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Synthesis and characterization of Mg/TiO_2 nano-composites for electrical resistivity

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Magnesium (Mg) matrix reinforced with TiO_2 particles, due to the good electrical and thermal conductivity and strength at high temperature are suitable for contact materials. In this work Mg /TiO_2 nano-composites with different concentrations of TiO2, were synthesized using in-situ oxidation of Mg-Ti pre alloyed powders. The morphology of prepared nano-composite specimens were characterized using scanning electrone microscope (SEM). X-ray diffraction (XRD) analysis was used to investigate the mechanical behavior of Mg and Ti powders mixture. The physical and mechanical properties results of specimens indicated that the density, specific electrical resistivity, hardness and wear rate values can change by enhancement in TiO_2-loaded Mg matrix.

Keywords: Metal- matrix composites; Mg/TiO_2; Electrical properties; Mechanical properties.

INTRODUCTION

Magnesium and its alloys due to the good castability, machinability, thermal stability, good damping characteristics, high specific mechanical properties and resistance to electromagnetic radiation have been used for various applications in automobile, aerospace, sports-related and electronics industries [1-2]. Addition of ceramic particulates such as SiC, nanoparticles (NPs) such as TiB_2, other nanomaterials such as carbon nanotubes (CNTs) and addition of nano/micron sized metallic particles such as Ti can simultaneous improve in strengths and ductility of the magnesium composites [3,5].

Both pure magnesium and titanium dioxide are biocompatible materials. Therefore it is necessary to study the mechanical properties of pure magnesium reinforced with TiO_2 nano-particulates [6,9]. Internal oxidation, as in-situ production route of oxide dispersion strengthened (ODS) materials, has been the subject of numerous investigations during the past decade. This process has two major benefits first, it can prevent the formation of external oxide scale and second, internal oxidation provides a method of introducing second phase particles into an alloy which can affect the mechanical and other properties of alloys [10,15]. Due to limited works on Mg/TiO_2 composite as materials used in electrical contacts, the present work concentrates on this system. Mg/TiO_2 nano-composites have been produced by in-situ internal oxidation of Mg-Ti alloyed powder. In order to investigate the effect of various amounts of TiO_2 particles on the density, electrical conductivity, hardness and wear rate of Mg/TiO_2 nano-composites, the Ti values was selected at the range of 1-3 wt.%.

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2. EXPERIMENTAL

2.1 Synthesis of Mg/TiO_2 nanocomposites

In the present study, >99.9% pure MgO and Ti powder (with average particle sizes of 10–20nm) were obtained from Sigma–Aldrich. MgO powder was used 6,12 and 18 g as an oxidant. At the firs tstage, elemental Mg and Ti powders were mechanically alloyed for 3 days in argon atmosphere. The stainless steel balls to powder weight ratios (BPR) and mill rotation speed were selected as 20:1, 10:1 and 250 rpm, respectively. The Ti content was in the range of 1-3 wt. % in Mg-Ti powder composition.

Following mechanical alloying, the Mg-Ti alloyed powder and MgO were milled for 40 h and 60 h under Argon atmosphere. To prevent oxidation of very fine powder particles, compacting was conducted in a hot press under 30MPa applied pressure at 400˚C in glove box. Heating rate was considered as 5˚C/min. Finally, the specimens were cooled down for 12 h.

2.2 Characterization tests

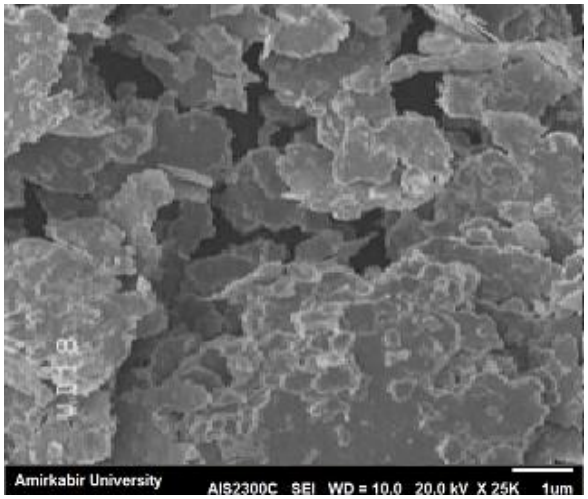
X-ray diffraction analysis was used to determine the mechanical alloying process during milling. The density value of specimens was specified by usual Archimedes method. The electrical resistivity was measured by micro-ohmmeter LOM-D500.

The specific electrical resistance were then calculated by considering specimens dimensions. The Vickers hardness was measured under applied load of 5 N. The weight loss was measured using a precise electronic balance. The wear rate was given as volume loss per unit sliding distance. To study the wear mechanisms of the specimens, worn surfaces of the pins were investigated using scanneing electron microscope equipped with EDAX analysis.

