_3Ti phase must decompose continuously in order to keep the bal-

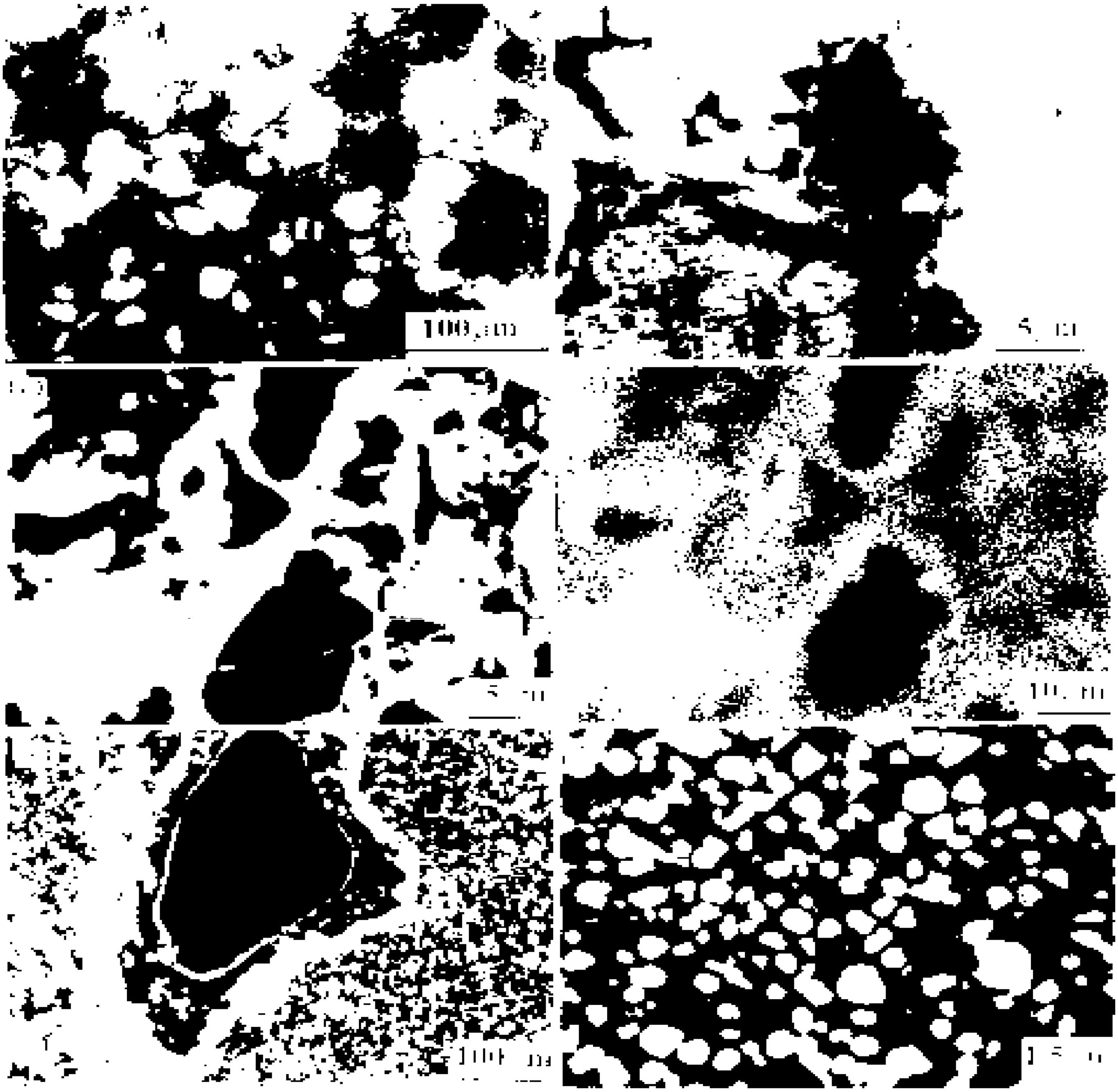

Fig. 3 Microstructures of specimens quenched at different temperatures
(a) —660 ℃; (b) —685 ℃; (c) —(d) 740 ℃; (e) —770 ℃; (f) —1 500 ℃
(Here, Fig. 3(d) is a Ti element image of Fig. 3(c))

ance of the concentration of titanium in the melted aluminum. As the time go on and temperature increase, the content of the synthesized TiC increases and that of Al_3Ti induces, After the reaction, TiC particles are only synthesized in the aluminium melt, as shown in Fig. 4(f). It can be concluded that the mechanism of reaction synthesis TiC is a solution-precipitation mechanism, in which titanium dissolves into melted aluminium and reacts with carbon atom at the surface of carbon to form TiC particles.

