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Research Article

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Investigating the effects of Lanthanum and Tin additions on the structure and physic-mechanical properties of Cu-30%Zn Alloy

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Abstract
The study explored the effects of lanthanum (La) and tin (Sn) contents on the structure, electrical and mechanical properties of Cu-30wt%Zn alloys. The Cu-30Zn alloy was incorporated with varying concentrations of lanthanum and tin (0.1- 0.5wt% and 1.0-5.0wt% at 0.1 and 1.0 intervals respectively) and fabricated using a stir-casting technique. The Tensile strength, hardness, impact strength, electrical conductivity, and resistivity were examined. The microstructures of the cast alloys were analyzed using an optical microscope (OM), Scanning electron microscope (SEM), and Energy dispersive spectroscope (EDS). Results showed that the additions of lanthanum (La) and tin (Sn) refined and modified the structure of the alloy resulting in improvements of ultimate tensile strength, percentage elongation, hardness, impact strength, and electrical conductivity of the alloy, with 3wt% lanthanum and 5wt% tin recording the maximum mechanical performances and 0.1wt% lanthanum and tin exhibited the highest electrical conductivity. The electrical resistivity of the doped alloy decreased compared to the undoped alloy.

Keywords: Lanthanum, Tin, structure, physical and mechanical properties, Cu-30%Zn alloy.

1. Introduction

Copper and its alloys stand out among non-ferrous metals due to their exceptional electrical conductivity, thermal conductivity, corrosion resistance, ductility, malleability, and reasonable tensile strength. They are used in applications requiring high electrical conductivity, good formability, excellent corrosion resistance and good mechanical properties (Okelekwe et al., 2024; Nwambu et al., 2017). Additionally, its superior acoustic qualities make it an ideal material for musical instruments such as trumpets, trombones, and horns, as it produces a deep, resonant sound. Also, it demonstrates good thermal conductivity, which is beneficial for efficient heat dispersion, making it suitable for use in heat exchangers and radiator cores. Furthermore, it is a reasonably effective electrical conductor, often used in the manufacturing of electrical connectors, terminals, and similar components (Fortune, 1993; Hammond, 2004; Zhuangzhuang et al., 2020; Hassanein Ibraheem Khalaf , 2021). Structural applications are mostly based on ferrous materials, steels in particular (Nnuka, 1991) but findings have shown that copper alloys are quickly replacing contemporary steel materials for some specific applications especially in components for marine/subsea applications (Nwambu et al., 2018).

Cu- Zn alloy is known as brass. Bringing these two elements in different ratios, form brass with specific desired traits. Including zinc modifies the metal's properties, developing distinctive qualities and advantages in the material (Imai et al., 2014; Arisgraha et al., 2018). Brass consists of varying ratios of copper and zinc, typically ranging from 60% to 90% copper and 10% to 40% zinc. Additionally, small amounts of other elements can be added to further modify the characteristics of brass to suit particular needs (Nowosielski and Sakiewicz, 2006; Sujit et al., 2015).

Addition of dopants to Cu based alloys has been found to yield alloys with good mechanical properties and electrical conductivity (Shankar & Sellamuthu, 2017; Kim et al., 1999; Plewes, 1975 ; Cribb et al., 2013; Cribb & Grensing, 2011; Rhu et al., 1999). However, some previous researchers (Cribb & Grensing, 2011), reported that a serious segregation phenomenon of dopants exist in the conventional casting process for alloys, which has a negative influence on the subsequent processing and mechanical properties of the alloys. Lanthanum and tin showed significantly improvement on the properties of brass. The hardness for the alloy without Lanthanum and tin is 108 HBW and 94 HBW and for the alloy with 0.3% Lanthanum and tin is 130 HBW and 110 HBW respectively (Wenjing et al., 2021). Sadayappan et al. (2012) conducted a study to examine the impact of adding tin and other elements on the microstructure of Cu-Zn alloy. They also investigated the interaction between the grain refiner and minor alloy additions, such as Sn, Al, Bi, Se, and Pb. The grain size of the resulting castings was evaluated using a scale developed as part of the investigation. The macro and microstructures were also analyzed and presented. The alloy exhibited a large grain size, measured at 2.5μm. The microstructure of this alloy consisted of primary α dendrites with some β phase in the interdendritic areas and grain boundaries. It was observed that adding other elements to this alloy caused modifications in the constituents and the size of the structure. This work will report the effect of lanthanum and tin additions on the structural sensitive properties of Cu-30%Zn alloys.

2.0 Material 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 lanthanum and tin in concentrations of 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 1.0%, 2.0%, 3.0%, 4.0% and 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 15min to ensure complete dissolution of zinc in the copper melt and stirred again to achieve homogeneity before pouring into preheated permanent mould 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 lanthanum and tin.

A tensile test was carried out on the cast specimens using an automated 100KN JPL tensile strength tester (Model: 130812) was used for determining the tensile strength and % elongation of the developed alloys according to ASTM D638 standard Universal Testing. The Brinell hardness test was conducted using a portable dynamic hardness testing machine (Model: DHT-6) using British standard (BS EN ISO 6505- 1:2014). The specimen was placed on an Equotip test block and the machine was operated automatically until the indenter touched the surface of the specimen. The value was read directly from the machine scale and the result recorded.

Impact testing was performed on the cast samples following the ASTM D256 standard using a using a pendulum impact testing machine (Model: U1820). 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. Prior to 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 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 cm3 of hydrochloric acid and 120 cm^3 of water for 60 seconds. Finally, the surface morphology of the etched samples was examined using an optical metallurgical microscope (Model: L2003A), scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS).

3.0 Results and Discussions

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

The optical, scanning electron microscopy and electron dispersive X-ray diffraction analyses of the alloys are presented in Figures 1-27. Figure 1 presents the micrograph of undoped Cu-30wt%Zn alloy casting showing microstructures in which the primaryα-copper phase (solid solution of zinc in copper), $CuZn_5$ and Cu_5Zn_8 intermetallic phases are present. Coarse Cu_5Zn_8 intermetallic phase (Figure 22) can be observed at the grain boundaries in the microstructure of the alloy (Figure 1) and owing to this, the mechanical properties of the undoped alloy are poor.

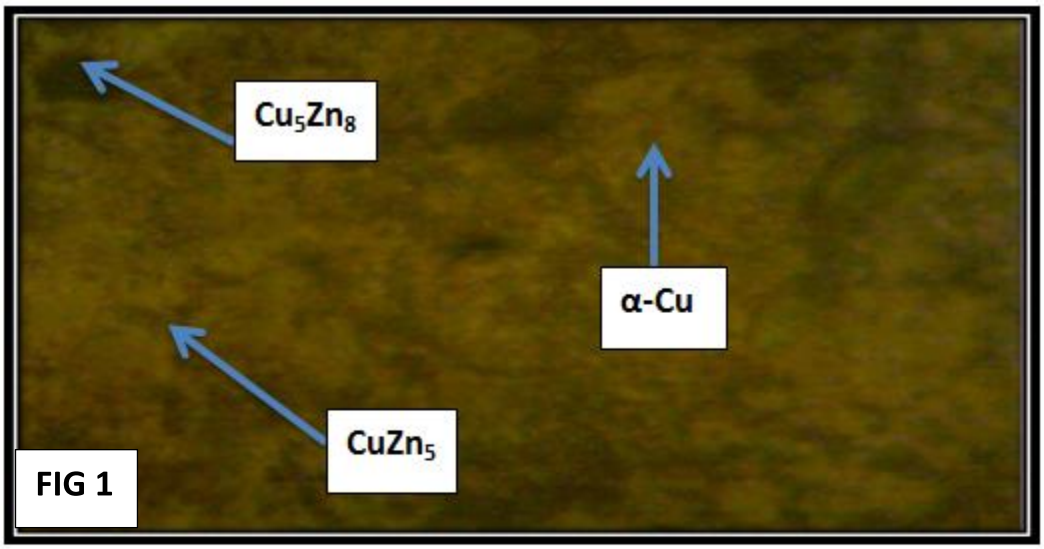

Figure 1. Micrograph of Cu-30wt%Zn alloy.

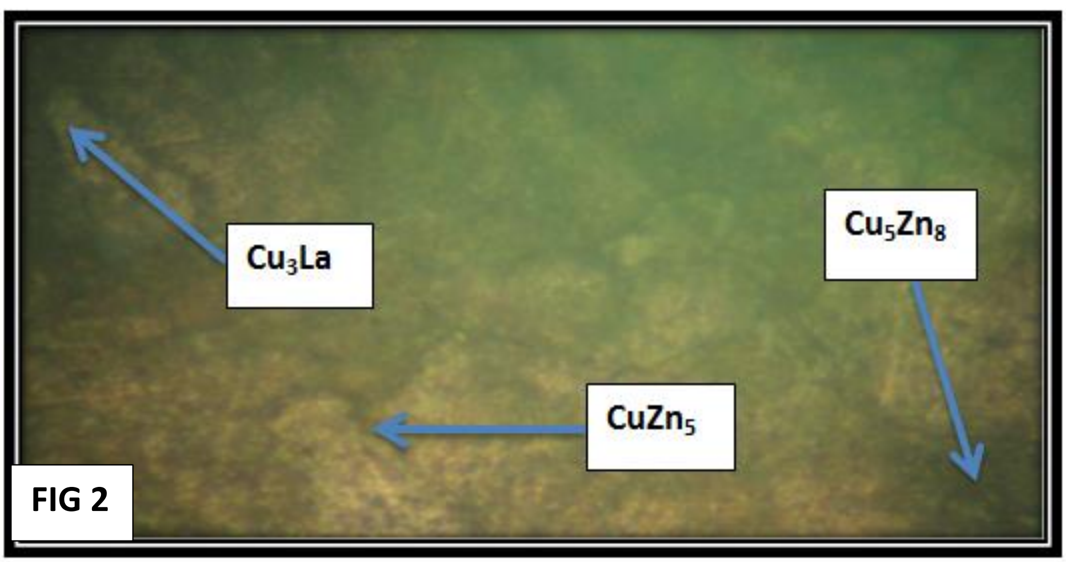

Figure 2. Micrograph of Cu-30wt%Zn - 0.1wt%La alloy.

