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Experimental Investigations for Evaluation of Mechanical Properties of Aluminum Matrix Composites Reinforced with Copper Particles

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Abstract

In this study, aluminum alloy Al 6061-copper particulate metal matrix composites were prepared with three different volume fractions of reinforcement 75 µm (1%, 2% and 3%) using stir casting route. The particles distribution, mechanical and physical properties are observed using SEM and XRD. Analysis is discussed on microstructure study and hardness; compression and density are explained in sight of mechanical and physical properties. Finally, it was observed from the results that the hardness, density and compression strength were increased by increasing in wt% of reinforcement.

Keyword: *Density, hardness, metal particulates, metal matrix composites*

INTRODUCTION

Selection of appropriate material and manufacturing process for a chosen application has become a great challenge in the present industry. Though there are millions of materials available in the catalogues still search for newer materials are booming in the engineering world. Because of the improved properties like high specific strength, damp ability specific modulus, resistance to erosion, metal matrix composites (MMCs) are detecting increased uses in the sector of automobile, marine, sports aerospace, defense and restoration MMCs consists of a metal matrix (Al, Mg, Ti, Cu etc.) and a ceramic aspect (carbides, oxides) or metal phase (Mo, Pb, W etc.). Ceramic reinforcements are in the appearance of silicon nitride, silicon carbide (Sic), Al2O3, B4C, boron nitride etc., and metallic reinforcement in the form of rocket wire, molybdenum, tungsten, beryllium etc. Among these materials aluminum metal matrix composites (AMCs) with addition of ceramic reinforcement are broadly used for the design of components for most of the assist applications [1]. After that iron aluminum is the second most used metal competing with copper. Aluminum is the second broadly used metal in the world because of its unique combinations of stunning properties like low weight, high strength, easy machining, corrosion resistance, superior malleability and thermal and electrical conductivity while nickel and copper are well known for their high resistant to corrosion and most acids. A composite material is made up of two or more constituents with suggestively different physical or chemical properties that produce a material with different characteristics when combined. A composite material has a property of remaining its constituent particles separately in a combined state with different properties. Aluminum matrix composites have been extensively studied as an attractive choice for more industries because of their interesting properties like, high strength to weight ratio, stiffness, wear resistance than that of the alloy. A very little number of researches have shown their own interest on metal reinforcement in metal matrix composites and a few of them include, Velugula Mani Kumar et al., [2] have investigated the fabricated composite Al6061 with addition of copper in the constitutions viz., 4%, 6%, 8%, 10% using die casting process and it is observed from results that the hardness of Al alloy (6061) with Cu MMC increase by increasing wt% of copper particles unto 8wt% and then decreases with increasing wt% of copper particles.

N. Radhika et al., [3] fabricated Cu-10Sn alloy and its composites reinforced with varying wt% of SiC (5, 10 and 15) copper alloy is used as matrix material. He revealed the decrease of wear rate with increasing the velocity for both 5 and 10 wt% SiC composite due to formation of mechanically mixed layer. Narsipalli Bhargava Rama et.al [4] studied particulate constitutions effect by varying the copper reinforcement fractions in between 5 and 15 wt%, with increasing in the particulate content Hardness increased in both as cast and homogenized conditions. C.E da Costa et.al [5] has investigated on wear characteristics of Aluminum reinforced matrix composites. In his research it is proposed an increase of wear characteristics highly on an order of twice to thrice than that of the base alloys when reinforced with intermetallic. Devinder Yadav et.al [6] has investigated on fabrication of Nickel reinforced Aluminum matrix by friction stir processing. It is observed that the process resulted in uniform dispersion of nickel particles with excellent interfacial bonding with the Aluminum matrix and also lead to significant grain reinforcement of matrix. Manoj Kumar Pal et al [7] has investigated on the fabrication of nickel reinforced aluminum matrix composites by stir casting technique. In his research, it was found that the optimal composition material is a composite with 20% of Nickel as reinforcement. The optimal composite material has all the properties improved than parent material except thermal conductivity which is found to be detoriated.

