Journal of Industrial and Engineering Chemistry 18 (2012) 2129–2134

Contents lists available at SciVerse ScienceDirect

Journal of Industrial and Engineering Chemistry

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

Effects of sintering temperature and graphite addition on the mechanical properties of aluminum

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ARTICLE INFO

Article history:
Received 4 March 2012
Accepted 12 June 2012
Available online 19 June 2012

Keywords:
Aluminum alloys
Exfoliated graphite
Mechanical properties
Nanoparticles
Sintering temperature

ABSTRACT

The effects of different sintering temperatures, namely 400, 500 and 600 °C, on the mechanical properties of four aluminum–graphite alloys were reported. Different percentages of exfoliated graphite nanoplatelets particles (xGnP) were added to pure aluminum by using the powder metallurgy technique to produce Al-0 wt.%xGnP, Al-1 wt.%xGnP, Al-3 wt.%xGnP, and Al-5 wt.%xGnP. The density, fracture surface, compression, and hardness measurements were carried out to report the mechanical properties of the different aluminum–xGnP alloys. Combined data indicated that the Vickers hardness and compressive strength increase, on the other hand, the density decreases with increasing the graphite content in the Al alloys.

1. Introduction

Aluminum and its alloys are widely used in many industrial applications owing to their important characteristics. They are characterized by their good electrical and thermal conductivities, high strength to weight ratio, easy to deform, high ductility, good workability, and good corrosion resistance [1–5]. Therefore aluminum alloys have been used as a material in manufacturing automobile and aircraft components due to their high strength to weight ratio in order to make the moving vehicle lighter, which results in saving in fuel consumption, household appliances, aviation, containers, etc. [5–9].

The powder metallurgy (P/M) technique can be used in fabricating different alloys in the solid state including aluminum alloys. P/M has great versatility and low cost of production besides it is highly evolved method of manufacturing reliable net shaped components by blending elementalor pre-alloyed powders together. The P/M fabrication takes place by mixing the hardening particles with the metallic powders followed by consolidation and sintering [9–14]. The way of mixing raw materials controls both the distribution of particles and porosity of the alloy matrix. The distribution of particles and porosity of the alloy affect the mechanical properties as well as the tribological behavior of the fabricated alloys [13,14]. It has been reported that [14–17] the mechanical properties of an alloy depends mainly on the size of particles, i.e. increased mechanical properties will be obtained by using very fine particles and vice versa. However, the efficiency by which reinforcement particles strengthen the matrix depends on their type, size, morphology, volume fraction and overall distribution [18].

Exfoliated graphite nanoplatelets (xGnP) have attracted the attention as a substitute for carbon nanotubes, given the predicted excellent mechanical, structural, thermal and electrical properties of graphite and their similar properties to nanoscale carbon black and carbon nanotubes [19,20]. It is proven that the structure of graphite and carbon nanotubes are made up of the same building blocks [21]. Biswas and Drzal [22] have developed a process that can produce exfoliated graphite nanoplatelets of 4–10 nm in thickness and from 1 to 15 μm in diameter.

The objective of our current work was to fabricate different aluminum-graphite alloys using the PM technique. The work has led to fabrication of three alloys, namely, Al-1 wt.%xGnP, Al-3 wt.%xGnP, and Al-5 wt.%xGnP, in addition to the pure aluminum, Al-0 wt.%xGnP. The objective was extended to report the effect of sintering temperature and the percentage of graphite additions on the density, microstructure, compression strength and micro-hardness of aluminum.

2. Experimental

2.1. Materials

An aluminum powder with 99.0% purity was supplied by Riedel-De Haen Ag Seelze-Hannover, Germany. The exfoliated graphite nanoplatelets particles were supplied by Asbury Graphite Mills, USA, with label of Asbury 3772.

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1226-086X/$ – see front matter
http://dx.doi.org/10.1016/j.jiec.2012.06.007

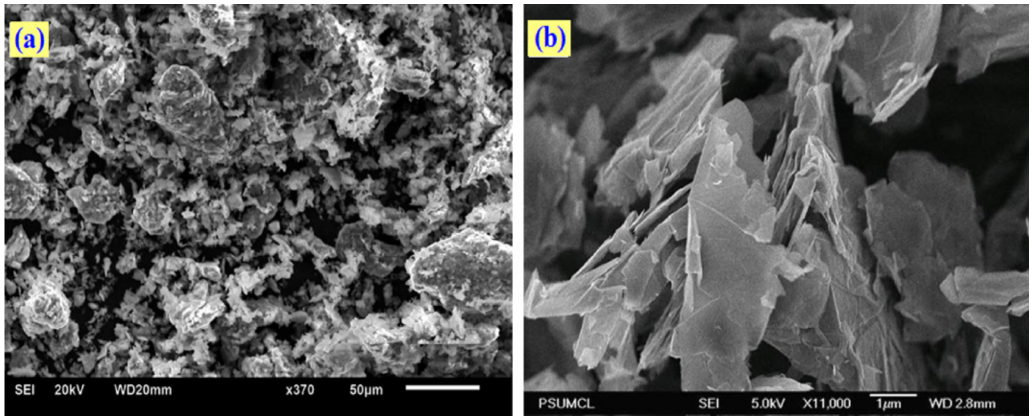

Fig. 1. SEM micrographs of (a) Al powder and (b) exfoliated graphite nanoplatelets.

