PRODUCTION AND CHARACTERIZATION OF MICRO AND NANO Al_2O_3 PARTICLE-REINFORCED LM25 ALUMINIUM ALLOY COMPOSITES

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ABSTRACT

LM25 aluminum alloy metal matrix composites (MMCs) reinforced with weight fractions of micro and nano Al_2O_3 particles up to 10 wt. % were produced by stir casting. The composites thus produced were characterized for their mechanical properties such as hardness and tensile strength as well as for the dispersion of the micro and nano Al_2O_3 particles. The results reveal that stir casting could be an economical route for the production of nano composites. Nano particle reinforced MMCs exhibit better hardness and strength when compared to micro particles reinforced composites. Scanning electron microscopic observations of the microstructures revealed that the dispersion of the micron size particles where more uniform while nano particles led to agglomeration of the particles.

Keywords: metal matrix composites, nano Al_2O_3 particle, stir casting, hardness, strength.

1. INTRODUCTION

Demand for developing metal matrix composites for use in high performance applications; have significantly increased in the recent times. Among these composites, aluminum alloy matrix composites attract much attention due to their lightness, high thermal conductivity, moderate casting temperature and others. Various kinds of ceramic materials, e.g. SiC, Al_2O_3, MgO and B_4C are extensively used to reinforce aluminum alloy matrices. Superior properties of these materials such as refractoriness, high hardness, high compressive strength, wear resistance etc. make them suitable for use as reinforcement in MMCs [1-3].

The objective of developing metal matrix composite materials is to combine the desirable properties of metals and ceramics. The major advantages of aluminium matrix composites (AMCs) compared to unreinforced materials are greater strength, improved stiffness, reduced density (weight), improved high temperature properties, controlled thermal expansion coefficient, improved abrasion and wear resistance and improved damping capabilities [3]. Because of these properties, AMCs are increasingly being utilized in high tech structural and functional applications including aerospace, defense, automotive and thermal management areas as well as in sports and recreation.

Based on the literature survey it is evident that though the application scope for AMCs is expanding, the major hindrance is in the production of these AMCs. The primary process for producing AMCs on an industrial scale can be either solid state processing or liquid state processing [3]. The liquid state processing especially, stir casting is a promising route for the synthesis of AMCs because of their simplicity and scalability. However, stir casting has inherent problems such as good wetting between the particulate reinforcement and the liquid aluminium alloy melt. Moreover the problem with finer reinforcement particles especially nano particles would be agglomeration. If these challenges could be overcome, then stir casting would be a commercially viable technology for producing AMCs especially nano particle reinforced AMCs. A few researchers [2, 4, 5] have made attempts to develop stir casting setup that can overcome these problems and they have been quite successful. Most of the researchers have focused on using micron sized reinforcement particles and not much research has been done using nano size reinforcement particles.

Hashim *et al.*, [2] have identified four technical difficulties in stir casting: difficulty of achieving a uniform distribution of the reinforcement material; wettability between the two main substances; porosity in the cast metal matrix composites; and chemical reactions between the reinforcement material and the matrix alloy. These difficulties need to be overcome in order achieve a MMC with a broad range of mechanical properties. They have also identified the important process variables that affect the mechanical properties of MMC. The holding temperature, stirring speed, size of the impeller and the position of the impeller in the melt are to be considered in the production of cast metal matrix composites.

Sahin [4] has developed a setup for manufacturing MMCs. The setup has a bottom tapping facility. He has evaluated three methods for mixing of the reinforcement and has achieved full and homogenous distribution of the particles in the matrix alloy. However, the setup does not have the facility to change the position of the impeller in the melt. If investigated, this could further enhance the quality of the MMCs produced. The pouring molten mixture is tapped from the bottom of the crucible after mixing process is completed. Hardness of the aluminium alloy improved significantly by addition of SiC particles into it, while density of the composite also increased almost linearly with the weight fraction of particles [4].

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Kok [5] produced Al_2O_3 particle-reinforced 2024 aluminium alloy composites by stir casting followed by application of pressure. He studied the mechanical properties of the produced MMCs. SEM observations of the microstructures showed that the coarser particles were dispersed more uniformly, while the finer particles led to agglomeration and segregation of particles. The porosity of the composites increased with decreasing size and increasing weight percentage of particles. The tensile strength and hardness of MMCs increased but the elongation decreased, with decreasing size and increasing weight percentage of the particles.

