Journal of Alloys and Compounds 536S (2012) S26–S30

Contents lists available at SciVerse ScienceDirect

Journal of Alloys and Compounds

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

Characterization of Al_2O_3NP–Al_{2024} and Ag_CNP–Al_{2024} composites prepared by mechanical processing in a high energy ball mill

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ARTICLE INFO

Article history:
Received 8 July 2011
Received in revised form 5 December 2011
Accepted 7 December 2011
Available online 16 December 2011

Keywords:
Mechanical alloying
Nanocomposites
Reinforcement

ABSTRACT

Mechanical alloying was used to produce two kinds of metal matrix composites based on 2024 aluminum alloy. The nanocomposites were reinforced with different percentages of Al_2O_3 and Ag_C nanoparticles. The content of nanoparticles has an important role on the mechanical properties of the nanocomposites. A milling time of 10 h is enough to form the Al_{2024} nanocomposites. The thermograms obtained by differential scanning calorimeter show the temperatures of phase precipitation, which were identified by X-ray diffraction. The results revealed that mechanical alloying is an excellent route for the incorporation and distribution of nanoparticles into Al_{2024}.

1. Introduction

Aluminum-based metal matrix composites (MMCs) offer potential for advanced structural applications when high specific strength and modulus, as well as good elevated-temperature resistance, are important. Most of the commercial work on MMCs has focused on aluminum as the matrix metal.

The improvement of metal matrix composites has become a need in modern technology, to enhance physical and mechanical properties. MMCs have been developed in recent years, among which aluminum matrix composites have been found to have various applications in the industry. This is due to their low density, high toughness and corrosion resistance [1]. Major applications include aerospace, military and automotive industries. However, the drawback for these composites is their high production cost [2]. It has well been established that addition of ceramic particles to aluminum matrix improves strength, wear resistance, and corrosion resistance [3,4]. Al_2O_3 after SiC particles have made many applications in industry.

To achieve homogeneity of reinforcement particles distribution, several methods may be used, such as a proper choice of the particle size and the use of polar solvents that neutralize the charge on the surface of the particles [5]. A more efficient method to improve the particle distribution is to use mechanical alloying (MA) technique or ball mill process [6–8]. Mechanical alloying allows obtaining both, a very fine microstructure and to extent the solid solubility limits which may result in increased precipitation in a subsequent consolidation process [9].

The focus of this work is the formation of 2024 aluminum alloy (Al_{2024}) as well as the dispersion of NP (Al_2O_3NP and Ag_CNP) by a milling process. There are several works related to the dispersion of hard particles, but about the ductile particle dispersion, works are scarce or inexistent. The effect of two different kinds of nanoparticles (Al_2O_3NP and Ag_CNP) nanoparticles on the mechanical resistance of an aluminum alloy is characterized. Carbon shell helps to avoid the dissolution of silver into the aluminum matrix. Microstructural characterization as a function of milling time and nature of NP is presented.

2. Experimental procedure

The raw materials were elemental powder (Al, Cu, Mg, Mn, Si and Fe), alumina nanoparticles (Al_2O_3NP) and carbon-coated silver nanoparticles (Ag_CNP). Elemental powders were mixed in the correct proportion to form the Al_{2024}. MA is the milling process used to produce the Al_{2024} and the composites materials. Different concentrations of NP were dispersed into Al_{2024} matrix, Table 1 shows the different compositions used.

Milling runs were done in a high energy ball mill (SPEX 8000M). A ball to powder weight ratio of 5:1 was used in all milling runs. Due to the high ductile nature of Al, the use of PCA is imperative in order to minimize cold welding between powder particles and it also inhibits the agglomeration process. In order to avoid excessive welding of powders, 5 drops of methanol were added to the powder acting as a

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doi:10.1016/j.jallcom.2011.12.010

Table 1
Kind and concentration of nanoparticles reinforcement used in this work.

Matrix	Reinforcement agent	Concentration [wt.%]						
Al_{2024}	Al_2O_3NP	0.0	0.5	1.0	1.5	2.0	2.5	3.0
	Ag_CNP	0.0	0.5	1.0	1.5	2.0	2.5	3.0

process control agent. The millings were performed in argon atmosphere to avoid oxidation of the powders. Two milling times were 2 and selected 2 and 10 h based on previous works [10–13].

The particle size distribution and morphology were determined using a scanning electron microscopy (SEM) JEOL–SM 5800, operated at 20 kV. The microhardness measurements were done over polished surface (milled products were cold-mounted in resin and then carefully polished) of reinforced and unreinforced Al_{2024} using Future-Tech Corp model FM-7 with a load of 50 g with 15 s of dwell time.

The as-milled powders were characterized by X-ray diffraction (XRD) in a PANalytical XïPert Pro, with Cu Kα radiation (λ = 1.5406 Å), operated at 40 V and 25 A, in the 2θ range of 30–90°. Step and collection time were 0.05° and 5 s respectively. Differential scanning calorimetry (DSC) was done in a TA instrument M 2920 DSC equipment. DSC runs were from 25 °C to 575 °C under dynamic argon atmosphere, and heating-cooling rate of 20 °C/min were used in all runs. Milled products were consolidated under 330 MPa, solution treated at 450 °C during 2 h, followed by water quenching and aging heat treatment at 190 °C for 2 h. After heat treatment, products were characterized by X-ray diffraction (XRD) in a PANalyticalXïPert Pro, with Cu Kα radiation (λ = 1.5406 Å), operated at 40 V and 25 A, in the 2θ range of 10–90°.

