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Structural sensitivity properties of brass-modified alloying elements

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ABSTRACT : *The study investigated how the amounts of doping elements affected the tensile behavior and electrical conductivity of Cu-30wt%Zn alloys. The stir-casting method was used to produce the brass after it was mixed with different amounts of niobium and tin (0.1–0.5wt% and 1.0–5.0 wt%). We looked at the resistivity, electrical conductivity, and tensile strength. An energy dispersive spectroscope (EDS) and a scanning electron microscope (SEM) were used to examine the microstructures of the cast alloys. The findings demonstrated that the addition of niobium and tin improved the alloy's electrical conductivity and tensile strength by refining and altering its structure. The highest electrical conductivity was demonstrated by 0.1wt% niobium and tin, while the maximum tensile behavior performances were recorded by 3wt% niobium and 5wt% tin.*

KEYWORDS: *Tensile behavior, resistivity, conductivity, Cu-Zn alloy*

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I. INTRODUCTION

Among non-ferrous metals, copper and its alloys are important because of their remarkable ductility, malleability, corrosion resistance, electrical and thermal conductivity, and moderate tensile strength. Due to the electrical industry's increasing need for copper and its finite supply, there is a quest for less expensive substitutes for the currently pricey copper alloys (Ezeobi et al. 2024; Onyia et al. 2024a; Okelekwe et al. 2024a). Metallurgists have been improving the ductility of mild steel, and engineers have been devising more efficient metal-forming techniques. As a result, copper alloys are utilized in applications that require high electrical conductivity or suitable formability and good corrosion resistance (Iyebeye et al. 2024). Copper-based alloys encompass bronzes and brasses, with the latter being copper-rich alloys that contain tin, zinc, silicon, or beryllium (Nwambu et al, 2017). Brass is a popular industrial material due to its exceptional combination of properties, such as high strength and ductility (which make it stronger and harder than pure copper), ability to be easily shaped into various forms, good thermal and electrical conductivity, non-magnetism, and resistance to corrosion (particularly in saltwater environments). These properties make brass the preferred material for many components used in the general, electrical, and precision engineering industries (Kommel et al. 2007; Okelekwe et al. 2024b). In particular, the electronic and electrical components market with high performance and multi-functionality has increased, and the amount of Cu-Zn alloys in these products has also enlarged. However, in order to increase the energy efficiency of transport equipment or miniaturize items, it is imperative that parts and products be lighter. High specific gravity Cu-Zn alloy components have a major impact on the overall product's weight ratio. The high-strength Cu-Zn alloy can be used to make the small parts. As a result, the product's weight will be lowered greatly (Imai et al., 2014; Anyafulu et al. 2024).

Cu-Zn alloy, also known as brass, is utilized in manufacturing bulb and fuse sockets due to its favorable plastic properties and ability to be cold stamped. Additionally, it is employed in producing wires, gliding components, and sieve bottoms for condensers in the shipbuilding industry. Because of its exceptional thermal conductivity and corrosion resistance, brass is frequently used to create heat exchanger tubes (Iyebeye et al. 2024). The mechanical characteristics of brass rely mainly on the amount of zinc, the degree of deformation during production, and the heat treatment parameters, precisely the recrystallization temperature. Brass is also utilized to produce various other products such as pipes, tubes, weather-stripping, architectural trim pieces, screws, radiators, musical instruments, and cartridge casting for firearms, making it an essential material where long-lasting, economical service life is necessary and unmatched by other materials (Nowosielski and Sakiewicz, 2006).

