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Homogenization effect on the properties of magnesium bronze doped with carbide forming elements

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ABSTRACT : *Copper-magnesium alloys are essential for many industrial applications because of their excellent electrical conductivity and strong strength. Copper-magnesium alloys require careful microstructure management to provide the best mechanical characteristics. This paper explores the influence of homogenization effect on the grain characteristics and mechanical properties of magnesium bronze doped with carbide forming elements. The designed alloy compositions were melted, cast, and subjected to homogenization at 900ºC for 5 hours and homogenization heat treatment (400ºC, 450ºC & 500ºC) was conducted using a Pyradia benchtop muffle furnace. The grain characteristics of the produced alloys were analyzed using a scanning electron microscope. The properties investigated were tensile strength, hardness, and impact strength. The SEM results revealed the presence of segregated and coarse intermetallic phases in the alloy samples. The surface morphology of the doped alloys consisted of refined and modified intermetallic phases evenly dispersed in the alloy structure. The mechanical test results showed that the alloy's tensile strength and hardness increased significantly by adding molybdenum and nickel. Homogenization heat treatment led to a further increase in the tensile strength and hardness of Cu-4wt%Mg alloys to 71.7% and 54.2% respectively. The alloy samples showed decreasing trends in impact strength values after undergoing homogenization heat treatment. For the benefit of the automotive and aerospace industries, this study emphasizes the significance of controlled homogenization in optimizing the microstructure and improving the structurally sensitive properties of copper-magnesium alloys*

KEYWORDS: Copper; magnesium; molybdenum; nickel; heat treatment, mechanical properties.

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I. INTRODUCTION

According to Russell and Lee (2005), Caron (2001), and Nwambu et al. (2017), copper and its alloys are among the most commercially significant metals because they are reasonably easy to manufacture, have a wide range of applications, and are generally non-magnetic with medium strength and fatigue resistance. The major factors that justify their employment are their remarkable corrosion resistance, good electrical and thermal conductivity, and ease of manufacture. The majority of structural applications rely on ferrous materials, particularly steels (Onyia et al. 2023; Iyebeye et al. 2024), but research indicates that copper alloys, or bronzes, are rapidly displacing modern steel materials for certain specific uses, particularly in marine and subsea components (Nwambu et al., 2024a). Magnesium is the primary alloying ingredient of magnesium bronze, which is an alloy based on copper. The alloy's density, electrical conductivity, and melting point all drop when magnesium is added. Additionally, it enhances fluidity and provides Cu-Mg alloys with superior welding properties. Magnesium bronzes are used in the construction, automotive, electrical, and electronics industries to fabricate lead frames, bolts, screws, electrical conduits, tie rods, and connections (Kulczyk et al., 2012; Anyafulu et al. 2024; Iyebeye et al. 2024). According to Avner (1974), magnesium bronzes are also utilized in hydraulic pressure lines, tanks, pressure vessels, and marine construction. It has been discovered that the addition of dopants to Cu-Ni alloys followed by aging heat treatment produces Cu-4Mg alloy with favorable electrical conductivity and mechanical characteristics (Shankar & Sellamuthu, 2017; Okelekwe et al. 2024; Osakwe et al. 2024). However, some previous researchers (Mao et al. 2007; Ezeobi et al. 2024;) reported that a serious segregation phenomenon of doping elements exists in the conventional casting process for Cu-4Mg alloys, which has a negative influence on the subsequent processing and mechanical properties of the alloys. Some dopants had shown to significantly improve the tensile properties of Cu-Mg alloys. Watanabe et al. (2015) found that the addition of certain percentages of doping elements enhanced the strength of Cu-Mg alloy without reducing its electrical conductivity. The addition of Chromium and tungsten (Onyia et al. 2024; Nwambu et al., 2024b) to Cu-4wt%Mg alloys increased the hardness and ultimate tensile strength of the alloys. This work will report the effect of molybdenum and nickel additions on the physic-mechanical properties of Cu-4wt%Mg alloys.

