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New Synthesis Method and Mechanical Properties of Magnesium Matrix Composites

ABSTRACT: A new method to in situ fabricate magnesium alloy reinforced with 8 wt % of TiB_2 and TiC is described. The XRD result revealed the formation of TiB_2 and TiC in master alloy magnesium matrix composites. Uniform distribution of fine reinforcement in the matrix material obtained through microstructural characterization. Mechanical characterization revealed that the presence of TiB_2 and TiC leads to an increase on microhardness and tensile strength of magnesium matrix composites. Scanning electronic micrographs taken from the tensile fracture surface of magnesium matrix composites revealed typical brittle fracture.

KEYWORDS: magnesium matrix composites, in-situ synthesis method, mechanical properties

Introduction

Magnesium alloys are promising because of low density, high specific strength and specific stiffness, good dimensional stability, and high damping capacity. The use of magnesium alloys in automobile parts is predicted to increase globally at an average rate of 15 % per year [1]. However its ultimate tensile strength (UTS) is too low for wide use. Compared to magnesium alloys, magnesium matrix composites (Mg-MMCs) are excellent candidates because of than higher specific stiffness and specific strength, good dimensional stability, higher damping capacity, and good elevated temperature creeping properties [2]. So it is necessary to seek appropriate technique to fabricate high properties Mg-MMCs. Generally, the end properties of composite materials are governed by a number of factors such as type of processing, matrix constitution, type, size, volume fraction, and morphology of the reinforcement, secondary processing and the heat treatment procedure. Among these factors, type of processing and selection of reinforcement compatible with metallic matrix remain are the most critical factors in realizing the best properties from the resultant composite. As one of the present reinforcement, TiB_2 ceramics is coherent well with magnesium matrix because its crystal lattice is the same as magnesium matrix. In situ synthesis technique is a new processing method which is used to prepare metal matrix composites generally. Reinforcement fabricated with in situ synthesis is fine. Also composites synthesized by the in situ method have advanced performance and clear interface between metal matrix and reinforcement [3,4]. The remelting and dilution (RD) technique is one of the in situ synthesis methods. This technique contains two processes. The first is to prepare the master alloy that consists of reinforcements, and the second is to dilute the master alloy into metal matrix melt.

RD technique is easily controlled, and may be applicable in industry. Accordingly, the primary aim of the present work is to synthesize magnesium composite which is reinforced by TiB_2 and TiC ceramics particulate with the RD technique. The materials were examined in phase, microstructure characterization, and mechanical properties.

Experimental Procedures

In this study, pure magnesium was used as the base materials. Aluminum, titanium, and boron carbide powders were used as the base materials of master alloy. Al, Ti, and B_4C powders whose purity is up 99.0 % were mixed with a ball mill. After the mixed powders had been extruded into columned shape ($\Phi 30 \times 50$ mm), they reacted at 1400 K under vacuum atmosphere protection. Pure magnesium was superheated to 750°C under SF_6+CO_2 gas atmosphere protection in a steel crucible. After master alloy

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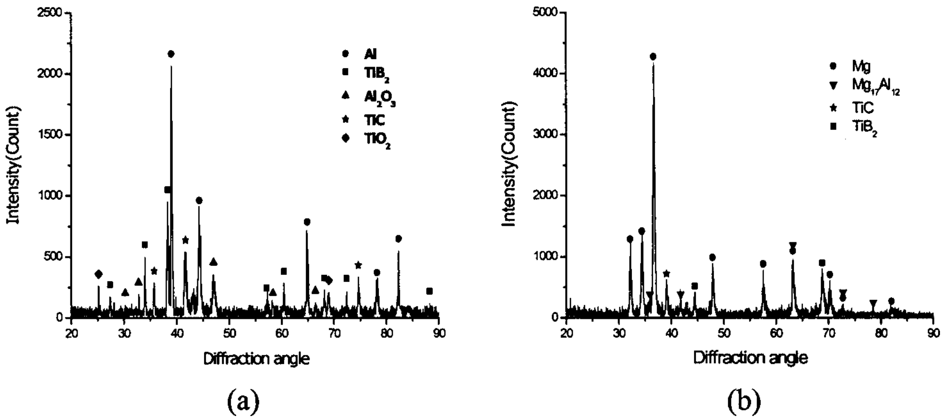

FIG. 1—*XRD patterns of samples [(a) prefabricated (b) magnesium matrix composite].*

was put into magnesium melt, the superheated slurry was stirred to facilitate the incorporation and uniform distribution of reinforcement particulates in the metallic matrix.

