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Effect of micro and macro alloying on damage tolerance of brass doped with carbide forming elements

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Abstract

The study focused on the damage tolerance of brass (Cu-30wt%Zn alloys) doped with molybdenum (Mo) and magnesium (Mg). The alloy was incorporated with varying concentrations (0.1- 0.5wt% and 1.0-5.0wt% at 0.1 and 1.0 intervals respectively) of molybdenum and magnesium and fabricated using a stir-casting technique. The hardness and impact strength were examined using a portable dynamic hardness testing machine (Model: DHT-6) and a pendulum impact testing machine (Model: U1820). The microstructures of the cast alloys were analyzed using an optical microscope (OM), Scanning electron microscope (SEM), and Energy dispersive spectroscope (EDS). Results depict that the additions of molybdenum and magnesium modified the structure of the alloy resulting in improvements of hardness and impact strength of the alloy by 53.4% and 49.1% respectively. The microstructure study revealed the existence of the fine stable phase, the intermetallic phases, and the primary α-phase which resulted in the improved mechanical properties.

Keywords: Brass, micro and macro-alloying, damage tolerance, microstructure molybdenum and magnesium

Introduction

Mixture of several elements that have properties superior to pure metals has been an aged longed practice typically to increase strength, increase corrosion resistance, or reduce cost (Anyafulu *et al.* 2024; Nwambu *et al.* 2024) [20, 16]. In most cases, alloys are mixed from commercially pure elements, relatively easy in the liquid state but slow and difficult in the solid state. Several reports have detailed information on the alloying process and many researchers have altered the properties of metals using alloying method however, this work dwelt on the micro and macro alloying which bothered on the varying concentration of the alloying elements (Arisgraha *et al.* 2018; Imai *et al.* 2014; Hassanein, 2021) [1, 7, 9].

For instance, Wenjing *et al.* (2021) [14] examined the effect of lanthanum addition on the microstructure and hardness of brass alloys produced by rheological squeeze casting. The study employed techniques such as metallography, scanning electron microscopy, energy-dispersive X-ray spectroscopy, X-ray diffraction, and hardness testing to investigate the microstructure and properties of brass alloy samples. The findings revealed that the addition of lanthanum had a significant impact on the alloy's hardness. Specifically, as the lanthanum content increased from 0 to 0.30 wt%, the hardness of the rheological squeeze-casting brass alloy experienced a notable 20.4% increase, rising from 108 to 130 HBW. The microstructural analysis demonstrated that lanthanum was crucial in refining the primary α-phase grains. This refinement primarily occurred due to constitutional undercooling and heterogeneous nucleation triggered by the enrichment of lanthanum at the solid-liquid interface's front. Also, the effect of zirconium and titanium on the structure and mechanical properties of copper based alloy (Cu-10%Al) was studied by (Nwambu et al, 2017) [4]. The study demonstrates that tensile strength, hardness, impact strength, and ductility all increased with the addition of dopants. Microstructure analysis revealed the primary α-phase, intermetallic phases, and a fine stable reinforcing kappa phase, which contributed to the enhancement of mechanical properties. Aluminum bronze doped with 2.5% zirconium and titanium showed significant improvements in tensile strength, ductility, impact strength, and hardness, and is therefore recommended for further use. Shaohua *et al.* (2019) [18] explored how cerium affects the microstructure, mechanical characteristics, and electrochemical behavior of the Cu-Zn-Mn-Al alloy.

