International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 1 Issue 6, August - 2012

Preparation, Characterization and Mechanical Properties of Al_2O_3 Reinforced 6061Al Particulate MMC's

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Abstract

Aluminum MMCs are preferred to other conventional materials in the fields of aerospace, automotive and marine applications owing to their improved properties like high strength to weight ratio, good wear resistance etc. In the present work an attempt has been made to synthesize Al6061-Al_2O_3 particulate metal matrix composites by liquid metallurgy route (stir casting technique). The addition level of reinforcement was 0, 6 and 9wt%. For each wt%, reinforcement particles were dispersed in steps of three into molten Al6061 alloy. Microstructural analysis was carried out for the above prepared composites to reveal distribution of particles. The prepared composites are subjected to the mechanical testing as per the ASTM standards. Microstructural characterization revealed fairly uniform distribution and some amount of grain refinement in the specimens. The Micro-Vickers hardness of the composite was found to increase with increase in filler content in the composite. The tensile strength of the composites was also found to increase confirming the enhancement of the mechanical properties.

Key Words: MMC's, Al_2O_3 particulates, 6061Al, stir-casting

1. Introduction

Metal–matrix composites (MMCs) are most promising in achieving enhanced mechanical properties such as: hardness, Young's modulus, 0.2% yield strength and ultimate tensile strength due to the presence of micro-sized reinforcement particles into the matrix. Generally, regards to the mechanical properties, the reinforcements result in higher strength and hardness, often at the expense of some ductility [1]. Aluminum-matrix composites (AMCs) reinforced with particles and whiskers are widely used for high performance applications such as in automotive, military, aerospace and electricity industries because of their improved physical and mechanical properties [2]. In the composites relatively soft alloy like aluminum can be made highly resistant by introducing predominantly hard but brittle particles such as Al_2O_3 and SiC.

Among Al-alloys, 6061Al-alloy is widely used in numerous engineering applications including transport and construction where superior mechanical properties such as tensile, strength, hardness etc., are essentially required [1]. Hard particles such as B_4C, Al_2O_3 and SiC are commonly used as reinforcement phases in the composites. The application of Al_2O_3 or SiC particle reinforced aluminum alloy matrix composites in the automotive and aircraft industries is gradually increasing for pistons, cylinder heads, connecting rods etc. where the tribological properties of the materials are very important [1–4]. In addition, the mechanical properties of MMCs are sensitive to the processing technique used to fabricate the materials. Considerable improvements may be achieved by applying science-based modelling techniques to optimize the processing procedure. Several techniques have been employed to prepare the composites including powder metallurgy, melt techniques and squeeze casting [2, 3]. However, powder metallurgy appears to be the preferred process in view of its ability to give more uniform dispersions. Hot extrusion is generally used as post-treatment to take the advantages of applying compressive forces and high temperatures, simultaneously [5].

Liquid state fabrication of MMC's include two methods depending on the temperature at which the particles are introduced into the melt. In melt stirring process, the particles are incorporated above the liquidus temperature of the molten alloy, while in compo-casting method the particles are incorporated at the semi-solid slurry temperature of the alloy. In both processes, the vortex is used for introducing reinforcement particles. However, the melting process has two major problems firstly, the ceramic particles are generally not wetted by the liquid metal matrix, and secondly, the particles tend to sink or float according to their density relative to the liquid metal. Consequently, the dispersion of the ceramic particles is not uniform. In order to decrease the porosity in the composite material, the pressure casting such as die and squeeze casting methods is needed [6]. Although powder metallurgy produces better mechanical properties in MMCs, melt processing has some important advantages. They are as: better matrix-particle bonding, easier control of matrix structure, simplicity, low cost of processing, nearer net shape and the wide selection of materials [1–4]. Investigation of mechanical behavior of aluminum alloys reinforced by micro hard particles such as Al_2O_3 and SiC is an interesting area of research. Therefore, the aim of this study is to investigate the effects of different factors such as: particle size, weight percentage of the particles, processing method on the microstructure and mechanical properties of the composites.

