SYNTHESIS AND MECHANICAL CHARACTERIZATION OF NANO Al_2O_3 REINFORCED COPPER-TIN METAL COMPOSITES

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Abstract

The work is carried out to investigate and study the mechanical properties of nano Al_2O_3 reinforced copper-tin alloy (Cu-Sn) metal matrix composites. In the present work copper-10% tin alloy was taken as the base matrix and 4 wt.% of nano Al_2O_3 particulates as reinforcement material to prepare metal matrix composites by stir casting method. For the composites, the reinforcement particulates were preheated to a temperature of 500ºC and dispersed into a vortex of molten copper alloy. The microstructure characterization was done using scanning electron microscope. Mechanical properties like hardness, ultimate tensile strength, yield strength and percentage elongation were evaluated as per ASTM standards. Further, scanning electron microphotographs revealed that there was uniform distribution of nano Al_2O_3 particulates in copper-tin alloy matrix. Hardness, ultimate tensile strength and yield strength increased in the case 4 wt. % of nano Al_2O_3 reinforced composites. Ductility of the composites was decreased in copper-tin-Al_2O_3 composites.

Keywords Copper-Tin Alloy, Nano Al_2O_3, Metal matrix composites, Stir casting, Mechanical properties

1. Introduction

Metal matrix composites are increasingly becoming attractive materials for advanced aerospace, automobile industries due to light weight, low cost, easy fabrication and ever increasing demands of modern technology [1]. Metal matrix composites are the combination of soft base metal with hard refinement material and have recently found special interest because of their specific strength and specific stiffness at room or elevated temperature. With the advancement of modern technology, there is a everlasting demand for an economical, light weight harder, stronger and energy saving material in the area of space, aircraft, advanced defense fighter jets and automobile application [2].

The metal matrix developed is very strong and tough. The initial MMC's are light metal matrix composites and the common matrix material used are the aluminum, magnesium, titanium and their alloys. Aluminum oxide, boron carbide, silicon carbide and typically used fibers or reinforcements [3]. When the metals are reinforced with the reinforcements will enhance the physical and mechanical properties such as strength, density, stiffness, wear and fatigue resistance, toughness, hardness, improve creep resistance, improvement in thermal and electrical properties, improved abrasive resistance and good retention at high level elevated temperature. Titanium reinforced metal matrix composites are used in the development of critical rotating components of gas turbine, Mach airframes and the components of aero system working at high temperature, magnesium reinforced composites are used in the aero gearbox for lighter weight. MMCs offer high strength and facture toughness compared to polymer matrix composites and these can sustain at corrosive and high temperature environment then polymer composites. High module characterization is done for light metal matrix for high temperature applications reinforced for the aforementioned reasons [4].

As early stated the MMCs of light weight are most appropriate for low temperature applications, Because of their low density many MMCs are suitable for new design and this adds the advantage to the lighter metal matrix composites [5]. Mechanical and physical properties and melting point of the composites at different temperatures finds composites service temperature.

Studies on the synthesis and characterization of nano particles dispersed copper metal matrix composites have been attracting scientific interest in recent years, since nanostructure-type materials are expected to have special physical and mechanical properties. In the copper–alumina system, the nano-scale Al_2O_3 particulate dispersion can provide unique characteristics, such as high thermal and electrical conductivities, as well as high strength and excellent resistance to high temperature annealing. Therefore, Cu-Tin based metal matrix composites are being used in many industrial applications such as: contact supports, frictional break parts, electrode materials for lead wires, spot welding [6]. The main requirement for structure of these materials is a homogenous distribution and small size of oxide particles on copper matrix. Many manufacturing processes have been used for producing such composites. In general most metal matrix composites are produced by squeeze or stir casting, spray forming or by powder metallurgy techniques. Among the above, stir casting technique is the simplest and most economical used technique is known as 'vortex technique' or stir casting technique' it is attractive because of simplicity, low cost of processing, flexibility, most economically for large sized components to be prepared as well as production of near net shaped components.

In the present study Cu-Sn-4wt.% of nano Al_2O_3 composites were synthesized and evaluated for mechanical properties like hardness, ultimate tensile strength, yield strength and elongation as per ASTM standards.