3. Results and discussion

Fig. 1 shows the morphology and particle size evolution of nanocomposites as a function of milling time. At the shorter milling time the welding is dominant over fracturing, giving-rise to powder particles with size in the order of 100–150 μm. Longer milling time (10 h) enhances the comminuting and a fine particle size is present. Apparently nanoparticles added have an effect over the final size in as-milled products.Fig. 2a and b shows the micro-hardness value in composites in the as-milled condition as a function of milling time and content of NP. A direct relationship of hardness with NP is observed. As the weight percent of NP is increased, the hardness increases as well. Fig. 2a shows the results for 2 h of milling. The most important increment was observed in composites with Ag_CNP, all the values are above the composites with alumina. The higher increment (∼40%) was observed at 3.0% Ag_CNP, for Al_2O_3NP the increment at same composition was in the order of ∼26 HV units.For the longer milling time (10 h), it was observed a different case. Higher hardness value was observed in composites with

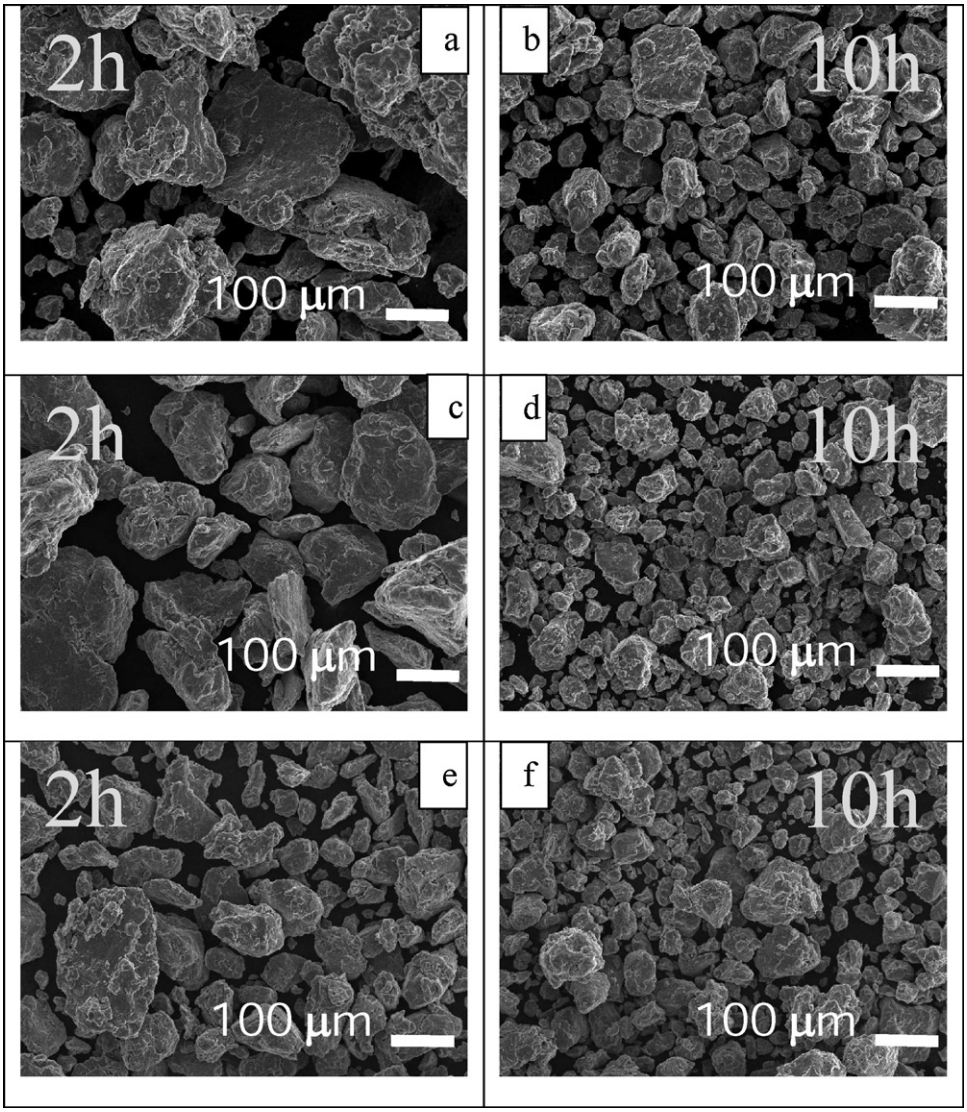

Fig. 1. Evolution of the morphologies and size in milled products: (a) Al_{2024} after MA for 2 h; (b) Al_{2024} after MA for 10 h; (c) Al_{2024}/Al_2O_3NP-3.0%/2 h; (d) Al_{2024}/Al_2O_3NP-3.0%/10 h; (e) Al_{2024}/Ag_CNP-3.0%/2 h; (f) Al_{2024}/Ag_CNP-3.0%/10 h.