The reported show that the introduction of cerium was crucial in reducing the grain size of the β phase in the base material. It also led to an increase in hard phases and made grains finer.The effect of silicon and tin addition on the microstructure and microhardness of Cu-Zn alloy was investigated by Puathawee *et al.* (2013) [19]. The experiment involved varying the tin concentration between 0.5, 1.0, 2.0, and 3.0wt%. The samples were prepared by melting pure elements in a graphite crucible using an induction furnace. The results of the study demonstrated that the hardness of the 60Cu-0.5Si-39.5Zn brass was measured at 123.4 HV. Sadayappan *et al.* (2012) [15] conducted a study to examine the impact of adding tin (Sn) 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. Cu-Zn alloy was melted in the first melt, and Sn, Al, and Pb were successively added. The Cu-36% Zn 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 (Sujit *et al.* 2015; Zhuangzhuang *et al.* 2020; Cribb *et al.* 2011) [11, 8, 13]. It was observed that adding other elements to this alloy caused modifications in the constituents and the size of the structure (Igelegbai *et al.* 2017; Kommela *et al.* 2007) [12, 3]. These studies depict that varying concentration of alloying elements significantly determine the properties of metal alloys but the extent their percentages affected the properties were not clearly elucidated as such will guide the application and affordability (Okelekwe et al 2024; Iyebeye *et al.* 2024) [2, 16].

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 molybdenum and magnesium 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 molybdenum and magnesium. 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). 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).

Results and Discussions

Mechanical behaviour of Cu-30wt%Zn alloys

Figure 1.0 show the brinell hardness of Cu-30%Zn alloy doped with molybdenum and magnesium. From the analysis of Figure 1.0, it was shown that addition of the alloying elements significantly improved the hardness of the alloy. Increase in hardness was noted as the concentration of the macro-alloying elements increased. This could be attributed to the presence of refined and modified intermetallic phase in the alloy structure. Molybdenum concentration gave the least value of hardness but higher than the control sample. In other words, Molybdenum showed a little significant effect on the hardness of Cu-30%Zn alloy. Also, molybdenum as alloying element affects the phase separation in copper matrix. The addition of molybdenum to Cu-30%Zn alloy changed the binary system with an intermediate phase that is coarse. Magnesium gave the highest hardness value of 267.6BHN and was achieved at 4.0wt% addition. The hardness of the Cu-30%Zn alloy increased as the concentrations of the alloying elements increased both in micro and macro addition. In comparison, macro-additions gave the highest hardness value. It could be noted that the hardness of the studied alloy improved significantly as the concentration of alloying elements increased. The effect could be attributed to the presence of refined and intermetallic phase in the alloy structure.

Figure 2.0 depict the analysis of the effect of dopants on the impact strength of Cu-30%Zn. A significant improvement in impact strength of the alloy was observed as the addition of the dopants increased. A systematic increase in impact strength was noted as the concentration of all dopants increased but in a different trend. The impact strength of Cu-30%Zn alloy improved as the concentration of magnesium increased when added both in micro and macro quantities, as shown in Figure 2, the peak impact strength value of 109j was obtained at 0.1wt% of the molybdenum doped Cu-30%Zn alloy. It was shown in that the impact strength decreases with an increased in the percentage weight composition of molybdenum. The Cu-30%Zn alloy’s impact energy responses to the appropriate compositional weight percentage of the alloying elements were considerably influenced by the type of microstructure that formed in the examined alloy.

The microstructure in which the best impact strength was obtained consists of fine dendrites that are homogenously dispersed, while the microstructures of the lowest impact energy consists of coarse clustered grains of the dendrite.