Copper and its alloys have been used for various applications for many years because of their outstanding properties. Nonetheless, pure copper is not suitable for structural engineering purposes due to its low strength and tendency to soften at moderate temperatures (Zhao et al. 2017; Osakwe et al. 2024; Nwambu et al. 2024). Research has focused on developing copper-based alloys to enhance properties like strength, conductivity, and the ability to maintain stress at high temperatures. Alloying has proven to improve the mechanical and physical properties of copper (Arisgraha et al. 2018; Zhuangzhuang et al. 2020). Additionally, by altering their composition and applying different heat treatments, copper alloys can be given a diverse range of properties. For this reason, they probably rank next to steel in importance to the engineer (Zhao et al. 2017). In Cu-Zn alloys, the zinc atoms replace copper atoms to create a substitutional solid solution that is random and non-homogeneous. This leads to the formation of a brittle coarse phase that causes a decrease in the mechanical and physical properties of the alloy. The study tends to examine the influence of doping elements on the structure, physical, and mechanical properties of copper -30%zinc alloy.

II. MATERIALS AND METHODS

The base alloy for the study was produced from commercial pure copper (99.99%) and commercial pure zinc (99.98%). The doped Cu-30%Zn alloy was produced by the addition of niobium and tin in concentrations of 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, and 1.0%, 2.0%, 3.0%, 4.0%, 5.0% by weight using permanent mould casting technique. A bailout crucible furnace was used for the melting process. For the production of the control alloy cast samples, the required amounts of pure copper in the form of copper wire were first charged into the preheated furnace and melted. A predetermined amount of zinc in piglet form was added to the molten copper and stirred. The melt was held for about 15 minutes to ensure the complete dissolution of zinc in the copper melt and stirred again to achieve homogeneity before pouring into a preheated permanent mold and allowed to cool at room temperature. Subsequently, the Cu-30wt%Zn alloys with the additives were produced by repeating the above-described procedure and introducing the different concentrations of niobium and tin. A tensile test was carried out on the cast specimens using an automated 100KN JPL tensile strength tester (Model: 130812) to determine the tensile strength (Iyebeye et al. 2024). The resistivity and conductivity of the experimental alloys were determined based on standard Ohm's experiment. Structural analysis was carried out on the cast alloy specimens. Before the structural analysis, the surfaces of the specimens were ground with different grades of emery papers from rough to fine grades (200, 400, 600, 800, and 1200 µm). After grinding, the specimens were polished to a mirror finish using an aluminum oxide (Al_2O_3) powder, rinsed with water, and dried using a hand drier. The dried samples were etched with a solution of 10 g of iron (III) chloride, 30 cm^3 of hydrochloric acid, and 120 cm^3 of water for 60 seconds. Finally, the surface morphology of the etched samples was examined using scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS).

III. RESULTS AND DISCUSSION

3.1. Tensile behavior, Conductivity, and Resistivity of Cu-30wt%Zn Alloy

Figs 1-3 show the effect of niobium and tin addition on the electrical conductivity and resistivity, and tensile behavior of the alloy. It is observed from the Fig.s that the tensile strength increased with increasing concentration of niobium and tin up to 3.0% for niobium before decreasing with further increase in concentration of the additive but for Tin, it increased up to 5.0%.

The addition of niobium and tin to Cu-30wt%Zn alloy resulted in improvement in the tensile strength of the experimental alloy. Maximum tensile strength values obtained were 614 MPa at 4.0%Nb, 371MPa at 1.0%Sn content respectively. The addition of 0.1wt%Nb and Sn resulted in an improvement in electrical conductivity of the alloy. The improvement in the tensile behavior and electrical conductivity of the alloys was attributed to the presence of refined and modified intermetallic phases in the structure of the alloys (Onyia et al. 2024b).

