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Original

Mechanical properties of Aluminum-Copper$_{(p)}$ composite metallic materials

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Abstract

Composite metallic materials (CMMs) are prepared by dispersing copper particulates in aluminum matrix using stir-cast technique. Their behavior is compared with the alloy having similar composition. The effect of particulate composition is studied by varying the copper concentration between 5 and 15 wt%. Hardness increased with increasing particulate contents in both cast and homogenized conditions. Composites show a 13% drop in strength and 15% drop in strain compared to the alloy. With increasing reinforcement content, the strength increased and dropped. Agglomeration due to increased reinforcement contents may be the reason for the decrease in strength values. Microstructures corroborate the above results.

Keywords: Stir casting; Microstructure; Mechanical properties; Interfaces; Intermetallics

1. Introduction

Metal matrix composites are designed to achieve high strength properties. Metal matrix composites (MMCs) reinforced with ceramic particles are widely used because of their high specific modulus, strength and wear resistance. Many of the investigations have shown improved mechanical properties but are limited with low and poor ductility. An optimized combination of surface and bulk mechanical properties may be achieved if Al-MMCs are processed with a controlled gradient of reinforcing particles and also by adopting a better method of manufacturing. Though there is no clear relation between the mechanical properties of the composites, type and volume fraction of reinforcement, surface nature of reinforcement and size of the reinforcement are proved to be effective in improving the strength of the composites. Composite ductility is governed by matrix processors that will be affected by the presence of the reinforcements. This is evidenced by the decrease in ductility while increasing reinforcement volume fraction. An increasing trend of hardness with increase in weight percentage of SiC has been reported by Singla, Dwivedi, Singh, and Chawla (2009). Several investigators Taya, Lulay, and Lloyd (1991), Wang and Rack (1991), Bhansali and Mehrabian (1982) reviewed the influence of the manufacturing route on the properties of MMCs and the factors which control the properties of particulate MMCs by Kelly (1973). Kok (2005) studied the mechanical properties of Al_2O_3 particle reinforced 2024 Al alloy composites produced through vortex method. It was reported that optimum conditions of the production process are 700 °C (pouring temperature), 550 °C (preheated mold temperature), 900 rev/min (stirring speed), 5 g/min (particle addition rate), 1 min (stirring time) and 6 MPa (applied pressure). Kumar, Lal, and Kumar (2013) reported that the hardness and tensile strength of A359/Al_2O_3 MMC has been increased. It was also observed that electromagnetic stirring action adopted during the fabrication resulted in smaller grain size and good particulate matrix interface bonding. A successful attempt has been made by Venkatesh and Harish (2015) on Al/SiC composites produced through the powder metallurgy route to achieve the desired properties and also to improve the mechanical properties. For a variety of reinforcements, improvement in strength,

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fatigue, modulus, wear resistance and creep has been demonstrated by Neih and Chellman (1984) and Friend (1987). Studies on trimodal aluminum metal matrix composites and the factors affecting their strength are reported by Yao et al. (2010). Of these, tensile strength is the most convenient and widely quoted measurement and is of central importance in many applications. Saravanan, Subramanian, Ananda Krishnan, and Sankara Narayanan (2015) observed that there is an increase of 30% in hardness and an increase in tensile strength that is almost twice that of base aluminum alloy for TiB_2 particulate reinforced composites. The effects of matrix microstructure and particle distribution on fracture of Al metal matrix composites are also reported by Nair, Tien, and Bates (1985). The influence of stirring speed and stirring time on the distribution of particles in SiC AMC has been analyzed by Prabu, Karunamoorthy, Kathiresan, and Mohan (2006). The ductility and fracture toughness of the MMC and hence indirectly the strength is governed by the reinforcement distribution apart from the reinforcement level. It is essential to have a uniform distribution of the reinforcement for effective utilization of the load carrying capacity of the resultant composite. Nieh, Raninen, and Chellman (1985) also observed, in the early stages of processing, a non-uniform distribution of reinforcement, which persists to the final product in the forms of steaks or clusters of reinforcement with their attendant porosity all of which lowered the strength, ductility, and toughness of the material. For a given matrix alloy, the elongation to failure is reduced by increasing volume fraction (Crowe, Gray, & Hasson, 1985; Kamat, Hirth, & Mehrabian, 1989; Liu, Ricket, & Lewandoski, 1989) and the size of the reinforcement (England & Hall, 1986; Girot, Quenisset, & Naslain, 1987; Manoharan & Lewandowski, 1989; Mummery & Derby, 1991). Though there are many applications for MMCs, fabrication, secondary processing, compatibility between the matrix and reinforcement and characterization are still the major hurdles in the application of these composites. The main damaging mechanisms of MMCs have been found to be loss of ductility, particle matrix interface debonding, particle cracking, particle pull out and agglomeration of particulates. Thought has been given to have the advantages of both MMCs and metal–metal combination systems by choosing conventional alloy systems for the manufacture of composites with restricted solubility. To have good compatibility between the matrix and the reinforcement, an established alloy system with proven application needs to be chosen, where the solvent acts as the matrix and the solute as the reinforcement.