Dr. C N Chandrappa et al., [8] have investigated on fabrication of Al-SiC composites by stir casting by varying the weight percentages of reinforcement. In his research, it is stated that tensile behavior of composite increases linearly with reinforcement percentage, except it comes to a lower value at 10% of reinforcement. V. Rama Kotteswara Rao et al., [9] have investigated on the varying properties of aluminum matrix composites with varying parameters. From the research, it is concluded that stir casting is best suited process. It is observed that by increasing the weight percentage and decreasing the particle size the hardness, tensile strength and yield strength of composite material increases up to a maximum of 20wt% for microstructural and 5%wt DSC respectively.

EXPERIMENTAL DETAILS

Preparation of Sample of Composites

For present research, Aluminum-6061 in the form of cylinder of ϕ80mm was selected as matrix material with copper powder as reinforcement with a mesh size of 75μm. The chemical composition of Al-6061 was tabulated in Table 1.

Table1: *Chemical constitutions of Al-6061.*

Constituent	%
Silicon	0.65
Iron	0.7
Copper	0.25
Manganese	0.15
Magnesium	0.9
Chromium	0.07
Zinc	0.25
Titanium	0.15
Aluminum	Reminder

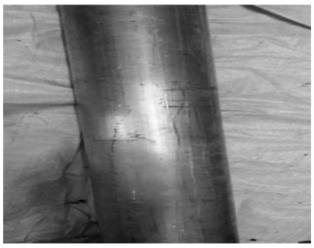

***Figure 1:** Al-6061 bar.*

***Figure 2:** Copper powder.*

In these composites, the Al-6061alloy properties are of low weight and high strength material, and the density of this alloy is 2.7 gr/c.c. in terms of reinforcement the copper powder have high refractive index and density of the material is 8.96 gr/c.c.

Fabrication of Composites

The die and reinforcement materials are placed in an oven for preheating at a temperature of 4000–4500°C for 45 minutes. Al-6061 alloy is placed in the furnace portion of stir casting equipment and allow it to heat up to 8000°C. Introduce the reinforcement material of copper into the molten through the injection chamber in step wise for uniform mixing and set the rotor speed at 400 rpm. Then introduce the reinforcement into the molten metal through the same chamber according to weight proportion. Allow the molten metal for uniform mixing thorugh rotaion of stirrer and moving up and down for about 15 min. Place the die at the opening of the furnace after taken out from preheating furnace. The molten metal is get filled up into the die, when valve is opened, through runner and riser. Allow the die to cool for some time and takeout the cast specimens from the die.

