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Synthesis of magnesium metallic matrix composites and the evaluation of aluminum nitride addition effect

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ABSTRACT

Metallic matrix composites (MMC) have been successfully fabricated using Mg-AZ91E alloy and AlN as reinforcement by pressure-less self-infiltration technique. Mechanical characterization such as Young Modulus and hardness test evaluations have shown a positive strengthening behavior on the composite, superior to the matrix alloy. The samples were worn by using a tribometer pin-on- disk system and a counter part of bearing 100Cr6 Steel. Wear resistance was evaluated under dry sliding condition at different loads. Wear mechanisms of the composites are basically abrasive-oxidative. The wear resistance in all cases was better at low loads for the composite Mg AZ91E/AlN and for the unreinforced Mg AZ91E alloy at 5 N.

1. Introduction

Metal matrix composites (MMC) have been studied widely in recent years, principally due to their promising light properties. Studies has been focused to aluminum matrixes which has been widely used as metallic matrix composite [1–3]. On the other hand, the main advantages of magnesium and its alloys used as composite's matrix, are the high specific strength and stiffness, good damping capacities, and relative good dimensional stability [4–11]. There are several reports concerning to the mechanical and tribological behavior of the MMC's during the end of the last century, some information related to the wear behavior of Mg-based MMCs indicated that tribological properties of Mg alloys can be improved by the addition of hard ceramic fiber or also by particulate reinforcement [9,12–17]. Other investigations have been developed concerning with the effect of different reinforcements on microstructural evaluation and mechanical properties of magnesium metallic matrix composites [20–23]. In a previous work [18] it is reported the characterization of Mg AZ91/TiCp composite, therefore, the focus of this study is to produce successfully the composite and to investigate the resulting mechanical properties of the composites such as hardness and wear behavior of Mg AZ91/reinforced with AlN particles and under the knowledge of the low density of the alloy as lightest structural material for light-weight applications, especially for the fabrication of electronic packing support components, in order to identify the optimal parameters for improve the alloy performance. Until now, limited information is available in literature concerning to the tribological properties of this alloy added with high content of AlN particles.

2. Experimental procedures

2.1. Sample preparation

MMC composites were produced by pressure-less self infiltration technique of AlN porous preforms. Table 1 and Table 2 presents the ICP chemical analysis for the alloy Mg AZ91E and the trace element analysis of the reinforcement AlN respectively.

The process consisted in add 12 g of AlN particulate (hardness 1100 kg/mm^2) with 10 μm average grain sizes (from Aldrich Chemical Co.) inside of a steel mold with a cross section of 65 × 10 mm and 10 mm high, under uniaxial pressure of 14 MPa. After that, the preforms where placed inside of a graphite crucible and 6.5 g of Mg AZ91 alloy from Thomson Aluminum Casting Co.

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Table 1
ICP chemical analysis for the alloy Mg AZ91E.

Chemical composition of base alloy						
Al	Mg	Zn	Si	Fe	Cu	Mg
8.50	0.23	0.70	0.01	0.001	0.01	90.549

Table 2
Trace element analysis of the reinforcement AlN.

Main elemental trace composition in ppm									
B	Ca	Cr	Cu	Fe	K	Na	Ni	W	Zn
1.4	3.4	2.8	4.5	20.0	0.6	4.0	5.0	1.6	3.8

was positioned on the preforms. Infiltration was carried out in a vertical furnace at 850 ± 5 °C for 12 min, under dynamic argon atmosphere and then furnace cooled, a graphical representation of the fabrication route is presented in Fig. 1. Microstructure of the alloys and the composites were obtained by means of grinding and polishing the surface sample up to alumina of 0.3 μm and after that etching with Nital 2 reagent, this surface preparation was also used for hardness test evaluations. Composite specimens for wear experiments were cut from bars, with a cross section of 25 mm^2 and 15 mm length. The surfaces samples to be worn, were ground up to paper grinding 1000 grade. X-ray diffraction analyses were carried out in a Siemens D5000 with a monochromic cooper radiation CuKα (λ = 1.54056 Å) using a scanning speed of 2°/min over the surface samples with an area of 1 cm^2. Young modulus was measured according to the ASTM E1876-97 standard, using a Grindo Sonic Lemmens MK-5 equipment. A series of five experiments were carried out in order to obtain a better approximation. Vickers microhardness tests with a pyramidal indenter were performed on polished samples, using a 0.2 kg load and a holding time of 15 s, using a Leco 300 MT micro-hardness tester. A Tribometer CSM Instruments pin-on-disk system was employed to evaluate the wear behavior of the pin samples under 1, 3 and 5 N load, at constant disk rotation of 0.05 m/s. The pin samples were worn against a bearing 100Cr6 steel disk with a bulk hardness of 64 HRC. The curves derived from the experiments were evaluated in order to identify the operating wear mechanism. Worn surfaces samples were observed in a LEO-1450VP scanning electron microscope, as well the chemical analyses on the worn surfaces were performed by using the EDAX (Energy Dispersive X-Ray Analysis) system of the equipment.

