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Processing of B_4C Particulate-reinforced Magnesium-matrix Composites by Metal-assisted Melt Infiltration Technique

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In fabricating magnesium-matrix composites, an easy and cost-effective route is to infiltrate the ceramic preform with molten Mg without any external pressure. However, a rather well wettability of molten Mg with ceramic reinforcement is needed for this process. In order to improve the wettability of the metal melt with ceramic preform during fabricating composites by metal melt infiltration, a simple and viable method has been proposed in this paper where a small amount of metal powder with higher melting point is added to the ceramic preform such that the surface tension of the Mg melt and the liquid–solid interfacial tension could be reduced. By using this method, boron carbide particulate-reinforced magnesium-matrix composites (B_4C/Mg) have been successfully fabricated where Ti powder immiscible with magnesium melt was introduced into B_4C preform as infiltration inducer. The infiltration ability of molten Mg to the ceramic preform was further studied in association with the processing conditions and the mechanism involved in this process was also analyzed.

KEY WORDS: Magnesium-matrix composites; Boron carbide; Melt infiltration; Microstructure; Mechanism

1. Introduction

Light-weight particulate-reinforced magnesium-matrix composites are gradually finding wide applications as promising structural and functional materials in electronic, aeronautical and aerospace fields, since they possess high specific strength and stiffness, excellent wear-resistant ability, good electrical and thermal conductivities, and vibration-damping capacity[1–4].

As for the fabrication of magnesium-matrix composites, several routes have been utilized to synthesize magnesium-matrix composites, which mainly include powder metallurgy[5], stir casting[6] and infiltration technique with or without the aid of pressure[7,8]. Recently, Habibi et al.[9] utilized powder metallurgy route using microwave assisted rapid sintering technique followed by hot extrusion to synthesize magnesium nano-composites in order to enhance the strength and ductility of magnesium simultaneously. Interpenetrating metal-matrix composites were prepared by Scherm et al.[10] through infiltrating of porous ceramic performs by a pressure supported casting process and the microstructure was also characterized by using different experimental methods. Composites containing pure magnesium and hybrid reinforcements were synthesized by Sankaranarayanan et al.[11] through disintegrated melt deposition technique (DMD) followed by hot extrusion and the effect of ball milling the hybrid reinforcements on the microstructure and mechanical properties of this kind of composites was also evaluated. Among these routes, metal melt infiltration into ceramic preform is recognized as having merits in low cost, high efficiency, near net-shape, availability of composites with high ceramic volume fraction and received much attention in recent years[12,13]. However, the prerequisite for effective infiltration of metal melt into the ceramic preform is good wettability of metal melt to the ceramic particulate[2]. Generally, the wettability between ceramic and magnesium melt is not so well and the infiltration process is unlikely to occur unless the fabrication temperature is extremely high, e.g. in conventional ceramic/magnesium systems as Mg–Ti–C, Mg–Ti–B, Mg–B_4C. Thus, promotion of the infiltration ability becomes a critical issue in fabricating magnesium-matrix composites by using this technique.

The usual way to enhance the wettability of metal melt to the ceramics is to raise the temperature much higher than the melting point. Undoubtedly, this method is suitable for the non-volatile molten metal and can not be used for volatile metal, e.g. Mg and Zn. In this paper, an effective way to improve the wettability of the metal melt with ceramic preform was proposed in fabricating magnesium-matrix composites via pressureless infiltration technique by adding small amount of metal particles with high melting point.

As an illustrative case, this conception was demonstrated in fabricating B_4C/Mg composite by magnesium melt infiltration

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into B_4C ceramic preform where some amount of Ti particles had been added, and the mechanism of effective infiltration involved in this process was also analyzed. Since B_4C has a lower density (2.52 g/cm^3), even when the B_4C takes 50% volume fraction, the composite system B_4C/Mg is extra-light and the density is only about 2 g/cm^3, much lighter than that of pure aluminum, a little higher than that of magnesium. It is worth noting that such a high volume fraction of ceramics in this composite system will bring about excellent wear resistance[14], so it will find wide applications in aeronautical and aerospace industries.

2. Experimental

The raw materials used in fabricating boron carbide reinforced magnesium composites were listed in Table 1 where the B_4C particulate has mean sizes of 28, 10 and 5 μm, respectively, and Ti particulate has an average size of 25 μm. The magnesium ingot was used as infiltration metal and it has a commercial purity of 99.95%.

