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Fabrication of TiC_p/Mg composites by powder metallurgy

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Increasing demands of light metal materials for aerospace and automobile applications have led to a continuous development of Mg-based metal matrix composites (MMCs) since they have a high strength-to-weight ratio, high specific stiffness, and high wear resistance at both room and elevated temperature, good elastic modulus, and creep as well as high damping capacity [1, 2]. The methods of fabricating Mg-based MMCs include stir casting, spray forming, powder metallurgy (P/M), squeeze cast, infiltration, and self-propagating high-temperature synthesis (SHS) [3, 4]. In P/M process, Mg-based MMCs is fabricated from powders without passing through a fully melting state without or with less excessive reactions between the matrix and reinforcement. Therefore the P/M technology provides a number of advantages for making the composites. It requires the low manufacturing temperature and can attain a more uniform distribution of particulates in the metal matrix, most of which is that P/M process can acquire materials with a large volume fraction of ceramic reinforcement in comparison with the conventional stir-casting route [5, 6].

Mg-based MMCs with the addition of noncontinuous reinforcements such as Al_2O_3 short fiber [7], nano-Al_2O_3 particulate [8, 9], SiC [4–6, 10, 11], or TiC [3, 12–14] particulate have been extensively studied by a number of researchers, specially in Mg-based MMCs reinforced with the TiC particulates due to high hardness and elastic modulus, low density, good wetting with magnesium, and low chemical reactivity of TiC [3, 13, 15–17]. The TiC_p (TiB_{2p})/AZ91 composites have been produced by author and coworkers using a stir-casting process [3, 12–14]. However, in the process, the stir casing has been used to prepare the composites with the volume fractions less than 10% TiC particulates under SF_6/CO_2 protective atmosphere and some agglomeration of TiC particulates exist in the magnesium alloy matrix, while it is too difficult to produce the composites with the volume fractions more than 10% TiC particulates. These make the process tedious, so it cannot be easily adaptable in conventional magnesium foundries. Hence, effort has been made to develop an affordable, easily adaptable, and economical process.

In the past decade, many of the studies have been focused on SiC_P/AZ91 [5, 6] and TiB_{2p} (B_4C_p)/Mg [18, 19] composites using P/M process while little work has been carried out on TiC_p/Mg composites by P/M process. The aim of this study is to investigate the feasibility of the fabrication of TiC particulate reinforced magnesium MMCs by P/M process. The microstructure, hardness, and wear resistance of the composites are also discussed.

The powder mixtures in this work were made from commercial powders of TiC (>99.0% purity) and Mg (>98.0% purity) with average particulate sizes less than 5 and 106 μm, respectively. Powder mixtures with designed compositions of 10, 15, 20, and 25 vol.% TiC were mixed by ball milling for 6 hr, and were cold pressed uniaxially into cylindrical preforms (57 mm diameter and 50 mm height) at pressures of ranging from 200 to 250 MPa. The green preforms with about 80 ± 3% theoretical density were heated to 550 °C in a vacuum electric resistance furnace of 3 kW and then argon gas was put into the furnace. The green preforms continued to be heated to 620 °C in an argon protective atmosphere, kept for 1 hr at the temperature. Subsequently, the heated preforms were pressed at a pressure of 5 MPa for 10 min, and cooled down to below 300 °C in the furnace to fabricate magnesium MMCs reinforced with TiC particulates.

The sliding abrasive wear rates of as-cast Mg ingot and TiC_p/Mg composites under 5 and 35 N loads were tested using a pin-on-disc apparatus. Both as-cast Mg ingot and the composite were used as pin materials with 6 mm diameter and 12 mm height, and 1000 grit SiC abrasive papers (corresponding to 8 μm abrasive particulates) were used as the counterface. After each test, the pins were carefully cleaned with alcohol and weighed using a photoelectric balance with an accuracy of 0.1 mg to determine the weight loss. The weight loss was converted to volume loss using the actual density.

The microstructure and phase analyses of magnesium MMCs were investigated with a scanning electron microscopy (SEM) (Model JSM-5310, Japan) equipped