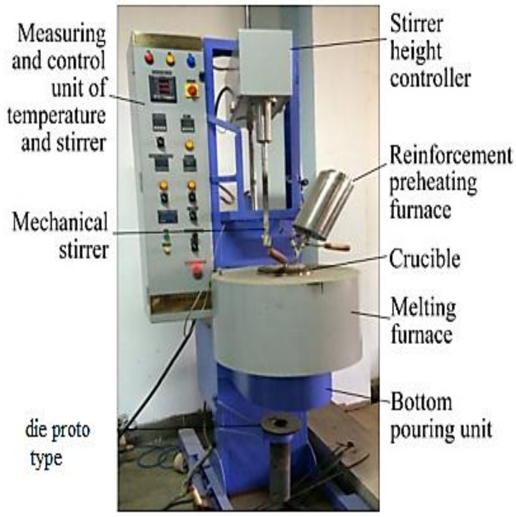

***Figure 3:** Bottom pouring stir casting machine.*

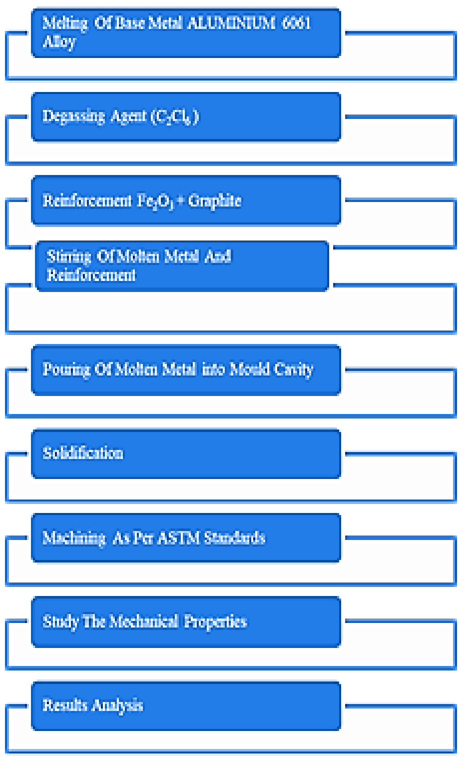

***Figure 4:** Flow chart.*

METHODOLOGY

Microstructure Study

Microstructural works were carried out on a specimen having dimensions of 10*10mm specimens. The specimens were polished through metallography by applying suitable etchents. Keller's reagent was used for etching the samples of aluminum composites. Microstructural personation of the specimens was carried out using scanning electron microscope.

Compression Test

The fabricated Al-6061 composite specimens for compression test are prepared, by using CNC machine as per ASTM standards. The compression tests are performed on a universal testing machine. The compression strength of composites at various reinforcement fractions is determined.

Hardness Test

The casted Al-6061 composite specimens for hardness test are equipped, by machining as per ASTM standards using CNC machine. The tests were carried out by Brinell hardness testing machine having dimensions of 10*10 mm and a unit load of 187.5kg. The loading time is 30secs. Three indentations readings are taken for each specimen and mean value is considered.

Density and Porosity Measurements

Experimental densities of composites were determined by using water displacement technique (Archimedes principal) and is calculated by using this equation (1).

$$\rho_{ex} = m/V \quad (1)$$

The porosity levels of a material can be evaluated by comparing the densities of the produced composite's theoretical (ρ_{th}) and experimental (ρ_{ex}). The fundamental rule of mixture is employed for calculating theoretical density.

$$m_{th} = \rho_m V_m + \rho_r V_r \quad (2)$$

Where ρ_m is matrix material theoretical density, v_m is the matrix material volume fraction, ρ_r is theoretical density of reinforcement and v_r is reinforcement volume fraction.

The porosity of the composites is taken as:

$$\text{Porosity} = (\boldsymbol{\rho}_{th} - \boldsymbol{\rho}_{exp})/\boldsymbol{\rho}_{th} * 100 \quad (3)$$

RESULTS AND DISCUSSIONS

XRD Analysis of Copper

XRD pattern and their analysis of Cu. It is revealed from the peak analysis that the concentration of Cu various interesting observations can be obtained from these diffraction patterns for the structural characterization of the powder.

In this research work, the prepared reinforcement are analyzed by using x-ray, diffraction method used to identify the crystallite size and structure. From Fig. 5, the presence of reinforcement in the XRD pattern can be seen.

