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Mechanical Behavior of Nano ZrO_2 Particulates Reinforced Copper Alloy Composites

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ABSTRACT
In the present investigation, microstructure study and tensile behavior of nano ZrO_2 particulate reinforced copper alloy composites has been reported. Copper matrix composite containing nano ZrO_2 were fabricated by conventional stir casting method.The composites containing 4 wt. % of nano ZrO_2 particulates were fabricated for the study. The microstructure of the composite was examined by scanning electron microscopy, images were taken to identify the presence of nano ZrO_2 particle in aluminum matrix. Further, tensile behavior of as cast copper alloy and copper alloy-4 wt. % nano ZrO_2 composites were studied. Tensile properties like ultimate tensile strength, yield strength and percentage elongation were evaluated as per ASTM standards. Microstructural observation revealed the uniform distribution of particles in the copper alloy matrix. From the analysis, it was found that the ultimate tensile strength and yield strength of composite was increased due to nano ZrO_2 particles in the composite. Further, from the study percentage elongation of the composite decreases with the addition of nano ZrO_2.
Keywords: Copper Alloy, nano ZrO_2, Ultimate Tensile Strength, Yield Strength, Stir casting, Percentage Elongation.

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I. INTRODUCTION

Metal matrix composites (MMCs) have emerged as advanced materials for several prospective applications. As they have high specific strength and stiffness, superior wear and seizure resistance, MMCs are used in automotive, aircraft and other engineering industries. The primary matrix materials are being used in the manufacture of MMCs such as aluminium, copper, titanium, magnesium and super alloys. The matrix is continuous phase which provides a binding support for the reinforcement. MMCs exhibit extremely good thermal stability associated with high strength, fatigue and toughness at higher temperature. These characteristics of MMCs are most desirable for design applications [1-2].

The attractive physical and mechanical properties that can be obtained with MMCs, such as high specific modulus, strength and thermal stability have been documented extensively. Metal matrix composites combine metallic properties, leading to greater strength in shear and compression and high service temperature capabilities [3]. Interest in MMCs for aerospace, automotive and other structural applications, has increased over last fifteen years as a result of availability of relatively inexpensive reinforcements, and the development of various processing routes which result in reproducible microstructure and properties [4].

Among any of other commonly used metals, copper is one characterized by the best thermal conductivity and resistance to corrosion which explains why it is commonly chosen in the first instance for metal material. On the other hand, having very low mechanical properties, it has to be strengthened by ceramic particles, for example, which is one of the most reliable methods of reinforcement. Copper based metal matrix composites (CMCs) have found greater applications in the field of automotive, aircrafts and machine tool industries owing to their low density and concomitant high wear resistance, strength, corrosion resistance, stiffness and thermal conductivity. Copper and its alloy are largely used as a material for bearings [5, 6].

Since copper based materials have a relativity high temperature and low wear resistance, the copper matrix has been successfully strengthened with nano zirconium oxide and graphite particles, continues or discontinuous

fibers, called metal matrix composite (MMCs). The incorporation of zirconium oxide reinforcement can significantly improve the mechanical properties and wear resistance without severe deterioration of electrical and thermal conductivity of the matrix therefore, this materials are considered to be promising candidates for supplications, where high mechanical property, high conductivity and good wear resistance are required [7, 8].
ZrO_2 particles reinforced to copper composite by using stir casting method were continues stirring process is carried out before and after the pouring of mixture of reinforcements to avoid clustering of particulates and to have uniform homogenous distribution of nano particulates in the melt. Zirconium Oxide is a superior reinforcement material due to its high hardness, high strength, high wear and impact resistance, high melting point, low coefficient of thermal expansion and good chemical stability and graphite reinforcement which is a solid lubricant reduces the wear of copper matrix it has very good electricity conductivity when fabricated with copper.
There is a growing interest worldwide in manufacturing ceramic particulate reinforced metal matrix composites which processes combined properties of its reinforcements and exhibit improved physical, mechanical and tribological properties.
In the present study, copper-10%Zn alloy based composites were fabricated by stir casting process. Nano ZrO_2 particulates were used as the reinforcement. The 4 wt. percentage of ceramics reinforcements were taken to fabricate the copper-ZrO_2 composites. The composites were tested for mechanical properties like hardness, ultimate tensile strength, yield strength and percentage elongation as per ASTM standards.