2. Experimental Details

2.1. Materials Used

For the metal matrix composite the base alloy copper-tin alloy is reinforced with nano Al_2O_3 particles o 150-200 nm in size and is fabricated as Cu-Sn- Al_2O_3 composites metal matrix composites. Density of copper is 8.9 g/cc and that of the reinforcement particle is Al_2O_3 3.9 g/cc. The chemical composition of Cu-Sn base alloy is shown in Table 1.

Table 1. Chemical composition of Cu-Sn alloy

Elements	Wt. Percentage
Sn	9.83
Si	0.30
Mn	0.10
Mg	0.30
Cu	Balance

2.2. Composite Preparation

The metal matrix composites of Cu-Sn- Al_2O_3 composites have been produced by simplest and most economical used technique known as vortex technique or stir casting technique. The Cu-Sn alloy was heated to the temperatures of 1150ºC in the electrical resistance furnace. Due to the nano size of reinforcement particulates Al_2O_3 porosity defect may occur during metal matrix composite. Whereas increasing the stirring time reduces the porosity level. The temperature of the electric furnace was controlled to an accuracy of ±30ºC using a digital temperature controller. Degassing agent solid hexa-chloroethane (C_2Cl_6) [7] 3 to 4 grams was added to expel all absorbed gases from the molten metal once the temperature have been reached. Before the addition of nano Al_2O_3 particulates, mechanical stirring process was carried out with the help of zirconia coated stirrer to form a fine vortex. The speed of the stirrer is rotated for 5-8 mins at a spindle speed of 300 rpm. The nano Al_2O_3 particulates were preheated to a temperature of 600ºC in a preheater to increase the wettability. The stirrer was immersed into the molten metal in the crucible at a depth of 2/3 from the bottom. The addition of the nano Al_2O_3 particulates to the molten metal was divided into two equal weights rather adding all at once to avoid agglomeration of the matrix. At every stage, stirring was carried out before and after introduction of reinforcement particulate to the molten metal. Before pouring the molten metal into the mould die, the molten metal was heated for about 5 mins. The melt poured into a preheated cast iron mould dimension of 120 mm x 15 mm diameter.

