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Materials Letters 57 (2003) 2580–2583

MATERIALS LETTERS

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Fabrication of TiC_p/Mg composites by the thermal explosion synthesis reaction in molten magnesium

Q.C. Jiang*, H.Y. Wang, J.G. Wang, Q.F. Guan, C.L. Xu

Department of Materials Science and Engineering, Jilin University at Nanling Campus, No. 142 Renmin Street, Changchun 130025, China

Received 27 August 2002; accepted 24 September 2002

Abstract

Magnesium reinforced by in situ particulates was successfully synthesized utilizing the thermal explosion synthesis reaction of Mg–Al–Ti–C system preforms in molten magnesium. The results show that aluminum content of preforms has a great effect on the reaction and as long as it is chosen adequately, tailored TiC_p/Mg composites can be fabricated.

Keywords: In situ; Particulates; Synthesis; Magnesium; Composites

1. Introduction

Aluminum and magnesium metal matrix composites (MMCs) have been receiving attention in recent years as an attractive choice for automotive and aerospace industries because of their low density and superior specific properties [1–3]. However, the various conventional ex situ processes of fabricating MMCs have some of the inherent problems, such as poor wettability of the reinforcement, reaction of matrix-reinforcement interface, too larger sizes of the reinforcement, and scaling-up of the process for industrial utilization and processing cost [4,5]. To overcome the limitations that are associated with conventionally processed MMCs, new in situ processing techniques have been developed. Composites fabricated by in situ processes generally exhibit the presence of a relatively uniform dispersion of reinforcement that tends to be fine and associated with a clean interface with the metallic matrix. Other advantages of in situ processing include cost effectiveness, improved wettability between reinforcement and matrix, and the elimination of deleterious interface reaction [5,6].

Recently, ceramic particulate reinforced aluminum MMCs fabricated by in situ processes have been extensively studied due to their potentially low fabrication cost [6–10], while less work has been carried out on magnesium MMCs [5,11]. TiC particulate reinforced MMCs are very interesting because TiC is thermodynamically stable and enhances the hardness and lightness of the composites [8]. Unfortunately, research efforts on the processing of TiC particulate reinforced magnesium MMCs were rather limited.

In the present study, the feasibility of the fabrication of in situ formed TiC_p/Mg composites utilizing the thermal explosion synthesis reaction of the preforms consisting of Mg, Al, Ti, and C powders in the molten magnesium was investigated. The aim was to develop

* Corresponding author. Tel./fax: +86-431-5705592.
E-mail address: jiangqc@mail.jlu.edu.cn (Q.C. Jiang).

0167-577X/02/$ - see front matter
doi:10.1016/S0167-577X(02)01314-9

a more economical and simplified casting process for in situ formed TiC_p/Mg composites production, and to fabricate high qualitative TiC_p/Mg composites compared with the various conventional ex situ process.

2. Experimental

The preforms in this study were made of 5 wt.% Mg (98.0% purity, 106 μm), 10–50 wt.% Al (98.0% purity, 29 μm), and Ti (99.5% purity, 15 μm) and C (99.9% purity, 38 μm) at a ratio corresponding to that of stoichiometric TiC. The powders were mixed in a ball mill filled with argon gas for 8 h and then pressed into green preforms with 75 ± 2% theoretical density. The preforms were dried in a vacuum dry oven for 3 h to remove any trace of moisture. About 1 kg of commercial AZ91D magnesium alloy melts were prepared in a graphite crucible in an electric resistance furnace at 750 °C under an SF_6/CO_2 protective atmosphere. A certain amount of the dried preforms were then put into the molten magnesium. After about 10 min, the molten magnesium was stirred with a graphite stirrer for 20 min to assist the dispersion of the generated TiC particulates into the molten magnesium. The composites melts were cast into a copper mold to produce ingots of Φ55 × 100 mm. Microstructure and phase of the composites were investigated using scanning electron microscopy (SEM) (Model JSM-5310, Japan), X-ray diffraction (XRD) (Model D/Max 2500PC Rigaku, Japan), and energy-dispersive spectral (EDS) (Model Link-Isis, Britain).