II. EXPERIMENTAL STUDY

Table1. The chemical composition of A356 alloy

Elements	Content wt. %
Copper	89.20
Zinc	9.90
Others	0.90

The Copper-Zn-nano ZrO_2 composites fabricated in this study contains 4 wt. % of ceramic nano ZrO_2 particulates. The density of copper-zinc alloy is 8.737 g/cm^3 and the density of ZrO_2 is 5.68 g/cm^3. The density of composites decreases with addition of nano ZrO_2 particulates. The chemical composition of copper-zinc alloy is shown in the Table 1.
The fabrication of copper-zinc-ZrO_2 composites was carried out by liquid metallurgy route via stir casting technique. The major components of the casting process consist of electrical resistance furnace; zirconium coated steel impeller and cast iron permanent mould. The power rating of electrical furnace used was 60kw and maximum temperature limit was 1200 degree Celsius. The mechanical stirrer used for stirring the molten alloy during the preparation of composites was coated by zirconium to withstand high temperature and to prevent migration of ferrous ions from the stirrer material into copper alloy melt. The permanent type of mould made of cast iron used in fabrication is shown in Fig. 1.

Figure 1: Cast iron die used to prepare the samples

Calculated amount of the copper alloy ingots were charged into the furnace for melting. The melting point of copper alloy is 1084˚C. The melt superheated to a temperature of 1130˚C. The temperature was recorded using a chrome-alumel thermocouple. The molten metal was then degassed using solid hexachloroethane (C_2Cl_6) for 3 min [9]. A stainless steel impeller coated with zirconium was used to stir the molten metal to create a vortex.

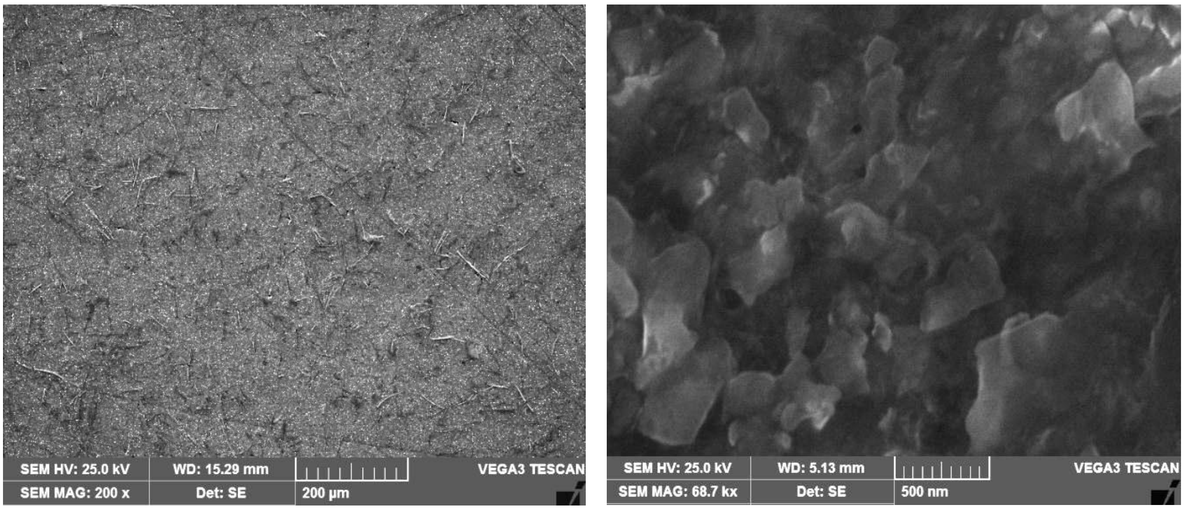
The stirrer was rotated at a speed of 300rpm and the depth of immersion of the impeller was 60 percent of the height of the molten metal from the surface of the melt. Further, the nano ZrO_2 particulates were preheated in a furnace upto 400˚C were introduced into the vortex. Stirring was continued until interface interactions between the reinforcement particulates and the matrix promotes wetting. Then, Copper alloy- 4 wt. % nano ZrO_2 mixture was poured into permanent cast iron mold having dimensions 125mm length and 15mm diameter.

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-ZrO_2 amalgam composites were directed to know the impact of small scale ZrO_2 particles in the network material ASTM E 10 standard [10]. 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 [11]. 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 alloy-4 wt. % nano ZrO_2 composites.

III. RESULTS AND DISCUSSION

3.1 Microstructural Analysis



(a) (b)

Figure 2: Showing the SEM micrographs of (a) as cast copper alloy (b) copper-4 wt. % ZrO_2 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 ZrO_2 composites are shown in Fig. 2 (a-b) respectively. The micrographs of copper- nano ZrO_2 composites reveal the uniform distribution of ZrO_2 particulates throughout the matrix. Uniformly distributed reinforcements increase the hardness and reduce the porosity of the metal matrix composites.