Figures 2-27 reveal the presence of $CuZn_5$, Cu_5Zn_8, Cu_3La and Cu_5Sn intermetallic phases in the structure of the alloys doped with lanthanum and tin. Scanning electron microscopy (SEM) and electron dispersive X-ray (EDX) analyses of the alloy samples also indicate the presence of these intermetallic in the structure of the alloys (Figures 22- 37). It can be observed that addition of lanthanum and tin refines and modifies the morphology of the intermetallic compounds with attendant increase in ultimate tensile strength, percentage elongation, hardness and impact strength reason (Microstructural changes like grain refinement can lead to improved mechanical properties across the board. Fine-grained structures often result in materials that are both stronger and more ductile also certain alloying elements can improve both ultimate tensile strength and hardness while also improving or maintaining ductility (measured by % elongation)). The grain size decreases with increase in concentration of lanthanum up to 3.0wt%La and 5.0wt%Sn. The small grain sizes result to increased number of grain boundaries which served as increased impediment to motion of dislocations and consequently increased the ultimate tensile strength, hardness, percentage elongation and impact strength of the alloys. Increase in concentration of lanthanum beyond 3.0wt% coarsened the morphology of the intermetallic compounds which resulted to decrease in the ultimate tensile strength, percentage elongation, impact strength and hardness of the alloy. The presence of Cu_3La and Cu_3Sn compounds in the structure of the alloy further improved the strength and hardness of the alloy.

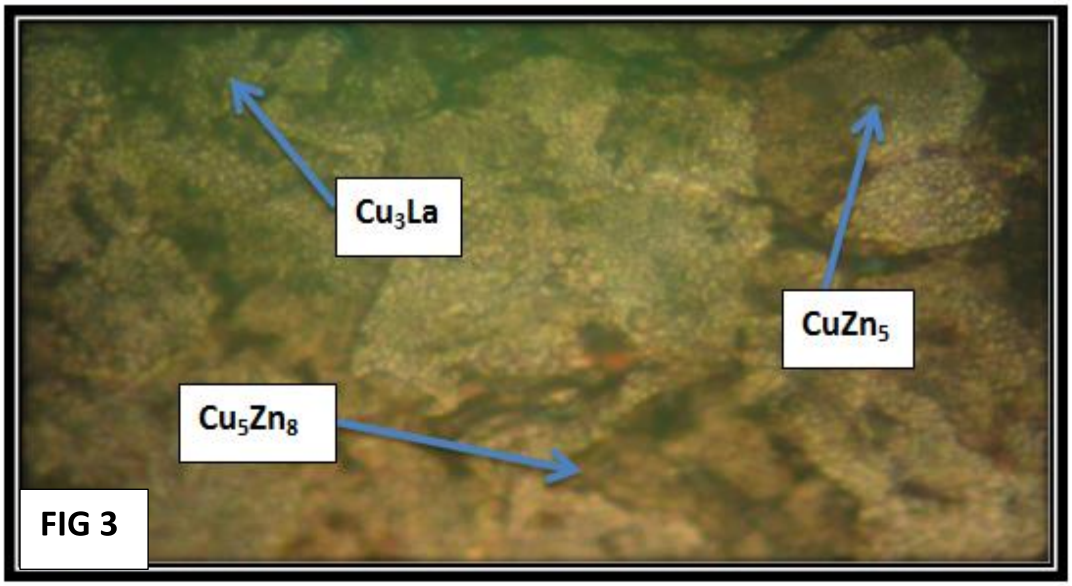

Figure 3. Micrograph of Cu-30wt%Zn - 0.2wt%La alloy.

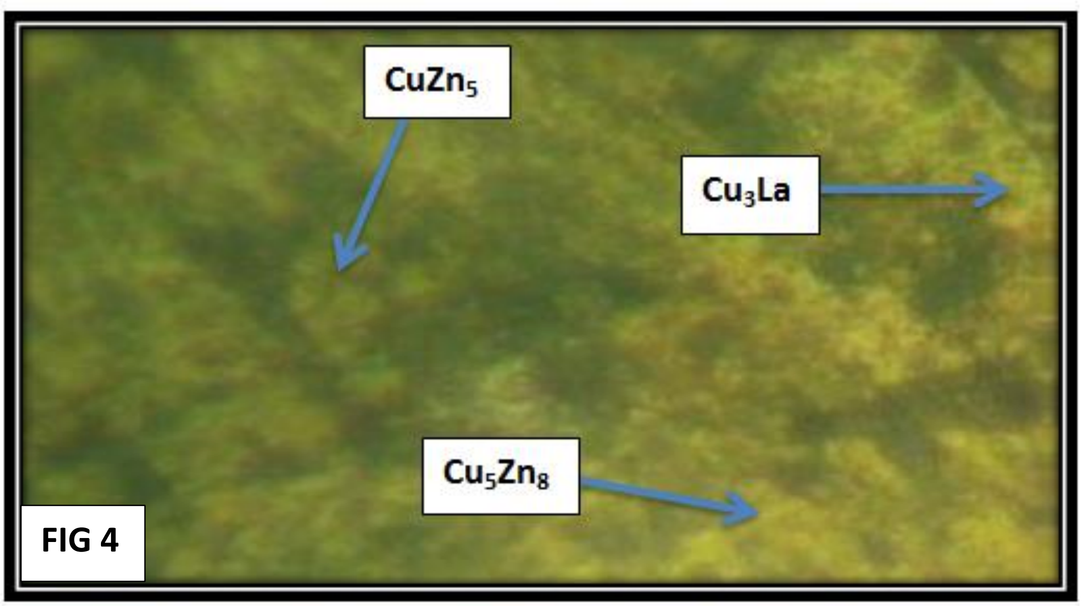

Figure 4. Micrograph of Cu-30wt%Zn - 0.3wt%La alloy.

Figure 5. Micrograph of Cu-30wt%Zn - 0.4wt%La alloy.

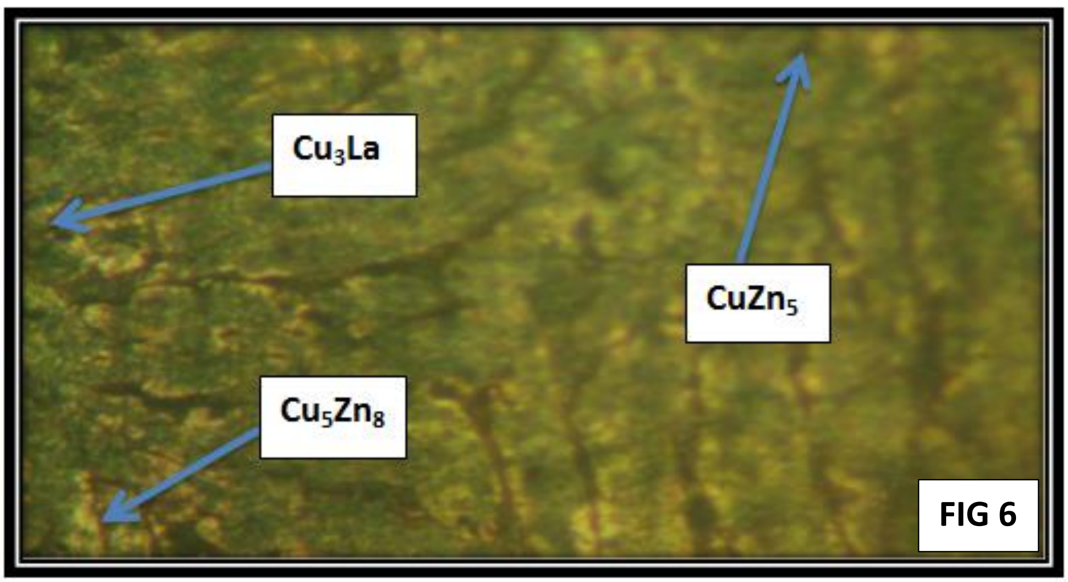

Figure 6. Micrograph of Cu-30wt%Zn - 0.5wt%La alloy.

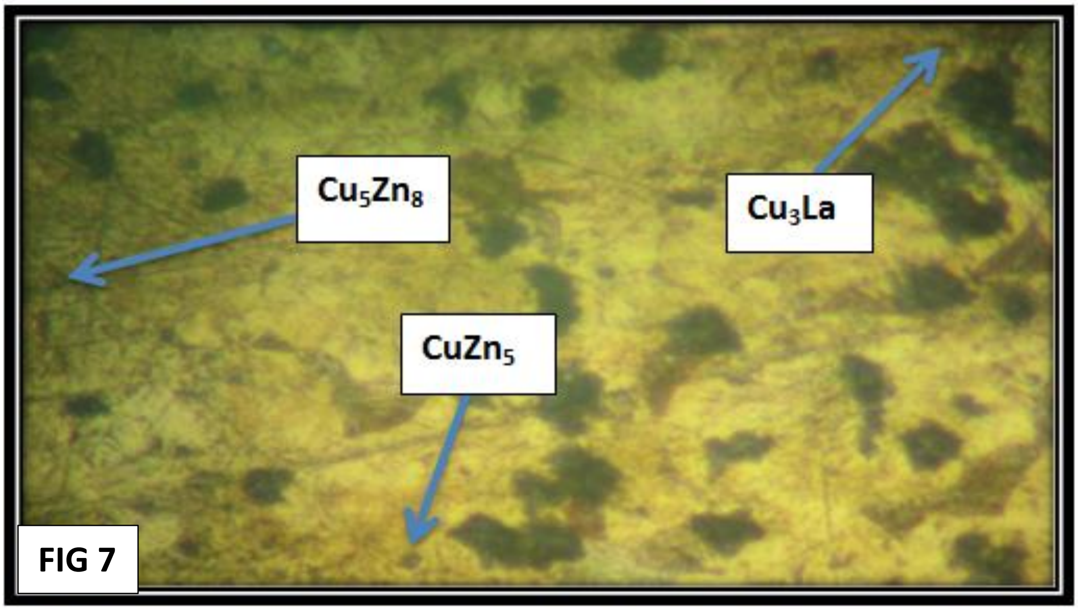

Figure 7. Micrograph of Cu-30wt%Zn - 1.0wt%La alloy.

