Original Article

Microstructure And Mechanical Properties Of Cu-Sn Alloy Reinforced With Al_2O_3 And Gr Metal Matrix Composite

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Abstract

In the current examination, an effort has been made to look into and examine the mechanical characteristics of stir cast composites manufactured from Cu+10wt% Sn alloy reinforced with graphene and Aluminum Oxide metal matrix. In this investigation, Cu+10wt% Sn Alloy was employed as the basic matrix and reinforcements included graphene and aluminium oxide particles. Casting in carried out in 3 different steps 2 wt. % of Gr and Al_2O_3 were added in to the basic matrix the hybrid composite is being prepared second and third casting of Cu+10wt% Sn alloy+ Gr and Cu+10wt% Sn alloy+ Al_2O_3 as reinforcements, namely Gr and Al_2O_3, were warmed to a temperature of 400 degrees Celsius and disseminated. Utilizing optical microscopy, the microstructural investigation produced a matrix alloy with uniformly distributed reinforced particles. The goal was to look at the viability of the method and the mechanical characteristics that would result, such as ultimate tensile strength, yield strength and hardness. The findings showed that adding Gr and Al_2O_3 particles to Cu-Sn alloy significantly improved the composite's mechanical characteristics.

Keywords: Cu-Sn alloy, Al_2O_3, Gr, SEM, ultimate tensile strength, yield strength, hardness

Introduction

Monolithic materials or its alloys are no longer of primary research or engineering interest. Metal-Matrix Composites (MMCs) are merely the combination of two or more materials, where the desired properties are obtained by carefully blending the various components [1]. The materialistic properties of traditional monolithic metals, such as wear resistance, electrical and thermal conductivity, friction coefficient etc., are constrained. However, specialised combinations of engineering properties are possible in composites thanks to systematic synthetic processes. Disc brakes, structural uses in all aircraft, metallic friction materials for high-speed motors are just a few examples of the applications for such MMCs [2, 3].

In composite materials, there are two phases that are Reinforcing phases are fibres, sheets, or particles that are encircled in the matrix phase. In several types of materials, the reinforcing substance and the matrix material may be separated, such as metals, ceramics, or polymers. Reinforcing materials are used in composites because they provide outstanding results at low densities, while matrixes are preferred because of their ductile or tough character. On the basis of the techniques used for reinforcement, composite materials are divided into three groups: dispersion, particle, and fiber reinforced. The strength of the reinforcement and the toughness of the matrix must be exactly coordinated in order to create a flawless composite. This allows for the achievement of desired qualities in composites that are not possible in a single material. Through observation, it has been shown that qualities like strength and stiffness may be readily changed in various composites owing to the orientation of the reinforcing material. A composite material has exceptional qualities that make it useful for usage, such as good stiffness, minimal density, amazing temperature stability, increased electrical and thermal conductivity, etc. As we can see, the worldwide market for composites has grown from 5% to 12%, which has positive employment effects due to the constant urbanisation of new materials, methods, and applications, such as quicker and more automated production and hybrid virgin and recycled fibres.

Most people are aware that copper inhibits a wide range of bacterial strains and germs that are often found in industrial, automotive, and medical processes. Copper has special, such as catalytic, antifungal/antibacterial, and conductive capabilities. First off, copper has a significant amount of catalytic surface area, which contributes to its very effective catalytic activity. As reagents in the synthesis of organic and organometallic compounds.

Tin is the main alloying element in tin bronze (Cu-Sn), which is made primarily of copper as the base metal. The composition range that is practical is 75 to 95% Cu and 5-25% Sn [4]. Tin bronze is utilised for applications like gears and bearings because it has strong corrosion resistance and strength [5]. They are widely used in the manufacture of hydraulic fittings, pump linings, kitchenware, bearings, sheets, rods, and wires, among other things. The main reason for this is due to their mechanical characteristics, which include excellent hardness, tensile strength, wear resistance, good corrosion resistance, and ductility.