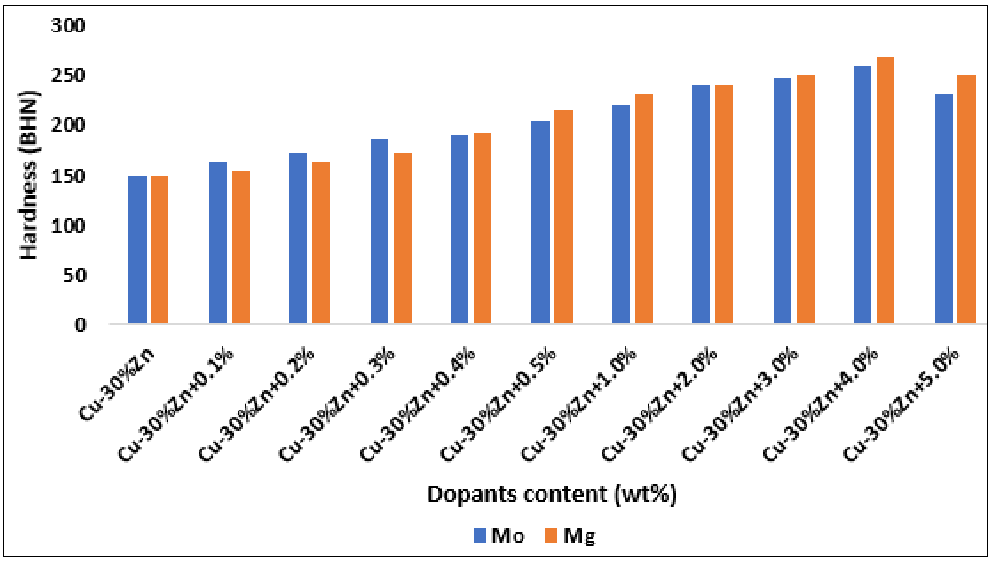

Fig 1: Effect of molybdenum and magnesium content on the hardness of Cu-30wt%Zn alloy.

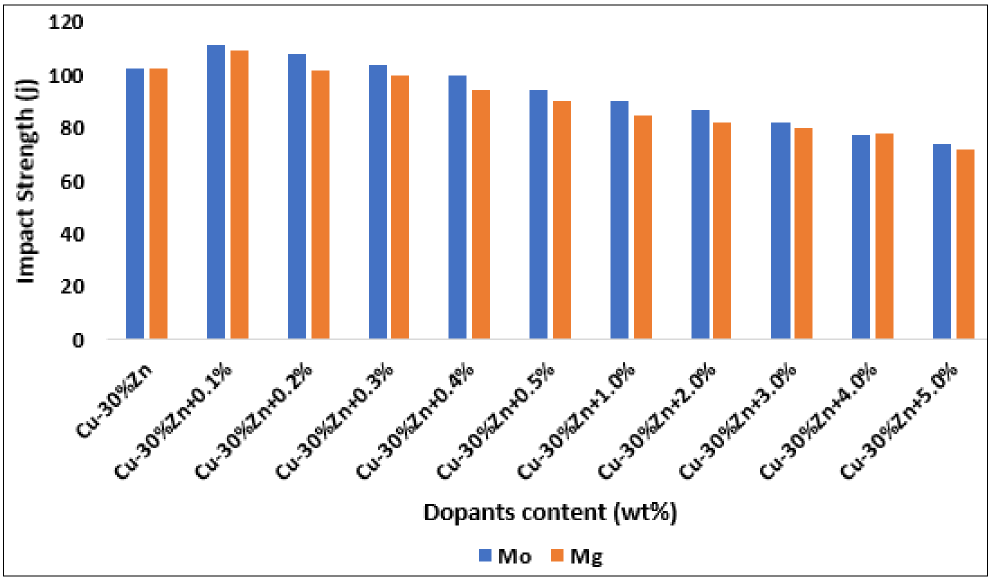

Fig 2: Effect of molybdenum and magnesium content on the tensile strength of Cu-30wt%Zn alloy.

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

The optical microstructure analyses of the alloys are presented in Figures 3 to 6. 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 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.

