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Mechanical Properties of Al - 4.5 wt. % Cu – SiC and Al - 4.5 wt. % Cu–Fly Ash Composites: A Comparative Study

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ABSTRACT

In the present analysis an effort has been made to compare the mechanical properties of Al - 4.5wt. % Cu Alloy reinforced with SiC and Fly ash by using Fluid Metallurgy route. Al - 4.5wt. % Cu Alloy was used as the matrix material. SiC and Fly ash particulates were used as reinforcements. In the incubation of composites 3 wt. % of SiC and 3 wt. % of Fly ash particulates were preheated to 400 degree Celsius and dispersed in dual steps into the turbulence of molten Al - 4.5 wt. % Cu Alloy. Al-Cu alloy reinforced with 3 wt. % of SiC and 3 wt. % of Fly ash were casted separately. 0.6 wt. % of Mg was added to increase the wettability of the liquefied metal. A comparative study was carried on mechanical properties of Al-Cu-3 % SiC and Al-Cu-3 % Fly ash composites. The microstructure study was carried out using optical microscopy which terminated in uniform distribution of reinforced particles in the matrix alloy. The results indicate that hardness, ultimate tensile strength and yield strength of the composites were found to be higher when reinforced with SiC compared to Al-Cu base matrix and Fly ash particulates reinforced composites.

Keywords: Al-Cu Alloy, SiC, Fly ash, Hardness, Ultimate Tensile Strength, Metal Matrix Composites.

1. INTRODUCTION

Metal Matrix Composites (MMCs) are increasingly becoming attractive materials for advanced aerospace applications but their properties can be tailored through the addition of selected reinforcement [1-3]. In particular particulate reinforced MMCs have recently found special interest because of their specific strength and specific stiffness at room or elevated temperatures. Due to advancement in technology, there is enlarged demand for an economical, light weight, harder, stronger and energy saving material in the area of space, aircraft, defence and automotive applications and aluminium matrix composites (AMCs) found applications in these areas[4,5]. Since last two decades there is wide exploration and pioneering development in the field of composite materials. In the past few years most of the researcher tried to reinforce monolithic metal and alloy with ceramic phase to enhance their properties [6].

The most commonly employed Metal Matrix Composites (MMCs) consists of aluminium alloy reinforced with hard ceramic particles usually silicon carbide, fly ash, alumina and soft particles usually graphite and talc [7]. Ceramic particles are known for low density, high strength, low thermal expansion, high thermal conductivity, high hardness, high elastic modulus, excellent thermal shock resistance and superior chemical inertness.

In fact, there are several fabrication techniques available to manufacture Al-SiC and Fly ash composites. The fabrication methods are solid phase processes, liquid phase process and semi-solid fabrication process [8, 9]. Compared with solid phase process, melt processing which involves the stirring of particles into melts, has some important advantages, such as easier control of matrix mixture, better matrix-particle bonding, simplicity, low cost of processing and nearer net shape.

Several researchers have investigated the mechanical properties of hard ceramic particulates reinforced Al alloy composites. Vijaya Ramnath et al. [10] evaluated the mechanical properties of aluminium alloy-alumina-boron carbide metal matrix composites and investigated mechanical properties like tensile, flexural, impact and hardness. It has been found that all mechanical properties were higher than base matrix. Zhang and co-workers studied on yield strength of LM24 alloy reinforced with Al_2O_3 particulates. Composites were fabricated by in-situ process by using 1 to 2 micron Al_2O_3 particulates. Compared to LM25 alloy the yield strength is increased by 52 MPa [11]. Baradeswaran et.al [12] studied on mechanical and wear properties of Al7075-Al_2O_3-Graphite reinforced hybrid composites. The hardness, tensile strength and compression strength Al7075 alloy hybrid composites are found to be increased by increased wt. % of ceramic phase.

Even though many researchers attempted Al with hard ceramic particulates as a reinforcement and evaluation of mechanical and wear properties of different Al alloys. Very less comparative studies have been made on mechanical properties of Al alloys by taking different reinforcements. In the present work an attempt has been made to develop Al 4.5% Cu alloy with 3 wt. % of SiC and Fly ash composites. A comparative study has been made on mechanical properties of Al- Cu alloy, Al-Cu-SiC and Al-Cu-Fly ash composites.