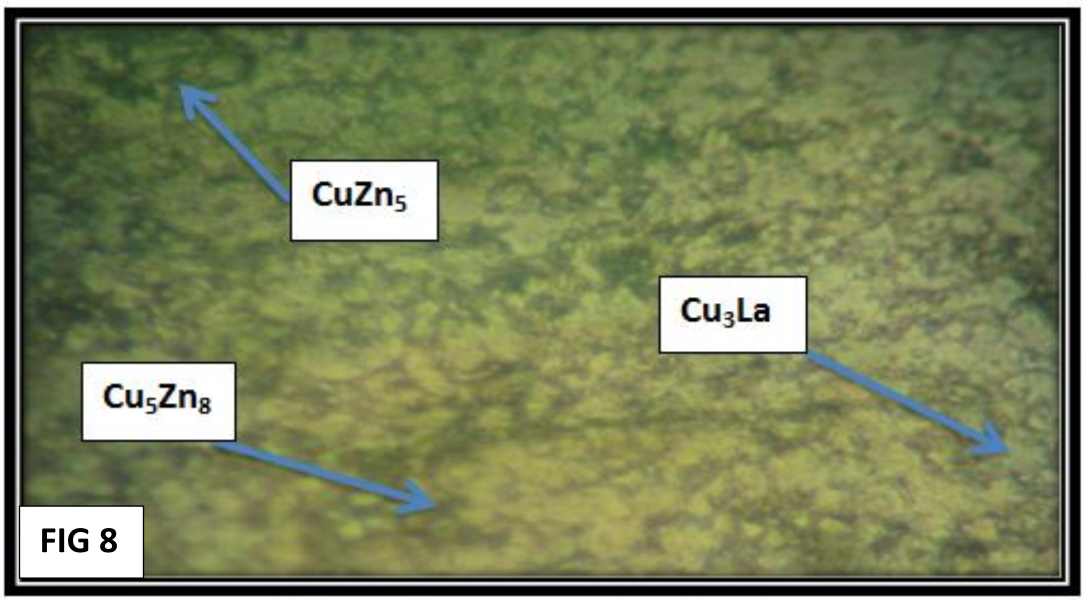

Figure 8. Micrograph of Cu-30wt%Zn - 2.0wt%La alloy.

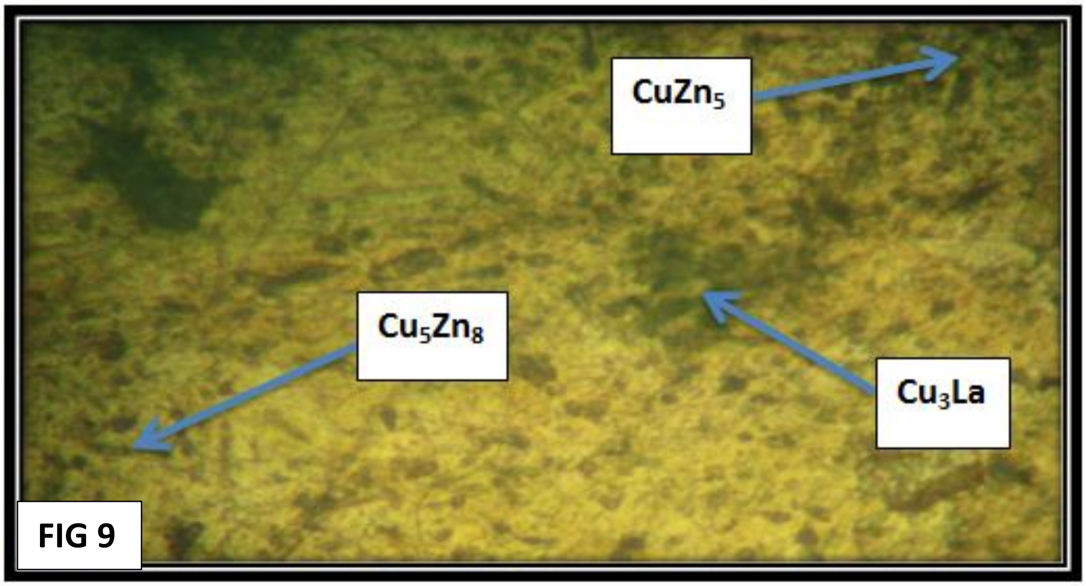

Figure 9. Micrograph of Cu-30wt%Zn - 3.0wt%La alloy.

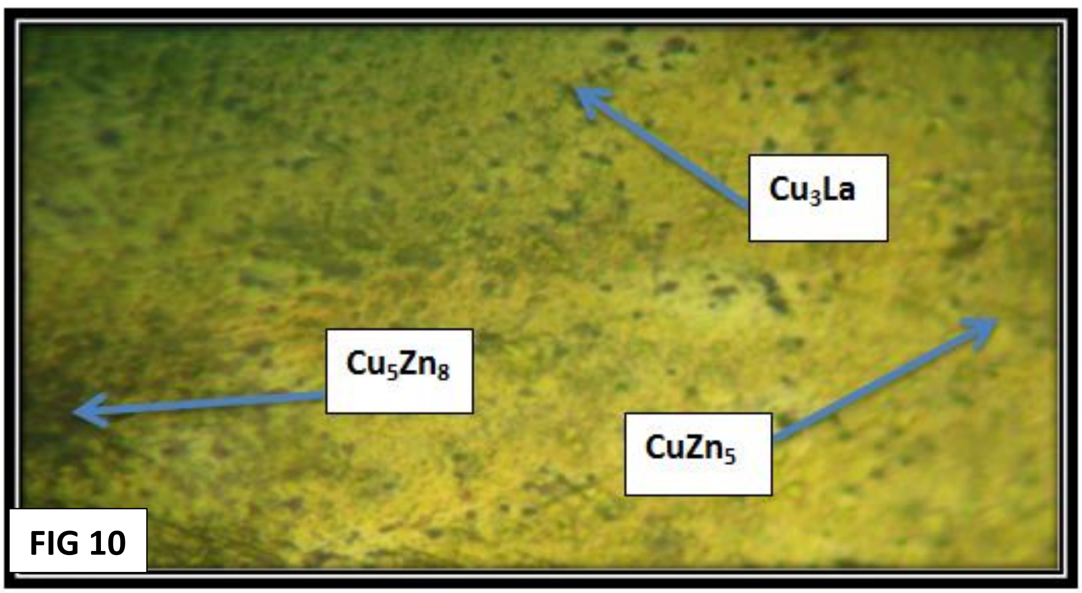

Figure 10. Micrograph of Cu-30wt%Zn - 4.0wt%La alloy.

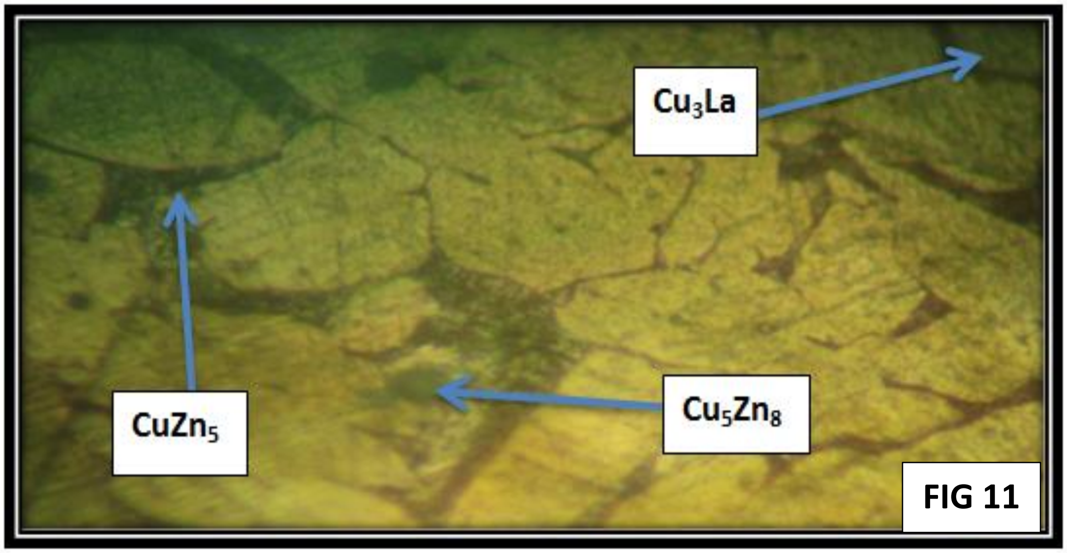

Figure 11. Micrograph of Cu-30wt%Zn - 5.0wt%La alloy.