4 CONCLUSIONS

Based on the experimental results, it can be concluded that the mechanism of direct reaction synthesis to prepare metal matrix composites is a solution-precipitation mechanism; and the react-

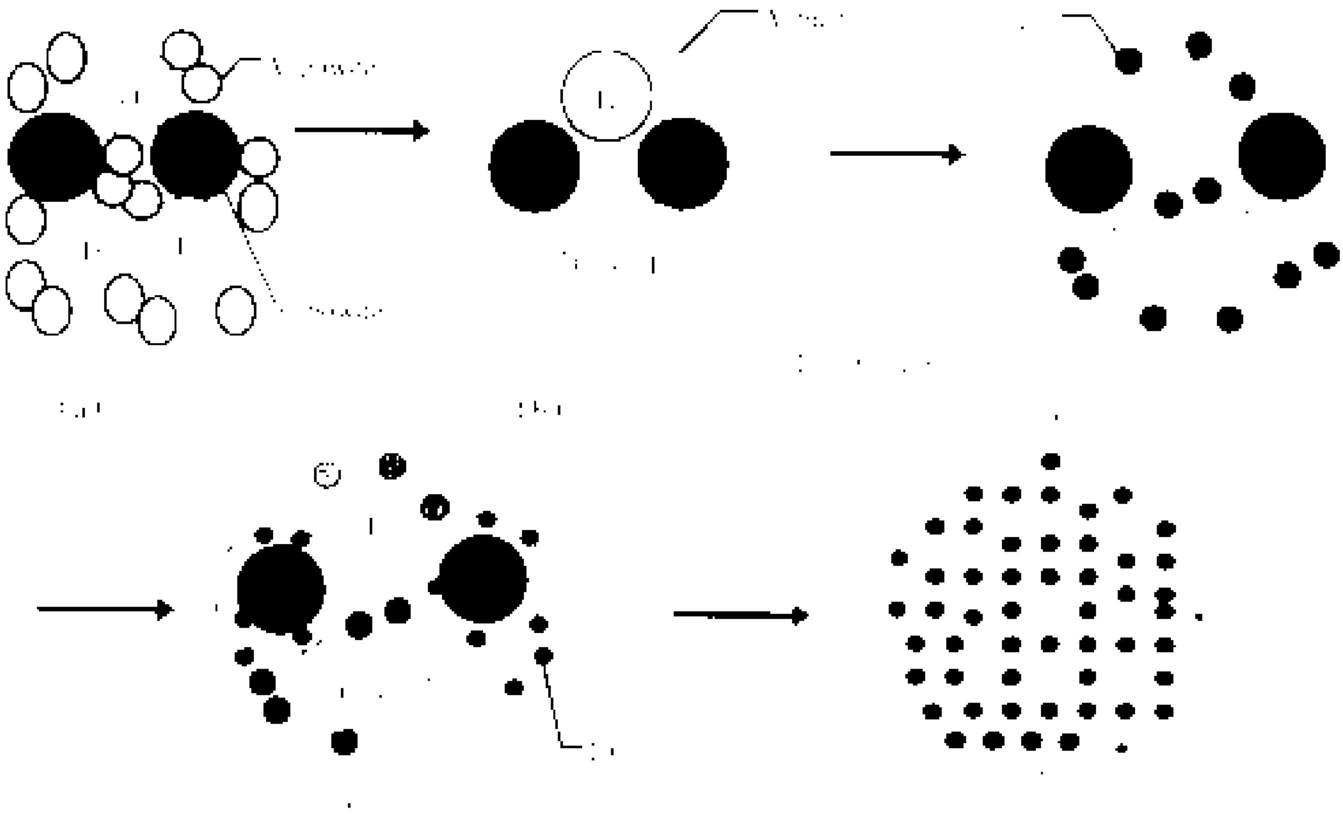

Fig. 4 A schematic mechanism of reaction synthesis TiC in DRS processing

ion process composes three stages: the aluminium powder in the preform is melted first and diffuses all over the preform; then titanium dissolves into the aluminium melt and Al_3Ti phase was formed around titanium powder; a Ti rich layer is formed around carbon powder, reaction between titanium and carbon happens and TiC phase is synthesized in this layer, then it precipitates from melt.

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