2. EXPERIMENTAL DETAILS

2.1 Materials Used

In the present investigation Al - 4.5 wt. % Cu alloy is used as the base matrix. SiC and Fly ash particulates are used as the reinforcement materials. An average particle size of SiC and Fly ash were taken as 40µm. The chemical composition of Fly Ash particulates is shown in Table 1.

Table1: Chemical composition of Fly ash in weight percentages.

Al_2O	SiO_2	Fe_2O	TiO_2	Loss on ignition
30.40	58.41	8.44	2.75	1.43

Al – 4.5 % of Cu alloy is an aluminium wrought alloy, which belongs to 2XXX series of aluminium alloy. With its relatively good fatigue resistance especially in thick plate forms it continues to be used for many aerospace structural applications, critical aircraft structures. Al 2XXX alloys are used in fuselage structures; wing tension members, shear webs and ribs, where stiffness, fatigue performance and good strength are required. Table 2 shows the chemical composition of base matrix used in this study.

Table2: Chemical composition of Al-Cu Alloy

Components	Wt. Percentage
Copper	4.52
Magnesium	0.05
Silicon	0.15
Iron	0.16
Manganese	0.07
Zinc	0.01
Lead	0.01
Tin	0.01
Titanium	0.01
Chromium	0.02
Al	Bal

2.2 Composites Preparation

The SiC and Fly ash reinforced Al-Cu alloy metal matrix composites have been produced by using a vortex method. Initially calculated amount of Al-Cu alloy was charged into graphite crucible and superheated to a temperature 750˚C in an electrical resistance furnace. The furnace temperature was controlled to an accuracy of ±25˚C using a digital temperature controller. Once the required temperature is achieved, degassing is carried out using solid hexachloroethane (C_2Cl_6) to expel all the absorbed gases. The melt is agitated with the help of a zirconia coated mechanical stirrer to form a fine vortex. A spindle speed of 300 rpm and stirring time 5-8 min. were adopted. The SiC and Fly ash particulates were preheated to a temperature of 400˚C in a pre-heater to increase the wettability. The pre-heated 3 wt. % of SiC particles introduced into melt in steps of two at constant feed rate of 1.2-1.4 g/sec. Two stage additions involve dividing entire weight of reinforcement into two equal weights and then individual weights are added to the melt in two steps rather than adding all at once [13]. At every stage, stirring is carried out before and after introduction of reinforcement to avoid agglomeration and separation of particles and to ensure homogeneous dispersion of SiC particles in the melt. After holding the melt for a period of 5 min., the melt was poured from 730˚C into a preheated cast iron mould having dimensions of 200mm length x 25mm diameter. Similarly, 3wt. % of Fly ash reinforced Al-Cu alloy composite was prepared. Al-Cu-SiC and Al-Cu-Fly ash composites were machined as per ASTM standard to evaluate and compare the mechanical properties.