Tin bronzes, which are technically Cu-Sn alloys, often have a -solution structure. According to the Sn concentration, they are divided into low-tin bronzes (5% Sn) and high-tin bronzes (> 5% Sn). The segregation phenomena is favoured by the large range of crystallisation temperatures of -solution bronzes. As a result, in the alloys cooling under actual conditions, the phases that, under equilibrium conditions, would occur at higher tin values, already exist at low tin content. The technological properties of the alloy, especially the sliding properties, improve with increasing tin content. Additionally, better castability, decreased hydrogen solubility, and increased corrosion resistance, especially in single phase alloys, are observed [6]. The high-tin bronzes were used, for instance, in the manufacture of bearings. It should be noted that the current bearings alloy is made up of Cu and Sn at a ratio of around 4:1. It is understandable why bearings bronze is renowned for its ability to resist corrosion while still being a very attractive alloy. Its strength characteristics present a different issue.

It is commonly known that a measure of a liquid's resistance to shear deformation is its viscosity, which is the reciprocal of fluidity. From both an academic and industrial perspective, the viscosity of metallic melts is a crucial thermophysical characteristic. The body of information about viscosity has grown significantly during the last 50 years[7-8]. However, when taking into account metallic melts, the aforementioned expressions seldom ever provide a completely appropriate assessment of their viscosity [9]. The examination of the relationship between viscosity and composition will serve as theoretical direction for the development of Cu-Sn materials since the viscosity of molten metals and alloys is a structurally sensitive feature.

Due to its intriguing mechanical, electrical, and chemical characteristics, copper alloys are widely used in the material, machine, and industrial areas, among others. The copper alloy system has exceptional qualities as a result of its intermetallic compound feature. Because the isotope replacement approach was originally used in neutron scattering investigations [10] and the medium-range order was covered in the reference [11], the liquid Cu–Sn system is well known. However, these investigations have not taken into account the connection between phase diagrams and viscosities with various compositions. [12].

The information provided by professional literature demonstrates that adding tin to copper alloys increases the tensile strength and hardness of the alloys formed in sand moulds while decreasing unit elongation. When alloys are poured into metal moulds, tin additions up to around 4% result in an increase in unit elongation. The unit elongation reduces if the tin content exceeds this level. The alloy's impact strength increases up to a tin concentration of roughly 5% before declining. Up to roughly 10% Sn more tin results in an increase in tensile strength, 20% Sn more tin results in an increase in yield strength, and continued tin content growth results in an increase in hardness. The alloy with 4% Sn has greater fatigue strength than the one with less tin, but when the tin percentage is increased to 8% Sn, the fatigue characteristics change less noticeably.

Material Selection and Composite Preparation

The basic matrix is copper alloy, which is created by incorporating tin (10 wt%) into the pure copper. In comparison to pure copper, copper alloy (density: 8.96 g/cm3) has greater wear resistance. Pure copper does not oxidise when tin (density: 7.31 g/cm3) is added, and it also has a strong corrosion resistance feature. Numerous uses for copper-tin alloy may be found in the production of piston rings, valves, bearings, and fittings. The graphene reinforcement (density: 2.26 g/cm3) with the Al_20_3 reinforcement (density: 3.95 g/cm3) wt% of 2 reinforcements. Al_20_3 and Gr reinforcement have improved copper wettability, which may increase mechanical characteristics and provide high temperature and voltage resistance.

Stir casting is used to create unreinforced copper alloy as well as reinforced copper alloy with different weight percentages of Al_20_3 and Gr. Stir casting is a productive technique for creating MMCs because it enhances the interfacial interaction between the metal and reinforcement. It provides benefits including adaptability to large-scale manufacturing, simplicity, and design adaptability. The crucible was initially filled with pure copper, It was then heated in the furnace to the temperature necessary to melt copper (1085 °C). Tin (10 wt%) was then added to the molten copper, and then the crucible was filled with preheated Al_20_3 and Gr particles (350 °C). In order to prevent a thermal imbalance with the matrix, reinforcements were warmed. For 20–25 minutes, the mixture was continually swirled at an ideal constant speed of 150 rpm to ensure that the reinforcements were distributed evenly throughout the matrix. To keep the mixture from oxidising and from hydrogen gas accumulating in the cast, an argon atmosphere was maintained. The melt was placed into a 150-mm-long, 15-mm-diameter permanent die casting mould that had been preheated to 450°C. To prevent thermal imbalances, the die was kept preheated. After solidifying, the cast material was then taken out of the mould. The aforementioned procedure was performed for alloy and other composites that had different reinforcing wt %. In Fig. 1,2 and 3 shows the cast iron mould, poring of molten metal in mould and the cast samples are shown respectively. In Table 1, the elemental makeup of copper alloy is listed. Table 2 shows the reinforcement of % added in copper alloy.