Mg-MMCs and master alloy samples were characterized by using an x-ray diffraction (XRD). Philip S-52 scanning electron microscope (SEM) and Olympus PME3 metallography microscope were applied on micrographs to determine the size and amount of reinforcement. Microhardness measurement was examined on the polish Mg-MMCs samples with HXD-1000 automatic digital microhardness tester. Mechanical characterization of magnesium matrix composite and AZ91 magnesium alloys were examined on testing machine for material strength.

Results and Discussion

Phase Analysis

During the sintering process, the mixed powder such as Al-Ti-B_4C reacted. The reaction equation and its reactive free energy at 1400 K were listed as the following [5,6]:

$$3\text{Al} + \text{Ti} \rightarrow \text{TiAl}_3 \quad \Delta G = -3.724 \text{ KJ/mol}$$

$$\text{TiAl}_3 + \text{B}_4\text{C} \rightarrow 3\text{Al} + \text{TiC} + 4[\text{B}] \quad \Delta G = -6.73 \text{ KJ/mol}$$

$$\text{TiC} + [\text{B}] \rightarrow \text{TiB} + [\text{C}] \quad \Delta G = -13.45 \text{ KJ/mol}$$

$$\text{TiAl}_3 + [\text{C}] \rightarrow 3\text{Al} + \text{TiC} \quad \Delta G = -74.02 \text{ KJ/mol}$$

$$\text{TiB} + [\text{B}] \rightarrow \text{TiB}_2 \quad \Delta G = -201.77 \text{ KJ/mol}$$

where the ΔG is the reactive free energy at 1400 K. According to the reactive equation and free energy, Al acts as a reactive intermedium to facilitate the reaction between Ti and B_4C. So the mixed powders react according as the reaction equation: $Al+Ti+B_4C=Al+TiB_2+TiC$ ideally. The final products in sintering are TiB_2, TiC and Al ideally.

The XRD results corresponding to the Mg-MMCs and master alloy samples are shown in Fig. 1. The XRD results reveal the formation of TiB_2 and TiC in the composites sample and master alloy sample. Additionally, alumina and titania are discovered in the master alloy because of being oxidized of aluminum during mixing and sintering process [as shown Fig. 1(*a*)]. Subsequenty, alumina and titania disappear in Mg-MMCs due to poor wettability between them and magnesium matrix. Alumina and titania deposit on the bottom with a fusing agent and impurities because of their larger density. Al in master alloy diffuses into magnesium melts and form the $Mg_{17}Al_{12}$ phase reacting with magnesium during solidifying process. The presence of the $Mg_{17}Al_{12}$ phase in the composites sample is revealed.

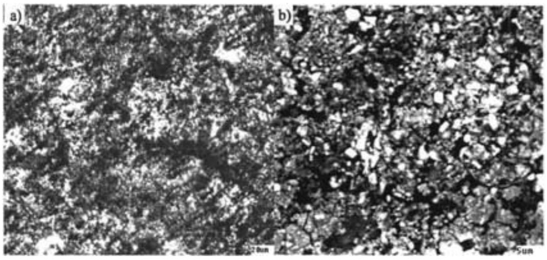

FIG. 2—*Photograph of master alloy [(a) metallography; (b) SEM].*

Microstructure Characterization

Microstructure of Master Alloy—The result of microstructure description conducted on master alloy is discussed in terms of size and distribution of reinforcements. The result of SEM and Olympus PME3 metallography microscope reveals a uniform distribution of reinforcements (as shown Fig. 2). Master alloy consists of white aluminum piece, gray structure, and white reinforcements spots that size is about 0.2–1 μm. The grey structure is mixing with aluminum and reinforcement particles. Aluminum powder acts as an intermedium to accelerate the reaction of Ti and B_4C during sintering process, and packet reinforcements to deconcentrate them during cooling process subsequently. The fine particulates and its uniform distribution are contributed to high efficient milling.

Microstructure of Mg-MMCs—The result of microstructure description is discussed in terms of size and distribution of reinforcements in magnesium matrix. The results of SEM and Olympus PME3 metallography microscope reveal a uniform distribution of fine reinforcements in magnesium matrix (as shown in Fig. 3).

When master alloy is put into magnesium melt, the reinforcements of TiB_2 and TiC disperse well due to their fine wettability with magnesium matrix [7]. The uniform distribution of TiB_2 particulates in the present study can also be attributed to minimal agglomeration of reinforcements. TiB_2 is fit for reinforcing magnesium matrix due to its hexagonal closed packed structure as being the same as magnesium. It is also important of judicious selection of stirring parameters which ensure uniform incorporation of reinforcement particulates in the magnesium matrix melt. It is estimated that the size of reinforcement particulates is about 0.2–1.0 μm (as shown in Fig. 3).