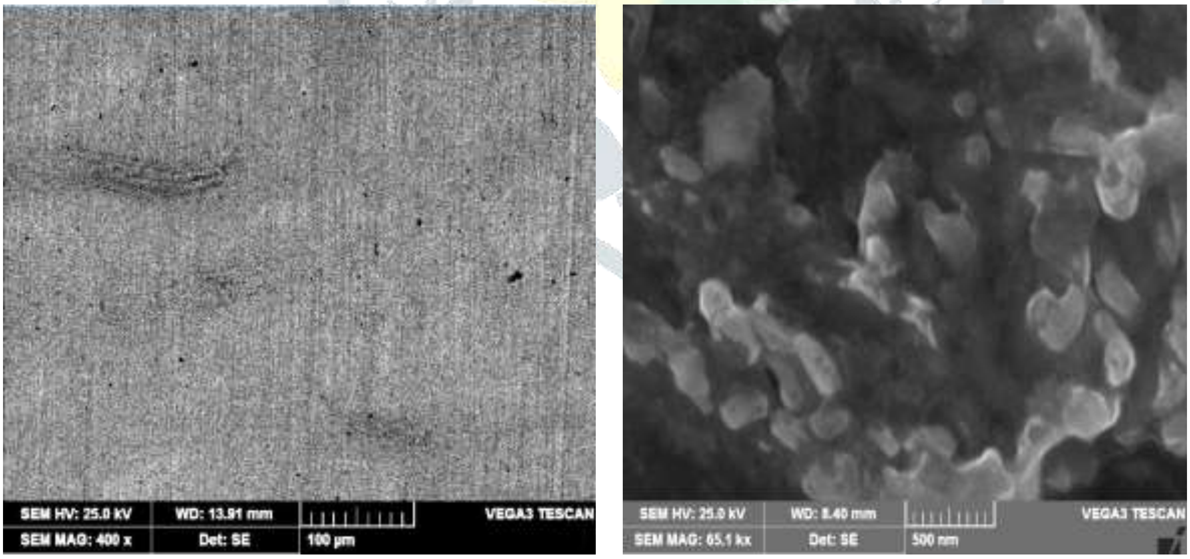
2.3. Composite Preparation

The microstructural study was carried out on the investigating composites using scanning electron microscope. Samples around 5 mm diameter cut from the castings and were polished properly. Keller's reagent was used to etch the samples. Tensile specimens were machined from the cast samples. Hardness of as cast copper tin-Al_2O_3 composites were directed to know the impact of small scale Al_2O_3 particles in the network material ASTM E 10 standard. The cleaned examples were tried for their hardness, utilizing Brinell hardness testing machine having ball indenter for 250 kg stack and abide time of 30 sec., three arrangements of readings were taken at better places of the example and a normal esteem was utilized for figuring.

The tensile specimens of circular cross section with a diameter of 9 mm and gauge length of 45mm were prepared according to the ASTM E8 standard testing procedure [8]. The tests were conducted on a universal testing machine. All the tests were conducted in a displacement control mode at a rate of 0.1 mm/min. Multiple tests were conducted and the best results were averaged. Various tensile properties like ultimate tensile strength, yield strength and percentage elongation were evaluated for both as cast copper alloy and copper-tin alloy-4 wt. % nano Al_2O_3 composites.

3. RESULTS AND DISCUSSION

3.1 Microstructural Analysis



(a) (b)

Figure 1: Showing the SEM micrographs of (a) as cast copper-tin alloy (b) copper-tin-4 wt. % Al_2O_3 composite

The micro structural studies are useful in determining the grain size, grain shape and distribution of reinforcement particulates within the base matrix, which have a greater effect on the mechanical and tribological properties. Microstructural features have been studied using scanning electron microscope (SEM). The SEM micrographs of as cast copper alloy and copper-4 wt. % nano Al_2O_3 composites are shown in Fig. 1 (a-b) respectively. The micrographs of copper-tin- nano Al_2O_3 composites reveal the uniform distribution of Al_2O_3 particulates throughout the matrix. Uniformly distributed reinforcements increase the hardness and reduce the porosity of the metal matrix composites.

3.2 Hardness Measurements

Hardness is a property of a material that indicates the ability of the material to resist local plastic deformation. Fig. 2 shows the influence of the nano Al_2O_3 particle contents on the hardness of the copper alloy. The hardness values are positively correlated with the weight percentage of nano particles, because particles strengthened the matrix. Furthermore, the results show that nano particles reinforced MMCs harder than copper alloy due to Hall-Petch and Orowan strengthening mechanisms[9] as well as the good interface between the reinforcement and matrix. Copper-tin-4 wt. % nano Al_2O_3 composites show more hardness, the increase in hardness of these composites can be attributed to the dispersion strengthening effect. By adding 4 wt. % nano Al_2O_3 particulates into the copper-tin alloy, the hardness of copper-tin alloy increased to 77.3 BHN from 90.5 BHN.