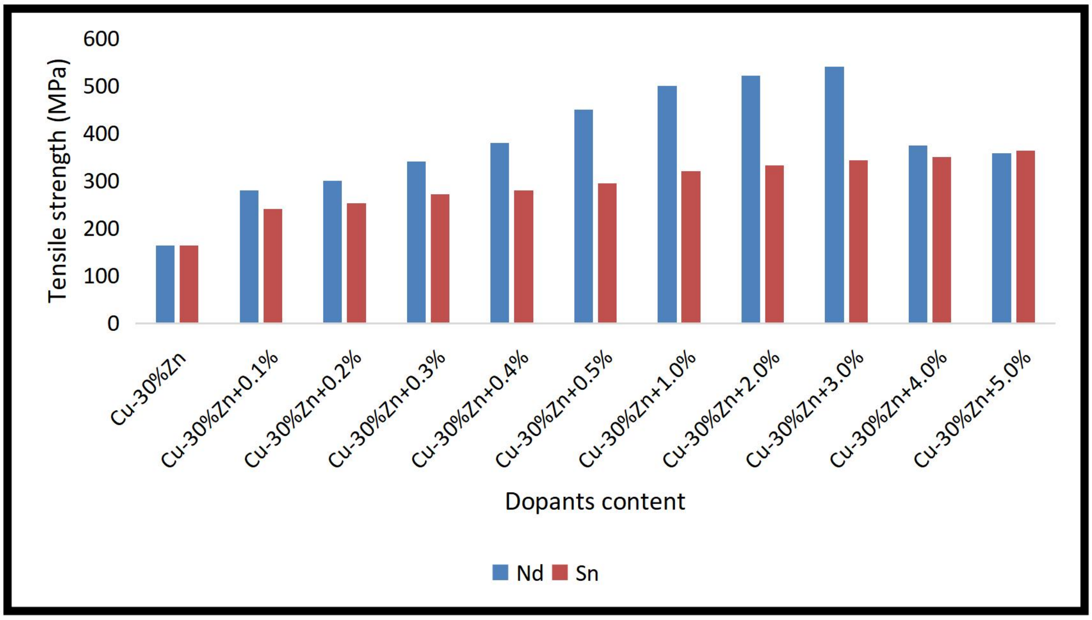

Fig. 1: Effect of niobium and tin content on the tensile strength of Cu-30wt%Zn alloy.

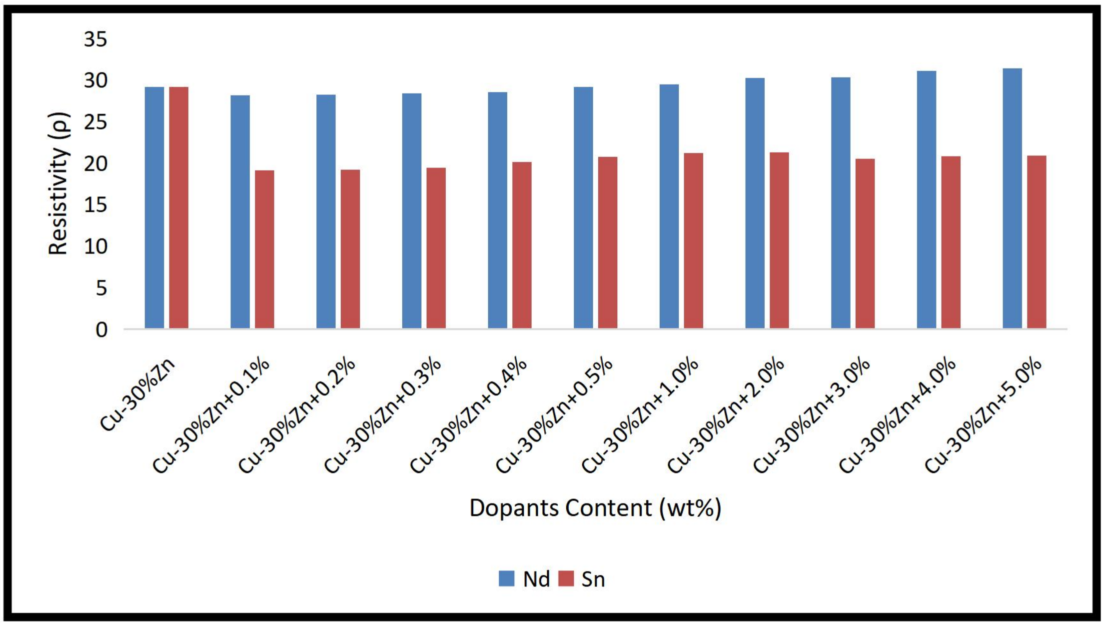

Fig.2: Effect of niobium and tin content on the electrical resistivity of Cu-30wt%Zn alloy.