Table1: The chemical composition

Elements	Content wt. %
Copper	89.20
Tin	9.90
Others	0.90

Table 2: Addition of reinforcement in Cu-Sn alloy

Sl.no	Wt% of Cu and Sn	Wt% of Al_2O_3 and Gr
1	90% Cu + 10% Sn	0
2	90% Cu + 10% Sn	2% Al_2O_3
3	90% Cu + 10% Sn	2% Gr
4	90% Cu + 10% Sn	2% Al_2O_3 +2% Gr

Fig.1. Cast iron mould with C-clamp attachment

Fig.2. Pouring of molten metal it to die

Fig.3. Cast specimens

Microstructure and Mechanical properties

To guarantee consistent distribution of reinforcing particles, to characterise the component's microstructure, samples from the stir cast component are taken. Using a bench grinder, it was first ground, then the burrs were removed with a linisher polisher. Using emery sheets of varying grit sizes, it was further completed (1000, 2000 and 3000). Finally, the specimen was prepared by polishing it with a disc in the presence of alumina to provide a smooth surface for seeing the microstructure. After being etched with $FeCl_3$, the specimen's surface was examined with an inverted metallurgical microscope. On additional alloy specimens and composites with Al_20_3 and Gr reinforcement, the aforementioned process was repeated. Figure 4 shows polish microstructure specimen

The Brinell hardness tester was used to determine the micro hardness of the specimens with changing reinforcement weight percentage. This tester had a diamond indenter that created microscopic dents on the specimen's surface. Figure 5 shows hardness specimen, the depth of the depression was seen via an objective lens under LED light. Emery sheets were used to polish the specimen's surface (2000 and 4000 grit size). On the tester, a load of 100gf for about 10 seconds was placed. A diamond-shaped indentation was created when the indenter descended and made contact with the surface; using a microscope, the indentation was measured. For three distinct trails, the hardness was gauged, and the data's average was calculated. For reinforcements with various compositions, the experiment was repeated.

Tension is used in the majority of well-known mechanical stress-strain tests. As will be demonstrated, a few mechanical characteristics of materials that are important in design may be determined using the tension test. An

ASTM E8 standard specimen is distorted, often leading to cracking, with a continually increasing malleable load applied uniaxially along the long pivot. The specimen is secured by its closures into the testing mechanical assembly's holding grasps. The tensile testing apparatus is designed to continuously and continuously monitor the instantaneous applied force (using a load cell) and the successive lengthenings while lengthening the specimen at a constant pace (utilizing an extensometer). A PC is often used to record the yield of a tensile test like this as load or force vs elongation. Figure 6 and 7 shows tensile specimen and ASTM standard tensile specimen.

Fig.4. Microstructure specimen

Fig.5. Hardness Specimen

Fig.6. Tensile Specimen

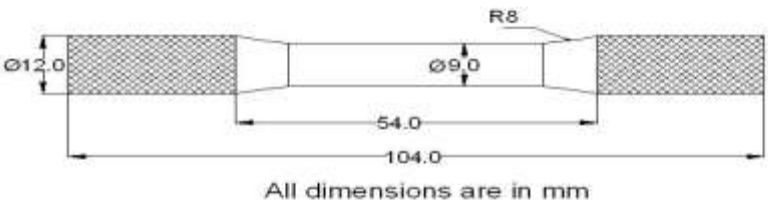
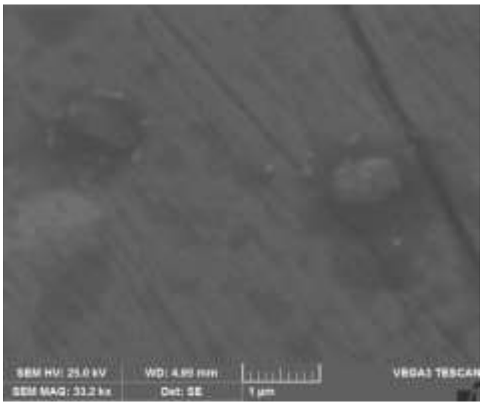


