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Effect of nano-silver on microstructure, mechanical and tribological properties of cast 6061 aluminum alloy

G. PITCHAYYAPILLAI[1], P. SEENIKANNAN[1], P. BALASUNDAR[2], P. NARAYANASAMY[3]

1. Department of Mechanical Engineering, Sethu Institute Technology, Kariapatti, Virudhunagar 626 115, Tamilnadu, India;
2. Department of Mechanical Engineering, Rajalakshmi Institute of Technology, Chennai 600 124, Tamil Nadu, India;
3. Department of Mechanical Engineering, Kamaraj College of Engineering and Technology, Virudhunagar 626 001, Tamil Nadu, India

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Abstract: Al6061 matrix with different amounts of nano-silver (1% and 2%) was produced by stir-casting method. Produced samples were characterized by hardness, tensile, compression and wear tests. The hardness of the specimens at room temperature was measured by Brinnell hardness testing machine. The magnitude of hardness increased evidently with the function of the mass fraction of the nano-Ag particle. The polished specimens were examined with an optical microscope. The fracture surfaces of tensile and compressive specimens were further examined by scanning electron microscopy. Wear mechanisms were discussed based on the scanning electron microscopy observations of worn surface and wear debris morphology. There is an increase in compressive strength, ultimate tensile strength, elongation and wear resistance of the Al−Ag composites compared with base alloy. The execution of stir-casting technique is relatively homogenous and fine microstructure which improves the addition of reinforcement material in the molten metal. The results show that Al6061−nano-silver which is the best combination of hardness can replace the conventional material for better performance and longer life.

Key words: Al6061 alloy; nano silver; stir casting; mechanical properties; tribological properties

1 Introduction

Aluminium and aluminium alloys are gaining huge industrial significance because of their outstanding combination of mechanical, physical and tribological properties over the base alloys [1]. Al6061 alloys have been paid increasing attention in the application in the field of structural, automobile and aerospace industries, for its high strength, good heat and good resistance [2]. The influences of alloying (major elements such as Si, Cu, Mg, Ni, Sn, Ti, B, Sr, Be, Mn, Yb, Cr, Zr, Fe, Zn, Ce and Li) on microstructures and mechanical properties of aluminium alloys are evaluated and reviewed [3−8]. Aluminum alloys have gained extensive applications in automotive and aerospace industries due to their specific characteristics. These include low density, high specific strength and stiffness, good fatigue properties, dimensional stability at high temperatures, and acceptable tribological properties. In recent centuries, among all the Al alloys, Al6061 alloys have been increased much attraction as a matrix material to prepare MMCs owing to their excellent mechanical properties and good corrosion resistance. They are used in the heat-treated condition in which an optimal ratio of physical and mechanical properties is obtained. It solidifies in a broad temperature interval and is suitable for the treatment in the semi-solid state as well as as-cast condition [7,8].

Silver has special properties that make it a very useful and precious metal. It has unique optical, electrical, and thermal properties and is being incorporated into products that range from photovoltaics to biological and chemical sensors [9,10]. An increasingly common application is the use of silver particles for antimicrobial coatings, and many textiles, keyboards, wound dressings, and biomedical devices now contain silver nano-particles that continuously

Corresponding author: G. PITCHAYYAPILLAI; Tel: +91-9443556047; E-mail: gp_pillai05@yahoo.com
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release a low level of silver ions to provide protection against bacteria [11]. The additions of Ag to Al−Cu−Mg alloys promote the precipitation of finely dispersed plates of the orthorhombic *Ω* phase with the {111} *α* habit plane [12].

An element with a fine and uniform dispersion of particles in the range of 10 nm−1 μm is referred to as "nano-alloying element". Mechanical properties of aluminum alloys such as strength and ductility may be improved, simultaneously if the dispersed particles are of nano-size [13]. The improvement in the mechanical properties of aluminum alloys at room and elevated temperatures strongly depends on the size, shape and distribution of the alloying element in the matrix. At present, a number of techniques are available for the production of micron-sized alloying element [14]. Stir casting and powder metallurgy techniques have been commercially used for production of aluminum alloys [15]. Stir casting is a primary process of alloys and composite production in which continuous stirring of molten base metal is done followed by introduction of alloying element and reinforcements [16]. The various advantages of stir casting are simplicity, flexibility, applicability to large quantity, near net shaping, lower cost of processing and easier control of the matrix structure [17]. High homogeneity is required to attain optimum mechanical properties for the alloying/ composite material [18,19]. Stir casting offers better matrix particle bonding due to stirring action of particles into the melts by selecting appropriate processing parameters, such as stirring speed, time, and temperature of molten metal, preheating temperature of mould and uniform feed rate of particles [20]. The porosity level of composite should be minimized and the chemical reaction between the reinforcement and matrix should be avoided [21,22].

The earlier studies clearly explained the strong interaction between the load and sliding distance as the cause for the wear of a material [23,24]. The study pertains to examine the sliding wear behaviour of composites at different sliding speeds over a range of applied loads and distances. The sliding load and distance are noted with a positive influence on wear with increase of either load or sliding distance or both. But speed shows a negative influence on wear, indicating decrease of wear with increase of speed. RAVINDRAN et al [25] and NARAYANASAMY et al [26] have also reported higher values of coefficient of friction of AMCs as compared to the base alloy. Tribological properties of a sliding system for the materials depend on the properties of the specimen materials, counterfeit materials and their interaction with the environment as well as the experimental conditions, including the applied load and sliding velocity. The wear resistance is mostly influenced by the reinforcement size, volume percentage, load, sliding speed and sliding distance [26]. There are excellent reviews on the tribological properties of aluminum alloys in which these composites are subjected to sliding type of wear with the counter bodies. It is noted that wear of the composites is generally a function of the matrix structure, the processing route, heat treatment as well as the porosity content, particle matrix bonding, reinforcement volume fraction, particle size, and the shape and nature of the reinforcing phase [27].

As a result, during the last decades, there has been a considerable interest in using aluminum alloys in the industry. However, no reference could be found in the literature relating to aluminum alloyed with nano-silver particles, although these alloys are very hopeful for improving the mechanical properties of aluminum alloy. It is tremendously demanding for the traditional mechanical stirring technique to dispense nano-size particles uniformly in Al6061 melts because of the poor wettability and high specific surface areas of nano-Ag particles which lead to agglomeration and particle clustering. In this study, the effects of the addition of Ag on the microstructure, mechanical and tribological properties of the Al6061 alloy were examined.

2 Materials and fabrication

This work is concerned with the study of nano-Ag incorporated aluminum alloy produced by the stir-casting method. The matrix material utilized in this study is Al6061. This alloy is best suited for mass production of lightweight metal castings. Al6061 alloy has copious reimbursement like formability, weldability, wear resistance, corrosion resistance and inexpensive. Al 6061 is available through M/s Coimbatore metal mart, Tamilnadu, India. The chemical composition of Al6061 alloy is given in Table 1. Silver is lustrous, soft, awfully ductile and malleable, which is an excellent conductor of heat and electricity, and can endure extreme temperatures. Nano-silver (Ag) of 60−100 nm in size used for this study was supplied by NaBond Technologies Co., Ltd., China. Table 2 lists the properties of matrix and reinforcing material.

Morphologies of the as-received Al6061 ingots and nano-silver powders were observed by scanning electron microscopy (Fig. 1(a)). The morphology of as-received Ag particles is shown in Fig. 1(b). The size distribution of the nano-Ag particles was measured by particle size

Table 1 Chemical composition of Al6061 (mass fraction, %)

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.62	0.23	0.22	0.03	0.84	0.22	0.1	0.1	Bal.