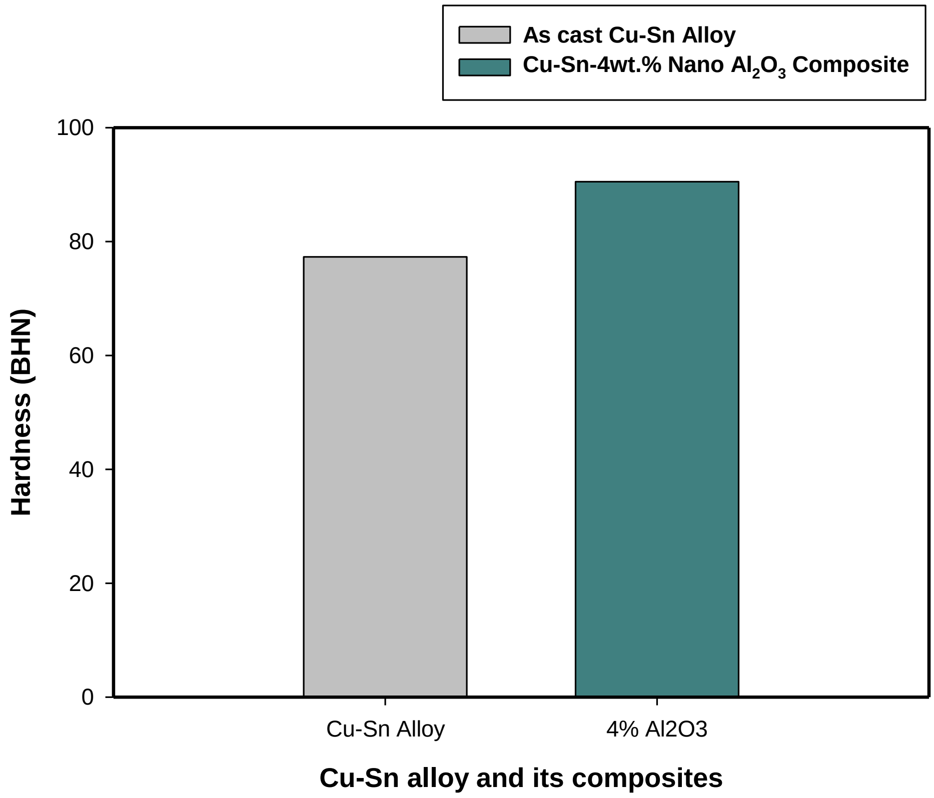


Figure 2: Hardness of copper-tin alloy and its nano Al_2O_3 composites

3.2 Tensile Properties

Fig. 3, 4 and 5 showing the tensile properties of as cast copper-tin alloy and 4wt. % nano Al_2O_3 composite. Fig. 3 showing the ultimate tensile strength (UTS) of copper-tin alloy and it's composite. From the figure, it is evident that UTS of copper and Al_2O_3 composite is higher than the base matrix alloy. By adding 4 wt. % of nano Al_2O_3 particles to the base alloy, UTS has been increased from 307.5 MPa to 357.5 MPa.

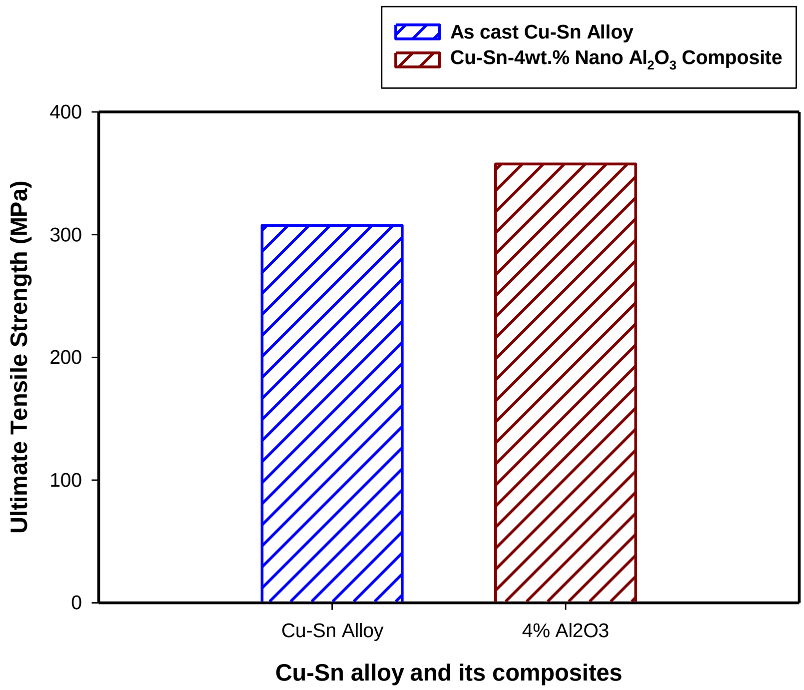


Figure 3: Ultimate tensile strength of copper-tin alloy and its nano Al_2O_3 composites

From the fig. 4 it was found that yield strength (YS) of the as cast copper-tin base alloy is 242.9 MPa and in copper-tin-4 wt. % nano Al_2O_3 composite is 274.7 MPa. It showed an improvement of 13.09 % in yield strength as compared with as cast base matrix.