2. Experimental Details

The following section highlights the material, its properties and methods of composite preparation and testing.

2.1 Materials used

The matrix material for the present study is Al6061. Al_2O_3 is used as reinforcement material in the preparation of composites. The chemical composition of matrix material is as shown in Table1. The particles size of the reinforcing material was about 125 µm. Table 2. gives the properties of Matrix and Reinforcing materials used in the present study taken from the literature.

Table.1 Shows the Chemical Composition of 6061Al alloy by wt%

Components	Amount (wt %)
Aluminium	Balance
Magnesium	0.8-1.2
Silicon	0.4-0.8
Iron.	Max 0.7
Copper	0.15-0.40
Zinc	Max 0.25
Titanium	Max 0.15
Manganese	Max 0.15
Chromium	0.04-0.35
Others	0.05

Table.2 shows the properties of matrix and reinforcing materials used in the study

Material/ Properties	Density gm/cc	Hardness (HB500)	Strength (Tensile/Compressive) (MPa)	Elastic modulus (GPa)
Matrix – 6061 Al	2.7	30	115 (T)	70-80
Reinforcement Al_2O_3 Particle	3.69	1175	2100 (C)	300

2.2 Preparation of composites

The liquid metallurgy route (stir casting technique) has been adopted to prepare the cast composites as described below. Preheated Al_2O_3 particles of laboratory grade purity of particle size 125 µm were introduced into the vortex of the molten alloy after effective degassing using solid hexachloroethane (C_2Cl_6). Before introducing reinforcement particles into the melt they were preheated to a temperature of 250^0C. The extent of incorporation of Al_2O_3 particles in the matrix alloy was achieved in steps of 3. i. e Total amount of reinforcement required was calculated and is being introduced into melt 3 times rather than introducing all at once. At every stage of before and after introduction of reinforcement particles, mechanical stirring of the molten alloy for a period of 10 min was achieved by using Zirconia-coated steel impeller. The stirrer was preheated before immersing into the melt, located approximately to a depth of 2/3 height of the molten metal from the bottom and run at a speed of 200 rpm. A pouring temperature of 750^0C was adopted and the molten composite was poured into permanent cast iron moulds. Thus composites containing particles 0, 6 and 9wt % were obtained in the form of cylinders of diameter 12.5mm and length 125mm.

2.3 Testing of composites

To study the microstructure of the specimens the central portion of the casting was cut by an automatic cutter device. The specimen surfaces were prepared by grinding through 300, 600 and 1000 grit papers and then by polishing with 3 µm diamond paste. Microscopic examination of the composites was carried out by optical microscopy. To investigate the mechanical behavior of the composites the hardness and tensile tests were carried out using Zwick and computerized uni-axial tensile testing machine as per ASTM standards. Fig. 1. Shows the dimensions of the mould and specimen used for tensile studies. The Micro-Vickers hardness values of the samples were measured on the polished samples using diamond cone indentor with a load of 20N. Hardness value reported is the average value of 100 readings taken at different locations on the polished specimen. For tensile results, test was repeated three times to obtain a precise average value.

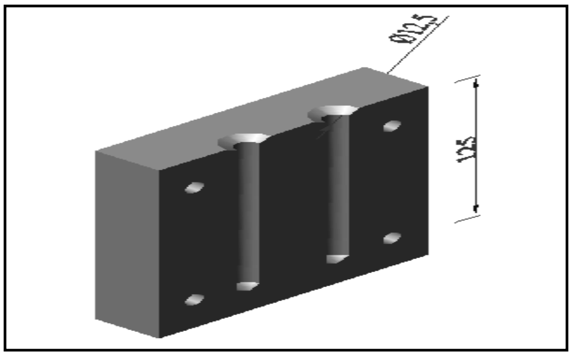


Figure (a)