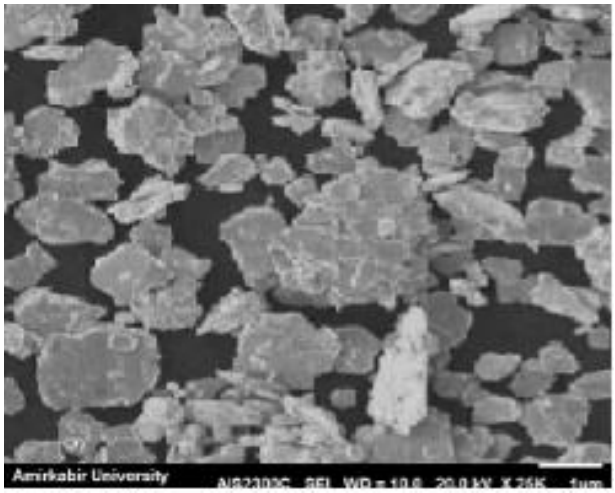
3. RESULTS AND DISCUSSION

3.1. Characterization of Mg/TiO_2

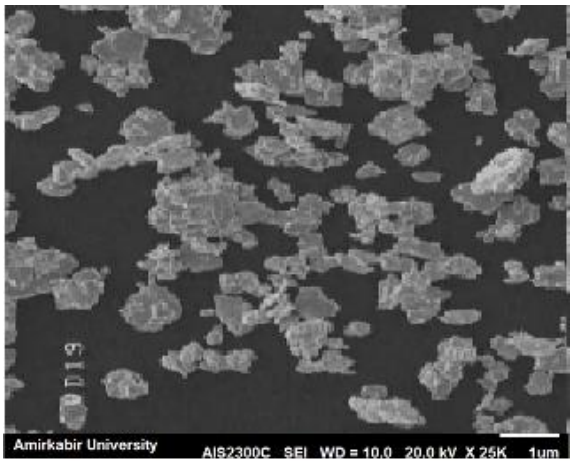
Fig. 1 shows SEM micrographs of Mg-2wt.% Ti powder milled at different conditions. In fact, the flaky powder particles in Fig.1a and 1b, indicated that more time was required to reach a proper state between cold welding and fracturing of powder particles. Milling in 60 hr 20:1 did not decreases average particle size A decrease in powder particle size and formation of thin layers between different particles maked the atoms diffusion path shorter. As shown in Fig 1c, the particle size of powders milled for 60 hours with BPR 20:1 was less.



(a)



(b)



(c)

Fig.1 SEM images of Mg-2wt.%Ti powder after mechanical milling of (a) 60 hr with BPR 10:1, (b) 40 hr with BPR 20:1, (c) 60 hr with BPR 20:1.

X-ray diffraction (XRD) was also applied to the Mg-Ti alloyed powders after 60 hr with BPR 10:1 and 20:1. The XRD results of Mg-2wt. % Ti powder after mechanical milling in different conditions are shown in Fig. 2.

The intensity of the peaks was decreased by increasing of BPR. Determination of crystallite size and lattice strain from the XRD data and using the Williamson-Hall equation [9], confirms this change. XRD peaks of alloyed Mg should be shifted to lower θ values. However, due to low difference in atomic radii of Mg and Ti, the displacement of peaks is very negligible. In addition, dissolving of limited amounts of oxygen atoms and their placement on interstitial sites of Mg lattice would led to strong decrease of lattice

parameter due to large difference in the atomic radii [16,18].

The XRD results of pressed and sintered specimens are illustrated in Fig.2. The intensity increment of the peaks is also sensible. However, due to very low amount of TiO2 and small particle size, the diffraction peaks of TiO2 are not appeared for this specimen.

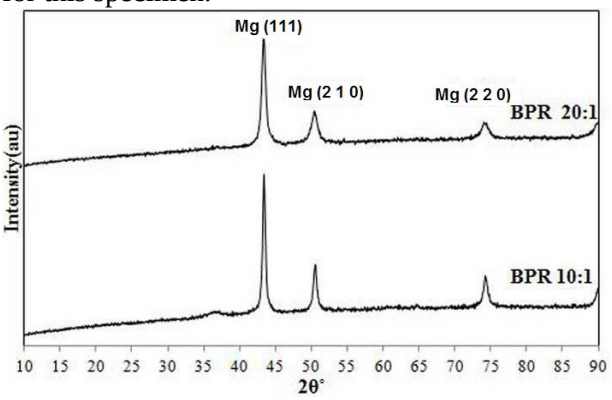


Fig.2. XRD analysis of Mg-2wt.%Ti powder after mechanical milling of 60 hrs with BPR 10:1 and 20:1.