2.3 Testing

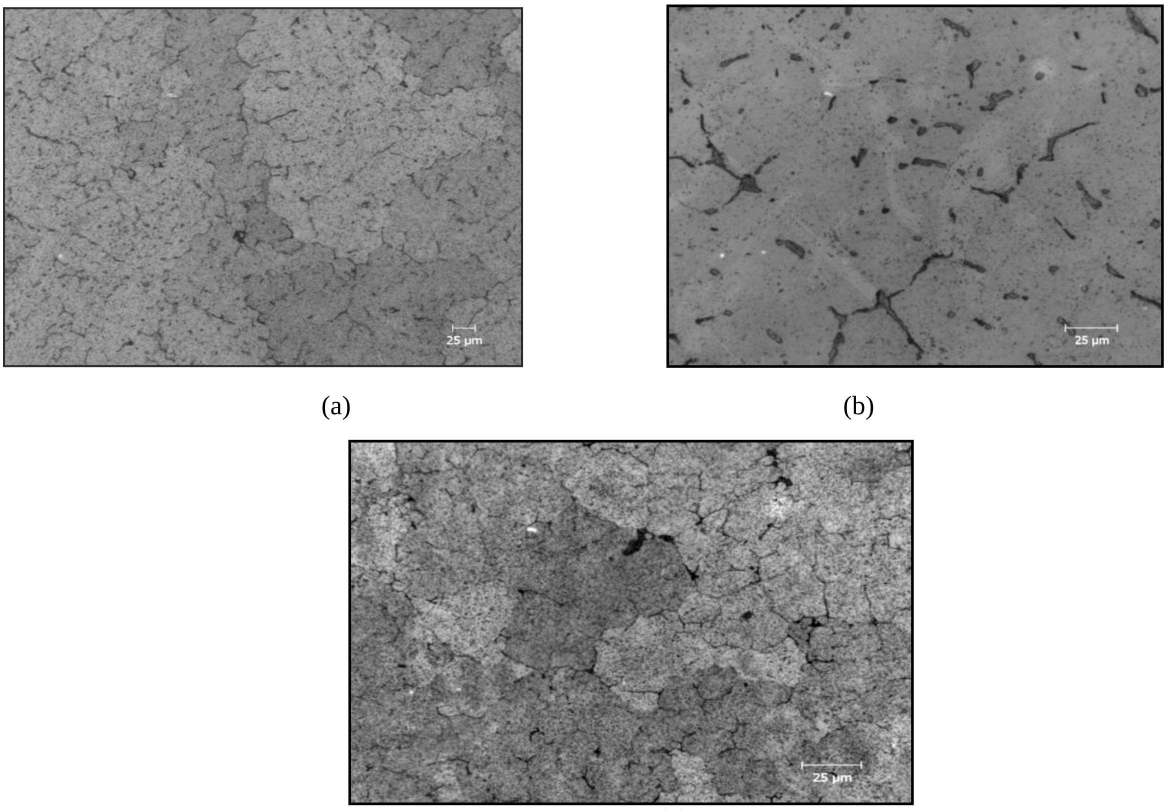
For microstructural characterization, metallographic samples sectioned from cylindrical castings were prepared as per metallographic procedure using series of emery papers and diamond grinders. Microstructures were examined using optical microscopy to identify morphology and distribution of SiC and Fly ash particles in Al-Cu alloy. The hardness of the composites and matrix alloy were measured after polishing to a 1µm finish. The hardness of the samples was measured using Brinnel hardness tester with a load of 187.5 kgf and dwell time of 10sec. The hardness measurements were carried out at 5 different locations on the specimen and average of all five readings is being reported. Tensile tests were used to assess the mechanical behavior of the composites and matrix alloy.

The composites and matrix alloy rods were machined to tensile specimens with a gauge diameter of 10 mm and gauge length of 80 mm. The surface of the samples was polished on 600 sand grit papers.. Tensile test was conducted on three specimens for each composition and average value was reported.

3. RESULTS AND DISCUSSION

3.1Microstructural Studies

The optical micrographs of the Al-Cu alloy, Al-Cu-3wt. % SiC and Al-Cu-3wt. % Fly ash particulate composites were shown in fig.2 (a-c).



(a) (b)

(c)

Figure 2: Showing the optical microphotographs of (a) Al-4.5 wt. % Cu alloy (b) Al-4.5wt. % Cu-3 wt.% SiC composites (c) Al-4.5wt. % Cu-3 wt. % Fly ash composites

Fig. 2 b-c reveals the uniform distribution of SiC and Fly ash particles and very low agglomeration and segregation of particles, and porosity. The vortex generated in the stirring process breaks solid dendrites due to higher friction between particles and Al matrix alloy which further induces a uniform distribution of particles.