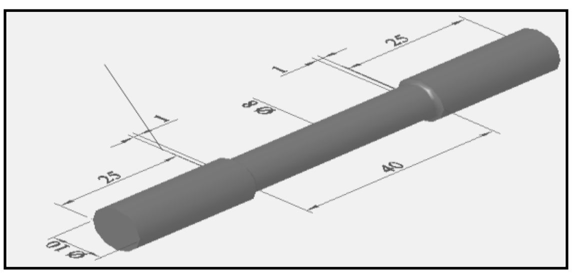


Figure (b)

Figure. 1 showing the details of (a) Permanent mould for producing composites (b) Dimensions of the tensile specimen.

3. Results and Discussions

3.1 Microstructural studies:

Fabrication of metal–matrix composites with alumina particles by casting processes is usually difficult because of the very low wettability of alumina particles and agglomeration phenomena which results in non-uniform distribution and weak mechanical properties. In the current work, Al6061 aluminum alloy matrix composites with micro size alumina particles were produced by stir casting method. The magnitude of alumina powder used in the composites were 6 and 9wt.%. The optical micrographs of the 6061-Al alloy with 0, 6 and 9wt. % alumina particulates were shown in Fig 3(a-d).

Fig. 3a-e shows microstructure of as cast 6061Al and 6061Al with 6 wt% (Fig. 3b-c) and 9wt% (Fig.3d-e) Al_2O_3 particulates. The microstructure of the prepared composites contains primary α-Al dendrites and eutectic silicon, while Al_2O_3 particles are separated at inter-dendritic regions and in eutectic silicon. The stirring of melt before and after introducing particles has resulted in breaking of dendrite shaped structure into equiaxed form, it improves the wettability and incorporation of particles within the melt and also it causes to disperse the particles more uniformly in the matrix. Fig. 3b-e reveals the distribution of alumina particles in different specimens and it can be observed that there is fairly uniform distribution of particles and also agglomeration of particles at few places were observed in both the composites reinforced with 6 wt.% and 9wt%Al_2O_3. The microphotographs also indicate that the Al_2O_3 particles have tendency to segregate and cluster at inter-dendritic regions which are surrounded by eutectic silicon (Fig. 3b–e). Further, the micrographs show that grain size of the reinforced composite (Fig.3.a-e) is smaller than the alloy without alumina particles (Fig. 3a) because, Al_2O_3 particles added to melt also act as heterogeneous nucleating sites during solidification.

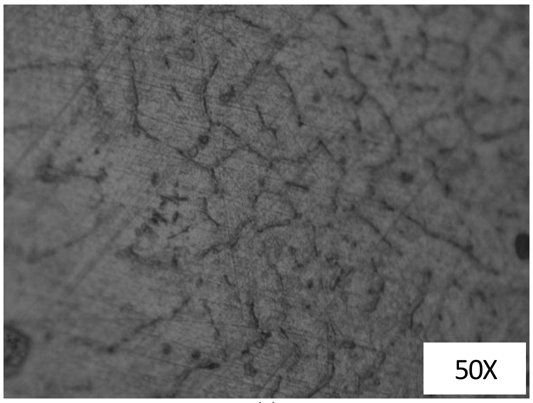
3.2 Density measurements:

Table 3.1 is presented with the comparison of theoretical density obtained by rule of mixture and measured density values by experiment for both the composites studied for different wt% of reinforcements. Experimentally, the density of a composite is obtained by displacement techniques [7] using a physical balance with density measuring kit as per ASTM: D 792-66 test method. Further, the density can also be calculated from porosity and apparent density values (sample mass and dimensions) [8].