Fig.7. Tensile Specimen According to ASTM Standard

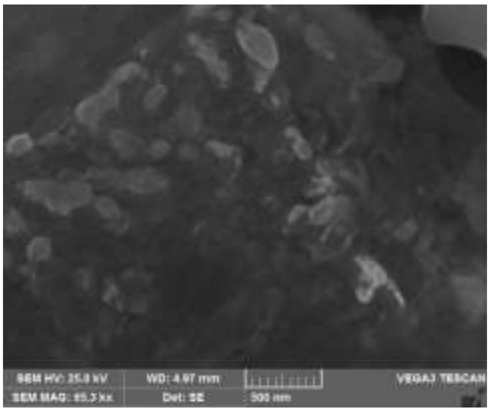
Results and Discussion

Microstructural Examination

Fig. 8a depicts the Cu-10Sn alloy's microstructure, which exhibits a typical dendritic structure as a result of the creation of a temperature gradient during solidification. Similar findings have been found in studies on in situ Al-12Si alloy [13]. Fig. 8b shows the microstructure of the composites containing 2 wt% of Al_20_3. It is evident that the reinforcement particles in the Copper alloy reinforced with 2 wt% of Gr Fig. 8c and 2 wt% of Al_20_3 and Gr hybrid composites are evenly disseminated without any agglomeration Fig. 8d. This is a result of the melt being continuously stirred before being poured into the mould. In contrast to alloy and other cast composites, the composite containing wt% Al_20_3 and Gr Fig. 4d demonstrated strong bonding with the copper alloy matrix.



(a)



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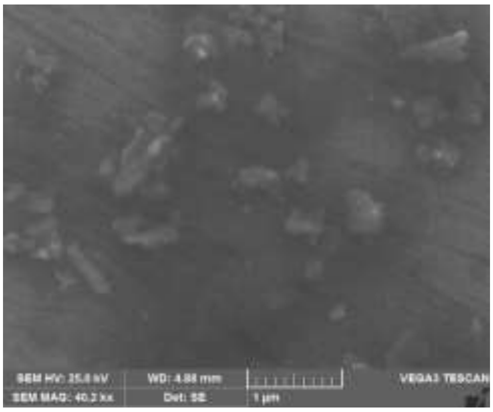

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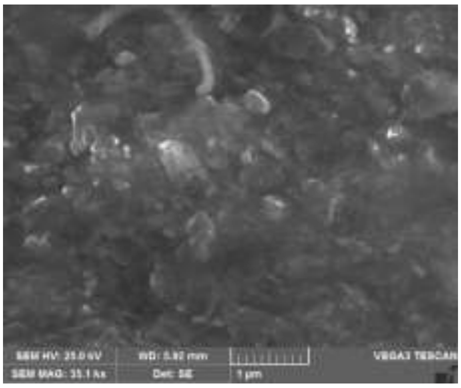

(d)

Fig.8.Microstructure images of a) Cu+Sn alloy b) Cu+Sn alloy+ Al_20_3 c) Cu+Sn alloy+Gr d) Cu+Sn alloy+ Al_20_3+Gr

Hardness Test

The copper alloy reinforced with 2 weight percent Al_20_3 yields better hardness (66 BHN) compared with unreinforced alloy (54 BHN), and the copper alloy reinforced with 2 weight percent Gr yields better hardness (57 BHN) compared with unreinforced alloy (54 BHN). Hybrid composites with 2 weight percent Al_20_3 +Gr have better hardness (63 BHN) than base alloy (54 BHN). Figure. 9 depicts the hardness at these various weight percentages. Because of the presence of better bound Al_20_3 particles in the copper matrix, the enhanced micro hardness value of the 2 wt% Al_20_3 composite was caused by particle-strengthening [14]. The scattered Al_20_3 particles occupy the interstitial sites in the copper metal matrix, preventing local deformations and fracture propagation. The reinforcement particles in the 2-weight percent Al_20_3 composite prevented the dislocation from moving, which caused it to bend and create loops around the reinforcement particles. Inducing back stress via these loops increased the material's strength; an analogous phenomenon is seen in Al_20_3 reinforced composite [15].