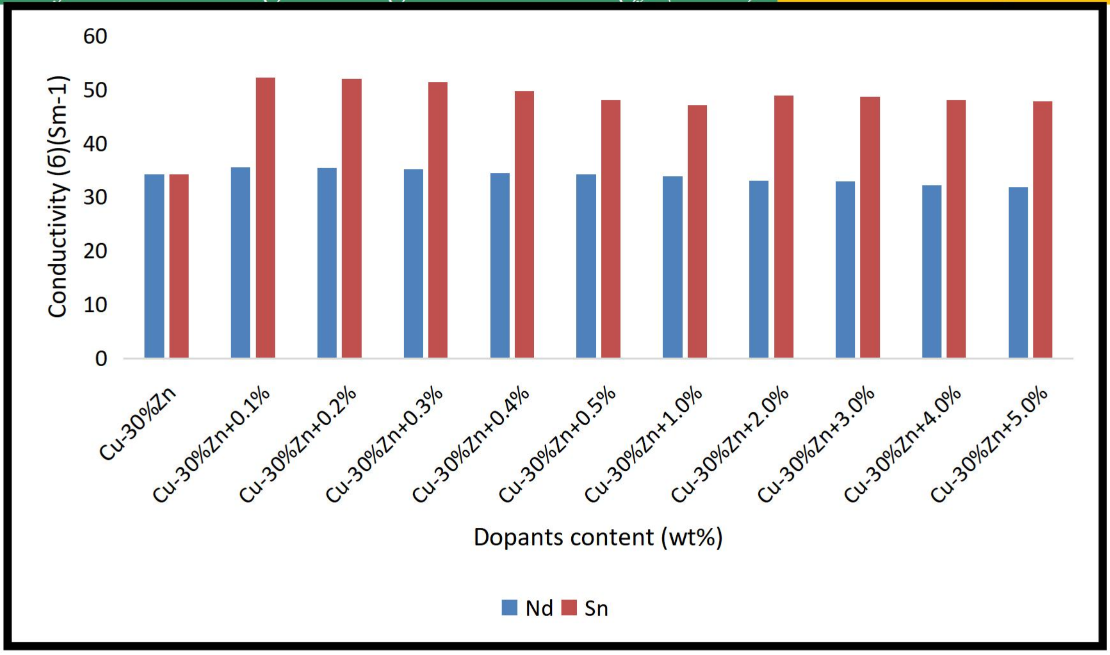

Fig.3: Effect of niobium and tin content on the electrical conductivity of Cu-30wt%Zn alloy.

3.2. Scanning Electron Microscopy (SEM) and Electron Dispersive X-ray (EDX) Analyses of the Alloys

The scanning electron microscopy and electron dispersive X-ray diffraction analyses of the alloys are presented in Figs 4-9.

The structure of the niobium and tin-doped alloys shows the existence of $CuZn_5$, Cu_5Zn_8, Cu_3Nb, and Cu_5Sn intermetallic phases (Fig. 4-9). The presence of these intermetallics in the alloys' structure is also demonstrated by studies of the alloy samples using electron dispersive X-ray (EDX) and scanning electron microscopy (SEM). The morphology of the intermetallic compounds is refined and altered by the addition of niobium and tin, which is seen to boost tensile strength. This is because microstructural changes, such as grain refinement, can produce higher mechanical qualities overall. Certain alloying elements can increase ultimate tensile strength and hardness while simultaneously enhancing or preserving ductility, and materials with fine-grained structures are frequently stronger and more ductile. Grain size falls as niobium concentration rises to 3.0wt%Nb and 5.0wt%Sn. Because there are more grain boundaries because of the smaller grain sizes, there are more obstacles to dislocation motion, which raises the alloys' tensile strength. An increase in niobium concentration above 3.0wt% coarsened the intermetallic compounds' morphology, lowering the alloy's tensile strength. Cu_3Nb and Cu_3Sn compounds incorporated into the alloy's structure significantly enhanced its electrical conductivity and strength (Iyebeye et al. 2024).