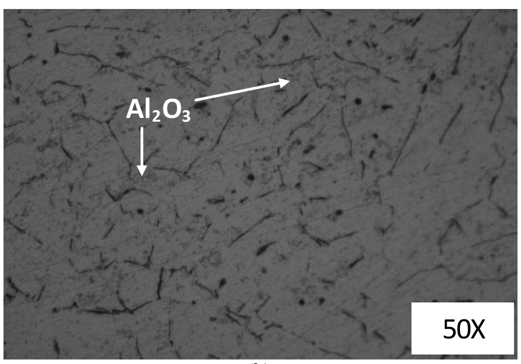
Table 3.1: showing the theoretical and measured densities of as cast 6061Al and with 6 wt% of Al_2O_{3p} respectively

Composition	Theoretical Density (g/cm^3)	Measured Density(g/cm^3)
6061Al+6% Al_2O_3p	2.74	2.57
6061Al+9% Al_2O_3p	2.76	2.58

From the table 3.1 it can be concluded that the experimental density of composite containing 6 and 9wt% Al_2O_{3p} is less when compared to the theoretical density. Further, measured density of composites is lesser than theoretical density, could be due to the presence of porosity. The porosity is probably due to



(a)



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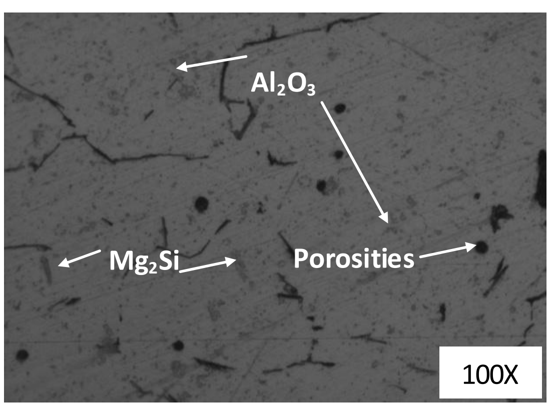

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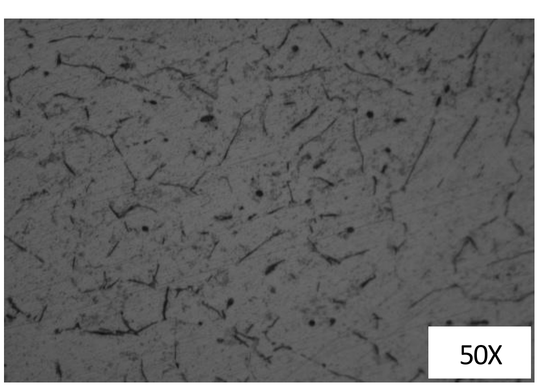
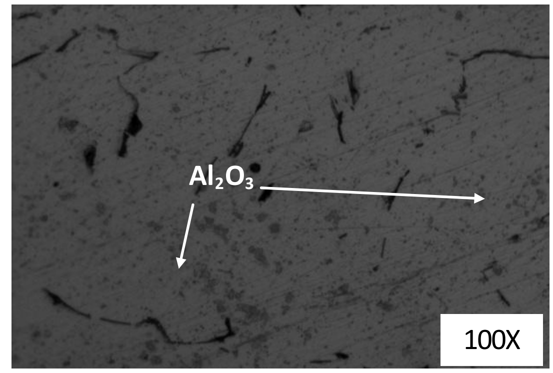


(d)



(e)

Fig.3-a-d Showing the optical microphotographs of 6061Al with and without Al_2O_3 particulates (a) As-cast 6061Al (b) with 6wt% of Al_2O_3p at 50X (c) with 6wt% of Al_2O_3 at 100X (d) with 9wt% of Al_2O_3p at 50X (e) with 9wt% of Al_2O_3p at 100X

i) increase in surface area in contact with air (ii) gas entrapment during stirring; (iii) gas injection of particles introduces a quantity of gas into the melt; (iv) hydrogen evolution; (v) the pouring distance from the crucible to the mold and (vi) shrinkage during solidification [9].