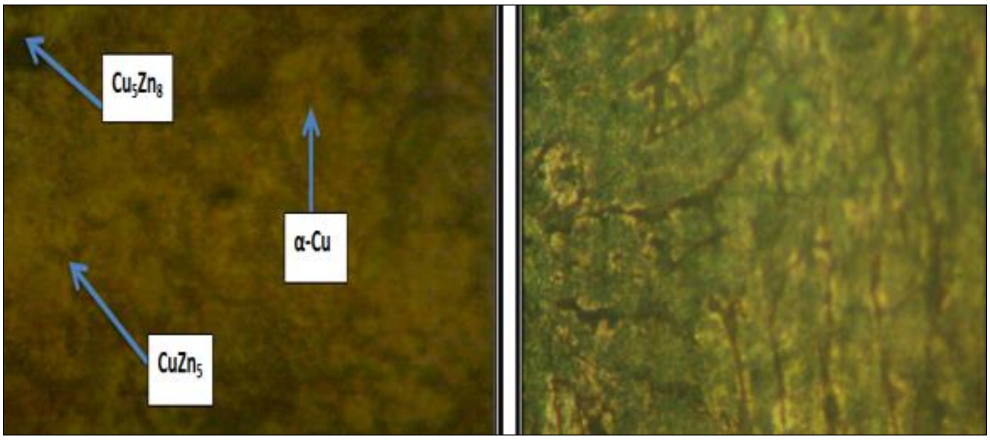

Fig 3: Micrograph of Cu-30wt%Zn alloy and 0.1wt%Mo alloy.

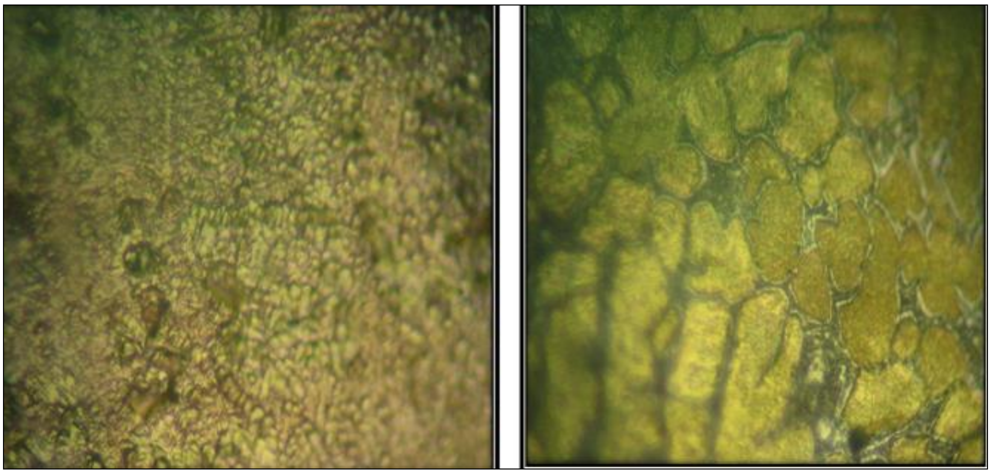

Fig 4: Micrograph of Cu-30%Zn+3.0wt%Mo and 4.0wt%Mo alloy.