3.2 Hardness Measurements

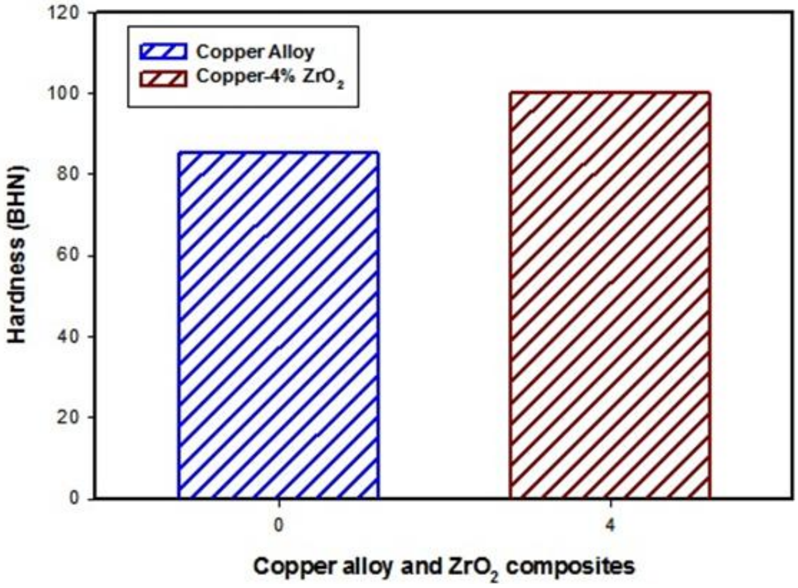


Figure 3: Showing the hardness of as cast copper alloy and copper-4wt. % nano ZrO_2 composite

Hardness is a property of a material that indicates the ability of the material to resist local plastic deformation. Fig. 3 shows the influence of the nano ZrO_2 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 as well as the good interface between the reinforcement and matrix [12]. Copper-4 wt. % nano ZrO_2 composites show more hardness, the increase in hardness of these composites can be attributed to the dispersion strengthening effect [13]. By adding 4 wt. % nano ZrO_2 particulates into the copper alloy, the hardness of copper alloy increased to 85.4 BHN from 100.1 BHN.

3.2 Tensile Properties

Fig. 4, 5 and 6 showing the tensile properties of as cast copper alloy and copper-4wt. % nano ZrO_2 composite. Fig. 4 showing the ultimate tensile strength (UTS) of copper alloy and it's composite. From the figure, it is evident that UTS of copper- ZrO_2 composite is higher than the base matrix alloy. By adding 4 wt. % of nano ZrO_2 particles to the base alloy, UTS has been increased from 329.7 MPa to 369.2MPa.

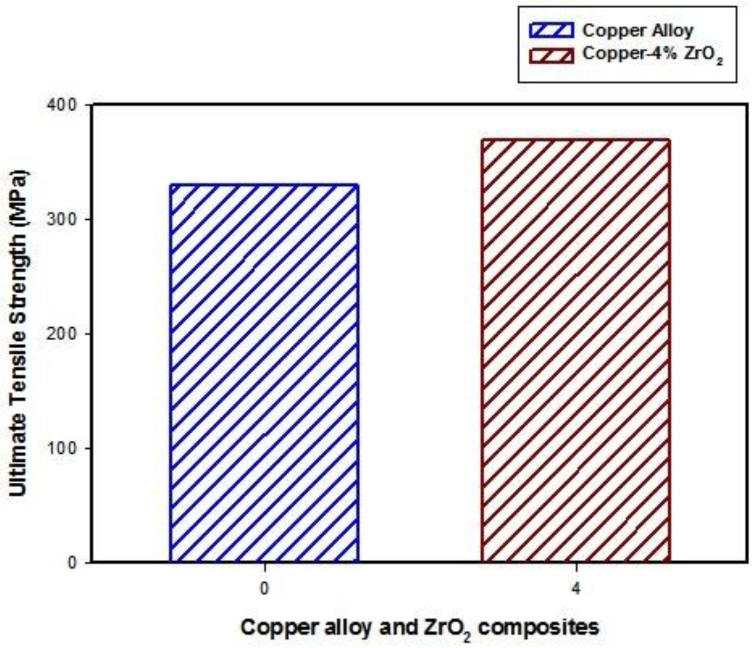


Figure 4: Showing the ultimate tensile strength of as cast copper alloy and copper-4wt. % nano ZrO_2 composite

From the fig. 5 it was found that yield strength (YS) of the as cast copper base alloy is 275.6 MPa and in copper-4 wt. % nano ZrO_2 composite is 306.8 MPa. It showed an improvement of 11.3% in yield strength as compared with as cast base matrix.