Mazahery *et al*., [6] developed a new method based on stir casting to fabricate nano-Al_2O_3 particulate reinforced aluminum composites in order to avoid agglomeration and segregation of particles. Different volume fraction of nano-alumina particles were incorporated into the A356 aluminum alloy by a mechanical stirrer and then cylindrical specimens were cast and tested. The micro structural characterization showed uniform distribution of reinforcement, grain refinement of aluminum matrix and presence of minimal porosity. Experimental results revealed that the presence of nano-Al_2O_3 reinforcement led to significant improvement in hardness, 0.2% yield strength, UTS and ductility.

From the above few literatures on development of stir casting setup, it is quite promising to pursue research in the area of production of nano particle reinforced MMCs. The objective of the present research is to produce both micro and nano Al_2O_3 particle reinforced LM25 MMCs by stir casting and characterize its properties especially hardness, strength and study the distribution of the reinforcement particles.

2. EXPERIMENTAL PROCEDURE

In this study, LM25 aluminium alloy was used as the matrix material while micro and nano Al_2O_3 (alumina) 10 wt% particles was used as the reinforcements. The chemical composition of aluminium alloy (LM25) %wt. shown in Table-1. The micro and Nano Al_2O_3 particles supplied by Alfa Aesar, United Kingdom are 25µm and 40nm, respectively. For manufacturing of the MMCs, 10wt. % of micro and nano Al_2O_3 particles were used.

Table-1. Composition of aluminium alloy (LM25) %Wt.

Cu	0.20
Si	7.50
Mg	0.06
Fe	0.50
Mn	0.30
Ni	0.10
Zn	0.10
Pb	0.10
Sn	0. 05
Ti	0.20
Al	Balance

Figure-1 shows the stir casting furnace used for producing the MMC composites. Initially, LM25 Al alloy was charged into the crucible, and heated to about 750°C, which is above the liquidus temperature of the Al alloy. Then, the mixer was lowered into the melt slowly to stir the molten metal. The micro and Nano Al_2O_3 particles were preheated before being mixed with the Al alloy melt. After the completion of particle feeding, the mixing was continued for a further 7 min. Then the molten mixture was poured in the pre heated mold positioned below the furnace. The furnace had a provision for bottom tapping and this permitted heating as well as stirring to be continued even during tapping of the melt. The casted billets are of 80mm diameter and of 270mm height.

The samples were sectioned and examined by optical microscopy and scanning electron microscopy (SEM). Specimens for metallographic observation were prepared by grinding with 220, 320, 600, 800, 1000 and 1200 grit papers, respectively. Finally the polishing was finished on cloth using diamond paste of 3 and 1µm. These samples were used for studying the dispersion of the reinforcement particles in the matrix.

Figure-1. Stir casting furnace setup.

The hardness tests were carried out using a Rockwell hardness tester on the polished sample using a 1/16 inch diameter steel ball at a load of 100 kg. For each sample, three hardness readings were taken and the average considered for analysis.

The tensile tests were carried out on a Universal Testing Machine (UTM). The micro and nano aluminium composite alloy rods were machined to prepare tensile specimens according to ASTM standards. The load displacement diagram and the load displacement data were recorded from the digital display attached with the UTM. These load and displacement data were transformed to true stress and true strain data using the standard methodology and ultimate tensile strength values were obtained for both micro and nano composites.

