Materials Science & Engineering A 574 (2013) 137–142

Contents lists available at SciVerse ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Mechanical behavior of porous magnesium/alumina composites with high strength and low density

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ARTICLE INFO

Article history:
Received 24 July 2012
Received in revised form
3 March 2013
Accepted 8 March 2013
Available online 15 March 2013

Keywords:
Porous magnesium (Mg)
Mechanical behavior
Metal matrix composites (MMC)
Powder metallurgy

ABSTRACT

Porous alumina-reinforced magnesium composites were synthesized through a powder metallurgical method and characterized using optical microscope, scanning electron microscope, and compression testing. The microstructural study exhibited that the average pore sizes increased with the increase of porosity and were about 25 μm, 70 μm, and 100 μm for the samples with 10%, 28%, and 38% porosities respectively. The mechanical characterization indicated that (i) the stress–strain curves were composed of three regimes: an initial regime that deformed elastically along an approximately linear line, a long and intermediate regime, and a densification regime with a steep increase of stress; (ii) the synthesized porous magnesium composites possessed lower density and higher yield strength than those of cast dense magnesium; (iii) the average yield strength and Young's modulus were anisotropic for the porous magnesium composites synthesized in this work.

1. Introduction

As the lightest metallic structural material, Mg attracts increasingly extensive research efforts and has high potential to serve for a variety of structural, energy and bio-related applications [1–21]. Various industries often require materials with high strength and low density. Thus, it is meaningful to develop materials with higher and higher strength and lower and lower density simultaneously. The increase of strength can be realized through one of the two primary methods. The first method is to change the microstructure through thermomechanical processing techniques (such as [4–7,14]). Differential speed rolling was employed on AZ31 Mg alloys [4]. Rolling/annealing processes on Mg showed that the strength of Mg could be increased over 100% [5]. The second method is to incorporate a strengthening/reinforcing phase and form composites [2,3,10,11,16,17]. This method is highly attractive and broadly utilized due to its flexibility and the existence of a wide range of reinforcing phases that can be employed.

Lowering the density of material can be realized through introducing pores into the material [18–28]. The addition of pores can not only lower the density of the produced materials, but also serve some multi-functionality [26–28]. The increased specific surface area can result in good absorbing properties and the materials can be good for oil spill cleanup [26]. The produced porous structure can also serve as scaffolds for bone substitute [28]. There are a large number of papers that reported research on porous aluminum and porous titanium. However, only a few papers reported the synthesis and characterization of porous Mg (e.g. [18–21]).

Generally, the existence of pores lowers the strength of materials. To resolve this problem, a feasible and appealing approach is to add a reinforcing phase to form Mg composites, and then we can expect to obtain porous Mg composites with both low density and high strength. In this work, we synthesized porous Mg composites through a powder metallurgical technique and investigated their microstructures and mechanical behavior. The fabricated samples were microstructurally and mechanically characterized using optical microscope (OM), scanning electron microscope (SEM), and compression testing respectively.

2. Experiments

Porous Mg composite samples were prepared by a powder metallurgical method. Pure Mg powder (purity≥99.9%, average powder size on the order of 40 μm) was used as the starting material. Carbamide ($CO(NH_2)_2$) with a purity of 99.0% was chosen as the space holder (SH). Alumina powders with the size of about 0.5 μm were used as the reinforcing phase. To fabricate porous Mg composites, we followed a route including mixing, compacting, and sintering. To realize a range of porosities of the synthesized porous composites, different weight ratios between the raw material (RM) and the SH were utilized. The removal of the SH left pores in the final products. Thus, a higher porosity

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http://dx.doi.org/10.1016/j.msea.2013.03.012

would be obtained with the utilization of a higher volume of the SH (i.e. the higher SH/RM weight ratio). The mixing process was conducted using a planetary ball mill to blend the mixture of Mg, alumina, and carbamide. After the mixing process, the mixture was pressed uniaxially at room temperature using a hydraulic press to form green compacts in a tubular mold with a square cross section. The press load was 12 t and the mold had a 10 mm × 10 mm cross section. The pressing pressure was about 120 MPa. Next, the pressed green compacts were sintered through a two-step sintering process under inert gas protection. The first sintering step was to burn out the SH at 250 °C for 4 h. The second sintering step was to sinter the compacts into the porous specimens at 630 °C for 2 h.

The studied compositions of the composites were Mg–0.05% alumina and Mg–1% alumina. The obtained porosities were 10%, 28%, and 38%. The sintered samples were observed under OM and SEM to examine their microstructures. The samples were also cut and prepared for uniaxial compression testing at room temperature. To alleviate the sample size effect, all samples contained at least 6 pores along the length and width direction of the cross section [29]. The compression tests were performed at a strain rate of $\sim 10^{-3}$/s using a universal mechanical testing machine. For each porous composite, two sets of samples were tested under compression and each set had three to five repeats. One set had the loading direction along the compacting direction, which was referred as the plane normal orientation. The other set had the loading direction perpendicular to the compacting direction, which was referred as the in-plane orientation. Meanwhile, the cross section planes that were perpendicular to the compacting direction were referred as the normal cross sections, and the cross section planes that were parallel to the compacting direction were referred as the parallel cross sections.