Major fraction of these composites are produced by foundry routes. The advantages include bulk production, ease of fabrication and cost effectiveness. The presence of dendritic structures restricts direct application to a major extent. And this effect is much more accentuated because of the presence of reinforcements. Ingots are secondary processed to nullify these effects. Several workability tests are available to study the deformation behavior under the combined stress and strain conditions which are usually found with bulk deformation processes. Rozovsky, Hahn, and Avitzur (1973) reported that the compression of a short cylinder between anvils is a much better test for metal working applications. The deformation behavior of solid cylinders of an aluminum alloy metal matrix composite under dry condition was estimated by Joardar, Sutradhar, and Das (2012). It was reported that a cylindrical preform can be successfully compressed to a height reduction by 28–32% without fracture. Dikshit et al. (2010) carried out cold upsetting experiments under unlubricated condition on cast and homogenized AA2014/SiC composites to study the effect of homogenization on deformation behavior. Orbulov and Ginsztler (2012) indicated that engineering factors such as the aspect ratio (height/diameter ratio) of the specimens and the temperature of the tests, have significant effect on the compressive strength and properties. The effect of reinforcing particle shape and interface strength on the deformation and fracture behavior of an Al/Al_2O_3 composite was investigated by Romanova, Balokhonov, and Schmauder (2009). It was also reported that interface debonding and particle cracking are the two mechanisms for a particle fracture. Minghetti et al. (2001) observed high deformation rates with crack free AA6061 – Al_2O_3 particulate MMC samples by the cold forming process.

Cored structures are most common in as-cast metals. For some applications, a cored structure is objectionable. There are two methods for solving the problem of coring. The method preferred by the industry is to achieve equalization of composition or homogenization of the cored structure by diffusion in the solid state. At room temperature, for most metals, the diffusion rate is very slow, but if the alloy is reheated to a temperature below solidus line, diffusion will be more rapid and homogenization will occur in a relatively short time.

With this background, in the present investigation an attempt has been made to know the homogenization effect, compression behavior and mechanical properties of Al–Cu composite metallic materials (CMMs). The results are compared with that of the alloy.

2. Experimental

2.1. Fabrication of alloy and composite

Cut ingots of pure aluminum are melted in a stationary pot type electric heating furnace in clay graphite crucible at 700 °C. Copper pieces wrapped in aluminum foil are added to the aluminum melt at 850 °C and the same temperature is maintained until copper melts completely. For the fabrication of the composite, the reinforcements (powders) are produced initially by filing the copper rod, rotating on a lathe. IE grade aluminum (99.5%), supplied by M/s National Aluminum Company, India, is used as the base matrix material in the present investigation. A pre-weighed quantity of aluminum is melted in a graphite crucible using a 3-phase bottom-pour electric resistance furnace (Bhargava, Samajdar, Ranganathan, & Surappa, 1998). The bath temperature is maintained at 720 °C. Pre-weighed quantities of copper particles (average particle size 250 μm), thoroughly dried at 200 °C in a muffle furnace, are added quickly and uniformly to the vortex in the melt, such that particles are suspended in the melt. Madhusudan, Sarcar, and Bhargava (2009) reported that the EDX analysis for the Al–Cu composite showed a gradual

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