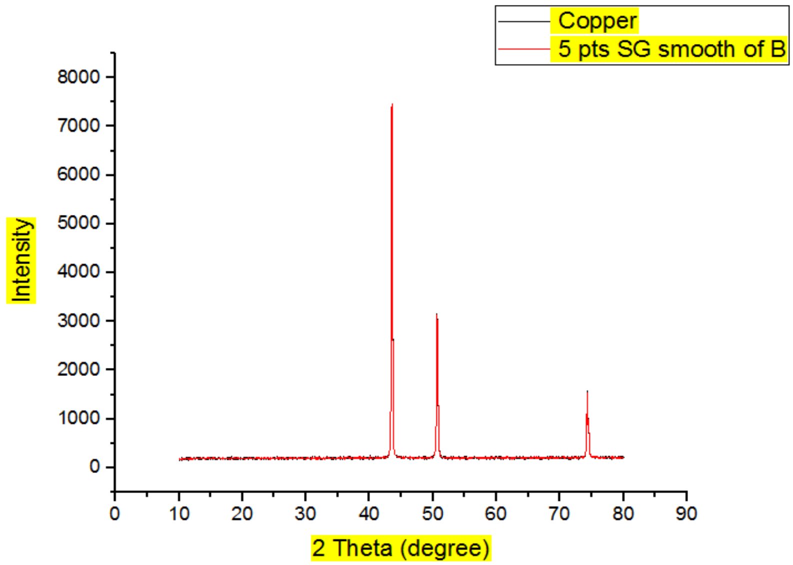

***Figure 5:** XRD pattern of Cu.*

Density and Porosity

Table 2: *Properties of fabricated composites materials.*

Type of materials	Hardness (B.H.N)	Compression strength (N/mm^2)	Density (gr/c.c)	Porosity%
Al6061	71.587	383.1	2.6662	1.4
Al6061 +1% Cu	75.001	396.22	2.67	3.2
Al6061 +2% Cu	78.62	425.44	2.71	3.9
Al6061 +3% Cu	86.53	686.35	2.74	4.86

Table 2 clears the densities of the composites materials increased with increase in the content of Cu percentage; this is because of the presence of high density of Cu in a fraction of composition. The theoretical and experimental densities variation is shown in Fig. 6.

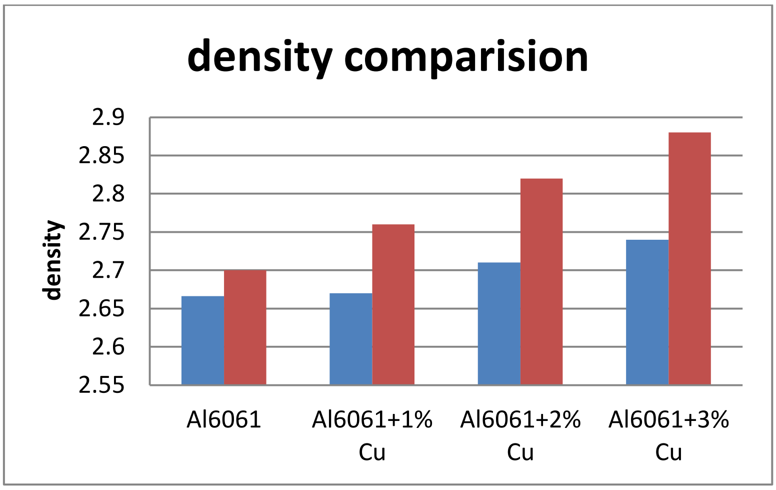

Figure 6: *Density comparison.*

There is difference in observation between the theoretical and experimental densities; this is because of porosity incurred in the casted specimens.

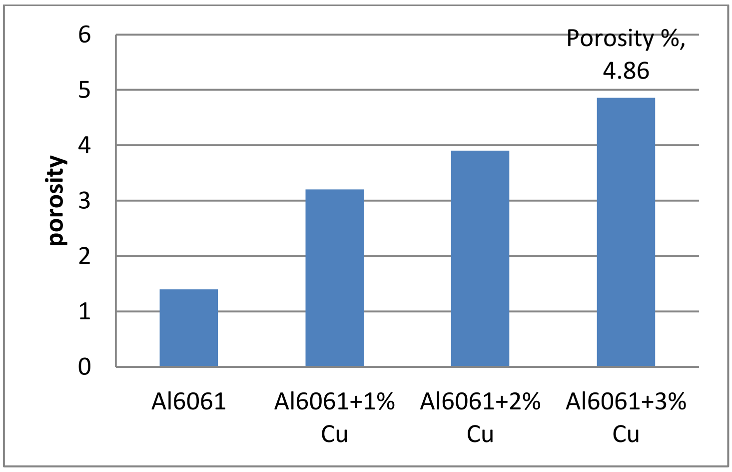

Figure 7: *Variation of porosity.*

Fig. 7 clearly show that the porosity of the composites increased with increase in the content of reinforcement. The maximum value attained at 3% of Cu than that value is 4.86 in terms of percentage.

