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Finite element analysis for mechanical response of magnesium foams with regular structure obtained by powder metallurgy method

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Abstract

Magnesium and Magnesium alloys have attracted immense attention as a biomedical implant material due to favourable mechanical properties and biocompatibility. Biodegradable nature of Magnesium dismisses the need of revision surgery for removal of implant. Porous Mg- foams are advantageous as presence of pores allows the higher degree of osseointegration. The mechanical properties of the porous foam material is a function of its density, thus a Finite Element Method (FEM) approach is required to predict the behaviour of Mg- foam under various stresses for real-time application. The author has attempted to quantitatively assess the mechanical properties of Mg foam with a 40-45% porosity with 100-300 µm pore size. The deformation behaviour of Mg- foams with different porosity under the compressive and bending loads has been described by "Deshpande and Fleck model" with ABAQUS FEM software. The simulation results have been compared with the recent publications. An agreeable comparison has been seen in the results.

Keywords: Finite elemental analysis, magnesium, biomedical, ABAQUS

1. Introduction:

Magnesium is the important element in the human body found in bone tissue. In the recent years, magnesium used as biomaterials for tissue engineering applications. The Mg biomaterial is biodegradable and exhibits good mechanical properties, and biocompatibility [1]. Biodegradable materials like polymers, with required strength and its young's modulus, is almost comparable with human bone and avoids the stress shielding effect [2].

Porous metals provide mechanical properties like elastic modulus, similar to the natural bone tissues [3]. In recent times, porous magnesium and their preparation methods have been studied [4–9]. Powder metallurgy is one of the outstanding technique to produce open-cellular porous magnesium materials [10,11]. Cellular foams are helpful in controlling the porosity and interconnectivity. Magnesium porous materials produced by using ammonium bicarbonate as spacer particles.

The finite elemental analysis is useful to generate the models of metal foams to minimize the irregularities (mechanical properties, porosity). The mechanical properties of open-pore Mg-foams 100-300 µm pores and with porosities of 40-45% were studied.

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2. Materials and Methods:

Porous Mg monoliths were prepared by powder metallurgy (P/M) process (sintering) using NH_4HCO_3 powder as a space holder material. Liquid hexane was added to avoid the segregation of powders at a volume fraction of 30%. Mg and NH_4HCO_3 powders were thoroughly mixed according to the weight content of NH_4HCO_3, respectively. The mixture powders were uniaxially cold-pressed under the pressure of 265 MPa into cylindrical green compacts with 13 mm in diameter and 16 mm in thickness. The obtained monoliths were treated further by a two-step heat treatment: (I) T=130°C for 4 h and (II) 550°C for 6 h, under an argon atmosphere in order to burn out the spacer particles and merge the Mg particles into larger grains.

Pycnometry is used to evaluate the porosity as a function of monoliths starting composition. The percentage porosity (*P*) in the sintered samples was determined according to the following equation $P = (1 - \rho/\rho_s) \times 100\%$ where $\rho s$is the density of Mg and ρ is the density of the porous Mg sample, being determined as volume/mass ratio.

The phase component of the Mg foams was analysed with XRD using Xpert-pro equipment with Cu Kα radiation (λ = 1.5406 A) in a continuous scan mode. The filament current of 30 mA and acceleration voltage of 45 kV were applied. The diffraction angles(2θ) range from 10° to 80° and at a scanning speed of 10°/min was used. SEM imaging performs using the microscope TESCAN. Uniaxial, unconfined compression test was performed on mechanical testing machine Shimatzu AG-X plus with 10 kN load cell, according to ASTM E9 standard.

3. Results and Discussion:

SEM micrograph of the Magnesium and ammonium bicarbonate powders as shown in Fig.1 and the prepared magnesium foam is shown in Fig.2, consist of two types of pores, type 1 has a diameter above 250µm and type II having up to 100 µm, which were created from incomplete compaction. The mechanical properties of the porous material as shown in Table 1.

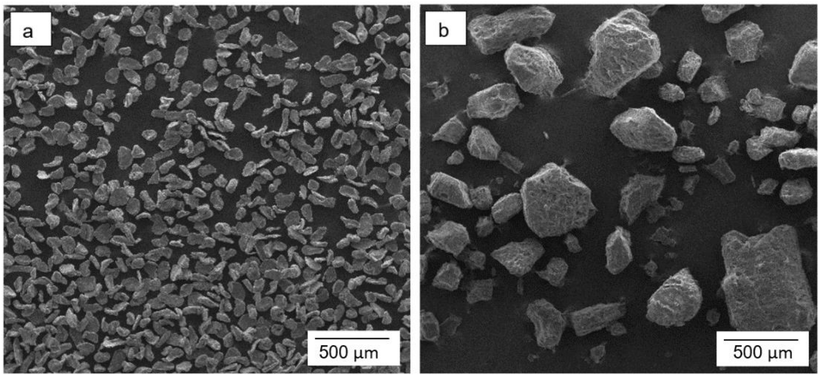

Fig. 1. Image of the powder materials: (a) Mg; (b) Ammonium bicarbonate

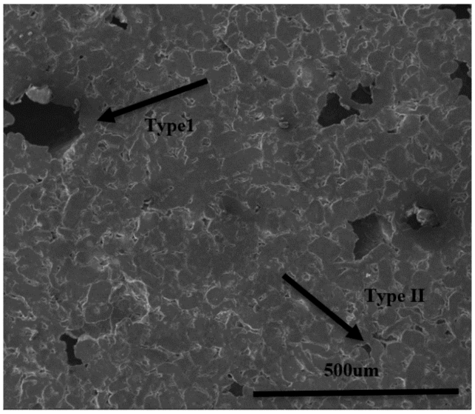

Fig. 2. SEM micrograph of 40 vol% porosity magnesium

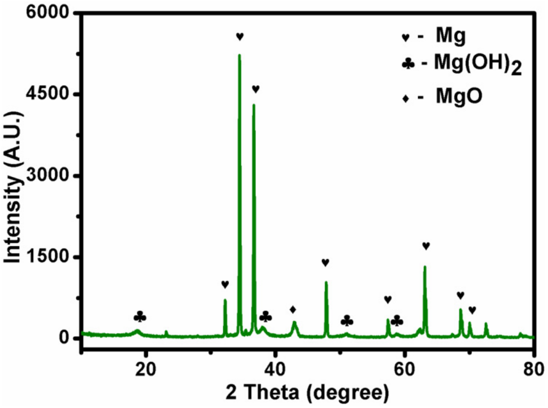

Fig. 3. XRD spectra of Mg foam

The XRD shown is of Magnesium foam in Fig 3. The Sharpe peaks in XRD pattern reveals the Magnesium is highly crystalline in nature. With the addition to major Magnesium peaks, there are peaks are of Magnesium hydroxide ($Mg(OH)_2$ and