3.2 Hardness Measurements

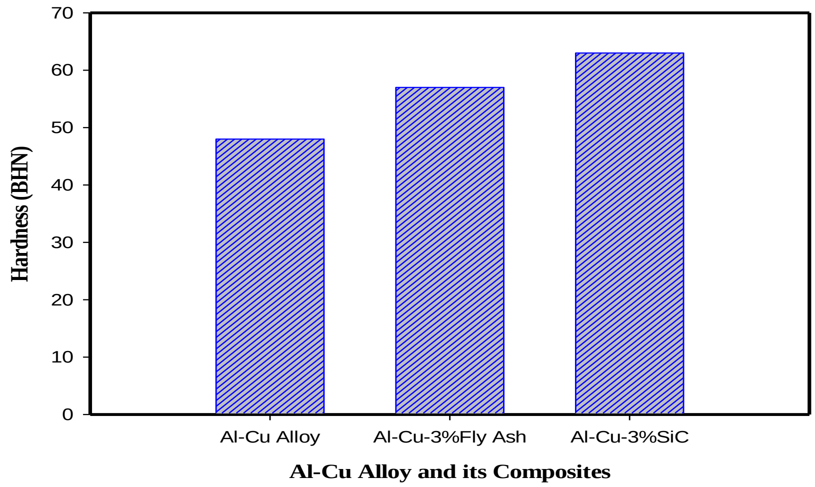


Figure 3: Showing the hardness of Al-Cu ally and its composites with SiC and Fly ash particulates

The hardness measurements on Al-Cu alloy, Al-Cu-SiC and Al-Cu-Fly ash composites are shown in fig. 3. The Brinell hardness of cast Al-Cu alloy, Al-Cu-SiC and Al-Cu-Fly ash composites containing 3 wt. % of SiC and Fly ash are evaluated using ball indenter at an applied load of 187.5 kgf with dwell time 10 secs for each sample at different locations. It can be observed that the hardness of the composite is greater than that of its cast Al-Cu alloy matrix. Further, Al-Cu-3% SiC composites were shown more hardness as compared to Al-Cu-3% Fly ash composites. The increase in the hardness of Al-Cu-SiC composites is mainly due to SiC particles being hard dispersoids contribute positively to the hardness of the composite. The increase in hardness is attributed to the hard SiC particles which act as a barrier to the movement of dislocation within the matrix. This dispersion-strengthening effect is expected to be retained even at elevated temperatures and for extended time periods because the particles are not reactive with the matrix phase. The hardness of Al-Cu-Flay ash composite is greater than that of base matrix Al-Cu alloy. Thus the hard fly ash particles help in increasing the hardness of the aluminium alloy (Al – Cu alloy) matrix [14]. The hardness increases with an increasing percentage of particulates. This may be due to the presence of hard fly ash particulates.

3.3 Ultimate Tensile and Yield Strength

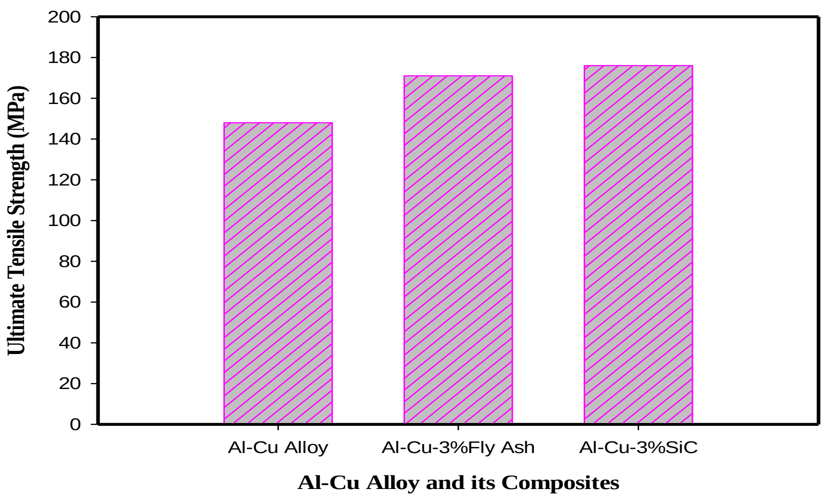


Figure 4: Showing the ultimate tensile strength of Al-Cu ally and its composites with SiC and Fly ash particulates

Fig.4 shows the variation of ultimate tensile strength (UTS) of base alloy, Al-Cu-3% SiC and Al-Cu-3% Fly ash particulates. The ultimate tensile strength of Al-Cu-3% SiC and Al-Cu-3% Fly ash composite material increased when compared to as cast base Al-Cu alloy. Further, ultimate tensile strength of Al-Cu-3% SiC composite is higher than that of Al-Cu-3% Fly ash composite. The microstructure and properties of hard ceramic SiC particulates control the deformation of the composites. Due to the strong interface bonding, load from the matrix transfers to the reinforcement resulting in increased ultimate tensile strength. This increase in ultimate tensile strength mainly is due to presence of SiC particles which are acting as barrier to dislocations in the microstructure. The UTS of Al-Cu-Fly ash composites are higher than base alloy, mainly due to presence of Fly ash particulates present in the soft matrix alloy. These particulate acts as a load carrying member.