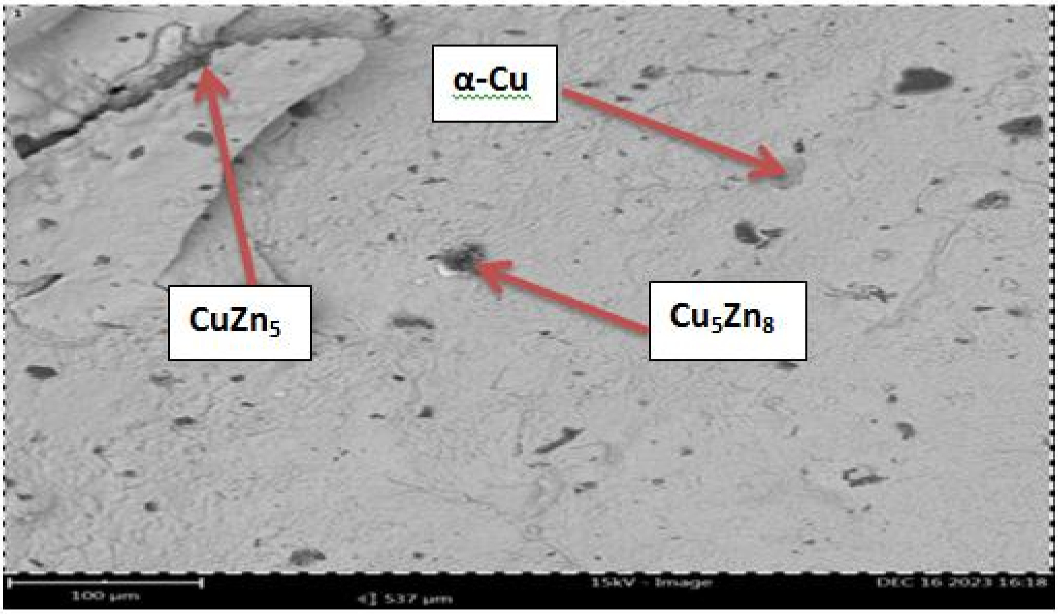

Fig.4: Scanning electron microscopy of Cu-30wt%Zn alloy

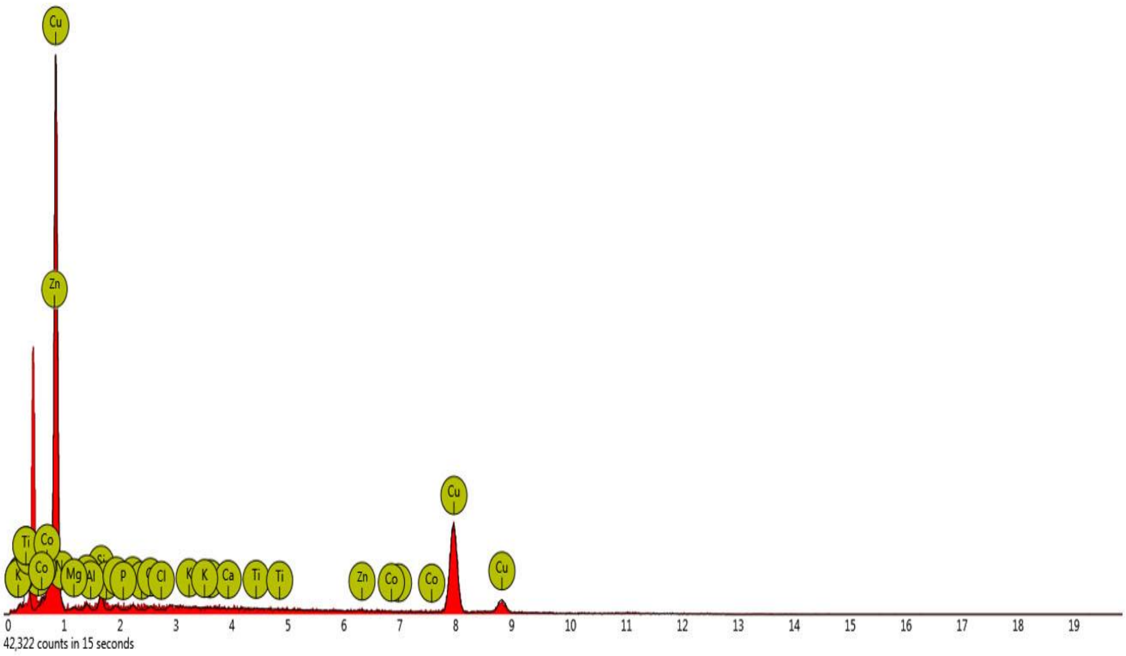

Fig.5: Energy dispersive X-ray diffraction (EDX) of Cu-30wt%Zn alloy.