3. Results and discussion

3.1. Microstructure

In Fig. 2a it is presented the microstructure obtained from the surface of the monolithic AZ91E alloy, in this figure it is observed that the main phase is predominantly the α-Mg phase which correspond to the alloy matrix with an approximately 70% in area fraction. The eutectic phase observed in the figure correspond to the aluminum rich eutectic phase and this phase it is precipitated around of the β-phase (secondary phase) which is composed of $Mg_{17}Al_{12}$. It is important to mention that eutectic phase and β-phase has precipitated together in the α-Mg phase.

Fig. 2b present the microstructure of the composite Mg AZ91E/AlN. It is observed both compounds, being the reinforcement of AlN (grey zone) the particles distributed homogeneously over the metallic matrix (dark zone), very few porosity zones are observed on the composite surface, this effect indicate that during the synthesis of the composite (where due to that matrix possess less melting point in comparison with the AlN reinforcement), it take form homogeneously, in such way the Mg AZ91E alloy produce the wetting effect over the compacted AlN particles. B. Ashok Kumara y N. Muruganb [12] report the synthesis of aluminum matrix composites improving the wetting effect with the addition of 2% of magnesium reinforced with AlN particles. In Fig. 2b are observed different AlN particles morphologies along the surface sample where predominantly exist the equiaxed particles with a bigger size (approximately 5 μm average) and enlarged particles which may produce an improved cohesion of the composite. It has been demonstrated that the addition of reinforcement particles to the alloy matrix may improve the wettability of the composite by means of reducing the interface energy of the metal/ceramic, producing new products of interfacial reaction with the reinforcement particles [13]. Thus, can be established that β-Mg17Al12 is an essential phase that may play an important role in strengthening crystal boundary and the consequent grain deformation.

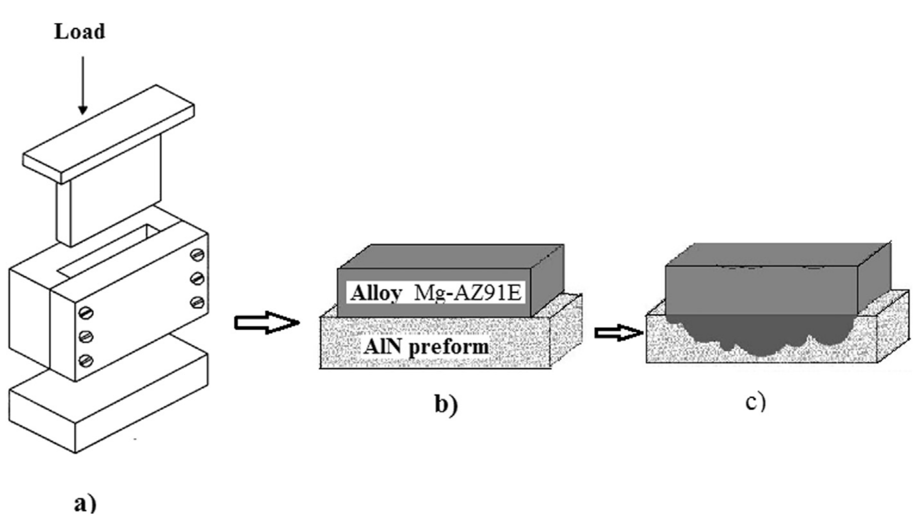

Fig. 1. Fabrication route of the composite by self-infiltration technique. a) Green preform compression of AlN sample. b) Joint of Mg-AZ91E alloy over AlN preform. c) Couple self-infiltration inside of furnace at 850 ± 5 °C.