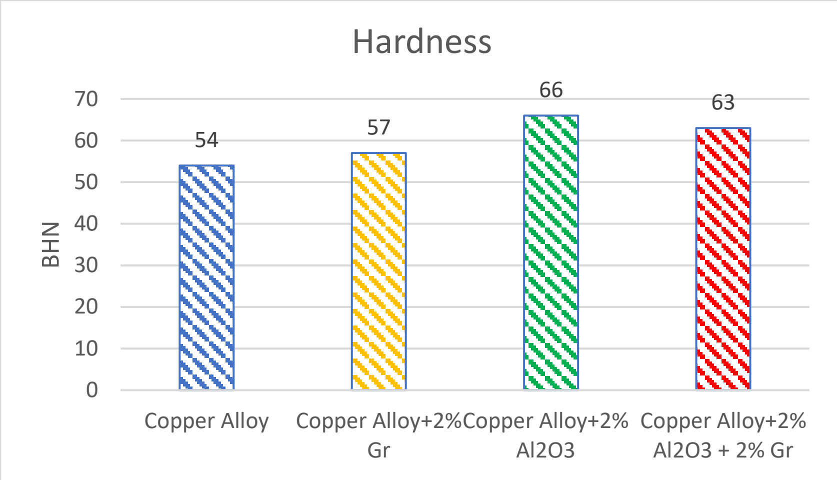

Fig.9. Hardness of Cu-Sn and its alloy

Tensile Behavior

The tensile characteristics of the copper-Sn alloy and the copper-Sn-2 wt% Al_20_3 and Gr composite are shown in Figures. 10 and 11, respectively. Figure 10 shows the ultimate strength (UTS) of composites made of Al_20_3 and Gr and a copper compound with 10% Sn. According to Figure.10, the copper-Sn- Al_20_3 composite's UTS is much higher than that of the base alloy combination and has increased from 348 MPa to 374 MPa. According to figure. 11, the yield quality of the copper-Sn base compound is 279 MPa, whereas the yield quality of the copper-Sn-2 wt.% Al_20_3 composite has increased from 279 MPa to 291.5 MPa.

The firm holding between fortification particles and the copper-Sn grid, which is a key factor in the load shifting from network to support, is primarily responsible for the growth of UTS and YS. This is the outcome of molecular fortification and grain refining [15]. The greater load bearing and confound fortifying brought on by nano Al_20_3 particles has an impact on quality improvements. The enormous quality increase in composites compared to base copper is the result of the particles proximity acting as barriers to restrict the migration of separations collected by Al_20_3 and Gr particulates. As a result, the nano composites strength will be increased during testing.