Compression Strength

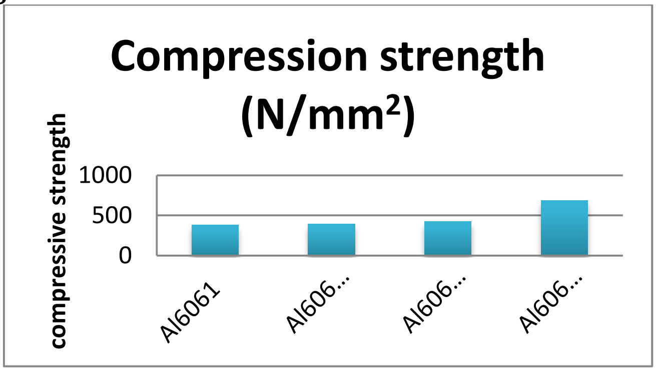

Figure 8: *Variation of compressive strength.*

Fig. 8 clearly shows the variation of the compressive strength of the composites with increase in the reinforcement concentration in them. The compressive strength values of AMCs with varying wt.% of Cu reinforcements. From the table, we can see that the compressive strength value of Al+3% Cu is greater as compared to remaining one. Hence, this shows that the increment of cooper particles in Al matrix enhances the compressive strength value of AMCs when comparing to the base materials.

Hardness

The Brinell hardness values of AMCs with varying wt% of Cu reinforcements. From the table, we can see that the hardness value of Al+3%Cu is greater as compared to hardness values of Al+2% Cu and pure Al. Hence, this shows that addition of Cu particles in Al matrix improves the hardness value of AMCs when comparing to the pure aluminum.

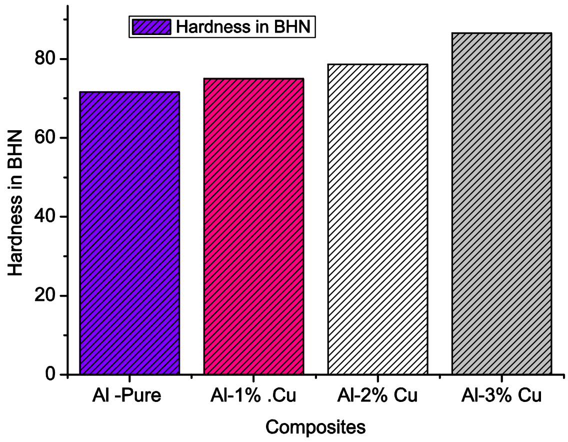

Figure 9: *Hardness comparison.*

Fig. 9 clearly shows the variation of the hardness of the composites with increase in the reinforcement concentration in them. The raise of the hardness is because of the presence of the Al-Cu composition in the composites. The Brinell hardness values of AMCs with varying wt% of Cu reinforcements. From the table, we can see that the hardness value of Al+3% Cu is greater as compared to hardness values of Al+2% Cu and pure Al. Hence, this shows that addition of Cu particles in Al matrix increases the hardness value of AMCs when comparing to the pure aluminum.

SEM Images

The microstructure of the developed composites material was investigated with the help of SEM. The microstructural study of casted aluminum alloy displays major Al dendrites and minor intermetallic phases throughout the dendrites. The copper particles are prominent to be uniform distribution within the metallic matrix. SEM observation revealed the interfacial adhesion created between Al6061 and copper powder.