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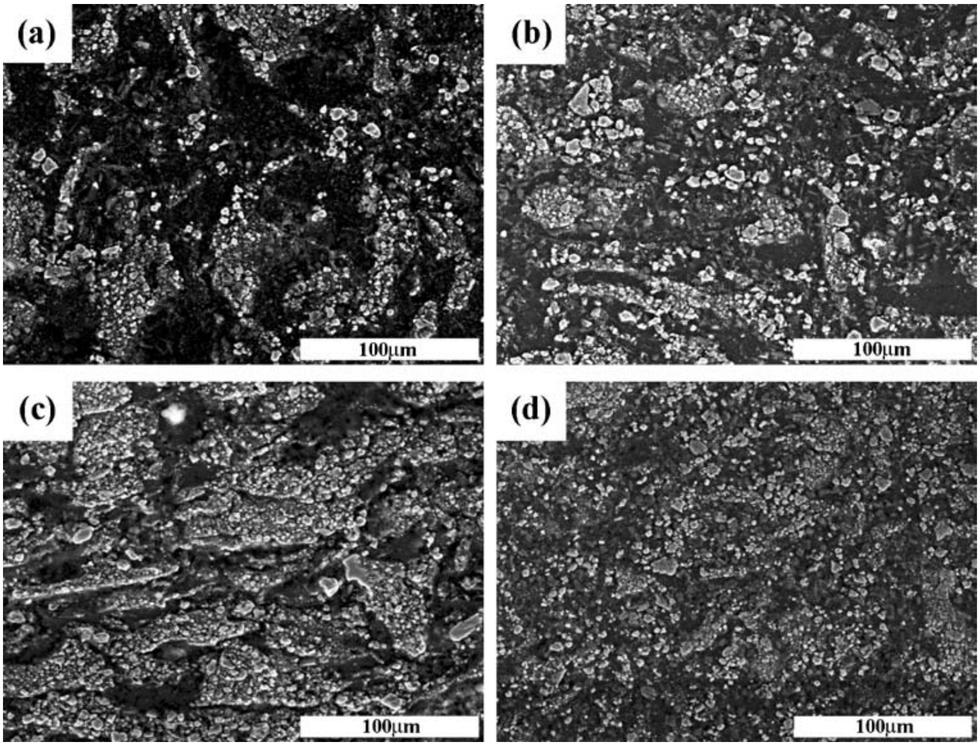

Figure 1 Typical microstructures of (a) 10, (b) 15, (c) 20, and (d) 25 vol.% TiC_p/Mg composites fabricated by P/M process.

with energy-dispersive spectrum (EDS) (Model Link-Isis, Britain) and X-ray diffraction (XRD) (Model D/Max 2500PC Rigaku, Japan), respectively.

Figs 1 and 2 display the SEM micrographs and XRD patterns of the 10, 15, 20, and 25 vol.% TiC particulate reinforced magnesium MMCs fabricated by P/M, respectively. According to the XRD patterns, it can be seen that, apart from the two predominant phases of Mg and TiC in the magnesium MMCs, there is a little MgO phase formed by the reaction between Mg and O remaining in the green preforms, which agrees with our previous work [19].

Magnesium MMCs reinforced with 10, 15, 20, and 25 vol.% TiC particulates, corresponding to 24, 34, 42, and 49 wt.% TiC particulates, were fabricated successfully, and their microstructures are shown in Figs 1a–d, respectively. It can be seen that the relatively homogeneous distribution of TiC particulates is throughout the magnesium matrix at the 25 vol.% level, while some agglomeration of TiC particulates are observed at the lower volume fractions (10, 15, and 20 vol.%). The agglomeration of TiC particulates may be caused by the large difference in TiC particulates and magnesium powder weight in the green preforms. According to literatures [20, 21], the inhomogeneous distribution may also be attributed to the great difference in the sizes of the raw Mg and TiC powders. Furthermore, studies of microstructure characterization also reveal that the minimal microporosity could be detected in all composites in spite of the absence of macro-pores.

Table I lists hardness values and volumetric wear rates of the magnesium MMCs reinforced with 10, 15, 20, and 25 vol.% TiC particulates, and as-cast Mg ingot, respectively. It is clear that the hardness of TiC_p/Mg composites is higher than that of as-cast magnesium ingot and hardness values of the composites also increase with the

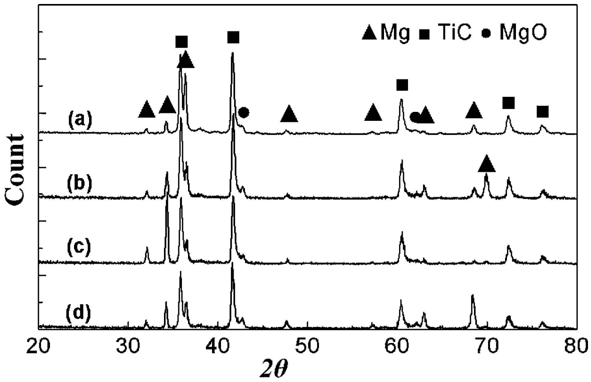

Figure 2 XRD patterns of (a) 10, (b) 15, (c) 20, and (d) 25 vol.% TiC_p/Mg composites fabricated by P/M process.