3. RESULTS AND DISCUSSIONS

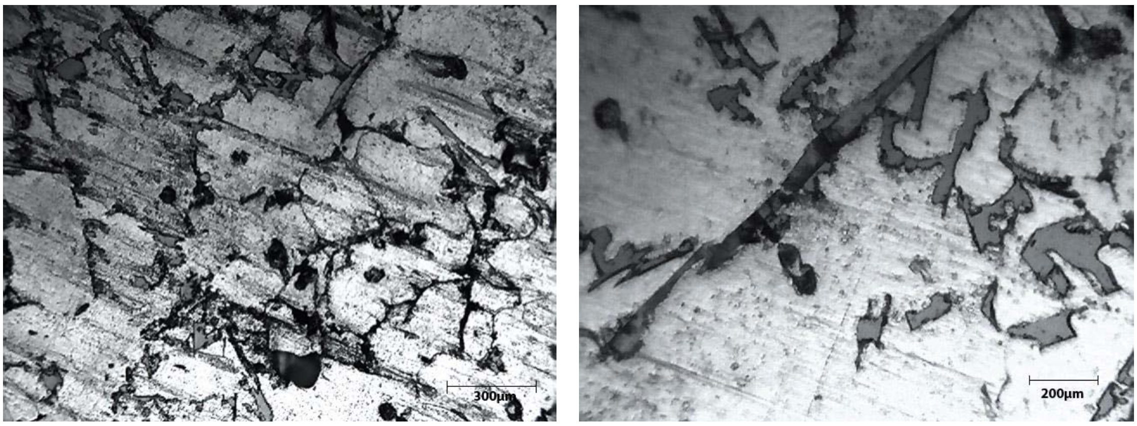
3.1 Hardness and tensile strength

An average hardness value of 36HRB and 58HRB were obtained for the micro and nano Al_2O_3 particle reinforce composites, respectively. The nano composite exhibit slight higher bulk (macro) hardness when compared to the micro reinforced composite. As the application is for large components, the bulk hardness is a better measure to indicate the hardness of the nano composite.

The tensile strength of nano composite is a modest superior than that of the composite reinforced with 10 wt. % of micro Al_2O_3 particles. The nano Al_2O_3 particle reinforced composite exhibited a breaking load of 4.05KN while the micro Al_2O_3 particle reinforced composite had a breaking load of 2.65KN. The elongation measured for the composites lies within a very low range, below 3%, depending on the Al_2O_3 particle size.

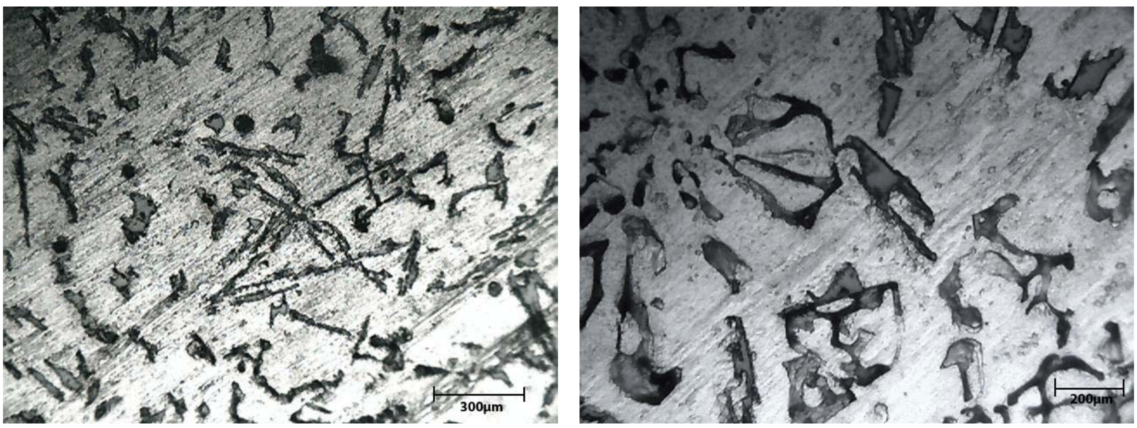
3.2 Optical microscopy

The properties of the MMCs depend not only on the matrix particle and the volume fraction, but also on the distribution of reinforcing particles and interface bonding between the particle and matrix. In practice, it is difficult to achieve a homogenous distribution. Hence, the above process parameters should be optimized. The optical micrograph of the aluminium composite reinforced with approximately 10 wt.% of micro and nano Al_2O_3 particle is shown in Figures 2 and 3, respectively. In both cases, the micrographs at lower magnification (300X) show to some extent uniform distribution of the reinforcement particles, however, at higher magnification (750X), agglomeration is obvious especially for the nano particle reinforced composite. In either case, no pores have been observed indication better wettablilty between the matrix and reinforcement particles.



(a) (b)

Figure-2. Optical micrographs of 10% weight micro alumina at different magnifications: (a) 300X; and (b) 750X, black regions are Al_2O_3 particles.



(a) (b)

Figure-3. Optical micrographs of the 10% weight nano alumina at different magnifications: (a) 300X; and (b) 750X.

3.3 Scanning electron microscopy (SEM)

SEM micrographs of the 10 wt% Micro and Nano Al_2O_3 particle reinforced composites are shown in Figures 4 and 5, respectively. The aluminium matrix being very soft, grinding and polishing of the samples for microscopy results in removal of the reinforcement particles from the matrix as well as marks are left on the surface. The nano composite at lower magnification (100X) exhibit a more uniform distribution of the particles, however, at higher magnification (500X) agglomeration is obvious. The dark black regions in the SEM pictures at high magnification indicate the presence of porosity and are found in both the micro and nano composites to some extent.