Fig. 5 shows variation of yield strength (YS) of Al-Cu alloy matrix with Al-Cu-3% SiC and Al-Cu-3% Fly ash particulate reinforced composite. The yield strength of Al-Cu-3% SiC and Al-Cu-3% Fly ash composite material increased when compared to as cast base Al-Cu alloy. Further, yield strength of Al-Cu-3% SiC composite is higher than that of Al-Cu-3% Fly ash composite. This increase in yield strength is in agreement with the results obtained by several researchers, who reported that the strength of the particle reinforced composites is more strongly dependent on the volume fraction of the reinforcement [15]. The increase in YS of the composite is obviously due to presence of hard SiC particles which impart strength to the soft aluminium matrix resulting in greater resistance of the composite against the tensile stress. In the case of particle reinforced composites, there is a restriction to the plastic flow due to the dispersion of the hard particles in the matrix, thereby providing enhanced strength to the composite.

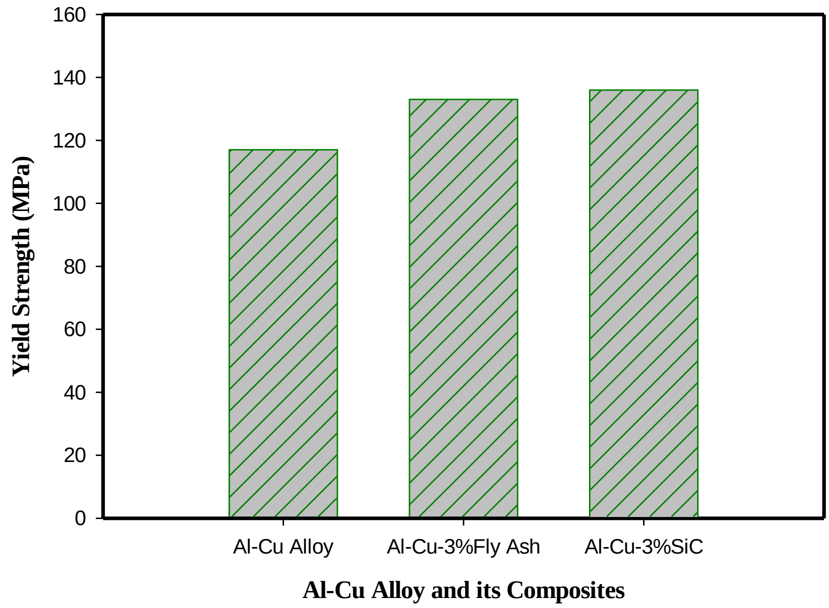


Figure 5: Showing the yield strength of Al-Cu ally and its composites with SiC and Fly ash particulates

4. CONCLUSIONS

The present work on Al-Cu-SiC and Al-Cu-Fly ash composites fabricated by stir casting process has lead to the following conclusions:

1. Al-Cu-3% SiC and Al-Cu-3% Fly ash composites were successfully synthesized by dual step stir casting route.
2. Optical microphotographs of Al-Cu-SiC and Al-Cu-Fly ash composites revealed the uniform distribution of SiC and Fly ash particulates in the Al-Cu alloy matrix.
3. Hardness of Al-Cu-3% SiC and Al-Cu-3% Fly ash composites were found to be higher than the Al-Cu base alloy. Further, hardness of Al-Cu-3 % SiC composite was more than Al-Cu-3 % Fly ash composite.
4. Ultimate tensile strength of Al-Cu-3% SiC and Al-Cu-3% Fly ash composites were found to be higher than the Al-Cu base alloy. Further, UTS of Al-Cu-3 % SiC composite was more than Al-Cu-3 % Fly ash composite.

5. Yield strength of Al-Cu-3%SiC composite was more than both the Al-Cu base alloy and Al-Cu-3% Fly ash composite.

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