There are two main steps in fabricating B_4C/Mg composites, i.e. preparation of the B_4C preform and spontaneous infiltration of magnesium melt into B_4C ceramic preform. Firstly, Ti powder of different volume fraction (0%, 2%, 4%, 6% and 8%) was added into B_4C powder. After adding a certain amount of binder and fully mechanical blending, the mixed Ti and B_4C powders were then cold compacted into green body of cylindrical shapes (16 mm in diameter, height variable) in a steel mould with various relative densities of 50%, 55% and 60%. The compacted preform together with a pure magnesium ingot on it was put into a graphite mould. Several small holes were drilled at the bottom of the graphite mould in order to release the air during fabricating the B_4C/Mg composites. The infiltration process was carried out in an electric furnace under the presence of a flowing argon (99.999% purity) atmosphere. The chamber of the furnace was degassed prior to heating and then backfilled with Ar. The infiltration system was finally heated up to temperatures of 953, 973 and 993 K, respectively, at a rate of 10 K/min. At each temperature, the holding time was all set as 90, 120 and 150 min. After that, the samples were cooled with the furnace down to the room temperature.

Metallographic microscopy (LEICA Q550IW), scanning electron microscopy (SEM, FEI Quanta 600) and X-ray diffractometer (XRD, X'Pert Pro) were used to characterize the microstructures and the phases of the as-infiltrated composites. The specimens were sectioned and polished in the infiltration direction in order to measure the infiltration distance to analyze the influence of processing parameters on the infiltration dynamics.

3. Results and Discussion

3.1. Microstructure and phase analysis

As expected, with the aid of Ti particulate in B_4C preform the magnesium melt can spontaneously infiltrate into the ceramic preform of B_4C when the heating temperature is at 953, 973, and 993 K for different holding time under the flowing argon atmosphere. It is noticeable that the infiltration process of magnesium melt into B_4C preform does not occur without the addition of Ti particulate into B_4C preform. This implies that the Ti particulate plays a predominant role in this process. That is to say, the B_4C/Mg composites can be successfully fabricated with the existence of Ti as an infiltration inducer.

Table 1 Raw materials used in fabricating B_4C/Mg composites

Materials	Particle size (μm)	Purity (%)
B_4C	28	94.66
	10	94.55
	5	93.78
Ti	25	99.5
Mg (ingot)	–	99.95

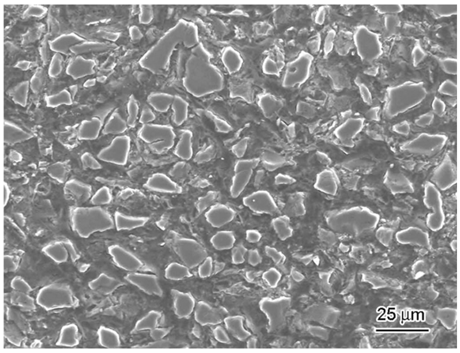

Fig. 1 SEM micrographs of the as-fabricated B_4C/Mg composites at 973 K for 120 min.

Fig. 1 shows the typical SEM micrograph of the as-prepared B_4C/Mg composites at 973 K for 120 min. The original preform has a 4% volume fraction of Ti particles and a relative density of 60%. It can be seen in Fig. 1 that B_4C particles with an irregular shape were uniformly distributed in the magnesium-matrix and very few Ti particles were found due to its extremely low volume fraction. Fig. 2 shows the XRD spectrum of the as-fabricated B_4C/Mg composites corresponding to Fig. 1 and it contains four phases, i.e. B_4C, Mg, MgB_2 and SiC. The presence of Mg and B_4C phases confirms that magnesium melt has infiltrated into the B_4C preform under the present processing conditions. No Ti peak was detected owing to its low addition and SiC was introduced as impurities during the blending of starting powders or the polishing of B_4C/Mg composites samples using silicon carbide paper. Besides, there is a weak peak corresponding to MgB_2 trace phase. It was reported that B_4C particles were easily oxidated during mixing the starting materials and an amorphous B_2O_3 surface layer was produced. After that, an interfacial reaction of B_2O_3 with magnesium melt occurred and rod-like MgB_2 produced[15].

It is obvious that the processing parameters, e.g. Ti content, heating temperature, holding time and relative density, have much influence on the fabricating process and thus the materials

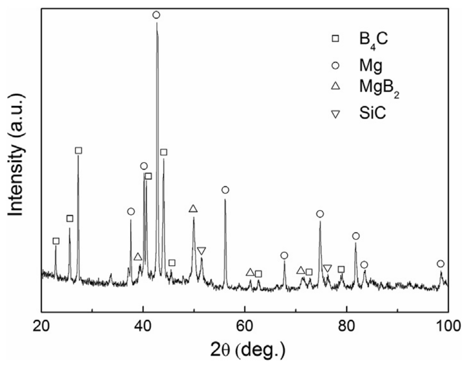

Fig. 2 XRD spectrum of the as-fabricated B_4C/Mg composites.