Cu_3Nb

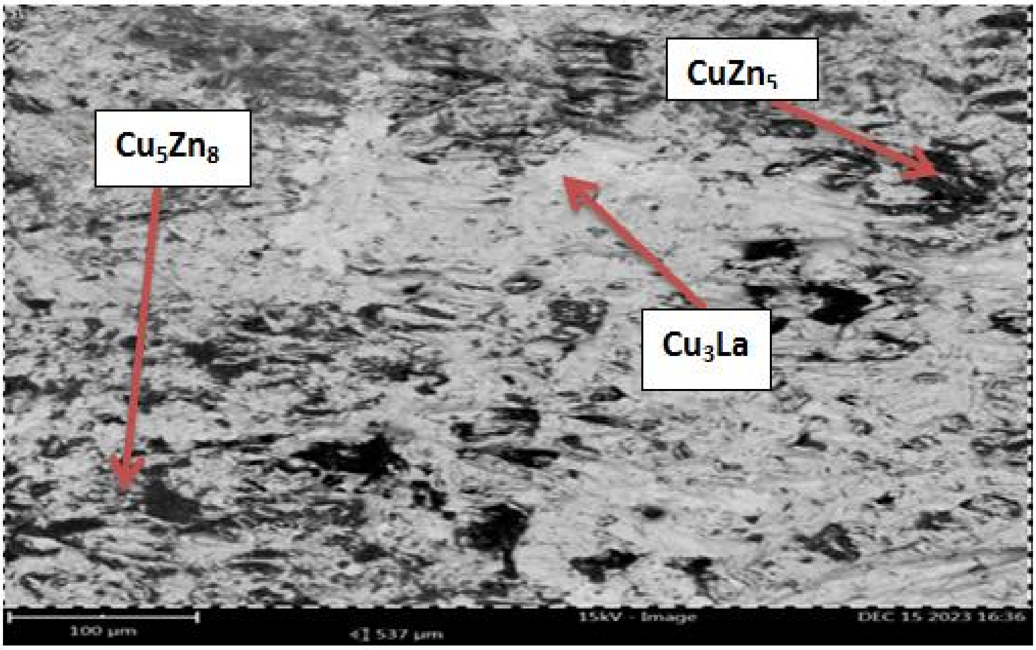

Fig.6: Scanning electron microscopy of Cu-30wt%Zn+3.0wt%Nb alloy

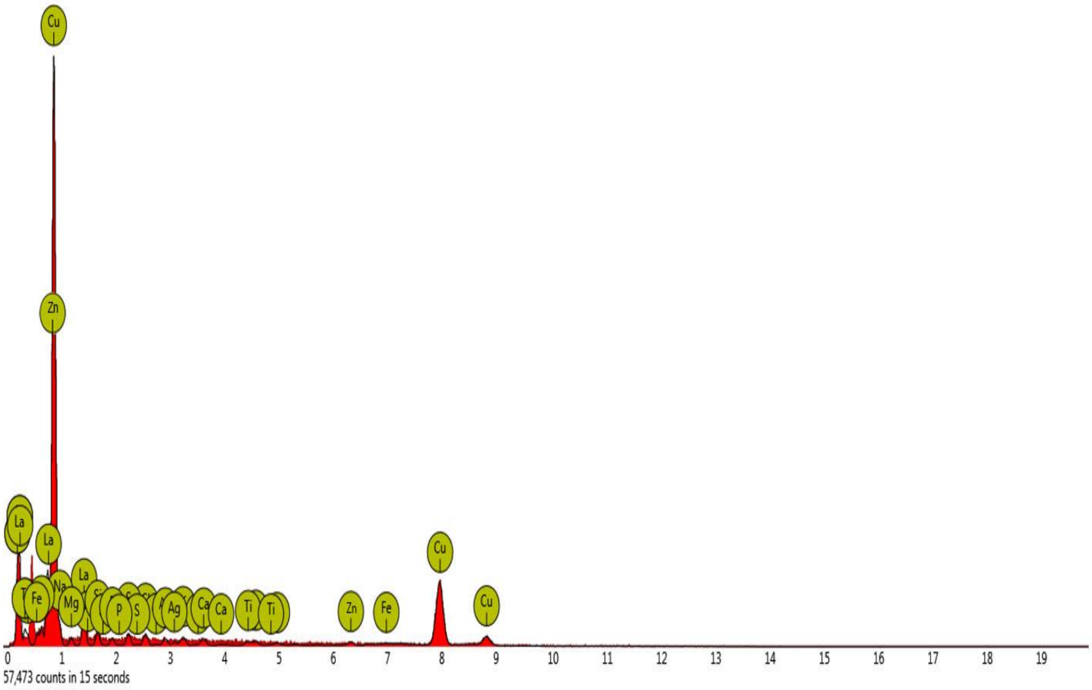

Fig.7: Energy dispersive X-ray diffraction (EDX) of Cu-30wt%Zn+3.0wt%Nb alloy

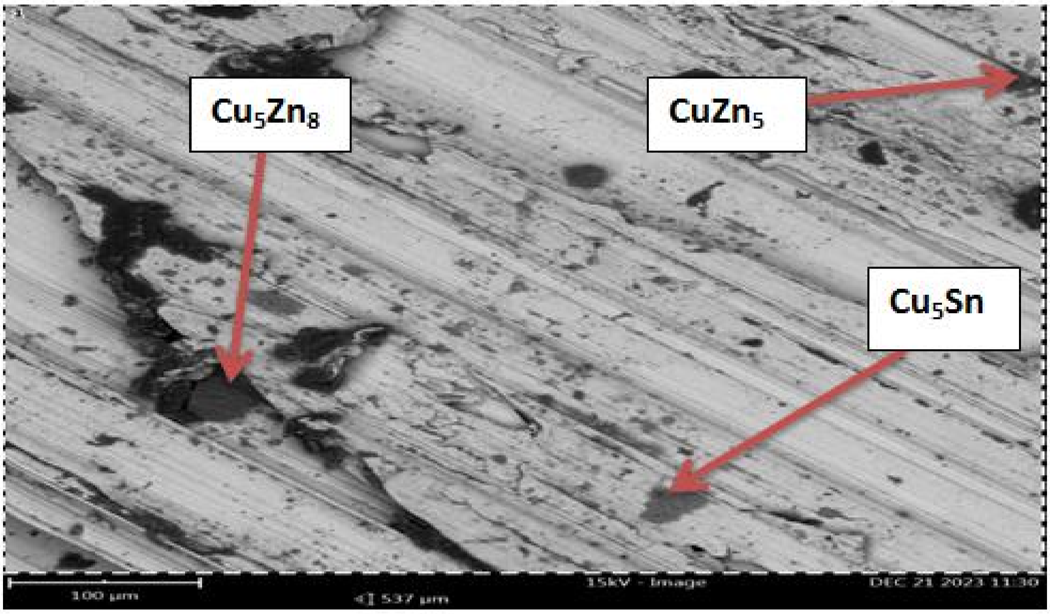

Fig. 8: Scanning electron microscopy of Cu-30wt%Zn+5.0wt%Sn alloy

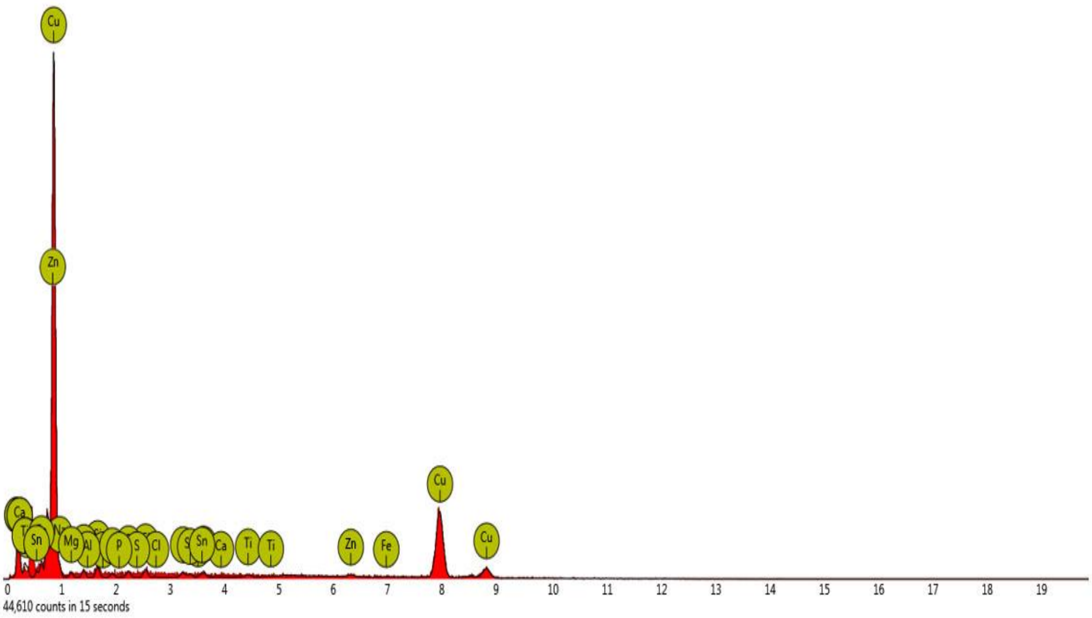

Fig. 9: Energy dispersive X-ray diffraction (EDX) of Cu-30wt%Zn+5.0wt%Sn alloy.

IV. CONCLUSION

The impact of niobium and tin content on the electrical conductivity and tensile behavior of Cu-30wt%Zn alloy has been studied. The outcomes of the experiment allow for the following deductions: By successfully refining and altering the alloys' structure, the addition of niobium and tin to Cu-30wt%Zn alloy improved the experimental alloy's mechanical and physical characteristics. When comparing niobium and tin's effects on Cu-30wt%Zn, lanthanum performed better than tin. It was also determined that the characteristics of the Cu-30wt%Zn alloy were better after macro alloying than after micro alloying.

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