TABLE I Hardness values and wear rates of as-cast Mg ingot, and 10, 15, 20, and 25 vol.%TiC_p/Mg composites fabricated by P/M process

	Wear rate (10^{-10} m^3/m)		
Material	5 N	35 N	Hardness (HB)
Magnesium ingot	8.7893	18.0175	32.7
10 vol.% TiC/Mg	3.2501	9.7955	63.2
15 vol.% TiC/Mg	2.5074	9.3925	70.6
20 vol.% TiC/Mg	2.3703	9.3076	87.6
25 vol.% TiC/Mg	1.6639	3.3113	108.2

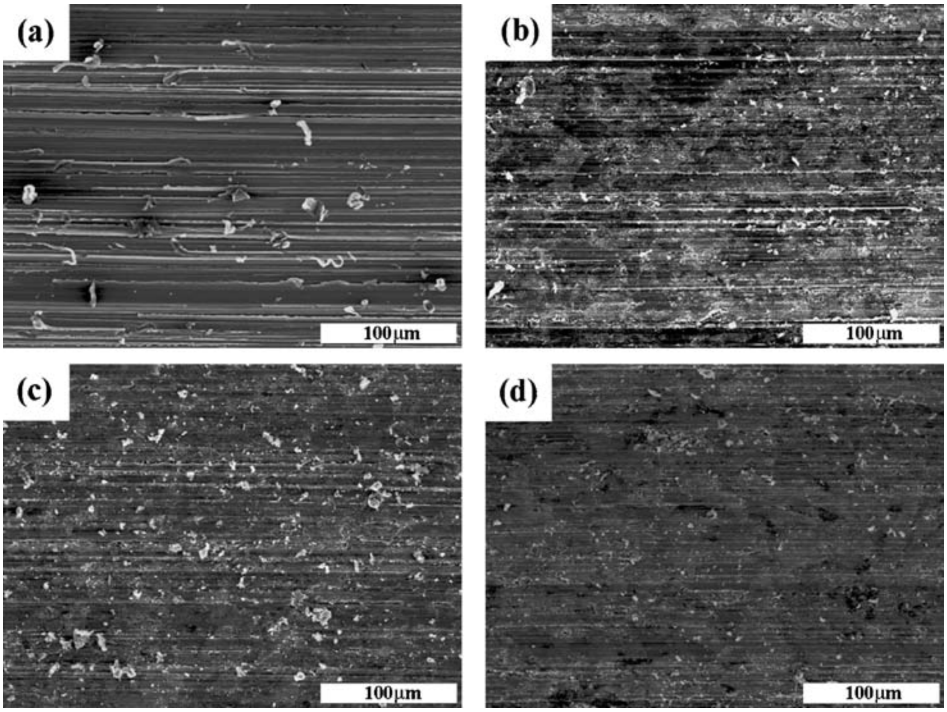

Figure 3 Worn surfaces of (a) as-cast Mg ingot, and (b) 10, (c) 15, and (d) 25 vol.% TiC_p/Mg composites fabricated by P/M process under 35 N load.

increasing of the volume fractions of the particulates. It should be mentioned that the hardness value of TiC_p/Mg composites reinforced with 25 vol.% TiC particulates is 108.2. The reason of the increasing of the composites hardness may be that the harder TiC particulates restrict the localized matrix deformation during indentation.

It can be seen from Table I that the volumetric wear rates of TiC_p/Mg composites all are obviously less than that of as-cast magnesium ingot as expected, i.e., the wear resistance of the composites is obviously better than that of as-cast magnesium ingot. The wear resistance of the composites also increases with the increasing of volume fractions of the particulates. Furthermore, the volumetric wear rate of 25 vol.% TiC/Mg composites has a sharp reduction compared with that of 10 vol.% TiC/Mg composites. Those may be explained that the presence of harder TiC particulates leads to a significant improvement in the wear resistance.

The SEM micrographs of worn surfaces of the as-cast Mg ingot and TiC_p/Mg composites reinforced with 10, 15, and 25 vol.% TiC particulates under 35 N load are illustrated in Fig. 3a–d, respectively. The well-defined wear grooves on the surface of TiC_p/Mg composites reinforced with 10, 15, and 25 vol.% TiC particulates and as-cast Mg ingot are visible from Fig. 3, indicating that the abrasive wear behavior of Mg ingot and TiC_p/Mg composites is a microploughing and microcutting abrasion. Qualitatively, an inspection of their worn surfaces reveals that the quantity, width, and depth of the grooves on the worn surface of the composites all are less than those of Mg ingot and decrease with the increasing of the volume fractions of the particulates. The results show that the TiC particulates in Mg matrix produce an excellent effect on resisting the abrasive particulate to enter into the matrix, bearing loads, strengthening matrix, and preventing deformation.

Magnesium metal matrix composites reinforced with 10, 15, 20, and 25 vol.% TiC particulates are fabricated successfully by P/M process. Microstructure examination shows that the relatively homogeneous distribution of TiC particulates is throughout the magnesium matrix at the 25 vol.% level, while some agglomeration of TiC particulates are observed at the lower volume fractions (10, 15, and 20 vol.%). By incorporating TiC particulates into the matrix material, the hardness and wear resistance of the composites are greatly improved as compared with those of as-cast magnesium ingot. The abrasive wear behavior of Mg ingot and TiC_p/Mg composites is a microploughing and microcutting abrasion and the TiC particulates in Mg matrix produce an excellent effect on resisting the abrasive particulate to enter into the matrix, bearing loads, strengthening matrix, and preventing deformation.

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