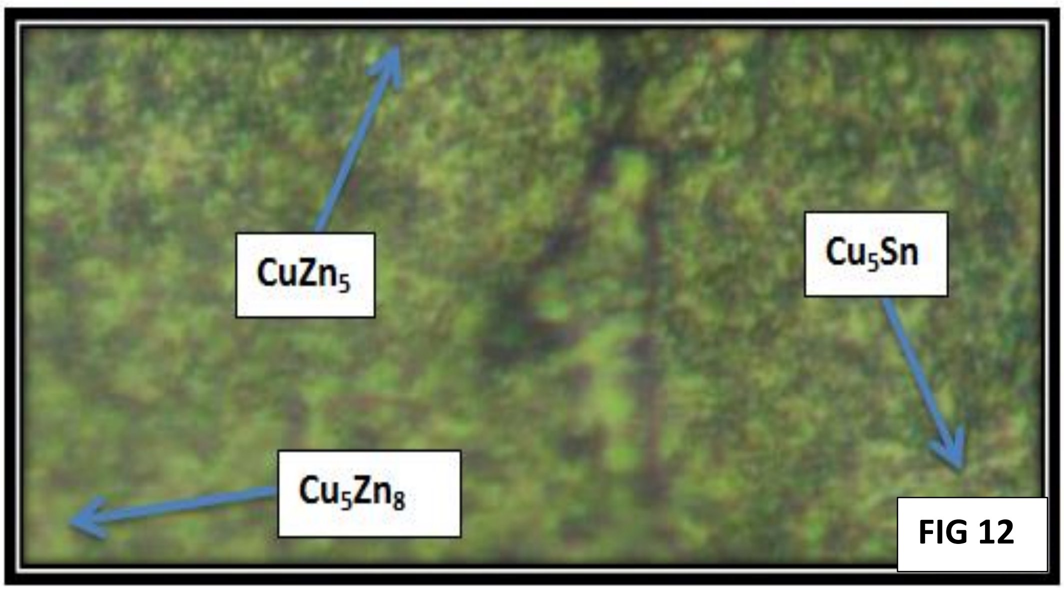

Figure 12. Micrograph of Cu-30wt%Zn – 0.1wt%Sn alloy.

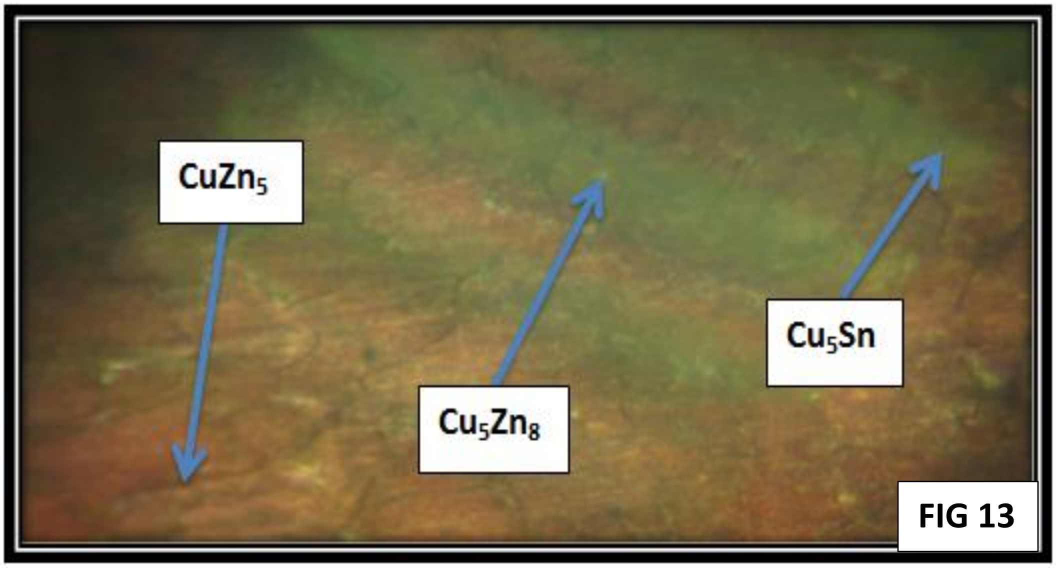

Figure 13. Micrograph of Cu-30wt%Zn – 0.2wt%Sn alloy.

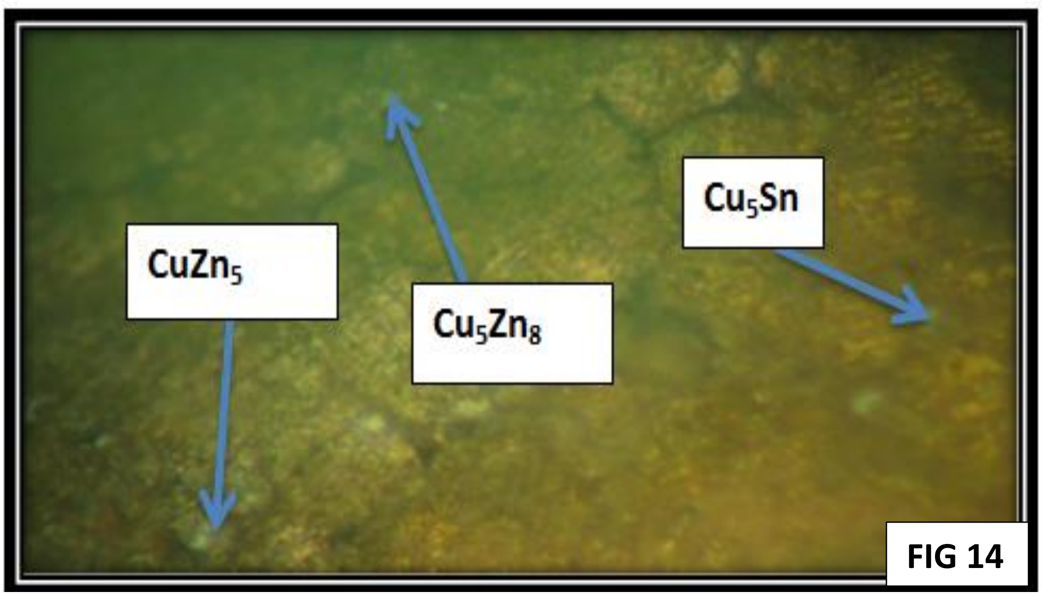

Figure 14. Micrograph of Cu-30wt%Zn – 0.3wt%Sn alloy.

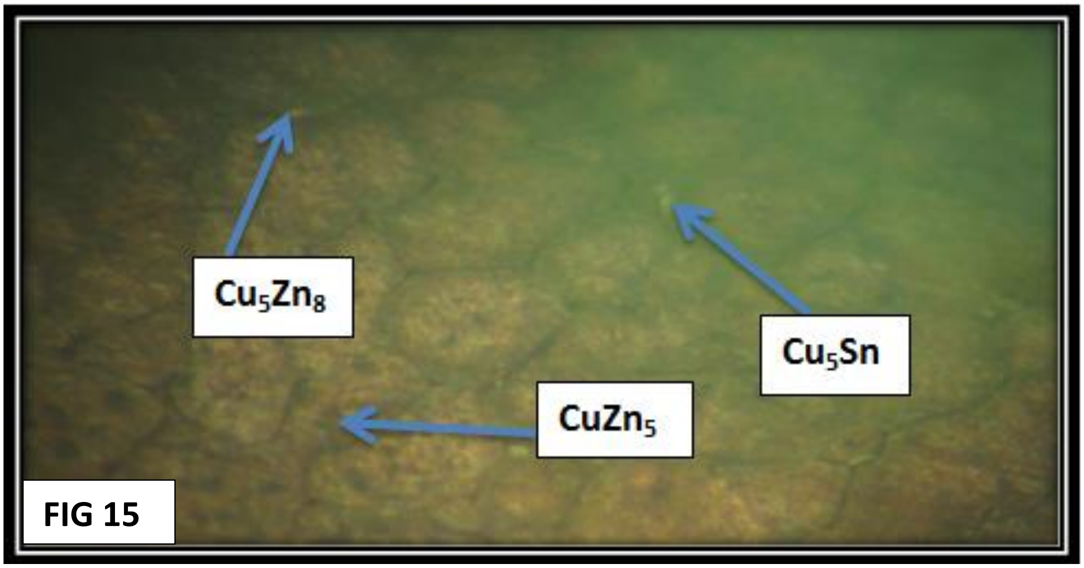

Figure 15. Micrograph of Cu-30wt%Zn – 0.4wt%Sn alloy.

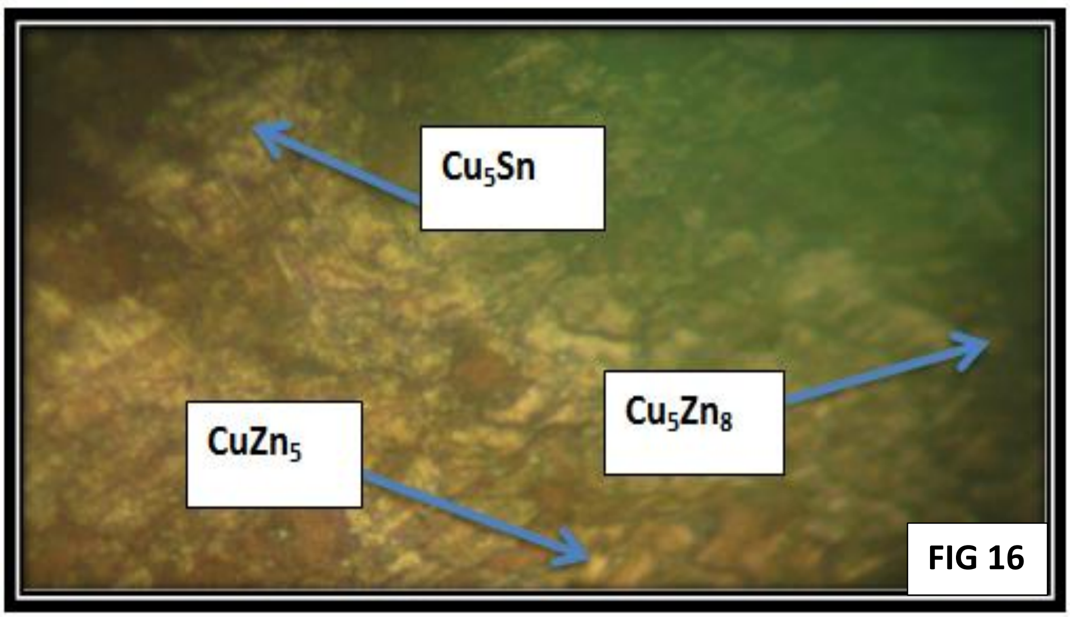

Figure 16. Micrograph of Cu-30wt%Zn – 0.5wt%Sn alloy.