II. METHODOLOGY

2.1 Experimental Proedure

The base alloy for this study was produced from commercial pure copper (99.99%), titanium (99.98%) and tungsten (99.8%). The doped magnesium bronze was produced by the addition of titanium and tungsten in concentrations of 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, and 1.0% by weight using the permanent mold 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 pre-determined amount of magnesium in powder form wrapped in aluminum foil was added to the molten copper and stirred. The melt was held for about 10 minutes to ensure the complete dissolution of magnesium in the copper melt and stirred again to achieve homogeneity before pouring into preheated permanent mould and being allowed to cool to ambient temperature (Onyia et al. 2023; Okelekwe et al. 2024). Subsequently, the Cu-4wt%Mg alloys with the additives were produced by repeating the above-described procedure and introducing the different concentrations of the additives.

A tensile test was carried out on the cast specimens using a Universal Testing Machine (model WDW-10) as per ASTM E8/E8M-22 standard to determine the ultimate tensile strength and % elongation. Hardness test was carried out on 10mm x 10mm test bars machined from the cast samples, using a digital Rockwell hardness tester (model HRS-150) according to ASTM E18-22 standard. A Charpy impact test was performed on the cast samples following the ASTM E23 standard using an impact tester (model JB-300B). Three (3) samples were used for each experiment and the value taken after each experiment was the average. 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 (400, 600, 800, and 1200µm). After grinding, the specimens were polished to mirror finish using an aluminum oxide powder, rinsed with water and dried using a hand drier. The dried samples were etched with a solution of 10g 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 an optical metallurgical microscope (Model: L2003A). Scanning electron microscopy (SEM) of the experimental alloys was carried out on the samples using a TESCAN scanning electron microscope, model number (VEGA III LMH).

III. RESULTS AND DISCUSSION

3.1 Microstructural analysis of magnesium bronze

Fig.s 1 to 4 show the scanning electron microscopy (SEM) analysis of the alloys doped with molybdenum and nickel. Cu-4%Mg alloy indicated uniform distribution of the intermetallic compounds of different morphology in the alloy structure but samples with dopants depict course and heterogeneous phrases. The Cu-4%Mg alloy samples doped with nickel show a better even distribution of fine grains after heat treatment compared to samples doped with molybdenum which shows coarse grains (Okelekwe et al. 2024; Ezeobi et al. 2024). This is linked to better improvement of the tensile strength and hardness of tungsten-doped alloy samples heat treated at 500°C.