3.3 Hardness measurements:

Fig.3.2 shows the results of micro hardness tests conducted on Al6061 alloy and the 6061Al composite containing different weight percentage of Al_2O_3 particles. The Micro-Vickers hardness were measured on the polished samples using diamond cone indentor with a load of 20N and the value reported is average of 100 readings taken at different locations. A significant increase in hardness of the alloy matrix can be seen with addition of Al_2O_3 particles. A hardness reading showed a higher value of hardness indicating that the existence particulates in the matrix have improved the overall hardness of the composites. This is true due to the fact that aluminum is a soft material and the reinforced particle especially ceramics material being hard, contributes positively to the hardness of the composites. The presence of stiffer and harder Al_2O_3 reinforcement leads to the increase in constraint to plastic deformation of the matrix during the hardness test. Thus increase of hardness of composites could be attributed to the relatively high hardness of Al_2O_3 itself.

3.4 Tensile Properties

To investigate the mechanical behavior of the composites the tensile tests were carried out using

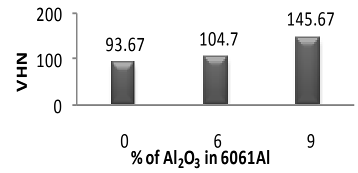
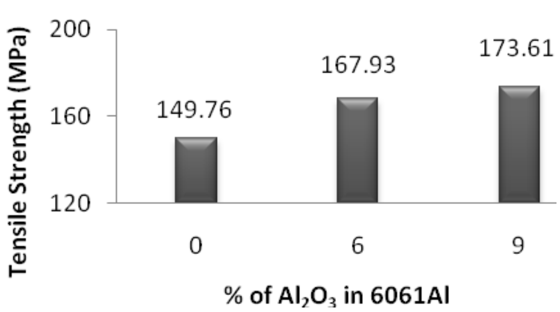


Figure.3.2 showing the variations in hardness of 6061Al before and after addition of different wt% of Al_2O_3 particulates

computerized uni-axial tensile testing machine as per ASTM standards. Three test specimens were used for each run. The tensile properties, such as, Tensile strength, Yield strength and Percentage elongation, were extracted from the stress-strain curves and are represented in Table 3.2. From Table it is clear that fracture strength incase of composites (both 6 and 9wt %) is greater when compared to as cast 6061Al. It is also clear from the tensile results that with increase in amount of reinforcement tensile strength increases, while there is decrease in ductility. As mentioned above, a thermal mismatch between the metal matrix and the reinforcement is a major mechanism for increasing the dislocation density of the matrix and therefore, increasing the composite strength. However, the composite materials exhibited lower elongation than that of unreinforced specimens. It is obvious that plastic deformation of the mixed soft metal matrix and the non-deformable reinforcement is more difficult than the base metal itself. Therefore, the ductility of the composite must be lower than that of unreinforced material.



4. Conclusions

The present work on synthesis and characterization of 6061Al-Al_2O_3 composites led to following conclusions

1. The composites containing 6061Al with 6 and 9wt% of Al_2O_3 particulates were successfully synthesized by melt stirring method.

Table 3.2: showing the tensile test results of as cast 6061Al, with addition of 6 and 9wt% of Al_2O_3 particulates to 6061Al

Sl No	Weight percentage of Al_2O_3 particles (%)	Yield Stress (N/mm^2)	Percentage Elongation (%)	Ultimate Tensile strength (N/mm^2)
1	0	138.06	15.16	149.76
2	6	145.51	10.63	167.93
3	9	155.94	8.34	173.61

2. The optical micrographs of composites produced by stir casting method shows fairly uniform distribution of Al_2O_3 particulates in the 6061Al metal matrix.
3. The microstructure of the composites contained the primary α-Al dendrites and eutectic silicon. While Al_2O_3 particles were separated at inter-dendritic regions and in the eutectic silicon.
4. It was revealed that the hardness of composite samples increased with increasing the weight percentage of Al_2O_3 particles.
5. Strength of prepared composites both tensile and yield was higher incase of composites, while ductility of composites was less when compared to as cast 6061Al. Further, with increasing wt% of Al_2O_3, the tensile strength shows an increasing trend.

5. References

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