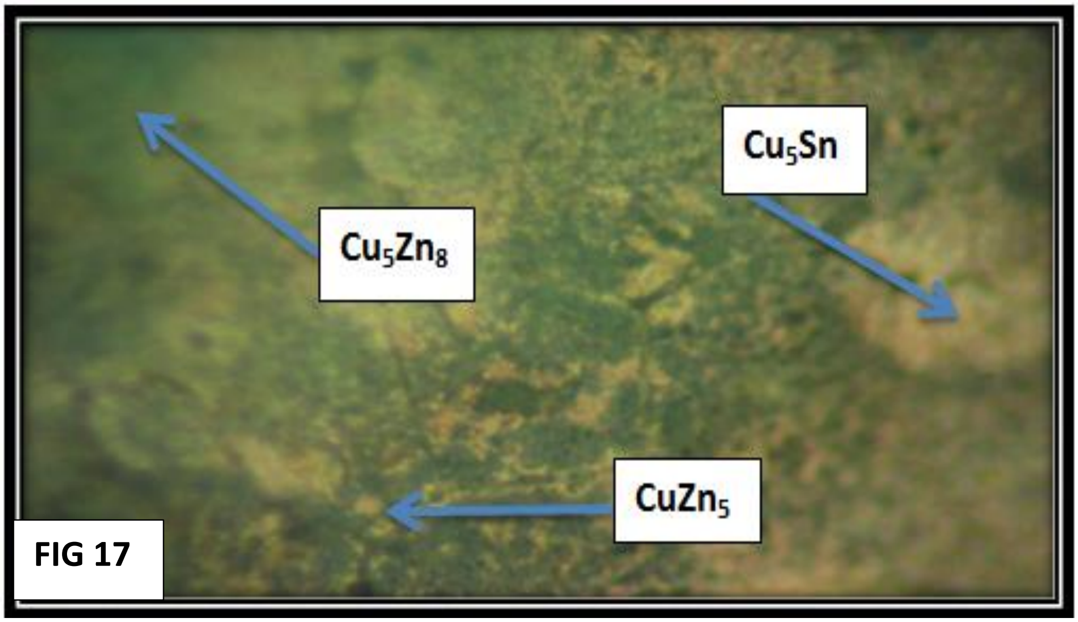

Figure 17. Micrograph of Cu-30wt%Zn – 1.0wt%Sn alloy.

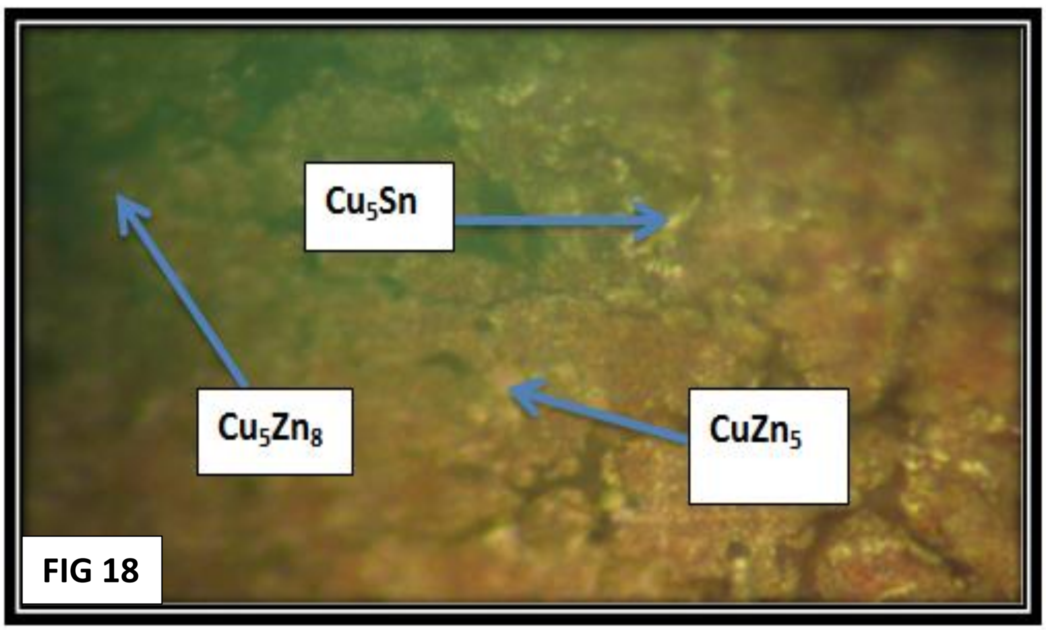

Figure 18. Micrograph of Cu-30wt%Zn – 2.0wt%Sn alloy.

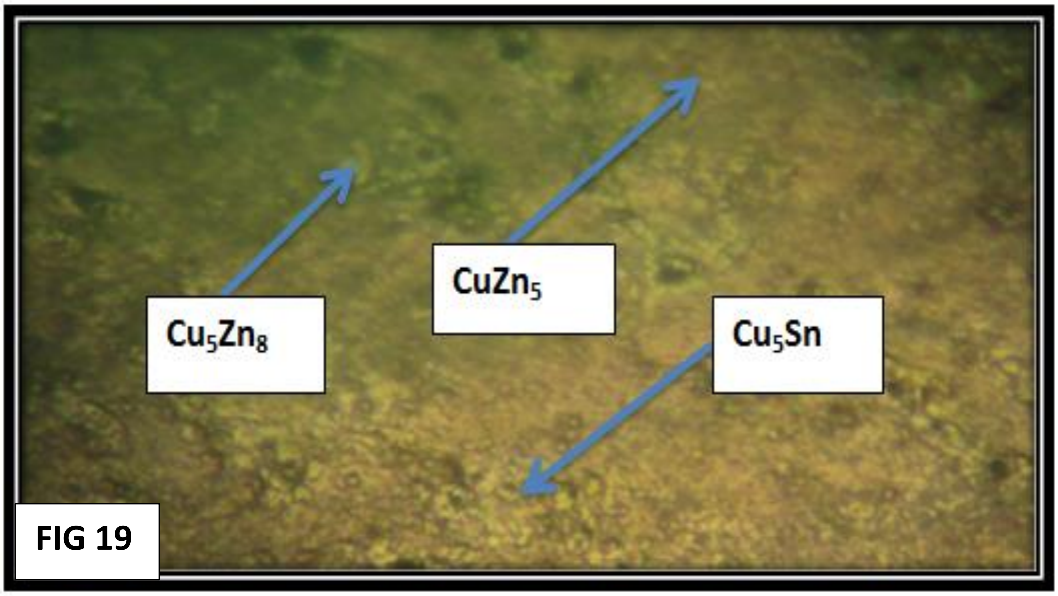

Figure 19. Micrograph of Cu-30wt%Zn – 3.0wt%Sn alloy.

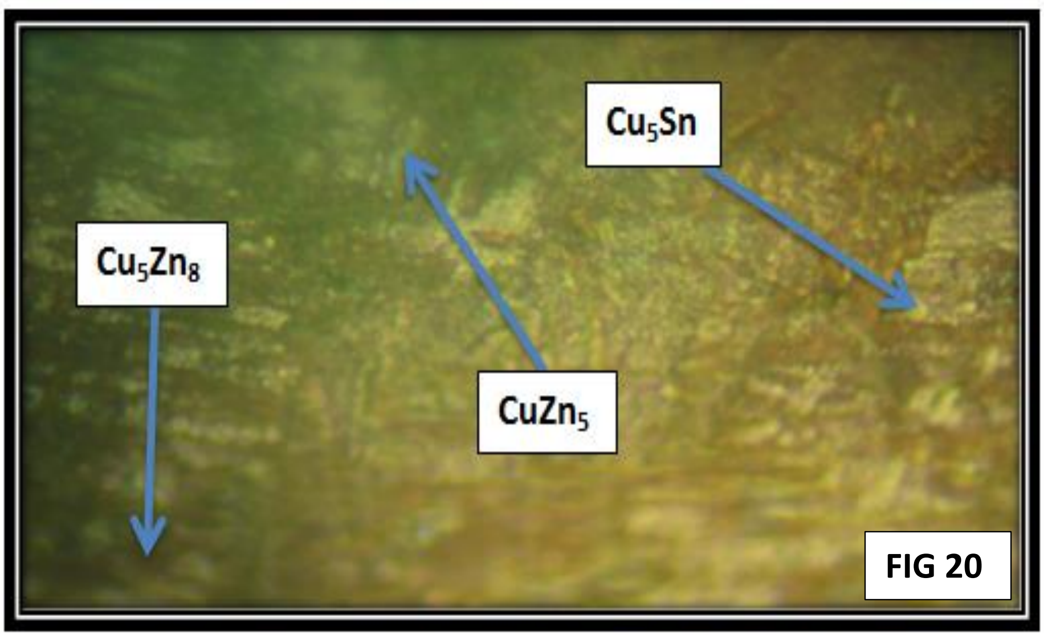

Figure 20. Micrograph of Cu-30wt%Zn – 4.0wt%Sn alloy.