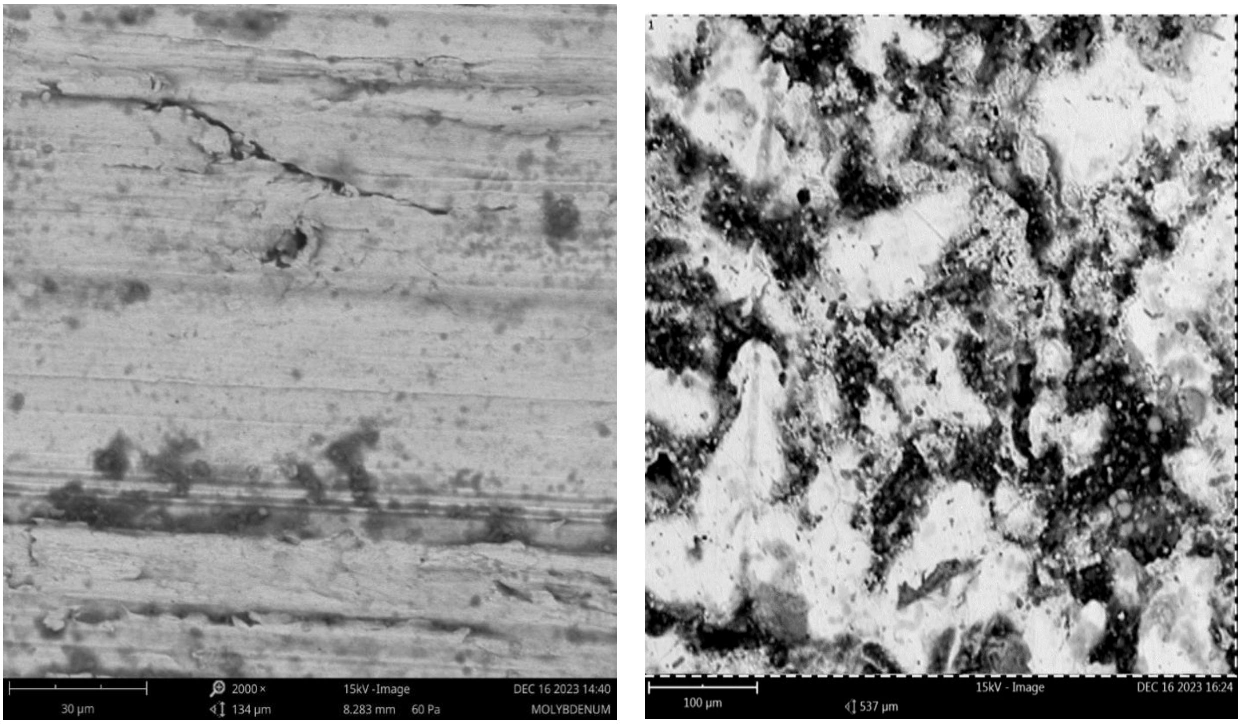

Fig. 1: Micrograph (SEM) of as-cast Cu-4%Mg-1%Ni and 0.9%Mo alloy.