(EDX) analysis of Mg-MMCs is conducted on square area in Fig. 3(*b*). The result of EDX analysis reveals that titanium is 4.83 wt %, and aluminum is 3.56 wt % in Mg-MMCs (as shown in Fig. 4). It can be calculated that there are 8.05 wt % reinforcement particulates in Mg-MMCs for titanium is being in the composites by mean of TiB_2 and TiC mainly. So the volume percent of reinforcement particulates is about 3.38 %. There is 8.56 wt % aluminum in the area of Mg-MMCs that is consilient with AZ91 alloy.

Mechanical Characterization

Mechanical properties of Mg-MMCs and AZ91 magnesium alloy is listed in Table 1. Compared to AZ91 alloy, material strength of Mg-MMCs improves. Contrarily, plasticity of Mg-MMCs decreases and there is a significant increase on microhardness of Mg-MMCs. It is suggested that there is a larger potential to improve mechanical properties of Mg-MMCs. The change of mechanical characterization about Mg-

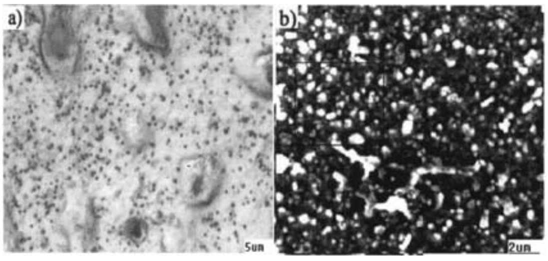

FIG. 3—*Photograph of magnesium matrix composite [(a) metallography, (b) SEM].*

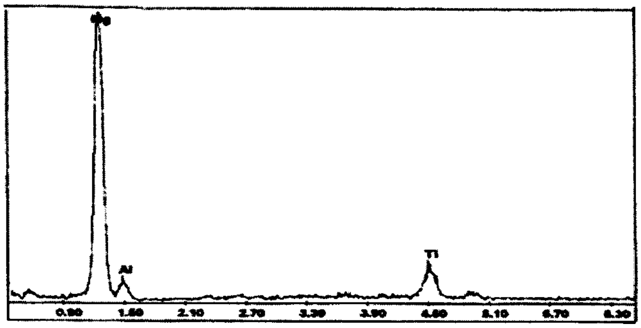

FIG. 4—*EDX analysis of Mg-MMCs.*

MMCs can be attributed primarily to (a) the presence of TiB_2 and TiC particulates in the matrix, and (b) a higher constraint to the localized matrix deformation during indentation due to their presence.

Fracture Behavior—SEM micrograph taken of the tensile fracture surface is shown in Fig. 5. The results of fracture analysis reveal typical brittle fracture. This can be attributed to the HCP crystal structure of magnesium that restricts the slip to the basal plane [8]. The areas exhibiting slight plastic deformation adjacent to the reinforcements particulates observed in the composite samples are indicative of strain accumulation at the interfacial zone between magnesium matrix and reinforcements. In addition, microcracks observed in the matrix indicate that the failure might have initiated in the matrix rather than from particulates. This is also indicative of strong interfacial integrity between magnesium matrix and reinforcement particulates in composite synthesized in the present study.

Conclusion

1. Mg-MMCs reinforced with TiB_2 and TiC ceramic particulates is successfully in situ synthesized using RD technique.
2. The uniform distribution of TiB_2 and TiC particulates in Mg-MMCs is revealed in Mg-MMCs, which is due to the fine size of reinforcements, the good wettability between magnesium and reinforcements, and the judicious selection of stirring parameters.
3. The results of mechanical properties reveal that the presence of reinforcement particulates leads to an improvement of mechanical properties of Mg-MMCs. The improvement of mechanical properties of Mg-MMCs can also be attributed to a higher constraint to the localized matrix deformation.
4. The results of fracture characterization of Mg-MMCs reveal typical brittle fracture, which can be attributed to the HCP crystal lattice of magnesium matrix and the addition of reinforcement particulates.

TABLE 1—*Mechanical properties of Mg-MMCs and AZ91 magnesium alloy.*

Material	0.2 % proof stress ($\sigma_{0.2,}MPa$)	UTS (σ_bMPa)	Elongation to failure (ε, %)	Hardness (Hv)
AZ91 alloy	85.15	223.56	2.5	45.6
Mg-MMCs	97.24	254.03	1.2	72.3

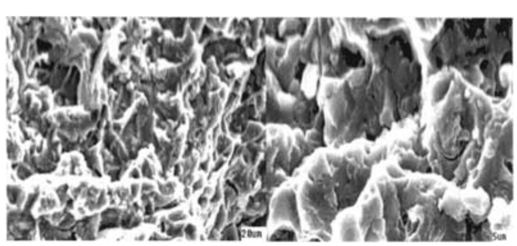

FIG. 5—*Representative SEM micrograph taken the tensile fracture surface.*

Acknowledgment

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