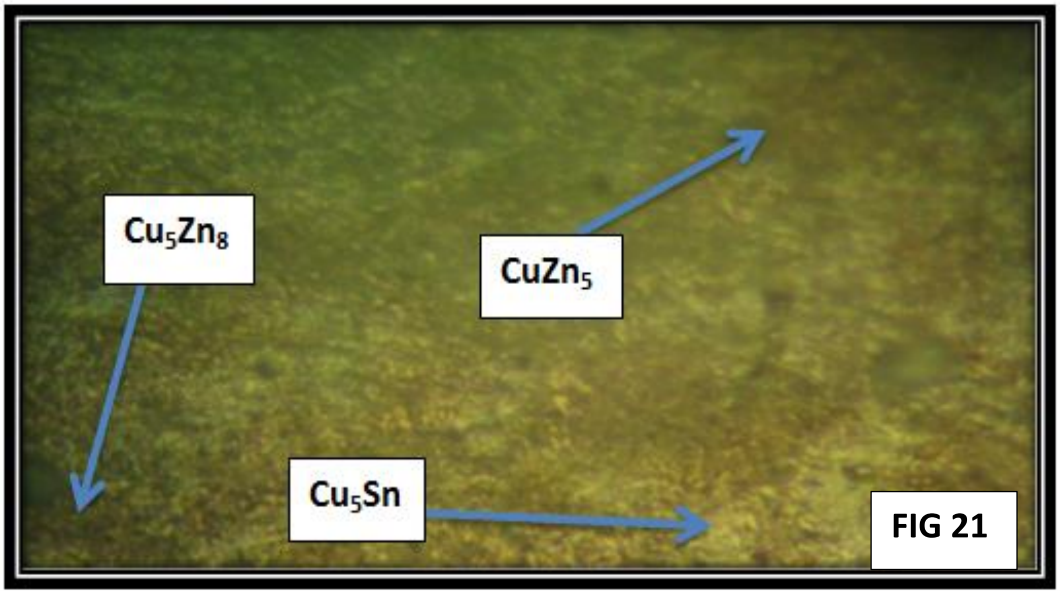

Figure 21. Micrograph of Cu-30wt%Zn – 5.0wt%Sn alloy.

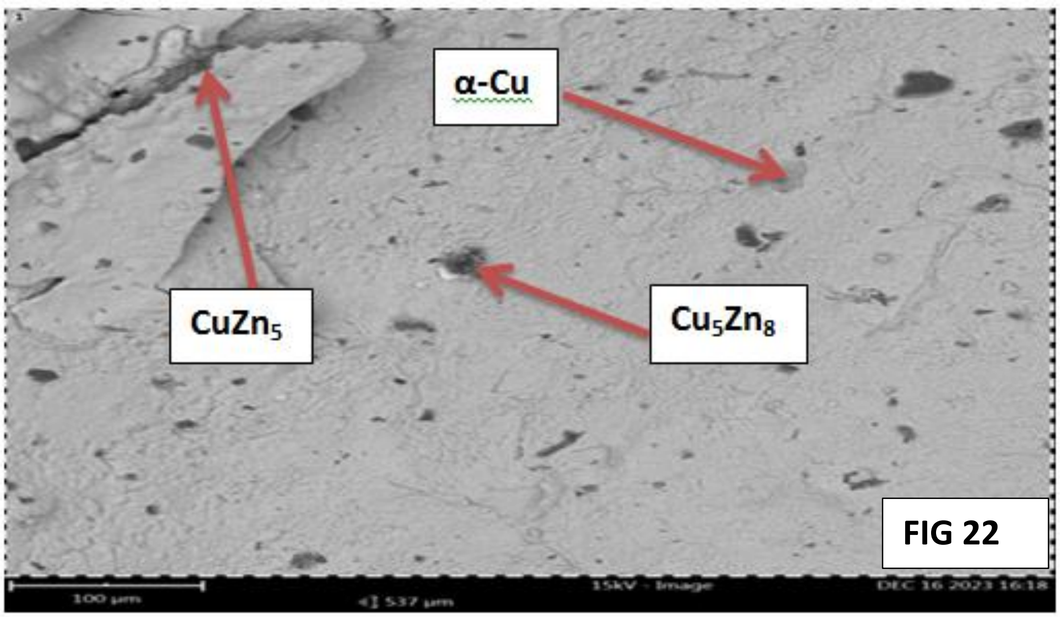

Figure 22. Scanning electron microscopy of Cu-30wt%Zn alloy

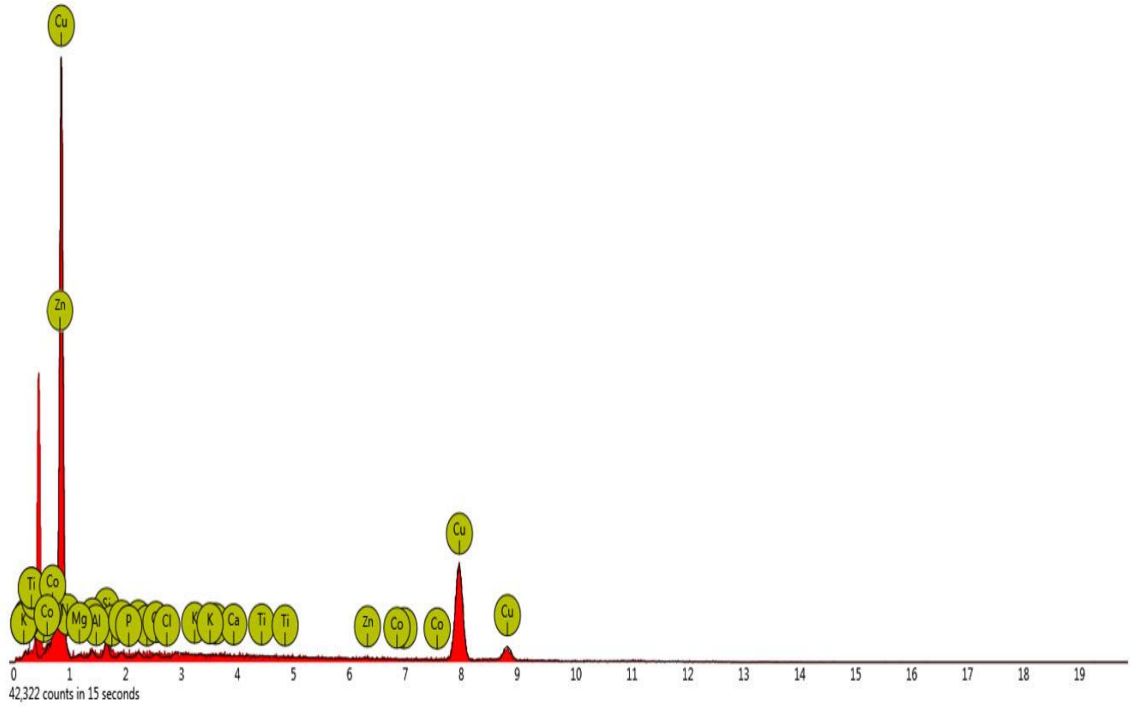

Figure 23. Energy dispersive X-ray diffraction (EDX) of Cu-30wt%Zn alloy.

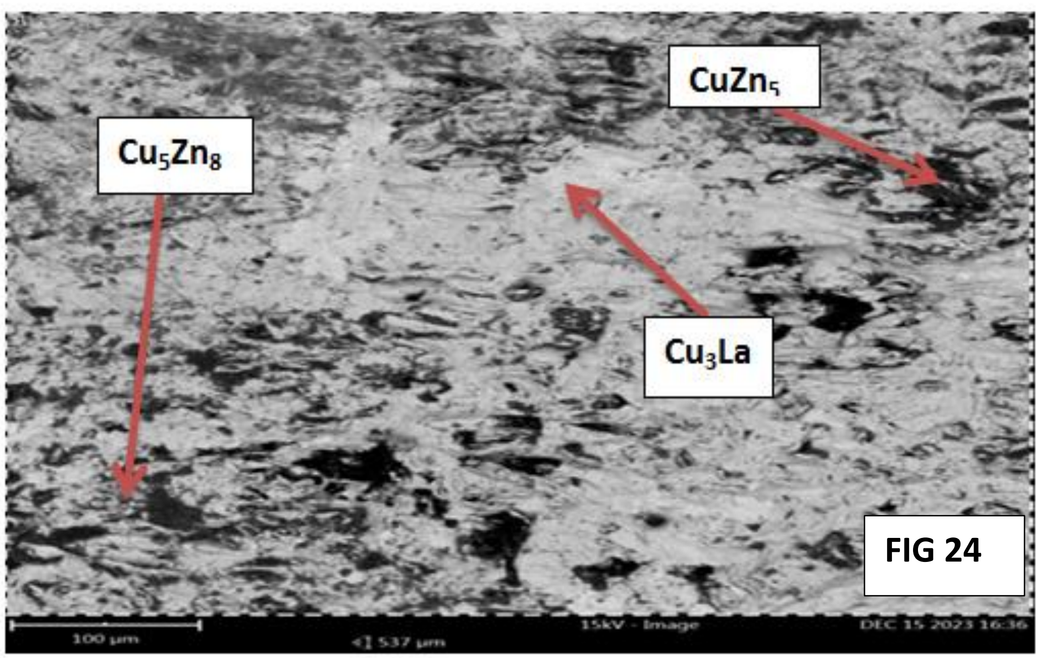

Figure 24. Scanning electron microscopy of Cu-30wt%Zn+3.0wt%La alloy

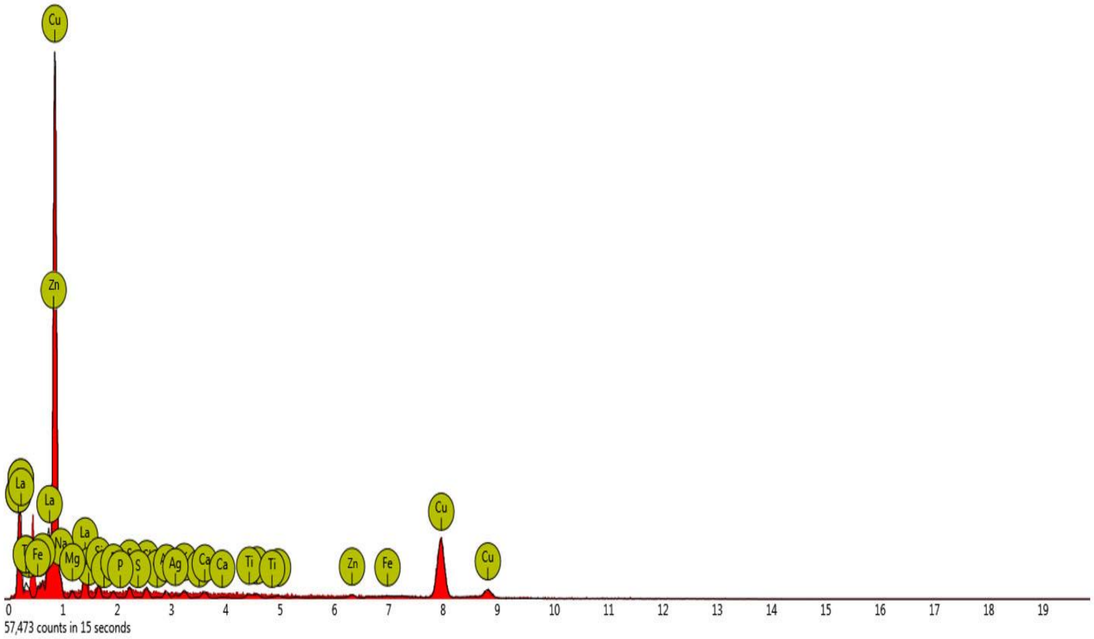

Figure 25. Energy dispersive X-ray diffraction (EDX) of Cu-30wt%Zn+3.0wt%La alloy.

