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Effect of iron addition on microstructure, mechanical and magnetic properties of Al-matrix composite produced by powder metallurgy route

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Abstract: The effect of iron addition on the microstructure, mechanical and magnetic properties of Al-matrix composite was studied. Mechanical mixing was used for the preparation of 0, 5%, 10% and 15% Fe−Al composites (mass fraction). Mixtures of Al−Fe were compacted and sintered in a vacuum furnace at 600 °C for 1 h. X-ray diffraction (XRD) of the samples containing 5% and 10% Fe indicates the presence of Al and Fe peaks, while sample containing 15% Fe reveals Al and $Al_{13}Fe_4$ peaks. The results show that both densification and thermal conductivity of the composites decrease by increasing the iron content. The presence of iron in the composite improves the compressive strength and the hardness. The strengthening mechanism is associated with the grain refinement of the matrix and uniform distribution of the Fe particles, as well as the formation of $Al_{13}Fe_4$ intermetallic. The measured magnetization values are equal to 0.3816×10^{-3} A·m^2/g for 5% Fe sample and increases up to 0.6597×10^{-3} A·m^2/g for 10% Fe sample, then decreases to 0.0702×10^{-3} A·m^2/g for 15% Fe sample. This can be explained by the formation of the diamagnetic $Al_{13}Fe_4$ intermetallic compound in the higher Fe content sample detected by XRD analysis.

Key words: Al−Fe composite; powder metallurgy; microstructure; mechanical properties; magnetic properties

1 Introduction

Aluminum matrix composites (AMCs) are one of the most demanding engineering materials in the category of metal matrix composites (MMCs) due to the combination of their light weight and excellent mechanical and tribological properties. These composites have been widely used for structural, and functional applications in automotive and aerospace industries [1−3]. The optimum properties of AMCs depend on good selection of the reinforcing phase and the processing technique/ parameters.

Powder metallurgy (P/M) route is one of the most widely used methods for producing AMCs due to its low processing costs as well as the ease and the accuracy to obtain near net shaped components of complex geometry. The most essential steps of P/M technique are mixing of powders, compaction, and sintering [4−6]. Compaction of loose powders under externally applied pressure and sintering of green compacts produced in earlier stage are the main processing parameters, and these parameters affect the density of the final product.

Al−Fe alloys are attractive for application at temperatures beyond those normally associated with conventional Al alloys because of the stability of the microstructure originating from the low diffusivity of Fe in Al. In addition, alloying Al with Fe increases its high temperature strength due to dispersion of second-phase particles [7]. The strengthening effect in Al−Fe alloys can be enhanced by increasing the solid solubility of Fe in Al matrix by nonequilibrium processing techniques [8−15].

In a comprehensive study, it was found that most of the earlier investigations related to Fe−Al binary phase system, were focused either on liquid-phase sintering and/or iron-rich composition (more than 20% Fe) [16]. Therefore, in the present investigation, an attempt has

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been made to examine the compaction and sintering behavior of Al-rich Al−Fe binary phase system. The aim of this work is the preparation of 0−15% Fe−Al metal matrix composites by P/M route. The major objective of the present investigation is to study the effect of Fe content on the physical, mechanical and magnetic properties of Al-matrix composites.

2 Experimental

2.1 Composite preparation

Commercially atomized aluminum powder with an average particle size of 20 μm and 99.7% purity (Fig. 1(a)) and Fe (99.5% purity and 10 μm in size) (Fig. 1(b)) were used as starting materials for composite fabrication. The appropriate amounts of Al with 5%, 10% and 15% Fe of the selected powders were thoroughly mixed in a conventional double-cone mixer at 180 r/min for 3 h to achieve homogenization and remove any clusters of powders. The powders were mixed with 0.5% paraffin wax as a lubricant to reduce friction during compaction, and liquid acetone was used as a process control agent. The mixed powders were dried at 80 °C for 30 min and cold compacted at room temperature in a uniaxial press at 500 MPa. The prepared green compacts were then dried for 30 min at 200 °C for complete removal of moisture, entrapped gases, and other impurities. Furthermore, sintering of all the green compacts was carried out using a ceramic tubular furnace in a vacuum atmosphere at 600 °C for 1 h and a heating rate of 10 °C /min.