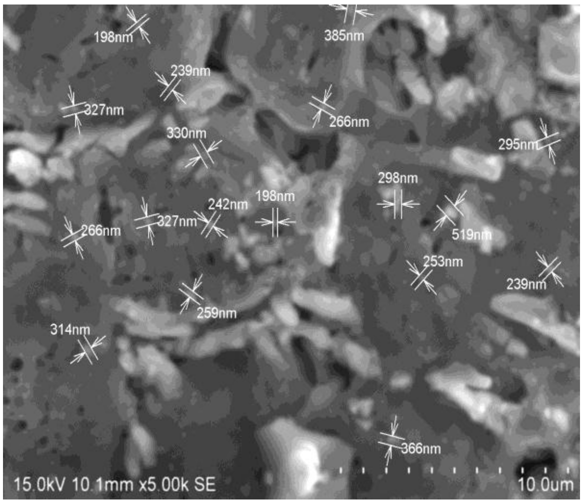

Figure 10: *SEM image of Al6061+1% Cu.*

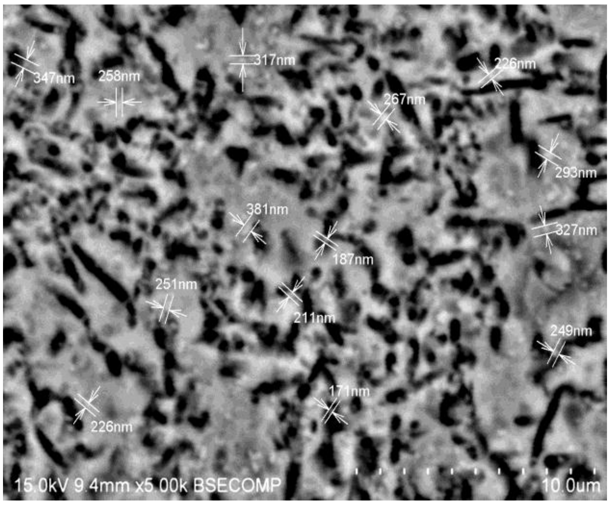

Figure 11: *SEM image of Al6061+2% Cu.*

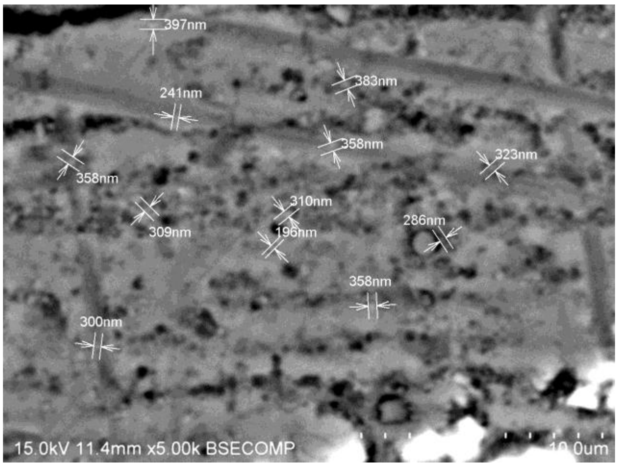

Figure 12: *Al6061+3% Cu.*

From the analysis of microstructural images, it can be detected that the copper contains of particulates with different configurations and magnitudes. The typical sizes of copper are found to be 310nm.

CONCLUSIONS

Aluminum metal matrix composites reinforced with copper are produced by stir casting technique. The composites are made at three different reinforcement wt%. For microstructure study, compressive strength, density and hardness measurement.

- The result was revealed in terms of hardness, the fabricated composites and their hardness values were increasing while increase in the reinforcement wt%.
- When observing compressive strength of copper reinforced composites, its value is the maximum compressive strength at 3% of reinforcement and that percent of increment in the compressive strength is 79.1%.
- When observing density Cu reinforced composites, the maximum values occurred at 3% of reinforcement with a percentage of increment is 2.76%.
- From XRD data, the crystallite size will be measured by using some analytical formulas and the value of Cu 11.46nm size.
- From the microstructural images, it can be observed that the copper contains of particulates by different shapes and sizes. The average sizes of copper are found to be 310nm.

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