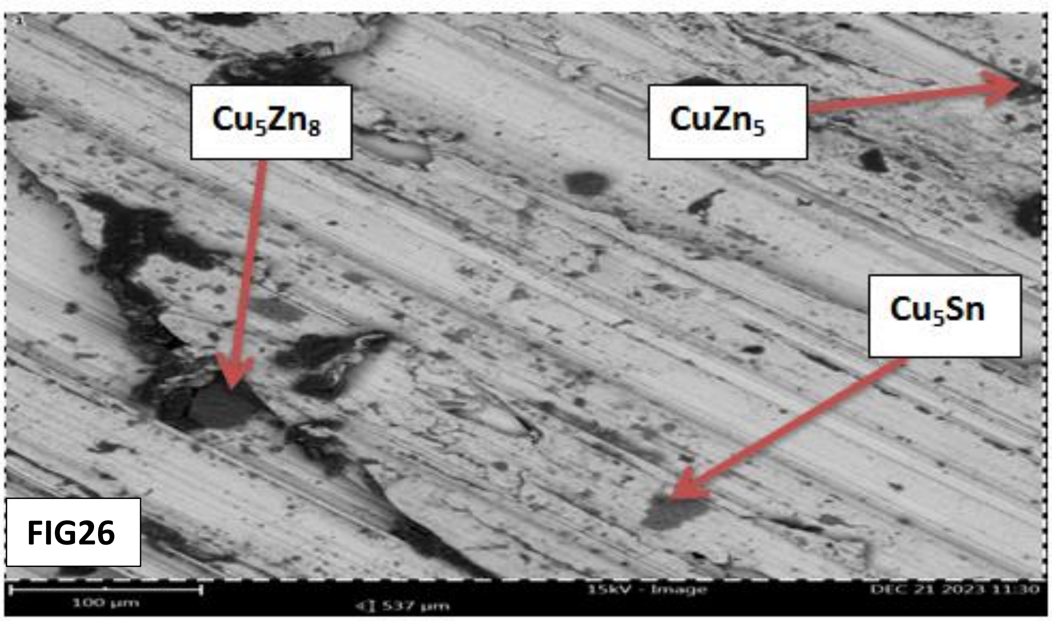

Figure 26. Scanning electron microscopy of Cu-30wt%Zn+5.0wt%Sn alloy

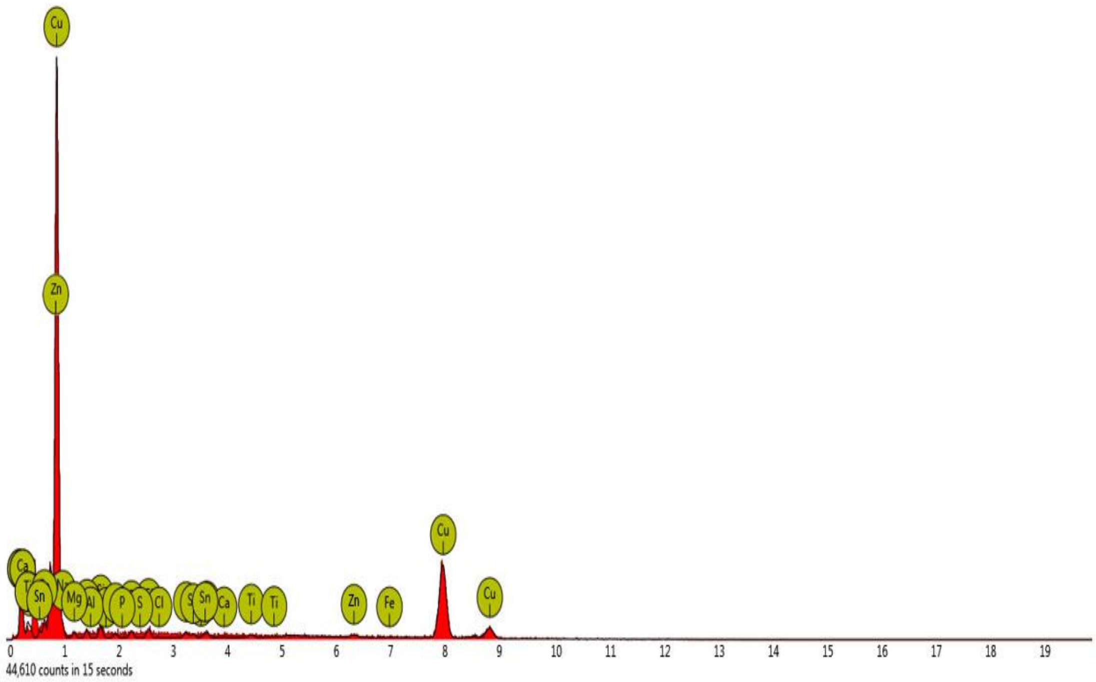

Figure 27. Energy dispersive X-ray diffraction (EDX) of Cu-30wt%Zn+5.0wt%Sn alloy.

3.2. Mechanical Properties, Conductivity and Resistivity of Cu-30wt%Zn Alloy

Figures 28-33 show the effect of lanthanum and tin addition on the electrical conductivity and resistivity, and mechanical properties – ultimate tensile strength (UTS), percentage elongation, hardness, and impact strength of the alloy.

It is observed from the Figures that the ultimate tensile strength, % elongation and impact strenght increased with increasing concentration of lanthanum and tin up to 3.0% for lanthanum before decreasing with further increase in concentration of the additive but for Tin, it increased up to 5.0%. The addition of lanthanum and tin to Cu-30wt%Zn alloy resulted in improvement in the ultimate tensile strength, % elongation and impact strength of the experimental alloy. Maximum ultimate tensile strength, % elongation, hardness and impact strength values obtained were 590 MPa, 21.86%, 135J at 3.0wt%La, for hardness, 277.6HBW at 4.0%La, 363MPa, 14.92%, 115J at 5.0wt%Sn, for hardness, 250.7HBW at 1.0%Sn content respectively. The addition of 0.1wt%La and Sn resulted in an improvement in electrical conductivity of the alloy. The improvement in the mechanical properties and electrical conductivity of the alloys was attributed to the presence of refined and modified intermetallic phases in the structure of the alloys. The decrease in the hardness of the alloys at high tin concentrations was attributed to the coarsening of the grains.

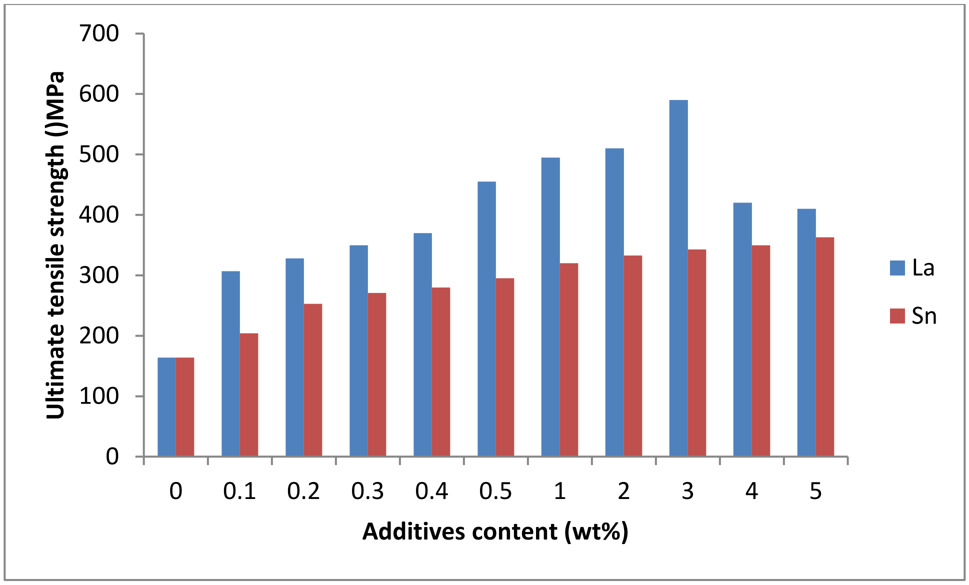

Figure 28. Effect of lanthanum and tin content on the ultimate tensile strength of Cu-30wt%Zn alloy.