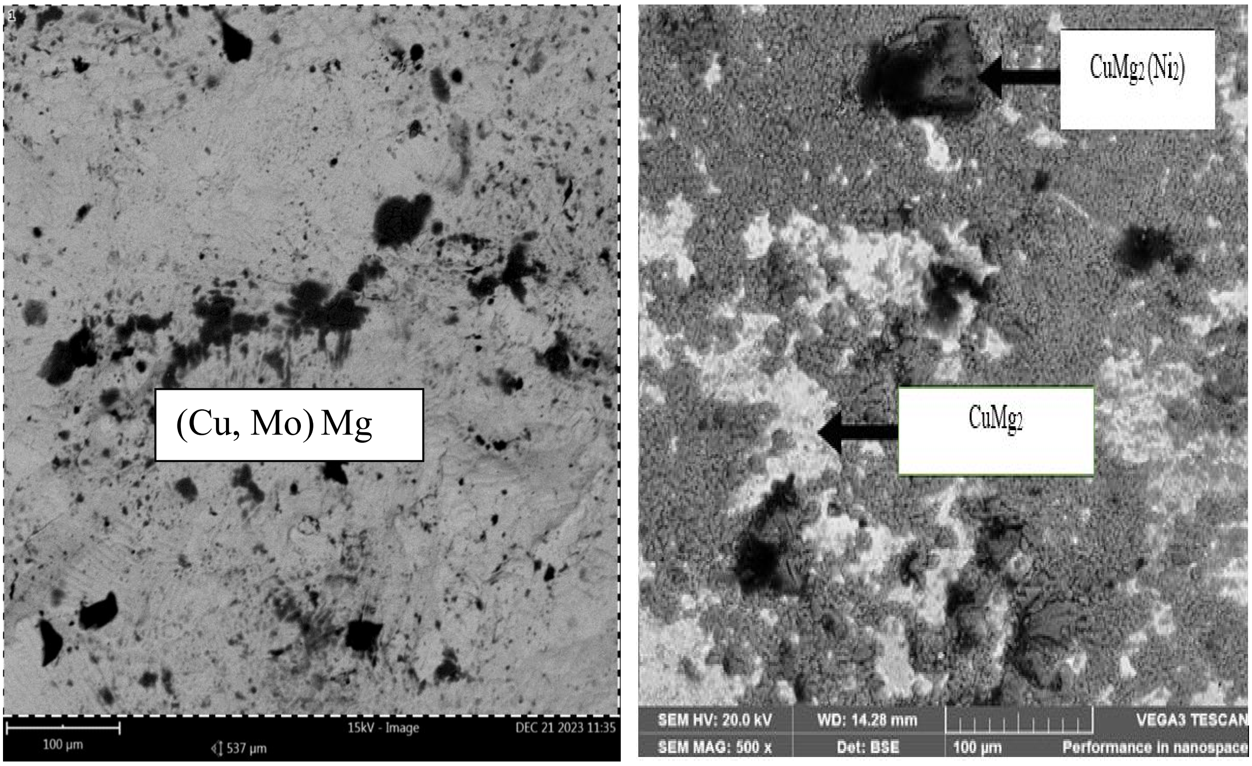

Fig. 2: Micrograph (SEM) of Cu-4%Mg-0.9%Ni and 0.9%Mo alloy heat treated at 400°C

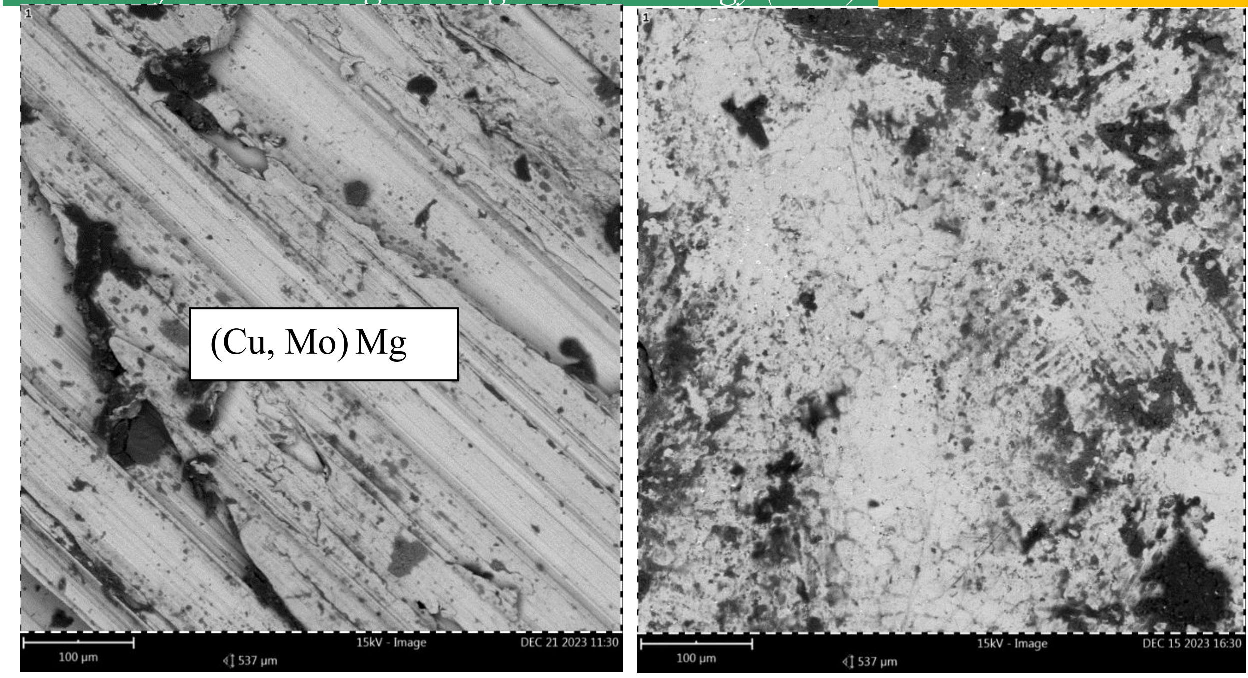

Fig. 3: Micrograph (SEM) of Cu-4%Mg-0.9%Ni and 0.9%Mo alloys heat treated at 450°C.