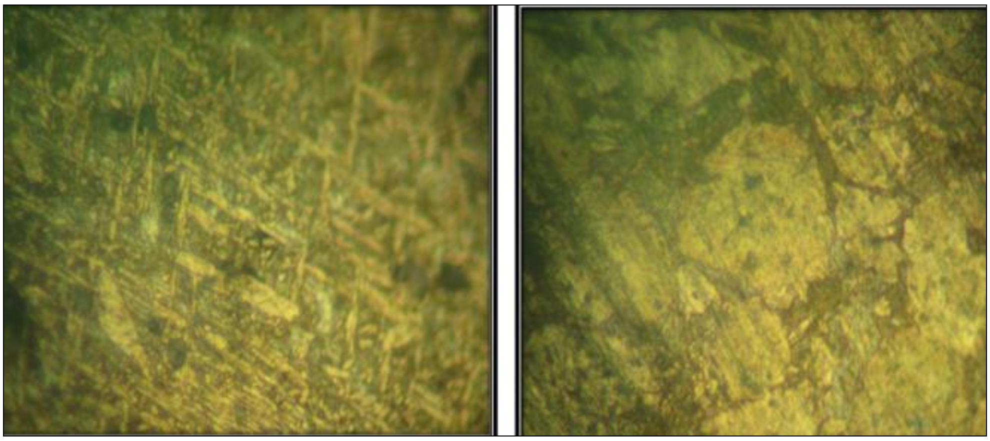

Fig 5: Micrograph of Cu-30%Zn+0.3wt%Mg and 0.4wt%Mg alloy

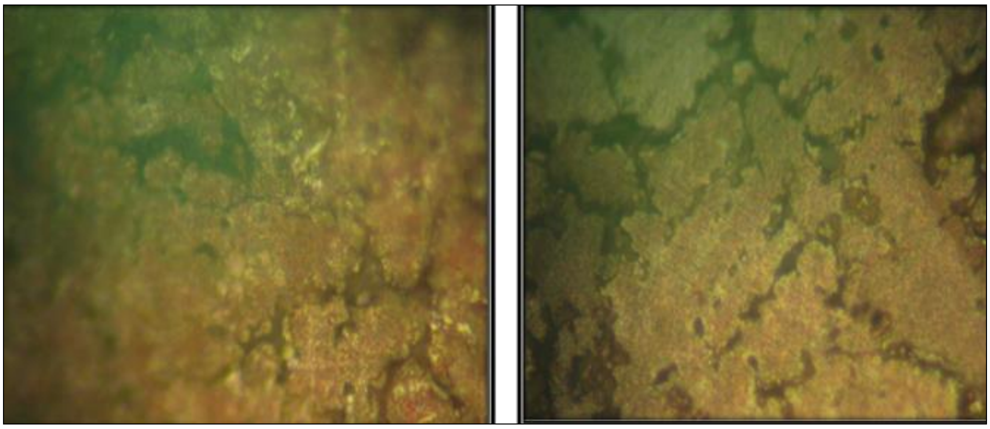

Fig 6: Micrograph of Cu-30%Zn+3.0wt%Mg alloy and 4.0wt%Mg alloy.

The microstructural analysis of Cu-30%Zn alloy doped with magnesium is presented in Figures 3 to 6. Figures 3 to 4 show the microstructural evolution of Cu-30%Zn alloy doped with molybdenum at different weight concentration (0.1-0.5 and 1.0-5.0). Analysis of Figures show that adding molybdenum to Cu-30%Zn alloy modified the dendritic structure of the alloy, which means that it decreased the size of the dendritic primary zinc; thereby improved the mechanical properties of the studied alloy. It revealed the presence of modified intermetallic compound evenly distributed in the copper matrix. The intermetallic compound coarsened as the concentration of molybdenum increased to 4wt%, thereby causing a decrease in ultimate tensile strength and hardness of the alloy. The micrographs revealed the presence of γ-phase (solid solubility of magnesium in copper matrix) and magnesium zincide ($MgZn_3$). The dendritic primary zinc was refined and modified by the addition of magnesium, thereby caused an increased in mechanical properties of the alloy as shown in Figures 5 and 6. It was revealed the volume of γ-phase and the intermetallic compound decreased and fine respectively as the magnesium content increased up to 5wt%. This resulted to increase in the hardness values of Cu-30Zn% alloy.

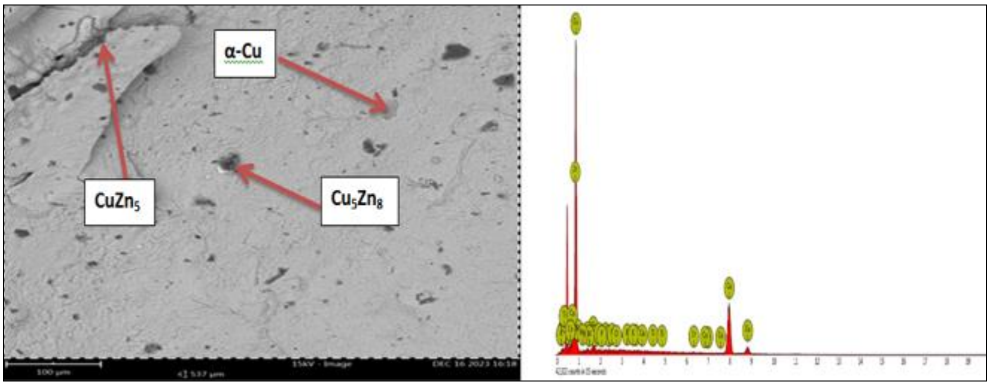

Fig 7: Scanning electron microscopy and energy dispersive spectroscopy of Cu-30wt%Zn alloy.