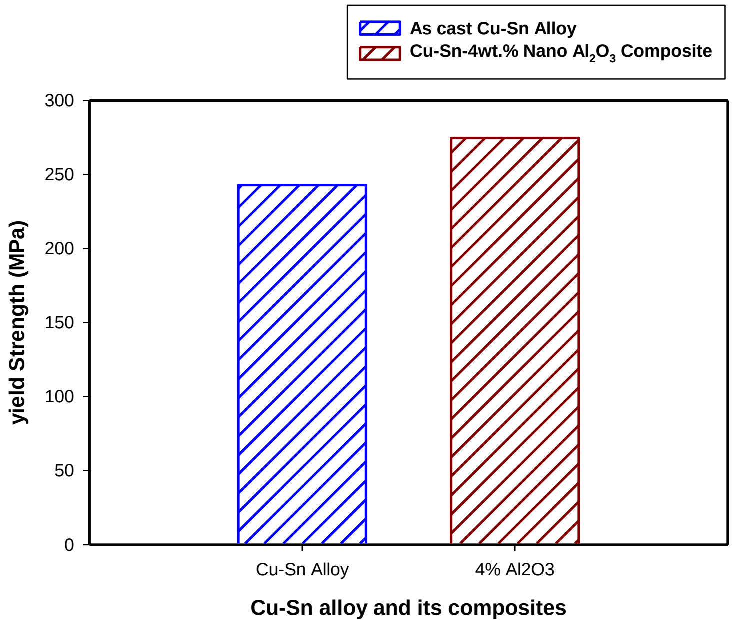


Figure 4: Yield strength of copper-tin alloy and its nano Al_2O_3 composites

The increase in UTS and YS is mainly due to strong bonding between reinforcement particles and copper matrix, plays an important role on the load transferring from matrix to reinforcement. This is because of grain refinement and particle strengthening. The enhancement of strength is affected by the higher load bearing and mismatch strengthening caused by nano Al_2O_3 particles. It is expected that due to the difference in the coefficients of thermal expansion between matrix and Al_2O_3 reinforcement and therefore thermal mismatch stress, there is a possibility of increased dislocation density within the matrix during cooling from solidification temperature [10, 11]. The dislocations might be lead to make local stress at the interface of particle and matrix. In comparison to the base copper, the great enhancement in the strength observed in the composites is due to the presence of the particles as obstacles that restrict the motion of dislocations trapped by Al_2O_3 particulates. This will lead to increase the tensile strength of the nano composites during tensile tests.

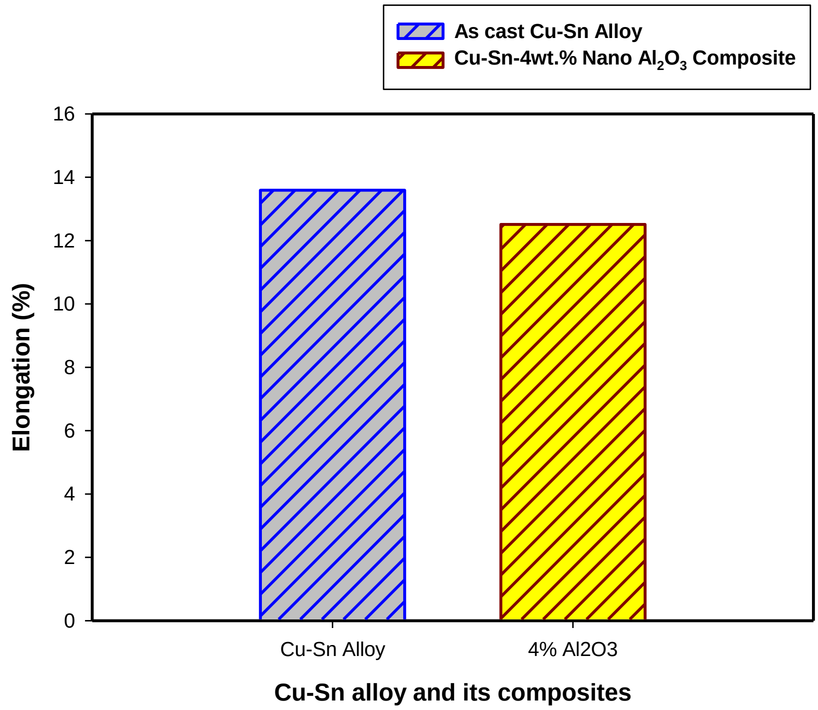


Figure 5: Showing the percentage elongation of as cast copper-tin alloy and copper-tin-4wt. % nano Al_2O_3 composite