3. Results and discussion

When the Al content was 20–40 wt.% in preforms, an exothermic reaction in the melts was observed immediately after the preforms were added into the molten magnesium; however, when the Al content was at 10 or 50 wt.%, the thermal explosion synthesis reaction in the melts could not perform, and there was a substantial amount of unreacted carbon floated above the surfaces of the melts during stirring. Fur-

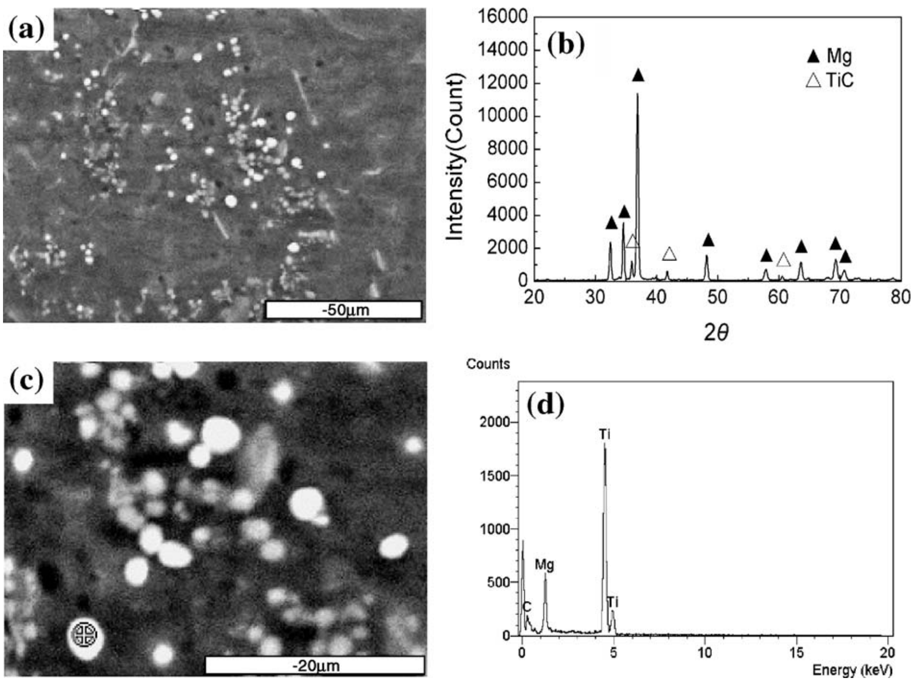

Fig. 1. (a) SEM microstructures of TiC_p(5 wt.%)/AZ91D composite fabricated by the thermal explosion synthesis reaction for preforms with a Ti/C (molar ratio) = 1.0 mixed with 5 wt.% Mg, and 20 wt.% Al. (b) XRD pattern of the composite. (c) Magnification of (a). (d) EDS result of TiC in (c).

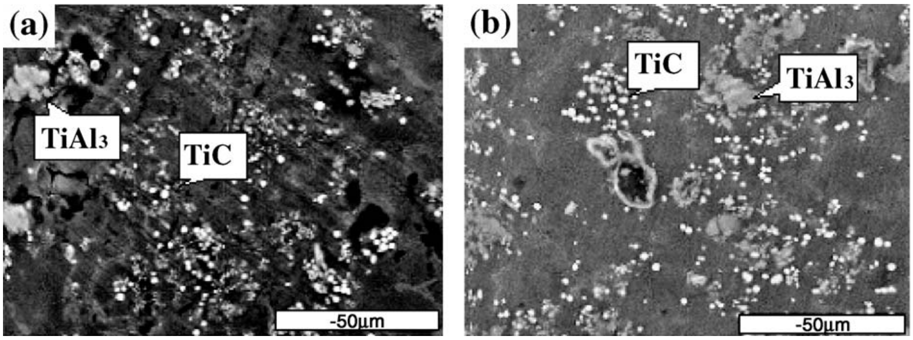

Fig. 2. SEM microstructures of TiC_p(5 wt.%)/AZ91D composites fabricated by the thermal explosion synthesis reaction for preforms with a Ti/C (molar ratio) = 1.0 mixed with 5 wt.% Mg, and (a) 30, (b) 40 wt.% Al.

thermore, the amount of residues was found in the bottom of the melts after stirring.