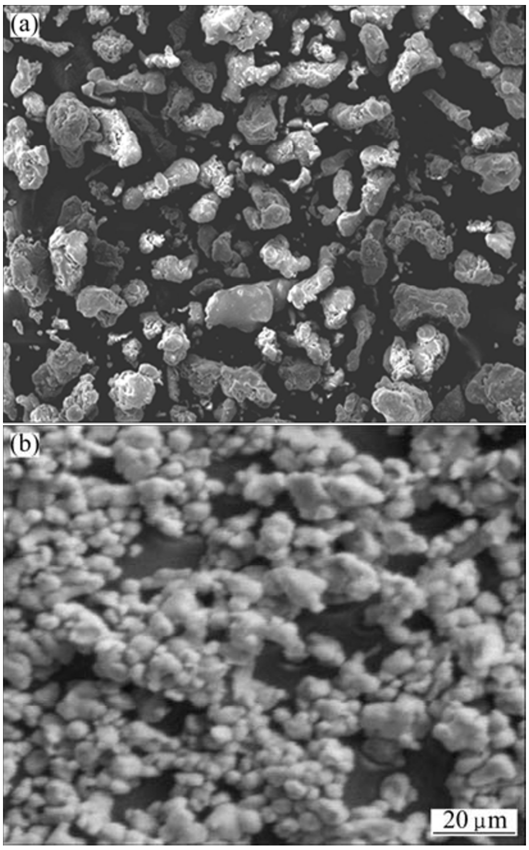

Fig. 1 SEM micrographs of elemental powders of aluminum (a) and iron (b)

2.2 Composite characterization

X-ray diffraction (XRD) analysis was carried out on a diffractometer model Burcker D8 Advance with Ni filtered and Cu target, K_α radiation. The crystallite size, the amount of dissolved Fe powders and the constituent phases of the sintered samples were estimated. True densities of the composites were measured by using the Archimedes' method (ASTM B962) and compared with the theoretical densities to obtain varying degree of densification. Electrical conductivity of the samples were measured and the thermal conductivity can be calculated according the Wiedemann-Franz law. The previous publication by the authors gave a detailed description of the procedures [17].

The microstructure of the prepared composites was examined by both optical model Olympus PMG 3−F3 microscope and scanning electron microscope (SEM, model: JEOL, JSM−5410). The elemental analysis of the specimens was performed using an energy dispersive spectroscopy (EDS) microanalyses equipped on scanning electron microscope (SEM). Hardness was measured using Vickers indentation technique with a load of 3 kg for a dwelling time of 10 s and an average of five readings was reported. The mechanical properties of the sintered samples were evaluated also by a compression test using a universal testing machine model HU−F500KN, according to standard ASTM E9. Cuboidal specimens of 2 mm × 2 mm × 4 mm at an initial strain rate of 1.0×10^{-3} s^{-1} at room temperature were used [18]. The compression experiments were terminated at 65% specimen strains.

The magnetic properties of investigated materials were measured using a 9600-1 LDJ vibrating sample magnetometer (VSM) in which the samples were vibrated at a constant frequency between a set of sense coils. As the magnetic field is varied through a specified range, the magnetic moment of the sample is measured by the sense coils with a lock-in amplifier. The dependency between the magnetization and magnetic field (hysteresis loop) for the prepared WHAs samples was measured. The measured properties included magnetic saturation (M_s), coercivity (H_c), permeability (μ_r) and remanence magnetization (retentivity) (M_r).

3 Results and discussion

3.1 X-ray diffraction analysis

Figure 2 shows the XRD patterns of pure Al, 5%, 10% and 15% Fe−Al composites. The XRD patterns for 5% and 10% Fe−Al composites show two types of peaks