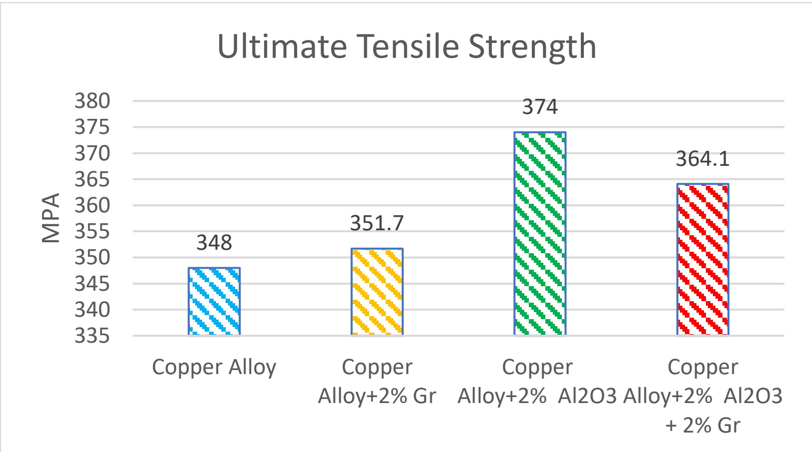

Fig.10. UTS of Cu-Sn and its alloy

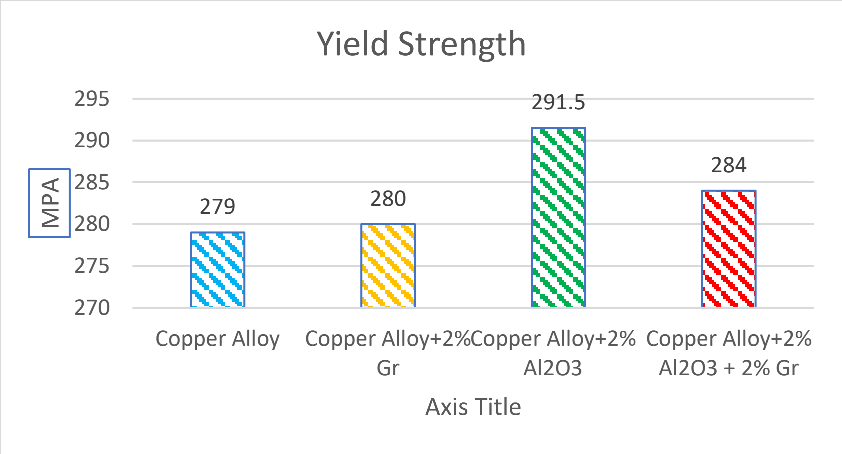

Fig.11. YS of Cu-Sn and its alloy

The elongation of the cast copper-Sn alloy and its composites is shown in Figure. 12. Comparing the copper-Sn-Al_20_3 and Gr composite to the base alloy, the rate prolonging was reduced. The figure clearly shows that the inclusion of reinforcing composites significantly reduces the elongtion of the composites. In Al_20_3 reinforcement metal matrix composites. The addition of Gr in copper alloy increases the elongation as the reinforcement acts like a solid lubrication which increases the ductile properties of alloy.

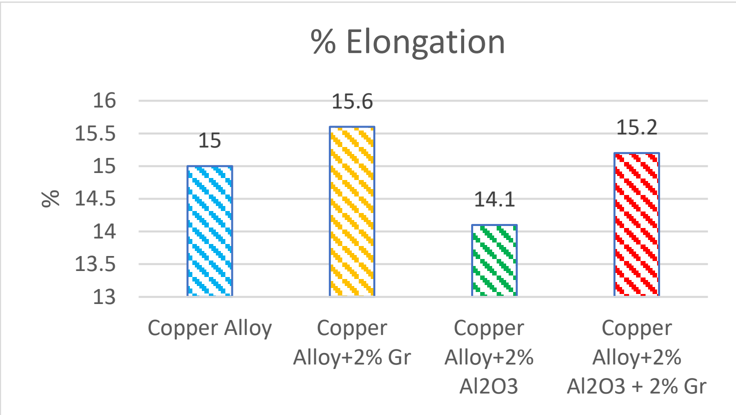

Fig.12. % Elongation of Cu-Sn and its alloy

Conclusion

- The influence of Al_20_3 and Gr 2 wt% on the microstructure, hardness, tensile behaviour, and other parameters of a bronze with a composition of 90% copper and 10% tin has been the subject of research.
- The microstructural investigation demonstrated that the particles are spread out in a consistent manner across the matrix structure.
- Utilizing liquid metallurgy, the Cu alloy and Cu/ Al_20_3 and Gr composites with a 2 wt% were effectively manufactured. Because the matrix's reinforcement particles are distributed consistently, the Cu-10Sn/2 wt% Al_20_3 composite showed the highest level of hardness in the hardness test.
- With the addition of Al_20_3, the UTS and YS rose. The improved strength of composites may be ascribed to the reinforcing material's and matrix's strong bonding.
- It has been observed that increasing the amount of Al_20_3 particles in the Cu-Sn alloy matrix caused a reduction in the percentage elongation.
- By acting as a solid lubricant, graphene creates a lubricating graphene coating on the friction surface that has a low friction coefficient and promotes elongation. This observation's originality adds to the body of work already written on the Cu-Sn alloy.

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