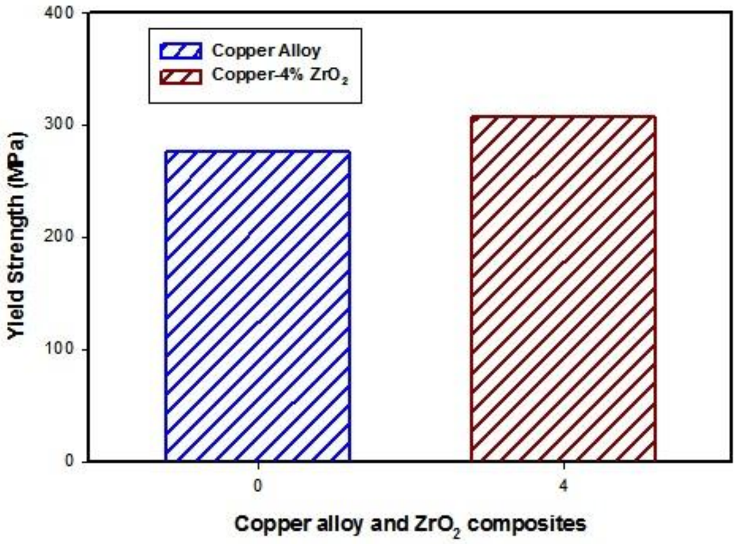


Figure 5: Showing the yield strength of as cast copper alloy and copper-4wt. % nano ZrO_2 composite

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 [14]. The enhancement of strength is affected by the higher load bearing and mismatch strengthening caused by nano ZrO_2 particles. It is expected that due to the difference in the coefficients of thermal expansion between matrix and ZrO_2 reinforcement and therefore thermal mismatch stress, there is a possibility of increased dislocation density within the matrix during cooling from solidification temperature [15]. 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 ZrO_2 particulates. This will lead to increase the tensile strength of the nano composites during tensile tests.

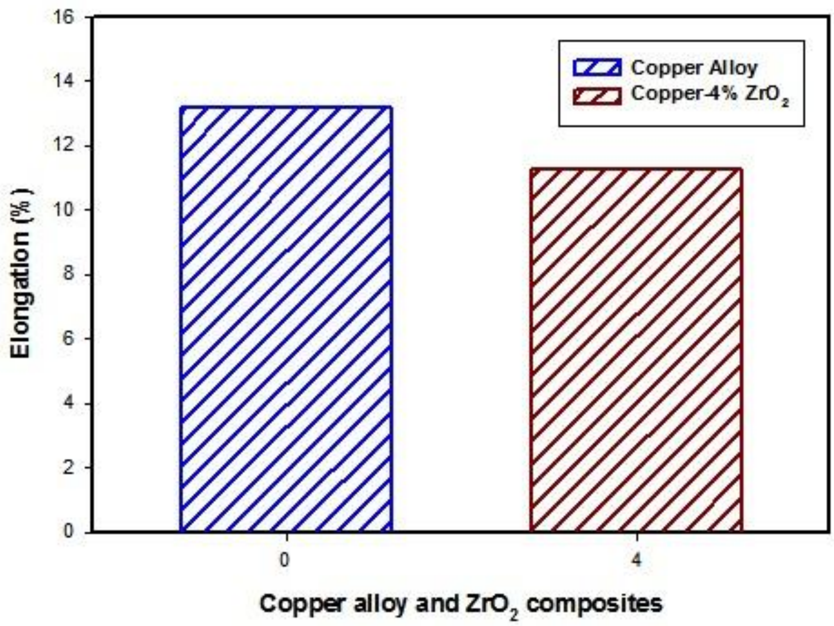


Figure 6: Showing the percentage elongation of as cast copper alloy and copper-4wt. % nano ZrO_2 composite

Fig. 6 shows the percentage elongation of as cast copper alloy and its composites. The percentage elongation was reduced in copper-ZrO_2 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 ZrO_2 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-4 wt. % composites can be attributed to the presence of ZrO_2 particulates which may get fractured and have sharp corners that make the composites prone to localised crack initiation and propagation. 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 [16].

IV. 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 ZrO_2 nano particles. From the above results and discussion the following conclusions are made:

1. From the liquid metallurgy techniques copper alloy- ZrO_2 nano composites were prepared successfully.
2. The scanning electron micrographs revealed the uniform distribution of nano ZrO_2 particulates in copper base alloy.
3. The hardness of copper base alloy increased with the addition of 4 wt. % of nano ZrO_2 particulates.
3. The ultimate tensile strength of copper base alloy and copper alloy-4% nano ZrO_2 composites were 329.7 MPa and 369.2 MPa respectively. This shown an improvement of 11.98 %, when compared with the base alloy copper.
4. The yield strength of copper base alloy and copper alloy-4% nano ZrO_2 composites were 275.6 MPa and 306.8 MPa respectively. This shown an improvement of 11.3 %, when compared with the base alloy copper.
5. The ductility of base alloy copper reduced with the addition of hard nano ZrO_2 particulates.

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