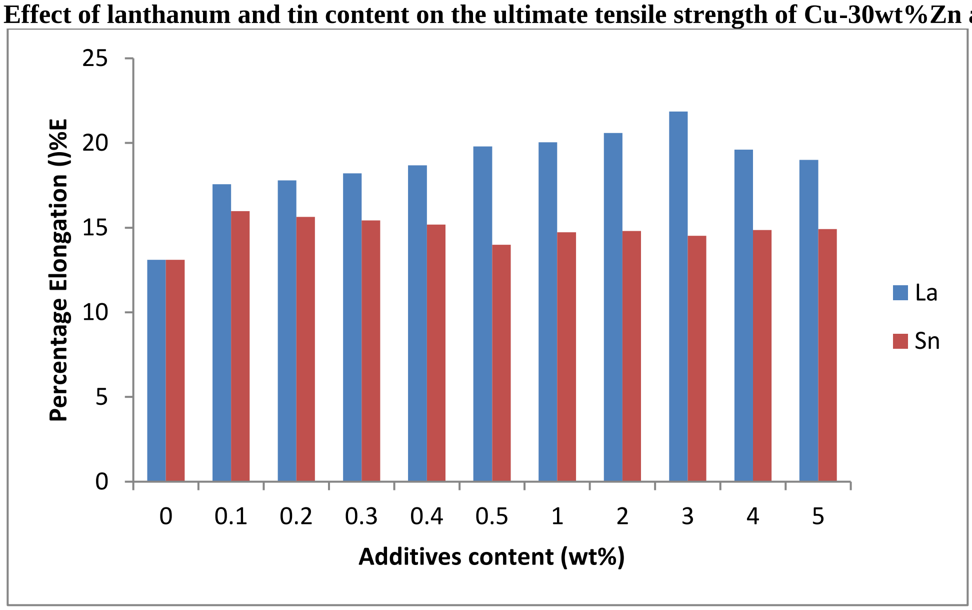

Figure 29. Effect of lanthanum and tin content on the percentage elongation of Cu-30wt%Zn alloy.

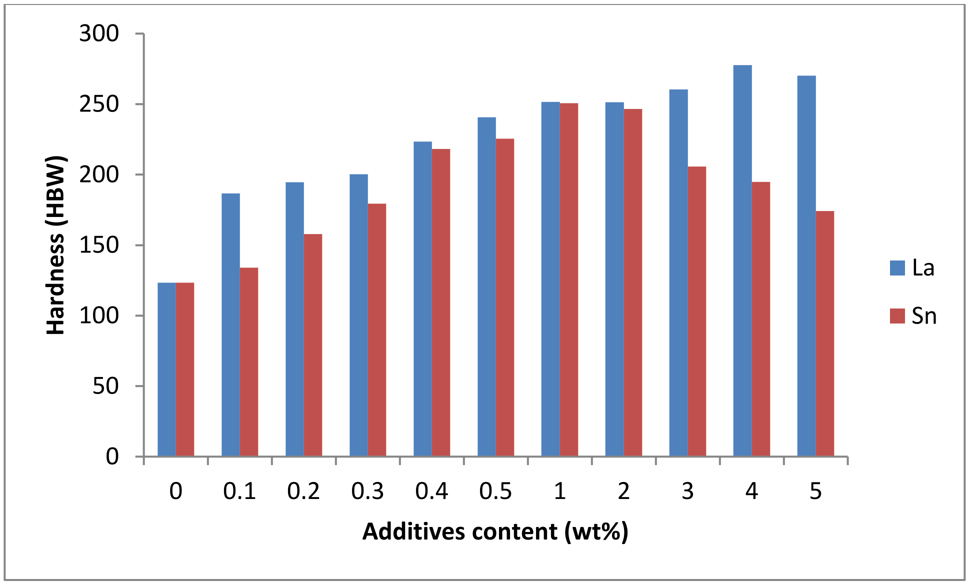

Figure 30. Effect of lanthanum and tin content on the hardness of Cu-30wt%Zn alloy.

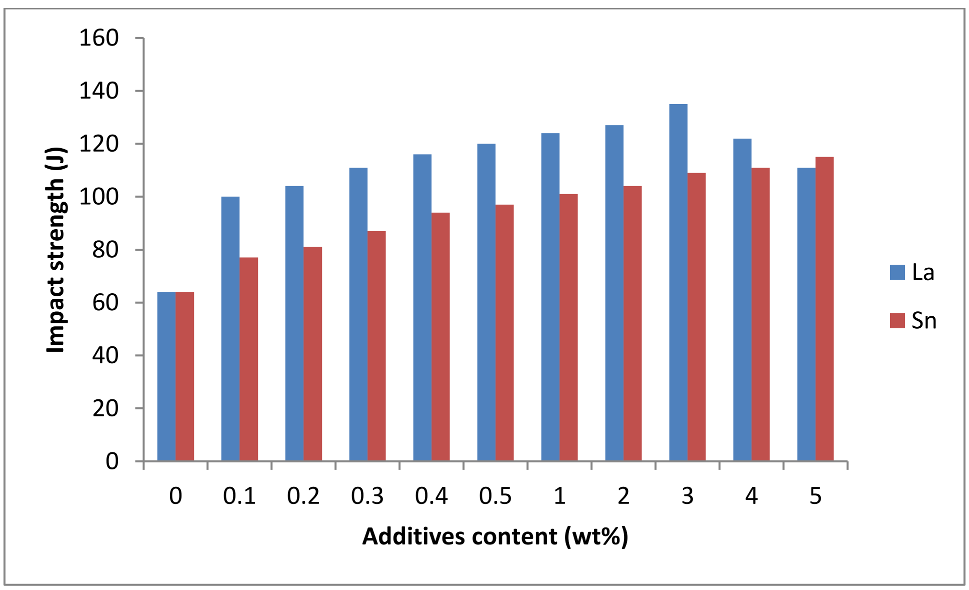

Figure 31. Effect of lanthanum and tin content on the impact strength of Cu-30wt%Zn alloy.

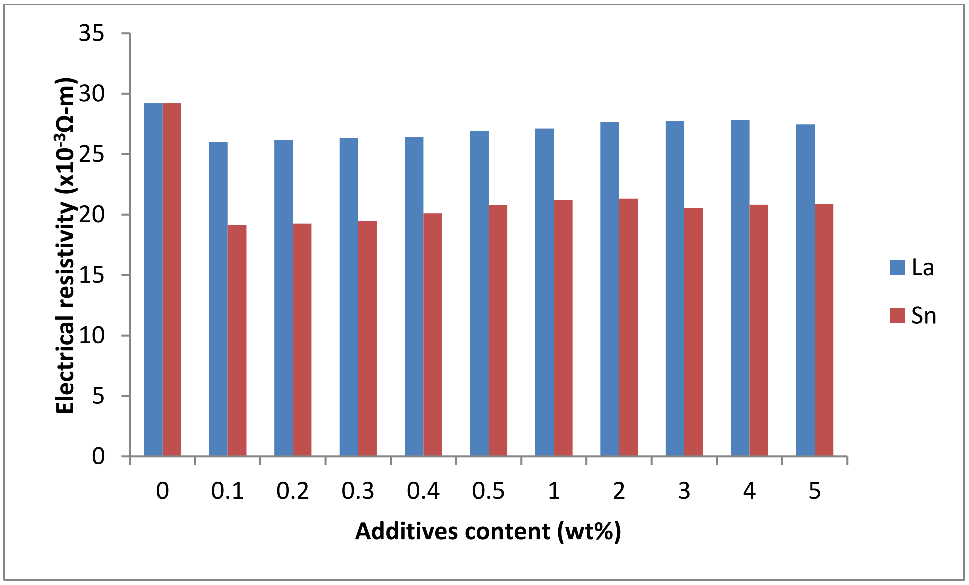

Figure 32. Effect of lanthanum and tin content on the electrical resistivity of Cu-30wt%Zn alloy.

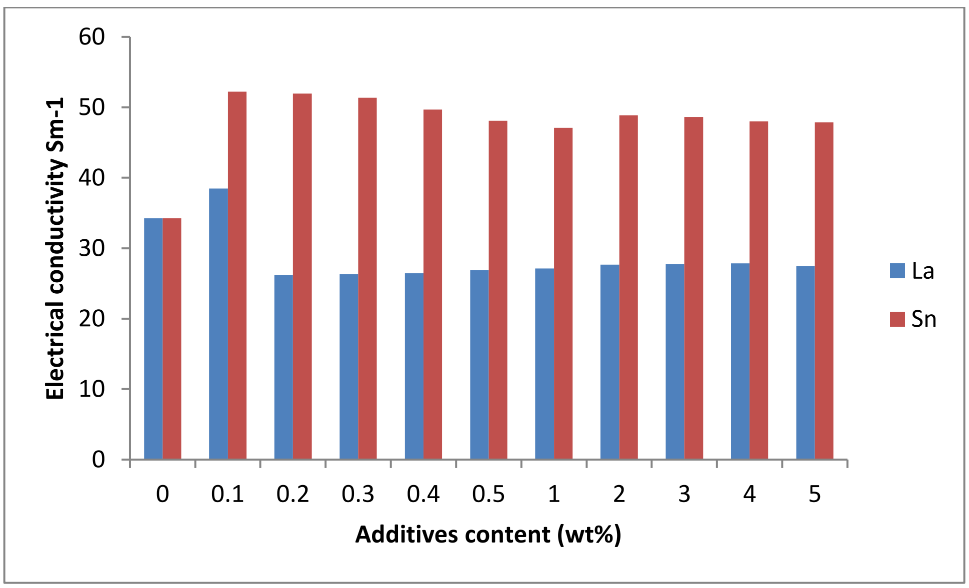

Figure 33. Effect of lanthanum and tin content on the electrical conductivity of Cu-30wt%Zn alloy.

4.0. Conclusion

The effect of lanthanum and tin content on the structure, physical and mechanical properties of Cu-30wt%Zn alloy has been investigated. The following conclusions can be made from the experimental results and theoretical analysis:

- Undoped Cu-30wt%Zn alloy has low physical and mechanical properties due to the presence of coarse intermetallic phase in the structure.

- The addition of lanthanum and tin to Cu-30wt%Zn alloy successfully refined and modified the structure of the alloys which resulted in improvement of the physical and mechanical properties of the experimental alloy.

- Comparing the effect of lanthanum and tin on Cu-30wt%Zn, lanthanum gave a better result than tin.

- It was also established that macro alloying of Cu-30wt%Zn alloy gave better properties than micro alloying.

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