Fig. 5 shows the percentage elongation of as cast copper alloy and its composites. The percentage elongation was reduced in copper-tin-Al_2O_3 composite as compared to the base alloy. It can be seen from the graph that the ductility of the composites decrease significantly with the 4 wt. % nano Al_2O_3 reinforced composites. This decrease in percentage elongation in comparison with the base alloys is a most commonly occurring disadvantage in particulate reinforced metal matrix composites. The reduced ductility in copper-tin-4 wt. % composites can be attributed to the presence of Al_2O_3 particulates which may get fractured and have sharp corners that make the composites prone to localised crack initiation and propagation [12]. The embrittlement effect that occurs due to the presence of the hard ceramic particles causing increased local stress concentration sites may also be the reason.

4. CONCLUSIONS

This present research is centered on the development and characterization of the microstructure and mechanical behavior of copper alloy and its composites containing 4 wt. % of Al_2O_3 nano particles. From the liquid metallurgy techniques copper-tin alloy and 4wt.% Al_2O_3 nano composites were prepared successfully. The scanning electron micrographs revealed the uniform distribution of nano Al_2O_3 particulates in copper base alloy. The hardness of copper-tin base alloy increased with the addition of 4 wt. % of nano Al_2O_3 particulates. The ultimate tensile strength and yield strength of copper-tin base alloy was increased with the addition of 4 wt.% nano Al_2O_3 particulates. The ductility of base alloy copper reduced with the addition of hard nano Al_2O_3 particulates.

REFERENCES

[1] A. Baradeshwaran, A. Elaya Perumal, "Study on mechanical and wear properties of Al7075-Al_2O_3-Graphite hybrid composites", Composites Part:B, 56, 2014, pp. 464-471.

[2] Kok M. Production and mechanical properties of Al_2O_3 particle reinforced 2024 aluminium alloy composites. Journal of Materials Processing Technology,161, 2005, 381-387.

[3] Madeva Nagaral, V Auradi and S A Kori, "Microstructure and mechanical properties of Al6061-Graphite composites fabricated by stir casting process", Applied Mechanics and Materials, Vol. 766-767, pp. 308-314, 2015.

[4] Sallahauddin Attar, Madeva Nagaral, H N Reddappa and V Auradi, "Effect B_4C particulates addition on wear properties of Al7025 alloy composites", American Journal of Materials Science, 5(3C), 2015, pp. 53-57. DOI: 10.5923/c.materials.201502.05.

[5] Sahin Y. Preparation and some properties of SiC particle reinforced aluminium alloy composites. Materials and Design, 24, 2003, 671-679.

[6] Prasad H Nayak, Srinivas H K, Madeva Nagaral, Mechanical behavior of nano ZrO_2 particulates reinforced copper alloy composites", International Journal of Computaional Engineering Research, 8, 7, pp. 1-6, 2018.

[7] Madeva Nagaral, Shivananda Kalgudi, Virupaxi Auradi, Shivaputrappa Kori, "Mechanical characterization of ceramic nano B_4C-Al2618 alloy composites synthesized by semi solid processing", Transactions of the Indian Ceramic Society, Vol.77, No.3, pp. 1-4, 2018.

[8] Sridhar Raja K S, Bupesh Raja V K. Effect of Boron Carbide particle in wear characteristic of cast aluminium A356 composite. IOSR Journal of Mechanical and Civil Engineering, 2014, 73-77.

[9] T.R.Vijayaram, V.P.M.Baskaralal, A review on the processing methods, properties and applications of metal matrix composites, International Journal of Engineering Research and Technology, (2016) 45-51.

[10] J. Kulasa, W. Malec, B. Juszcztk, S. Malara, B. Cwolek , Microstructure and tribological properties of tin Bronze –graphite composite made by stir casting ISSN 0543-5846.

[11] Alessandro Figini Albisetti, Carlo Alberto Biffi, Ausonio Tuissi, Synthesis and structural analysis of copper-Al_2O_3 oxide, (07)(2016).

[12] Shaaz Abulais, Vikrant Yadav, Aniruddha mulet, Fabrication and characterization of copper matrix hybrid composite, Published by international journal of mechanical and production engineering, (2016) 2320-2092.