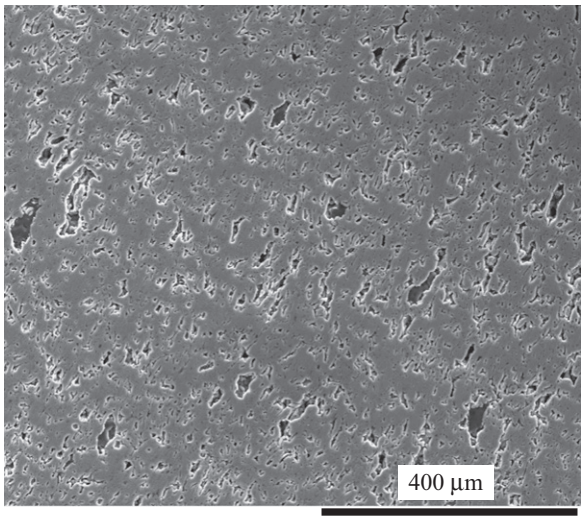

Fig. 2. SEM micrograph of Mg–1% alumina with 10% porosity along the direction that is perpendicular to the compacting direction.

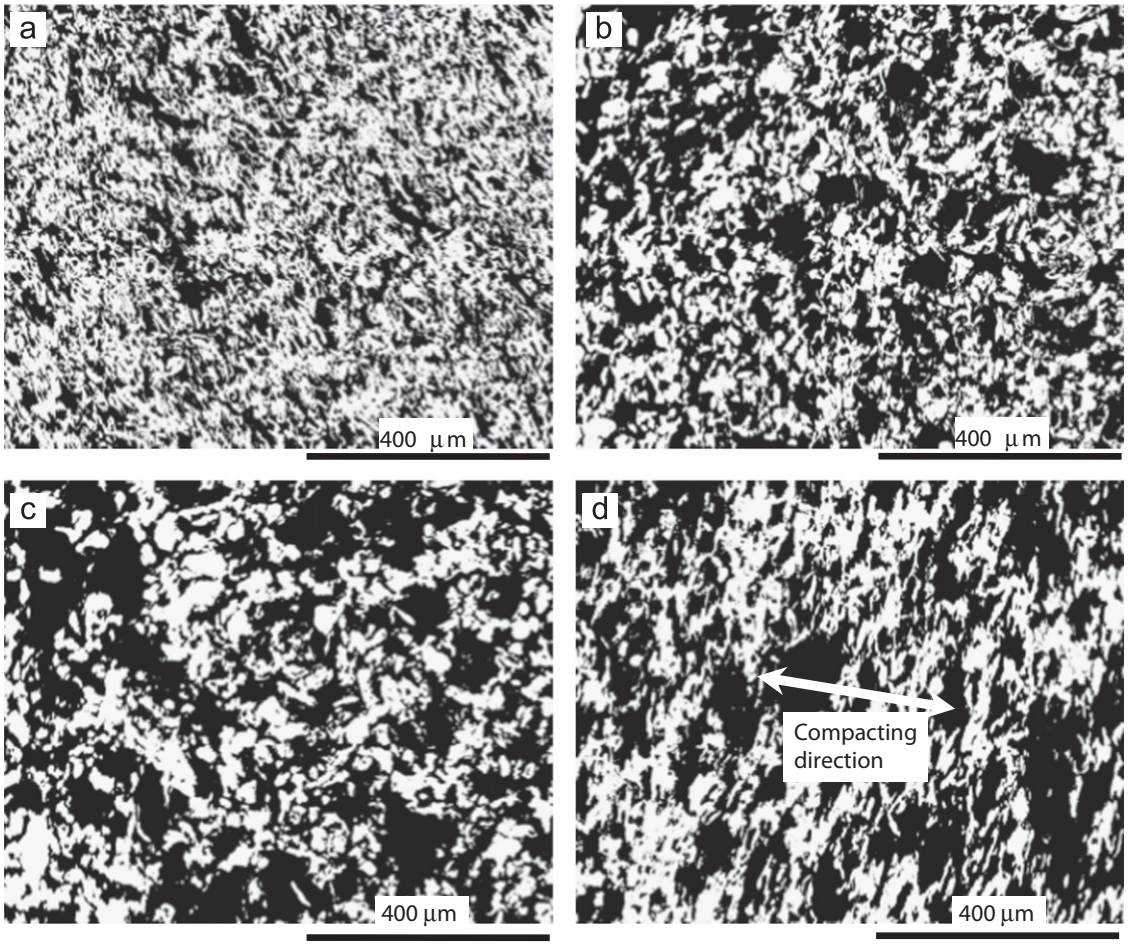

Fig. 1. Optical micrographs of (a) Mg–1% alumina with 10% porosity, (b) Mg–1% alumina with 28% porosity, and (c) Mg–1% alumina with 38% porosity along the direction that is perpendicular to the compacting direction; and (d) optical micrograph of Mg–1% alumina with 38% porosity along the direction that is parallel to the compacting direction. (*Note*: the samples were obtained from the fabricated products that experienced the sintering process.)