The morphology of the aluminum powder (a) and xGnP (b) as starting materials is shown respectively in Fig. 1. It is clearly seen from Fig. 1a that the aluminum powder shows a bigger thickness compared to the xGnP particles. On the other hand, the average thickness of xGnP particles was determined from the SEM micrograph shown in Fig. 1b to be circa 5–10 nm. This reflected also on the measured densities of aluminum and xGnP particles, where the density of the aluminum powder measured 2.7 g/cm^3 and the density of xGnP recorded nearly 2.2 g/cm^3.

The particle size distribution of Al powder and xGnPs was measured by particle size analyzer as demonstrated in Fig. 2. After measurement, the median particle size of the as received aluminum powder was 20 μm as shown in Fig. 2a. The median particle size of the xGnP particles that act as reinforcement was 7.5 μm as presented in Fig. 2b.

2.2. Fabrication of aluminum–graphite alloys

First, the xGnP was dispersed in acetone using a disperser machine at speed of 2000 round per minute (rpm) for 30 min. Second, the graphite particles were slowly added into solution with the xGnP particles content of 0, 1, 3 and 5 by weight percent. The mixing process was continuously performed for 1 h to obtain a homogenous mixture. The mixture was then filtered and dried at 80 °C for overnight to generate a dried mixture powders. The mixture powders were green compacted at pressure of 500 MPa for 5 min to produce a disc-shaped specimen with the ratio of 1:1 between diameter and height. Afterward, the disc specimens were sintered at temperatures of 400, 500 and 600 °C for 5 h in a pressureless furnace.

2.3. Surface morphology, density, compressive strength, hardness, and fracture surface

The prepared alloys were observed by a computer controlled optical microscopy (OM, Olympus, Model BX51M, Japanese made) to recognize the distribution of xGnP particles within aluminum.

The experimental density was measured according to the Archimedes principle (Bouyancy method), by using a balance with an accuracy of 0.1 mg. Meanwhile, the theoretical density of composites was measured by the rule of mixture using the theoretical density 2.7 g/cm^3 for Al powder and 2.0 g/cm^3 for xGnP particles. The phase of compacted alloys was determined using Philips automatic X-ray diffractometer with Cu target Kα radiation. Compression test was carried out under room temperature using an Instron Universal Testing Machine with a strain rate of 10^{-3} s^{-1}. At least three compressive specimens were tested for each composition. The hardness of composites was tested by a micro-indenter (Vickers hardness) under a load of 200 g and a dwell time of 15 s. The measurement was performed for five times from random locations on the central region of polished cross-section and they were then averaged. The morphology and fracture surface were observed by means of a JEOL (model JSM-6610LV) scanning electron microscope.

3. Results and discussion

3.1. Optical microstructure of the fabricated alloys

The optical microstructures of (a) pure Al, (b) Al-1 wt.%xGnP, (c) Al-3 wt.%xGnP, and (d) Al-5 wt.%xGnP alloys after sintering at

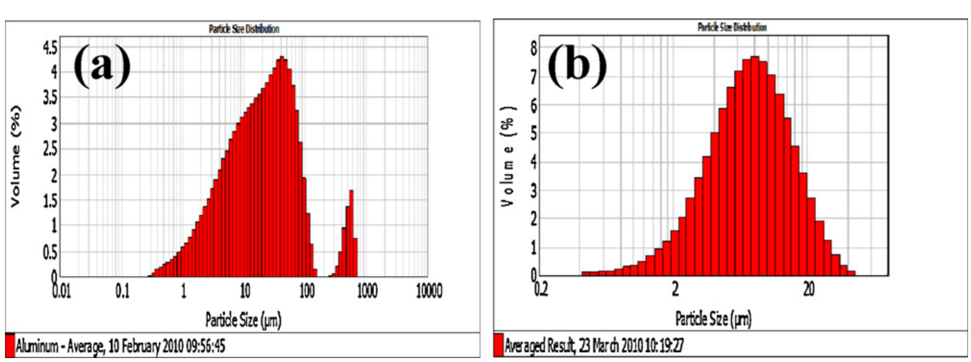

Fig. 2. Particle size distribution of (a) as-received Al powder and (b) exfoliated graphite nanoplatelets.