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Synthesis of Biodegradable Mg-Zn Alloy by Mechanical Alloying: Effect of Milling Time

Emee Marina Salleh[a], Sivakumar Ramakrishnan[a] and Zuhailawati Hussain[a*]

[a]*Structural Materials Niche Area, School of Materials and Mineral Resources Engineering, Engineering Campus, Universiti Sains Malaysia, 14300 Nibong Tebal, Penang, Malaysia.*

Abstract

Magnesium (Mg) is one such promising light weight metal, which is currently utilized for bio-engineering applications. Mg possesses a number of attractive characteristics that make Mg-based materials potential candidates to serve as implants for load-bearing applications in the medical industry due to its good biocompatibility and biodegradability. However, Mg and its alloys are susceptible to suffer attack in chloride containing solutions, e.g. the human body fluid or blood plasma. Thus, alloying with other metal elements is the most effective tool to improve mechanical properties and corrosion resistance of Mg. In this current work, binary Mg-Zn alloy was produced using mechanical alloying (MA) followed by compaction and sintering. The aim of this work was to study the effect of milling time on binary magnesium-zinc (Mg-Zn) alloy synthesized by mechanical alloying. A powder mixture of Mg and Zn with the composition of Mg-10wt%Zn was milled in a planetary mill under argon atmosphere using a stainless steel container and balls. Milling process was carried out at 250 rpm for various milling times i.e. 1, 2, 5, 10 and 15 hours. 3% n-heptane solution was added prior to milling process to avoid excessive cold welding of the powder. Then, as-milled powder was compacted under 400 MPa and sintered in a tube furnace at 350 °C in argon flow. The refinement analysis of the x-ray diffraction patterns shows the presence of Mg-Zn solid solution and formation of $MgZn_2$ when Mg-Zn powder was mechanically milled for 2 hours and further. A prolonged milling time has increased the density and microhardness of the sintered Mg-Zn alloy.

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Keywords: Mg-Zn alloy ; mechanical alloying; microhardness

Corresponding author. Tel.: +60 4 5995258; fax: +60 4 5941011
E-mail address: zuhaila@usm.my

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1. Introduction

Magnesium (Mg) stands out as a potential candidate for temporary implants in biomedical applications due to its light weight, as well as its elastic modulus and compressive yield strength that are compatible with those of natural bone[1, 2]. The density of Mg is 1.738 g/cm3, which is only slightly less than that of natural bone (1.8–2.1 g/cm3), while the elastic modulus of pure Mg is 45 GPa, as compared to human bone (40–57 GPa)[3]. Accordingly it can reduce the chance of stress shielding effects observed in the case of higher modulus materials such as titanium[4]. Mg is biocompatible and biodegradable in human body fluid, thus eliminating the need for a second operation to remove a temporary implant. However the use of Mg alloys is generally not advisable because most alloying elements can be toxic to the human body (except for Ca alloys, for example)[5]. For example, excessive copper amounts have been linked to neurodegenerative diseases like Alzheimerr's and in high doses of aluminium has been shown to increase estrogen-related gene expression in human breast cancer cell when cultured in a laboratory setting[6]. Compared to several other metal ions with similar chemical properties, zinc (Zn) is relatively harmless. It is vital for many biological functions and plays a crucial role in more than 300 metabolic activities of the body's enzymes and is considered essential for cell division and the synthesis of DNA and protein[7]. Whereas intoxication by excessive exposure is rare, Zn shortage is widespread and has a detrimental impact on growth, neuronal development, and immunity, and in severe cases its consequences are lethal. Thus, in this study, Mg-Zn was produced by mechanical alloying (MA) since it is an effective route to produce metallic alloys with fine microstructure[8,9]. MA i.e. high-energy ball milling enables high energy impact on the charged powder by collision between the grinding media and powder particles, which causes severe plastic deformation, repeated fracturing and cold welding of the particles leading to nanocrystalline materials formation[10, 11,12]. Generally, however, little information is available regarding the production and bulk properties of Mg alloy prepared by MA technique. Hence, further investigation need to be performed in order to produce Mg-Zn alloys with the desired properties. In this present study, density and microhardness were investigated in order to ensure the alloys produced have ranges close to that of human bones.

Nomenclature

MA	Mechanical alloying
Mg	Magnesium
XRD	X-ray diffraction
Zn	Zinc

2. Experimental Procedure

A mixture of elemental Mg powder (99.00 % pure, < 227.41 µm) and Zn powder (99.00 % pure, < 121.65 µm) corresponding to Mg-10wt%Zn was mechanically milled for various milling times of 1, 2, 5, 10 and 15 hours. Mechanical alloying was carried out using a high-energy Fritsch Pulveristte P-5 planetary mill under argon atmosphere. The powder to ball weight ratio of 1:10 was kept constant during the milling process using 20 mm-diameter stainless steel balls. 3% n-heptane solution was added onto the powder mixture prior to the milling process to prevent excessive cold welding of the elemental alloy powders. The as-milled powders were cold pressed under 400 MPa and subsequently were sintered at 350 ºC for an hour in argon flow. Qualitative X-ray diffraction (XRD) analysis was done to identify the presence of element and phases. Density of the green and sintered alloy was measured using pycnometer density equipment according to Archimedes' principle. Vickers microhardness test was carried out by applying an indentation load of 500 gf for 10 seconds.