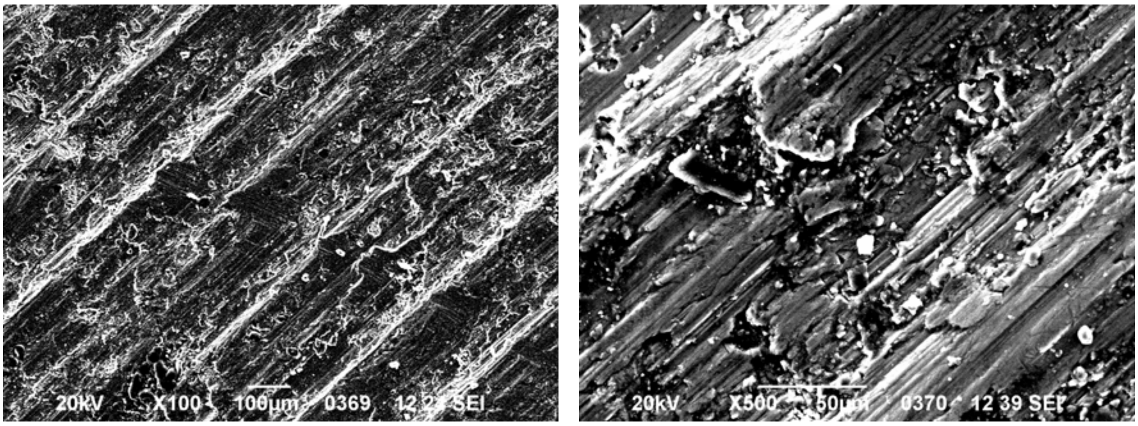
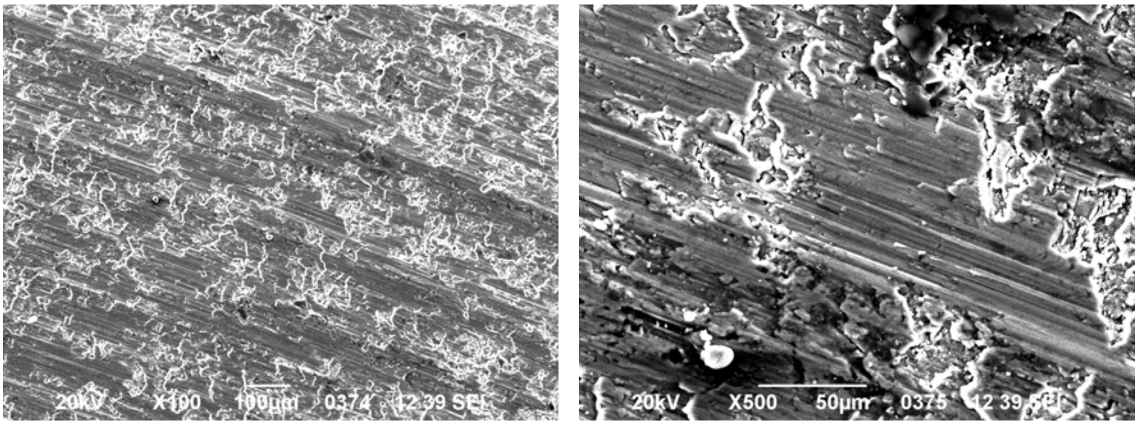


Figure-4. SEM micrographs of 10wt% micro Al_2O_3 particle reinforced composites at different magnifications: a) 100X and (b) 500X.



(a) (b)

Figure-5. SEM micrographs of 10wt% Nano Al_2O_3 particle reinforced composites at different magnifications: a) 100X; and (b) 500X

4. CONCLUSIONS

LM25 aluminum alloy reinforced with micro and nano-sized Al_2O_3 was successfully produced via stir casting method. The following conclusions can be made based on the studies carried out:

a) Nano Al_2O_3 particle reinforced MMC exhibit better hardness and strength when compared to micro Al_2O_3 reinforced MMC;
b) Uniform distribution of reinforcement particle has been achieved in both the MMCs, however, agglomeration is obvious;
c) Both MMCs have been found to have lower porosity and so exhibit better strength; and
d) By proper optimization of the process parameters, stir casting can be a promising and economically viable route for the production of nano particle reinforced MMCs.

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