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Influence of aluminium oxide and graphene on the mechanical properties of Cu-Sn alloy composites

Raja Shakarappa [a], A. Arul Peter [b], M.V. Mallikarjuna [a], S. Padmanabhan [c], P Rathna Kumar [a]

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Abstract

This study's primary goal was to examine how Copper and Tin additions affected the composition, structure, and mechanical characteristics of tin bronze (Cu-10%wt.Sn). Gr content and Al2O3 were both added at concentrations of 4wt% each. For the mechanical testing and structural analyses, the alloy samples were manufactured using the permanent die casting process and then machined to the desired dimension. The study of mechanical properties included measuring impact strength, Brinell hardness, ultimate tensile strength, and % elongation. Intermetallic phases with fine and uniform distribution were found in the Al_2O_3 and Gr reinforced alloys, respectively. The percentage elongation, ultimate tensile strength, hardness, and impact strength of tin bronze were all found to be greatly increased by the addition of Al_2O_3 and Gr, according to the mechanical properties results. The sample having 4wt% Gr content achieved the highest percentage elongation. Impact strength of 17% and 14J was found highest in 4wt% Al_2O_3, respectively, whereas the sample containing

4 wt% Al_2O_3 content achieved the best tensile strength and hardness values of 383.1 MPa, 296.2 MPa and 71 MPa respectively.

Introduction

Tin bronze, often known as the Cu-Sn alloy, has been used for a very long period. This alloy gave rise to the Bronze Age, which dates back to about 3000 BCE. Mankind has utilized it to create ornamental objects and tools. It should be emphasized, nevertheless, that the industry-standard Cu-Sn alloys have Sn contents below 40%. Tin bronze is an alloy with a copper basis that typically has a composition of 75% to 5% copper and 5 to 25% tin [1]. Tin bronze's strength and ductility rise with tin content up to 8%wt, at which point tin content increases cause a sharp decline in ductility. Tin bronze has an excellent wear resistance and is quite hard. It is relatively simple to roll into wires, rods, and sheets or to cast into desired shapes [2]. According to research [1], thermo-static bellows of the highest quality and other components requiring exceptional tensile strength, elastic characteristics, and resistance to extreme stretching are the main applications for tin bronzes (Cu Sn). Additionally, they serve as bearing materials in the automotive, shipbuilding, and aerospace sectors. In the manufacture of hydraulic fittings, pump linings, utensils, bearings, bushes, sheets, rods, wires, bells, and gongs, Cu-Sn alloys are often used [1]. This is mostly due to its unique mechanical characteristics, which include exceptional ductility, outstanding hardness, tensile strength, and wear resistance. It is well known [3] that the emergence of a hard and brittle intermetallic phase in the alloy structure causes tin bronze (Cu-10%Sn) to display poor strength and ductility. This issue led to the current study, whose main goal is to refine and adapt this existing phase in order to enhance the alloy's mechanical qualities via alloying.

Numerous studies on the composition, structure, and mechanical characteristics of Cu-10 wt% Sn have been conducted, but little emphasis has been placed on the structure's improvement and modification by alloying. The structure of tin bronze (Cu-20% Sn) was studied by Ketut et al. in their study [4] on the impact of annealing temperature. According to the research, raising the annealing temperature led to the precipitation of coarse grains, which in turn caused the grain boundary to shrink, lowering the alloy's tensile strength and hardness. The research also showed that when annealing temperature and grain size rose, so did damping capacity and impact strength. High tin bronze alloys (20–22% Sn) are often utilized in the manufacture of musical instruments such bells, saxophones, cymbals, materials for Javanese, Balinese gamelan and gong according to study [5]. They have strong acoustic qualities that, because to the vibrations' gradual dampening, may produce sound that lasts for a long time. At room temperature, they are stable and hard [5]. Eggenschwiler

[6] examined the effects of antimony addition on the composition, mechanical characteristics, and structure of a bearing bronze (Cu-10% Sn-10% Pb). The analysis showed that the alloy's impact strength was reduced by the inclusion of antimony. Additionally, it was found that adding antimony up to 0.2% only marginally enhanced the hardness of the alloy; adding antimony up to 0.58% did not significantly alter the alloy's hardness. Martorano and Capocchi, [7] explored the directionally solidified tin bronze castings' dendritic structure control. When the pouring temperature and heat extraction flux were both elevated concurrently, the structural analysis showed an expansion of the columnar zone length. Marcelo and Jose [8] examined how processing factors affected the micro-segregation of directionally cast Cu 8 wt%Sn alloy samples.