Based on SEM image of Mg/TiO2 nano-composite, the average grain size was about 50 nm (Fig.3). As shown the uniform particle size of Mg/ TiO_2 was produced.

3.2. Specific electrical resistivity

The physical and mechanical properties of pressed and sintered specimens are presented in Tables 1 and 2. As shown, due to presence of Ti in Mg lattice and formation of solid solution, remained porosity, presence of MgO and probably some TiO_2 particles, specific electrical resistivity of pressed specimens increases with increasing Ti content. In general, the values are higher than that pure Mg which is equal to 1.894 μΩ.cm. The specific electrical resistivity of Mg/TiO_2 composites was increased by increasing the amount of TiO_2 particles. Similar trends were obtained by other researchers [19, 20].

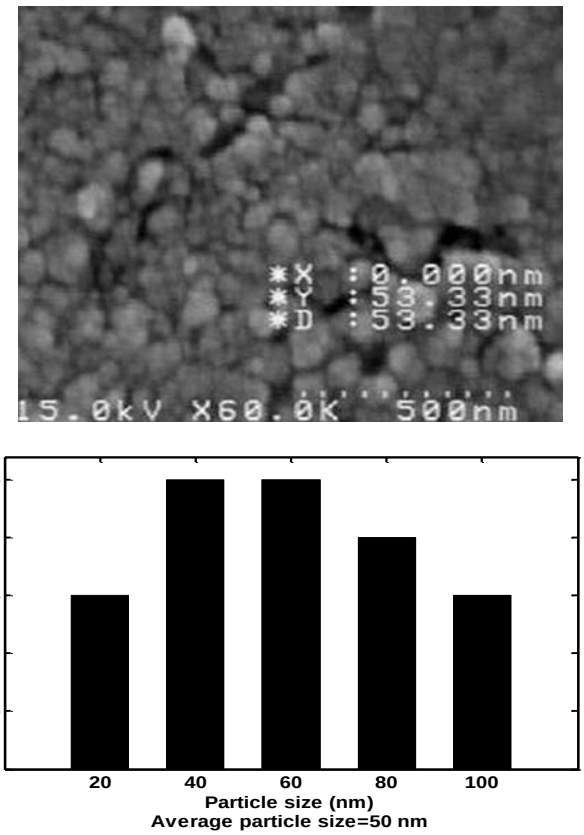


Fig.3. SEM image and particle size distribution of Mg/TiO_2..

Table 1. Properties of pressed specimens

Specimen Designation	Density (g/cm^3)	Specific electrical resistivity (μΩ.cm)
Mg/TiO_2 1	7.2	3.34
Mg/TiO_2 2	7.05	5.92
Mg/TiO_2 3	6.83	7.22

Table 2. Properties of sintered specimens

Specimen Designation	Density (g/cm^3)	Specific electrical resistivity (μΩ.cm)	Hardness (HV)
C1S	7.74	1.95	75.3
C2S	7.31	2.79	87.8
C3S	7.11	7.19	96.5

3.3. Vickers hardness

Vickers hardness of Mg/TiO_2 nano-composite samples are presented in Table 2. As shown, vickers hardness of Mg/TiO_2 nano-composite was increased by increasing TiO_2 amount. Two important strengthening and hardening mechanisms can be considered in the Mg/ TiO_2 nano-composite produced by in-situ oxidation: the oxide dispersion strengthening according to orowan mechanism and refined grains strengthening according to Hall-Petch relation [19].

3.4. EDAX analysis

The EDS analysis of Mg/TiO_2, confirmd that elemental such as Ti, Fe and O can be detected

besides the main element Mg. According to the Table 3, the oxygen and iron content wre increased by increasing sliding distance. Thus it can be concluded that the oxidation wear mechanism becomes more activated at larger distances.

Table. 3. EDS analysis of Mg/TiO_2 specimen after sliding of 3000 m

Element	Unn. C[wt.-%]	Norm. C	[at.-%]
Oxygen	0.65	0.75	2.89
Titanium	1.82	1.89	2.49
Iron	2.33	2.68	2.97
Mg	93.74	94.68	91.65

4. CONCLUSION

The effect of Ti content on the formation of in-situ TiO_2 particles in Mg matrix composites and evaluation of some physical and mechanical properties revealed that the formation of TiO_2 particles can be proceeded by mechanical milling and subsequent sintering of Mg (Ti)-MgO powders mixture. SEM image indicated that the unifom particles with average size of 50 nm were successfully synthesized. Specific electrical resistivity and hardness of Mg/TiO_2 nano-composites was increased with increasing oxide particles content.

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