Fig. 1(a)–(d) showed the SEM microstructures, XRD pattern, and EDS result of TiC_p(5 wt.%)/AZ91D composites fabricated by the thermal explosion synthesis reaction for preforms with a Ti/C (molar ratio) = 1.0 mixed with 5 wt.% Mg and 20 wt.% Al, respectively. As-cast microstructure of the in situ processed composites reveals a relatively uniform distribution of TiC particulates with the spherical sizes in the range from 1 to 2 µm. Because the reinforcement phases were in situ formed in the molten magnesium, the interface between TiC particulates and matrix was free from oxides, and the interfacial contact strength may be high. Obviously, the casting process provides the opportunity of producing near-net-shape components besides the intrinsic advantages of in situ synthesis.

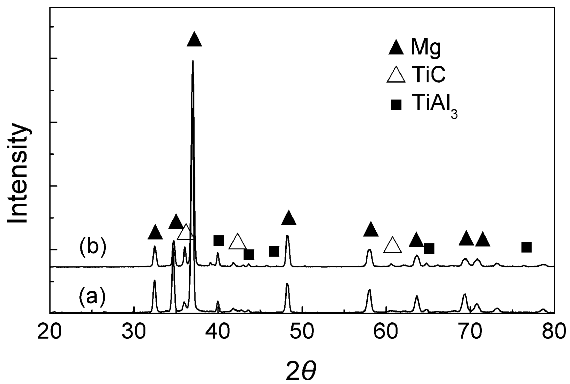

Fig. 3. XRD patterns of TiC_p(5 wt.%)/AZ91D composites fabricated by the thermal explosion synthesis reaction for preforms with a Ti/C (molar ratio) = 1.0 mixed with 5 wt.% Mg, and (a) 30, (b) 40 wt.% Al.

Figs. 2 and 3 showed the SEM microstructures and XRD patterns of TiC_p(5 wt.%)/AZ91D composites fabricated by the thermal explosion synthesis reaction for preforms with a Ti/C (molar ratio) = 1.0 mixed with 5 wt.% Mg, and (a) 30, (b) 40 wt.% Al, respectively. When the Al content was 30 or 40 wt.% in preforms, in addition to fine TiC particulates, a little amount of blocky $TiAl_3$ was also found in the composites. Therefore, it is believed that the aluminum should participate in the thermal explosion synthesis reaction besides serving as a diluent in preforms of the Mg–Al–Ti–C system. However, Mg served mainly as a diluent and assisted the dispersion of the generated TiC particulates into the magnesium matrix.

Therefore, the thermal explosion synthesis reaction may be as follows:

$$3Al + Ti \rightarrow TiAl_3 \quad (1)$$

$$TiAl_3 + C \rightarrow TiC + 3Al \quad (2)$$

$$Ti + C \rightarrow TiC \quad (3)$$

Of course, further work is required to investigate the mechanism of TiC formation in molten magnesium.

The as-cast hardness of unreinforced AZ91D alloy and TiC_p(5 wt.%)/AZ91D composites were listed in

Table 1
As-cast hardness of unreinforced AZ91D alloy and TiC_p(5 wt.%)/AZ91D composites

Material	AZ91D alloy	TiC_p(5 wt.%)/AZ91D composites (Al content in preforms, wt.%)		
		(20)	(30)	(40)
Hardness (HB)	60	78	80	83

Table 1. The hardness of TiC_p(5 wt.%)/AZ91D composites is higher than that of AZ91D alloy as expected.

Hardness of composites was increased with the Al content increasing in preforms, as shown in Table 1. It may be the main reason that Al content increase in preforms resulted in that of the increase in composites.

4. Conclusions

The present study shows that in situ formed TiC/Mg composites can be fabricated utilizing the thermal explosion reaction of the preforms consisting of Mg, Al, Ti, and C powders in the molten magnesium. As long as an adequate Al content is chosen, tailored TiC_p/Mg composites can be made successfully. It is believed that the approach is amenable to large-scale production.

Acknowledgements

This work was supported by Natural Science Foundation of China (No. 50171029) and Nanoscience Foundation of Jilin University.

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