According to the research, there was a decline in micro segregation as it moved closer the cast sample surface along the longitudinal axis. Kumoto et al., [9] studied the dendritic arm coarsening and micro segregation in tin bronze. The secondary dendritic arm spacing 2 was shown to decrease with an increase in cooling rate or a reduction in local solidification time. In specimens treated to comparable cooling rates, higher tin concentration in the alloy resulted in a reduction in secondary dendrite arm spacing. After solidification, the majority of the specimens quenched in water showed micro-segregation indices that were higher than those seen in unquenched specimens that had been treated to the same solidification cooling rate. Researchers looked examined how tin affected the hardness, wear rate, and coefficient of friction of cast Cu-Ni-Sn alloys [10]. According to the study's findings, hardness rose as tin (Sn) concentration rose from 4% to 8% under solution heat treatment conditions. It was discovered that when the Sn content rose, the peak ageing time shrank. Furthermore, it was shown that, regardless of Sn concentration, the wear rate reduced linearly with hardness whereas the coefficient of friction was found to be independent of hardness. Krivtsova et al., [11] They found that the size of the grain was consistently reduced with each subsequent cycle of deformation in their investigation of the effects of equal channel angular pressing on the microstructure and mechanical characteristics of single phase tin bronze. Maximum hardness and tensile strength were found to exist at pressing temperatures of up to 230°C and 520°C, respectively, according to the research. The mechanical characteristics of high-tin bronzes were evaluated. investigated by Nadolski [12]. The research showed that as the tin concentration grew, the alloy's ultimate tensile strength and impact strength fell, while their respective hardness levels increased. This trend in mechanical characteristics was ascribed to the acicular -phase precipitates that formed when the alloy's tin concentration increased to 23 wt% or greater from the dendritic ones that formed when the alloy's tin level was between 20 and 22 wt%. It was also said to have resulted from nuclei immediately forming in the form of phase nucleating from the liquid phase. Leaded tin bronze's crystallisation circumstances had an impact on the microstructure characteristics that were measured examined by Martyushev et al. [13]. The study's findings showed that while casting into a mould at room temperature, maximum mechanical characteristics were attained at high cooling rates as opposed to low cooling rates (casting into mould heated up to 800 °C). Sergejevs et al. [14]. The effect of casting velocity on mechanical characteristics and macrostructure was examined, and the best casting velocity values were suggested.

The results of the investigation showed a considerable impact of continuous casting velocity on the mechanical characteristics of tin bronze, which was also shown in the macrostructure of the chosen samples. Kexing et al. [15].Cu 10Sn-4Ni-3Pb alloy crystallisation under pressure processing was examined in an effort to enhance the alloy's wear resistance, segregation, and mechanical characteristics [16]. The findings demonstrated that, in contrast to the alloy prepared using conventional melting and casting technology[17], which had a strikingly dendritic microstructure and severe as-cast defects[18], the dendrite had clearly vanished and the dendritic segregation had been reduced by using the crystallization under 680 MPa pressure process [19]. The characteristics and microstructures of Cu-10Sn-4Ni-3Pb tin bronze produced by crystallization under pressure were greatly enhanced as a result of the experimental investigation [20].

From the literature it is clear that pure copper is used as the matrix phase in the majority of investigations on copper-based metal matrix composites. Moreover, relatively few studies on Cu-based hybrid composites where the copper-Sn alloy has been has not yet been utilised as a matrix material. In this study, a low-cost stir-casting technology is used to manufacture Cu-10%wt.Sn alloy hybrid composites. Also, a comparison of the mechanical behaviour of Al_2O_3, Graphene and Hybrid composites of Cu-10%wt.Sn/Al2O3/Graphene particulate-reinforced composites is attempted. The tensile strength, impact strength, elongation in tensile loading and hardness of the hybrid composites, were used to develop the comparative analysis.

Section snippets

Materials and method

For this experimental work, 99.9% pure copper and 97.8% pure tin were employed as the basic materials, while 98.7% and 99.5% pure aluminum oxide and graphene, respectively, were used as the reinforcing materials. A warmed bailout crucible furnace was filled with 1000g of pure copper, and the copper was heated there until melting was reached at a temperature of 1200°C. Then, to completely dissolve the tin metal, 100g of pure tin wrapped in aluminum foil was added to the melt and rapidly

Hardness

Fig. 4 displays the hardness measurements on Cu-Sn- Al_2O_3 and Gr hybrid composites. It can be seen that the composite has a harder surface than its cast matrix. Since the Al_2O_3 dispersions are hard, they favorably affect the composite's hardness. The hard Al_2O_3 particles, which serve as a barrier to the passage of dislocation within the matrix, are responsible for the increase in hardness. Because the particles are not reactive with the matrix phase, it is anticipated that this dispersion

Conclusion

This study has shown that tin bronze's mechanical characteristics improved when micro additives were added to it. In conclusion, this study's findings demonstrated that adding Al_2O_3 and Gr enhanced the mechanical characteristics and structure of tin bronze. In engineering designs and constructions, the high value of UTS, ductility, and impact strength decreases the cause of failure.

- Stir casting technique successfully used to synthesize Cu-Sn alloy metal matrix composites reinforced with Alumina

CRediT authorship contribution statement

Raja Shakarappa: Conceptualization, Methodology, Data curation, Writing – original draft, Investigation. **A. Arul Peter:** Supervision, Writing – review & editing, Validation, Visualization, Data curation. **M.V. Mallikarjuna:** Supervision, Writing – review & editing, Validation, Visualization, Data curation. **S. Padmanabhan:** Supervision, Writing – review & editing, Validation, Visualization, Data curation. **P Rathna Kumar:** Supervision, Writing – review & editing, Validation, Visualization, Data

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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