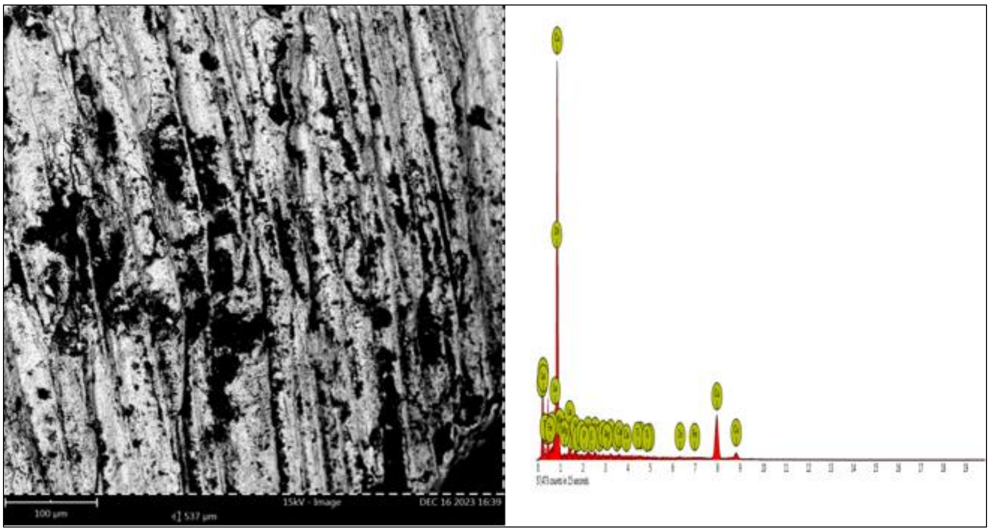

Fig 8: Scanning electron microscopy and energy dispersive spectroscopy of Cu-30wt%Zn+4.0wt%Mg alloy.

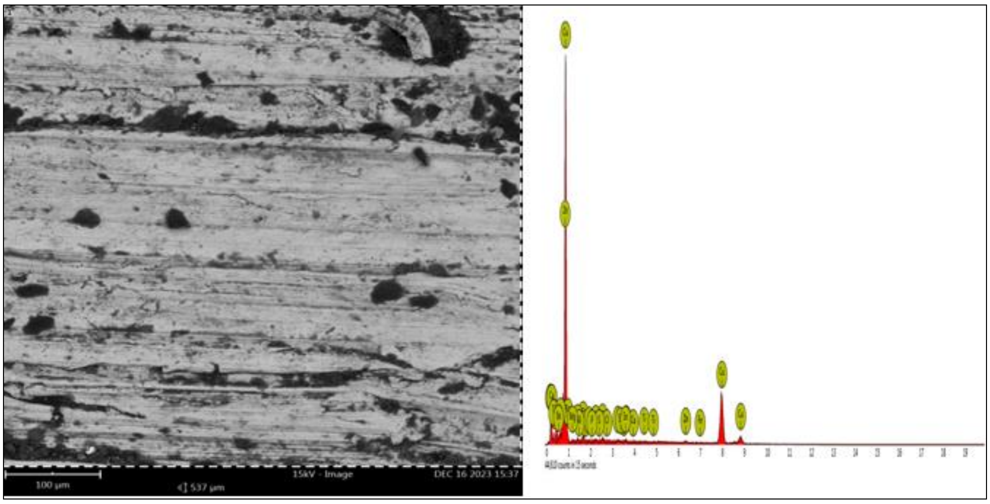

Fig 9: Scanning electron microscopy and energy dispersive spectroscopy of Cu-30wt%Zn+4.0wt%Mo alloy.

Conclusion

The effect of magnesium and molybdenum content on the structure, and mechanical properties of Cu-30wt%Zn alloy has been investigated. The following conclusions can be made from the experimental results. The addition of magnesium and molybdenum to Cu-30wt%Zn alloy successfully modified the structure of the alloys which resulted in improvement of the hardness of the 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 hardness than micro alloying likewise micro alloying produced superior impact strength over macro alloying.

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