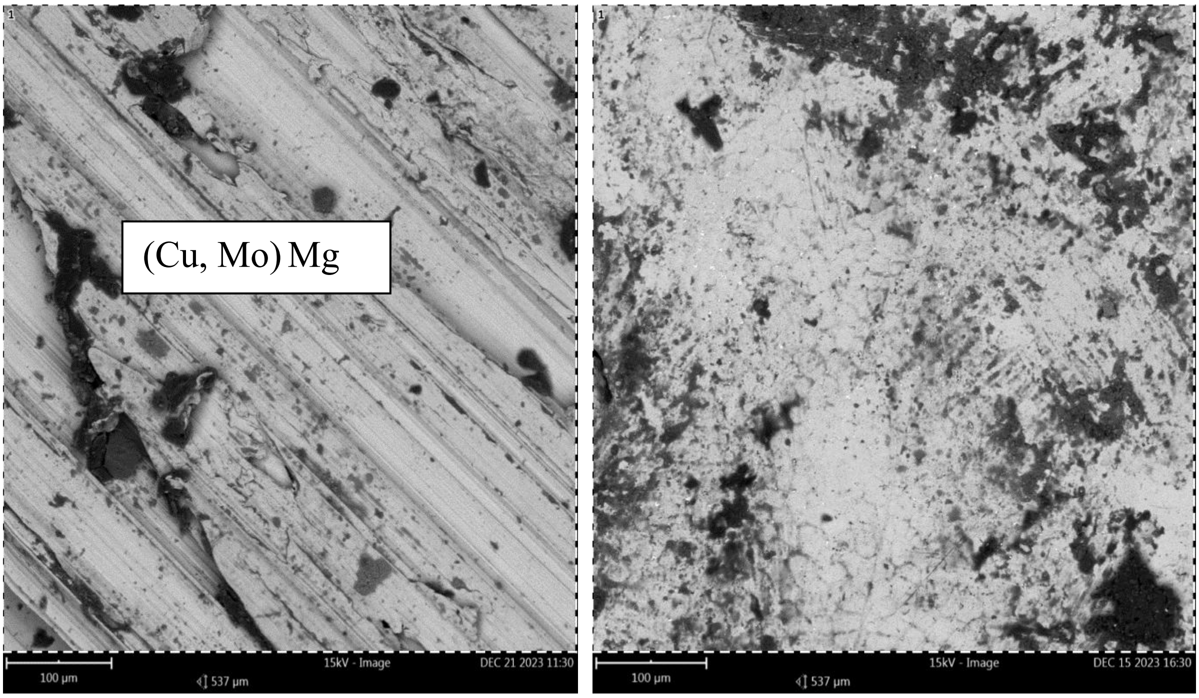

Fig. 4: Micrograph (SEM) of Cu-4%Mg-0.9%Ni and 0.9%Mo alloys heat treated at 500°C.

3.2 Mechanical properties analysis of magnesium bronze

The effects of heat treatment and the addition of nickel and molybdenum on the tensile strength, hardness, and impact energy of the Cu-4wt%Mg alloy are shown in Fig.s 5-7. It has been noted that the addition of titanium and tungsten considerably increased the doped Cu-4Mg alloy samples' tensile strength and hardness values. The doped Cu-4Mg alloys' tensile strength and hardness rose with dopant additions, reaching 60.6% and 43.6% for nickel and 54.7% and 37.1% for molybdenum, respectively. When comparing nickel-doped samples to Cu-4Mg samples doped with molybdenum, it is evident from the tensile strength and hardness values of the doped samples of the Cu-4Mg alloy that the former have much improved mechanical properties.

The doped alloy samples exhibit a downward trend in their impact strength values (Okelekwe et al. 2024). When compared to the tensile strength and hardness values of as-cast Cu-4Mg alloys, the mechanical properties of the heat-treated (400ºC, 450ºC, and 500ºC) samples showed a notable improvement. However, the samples heat-treated at 500ºC demonstrated superior tensile strength and hardness qualities. This may be related to the uniform fine-grained distributions and plate-like coarse-grain precipitation in a section of the copper matrix (Onyia et al. 2024).

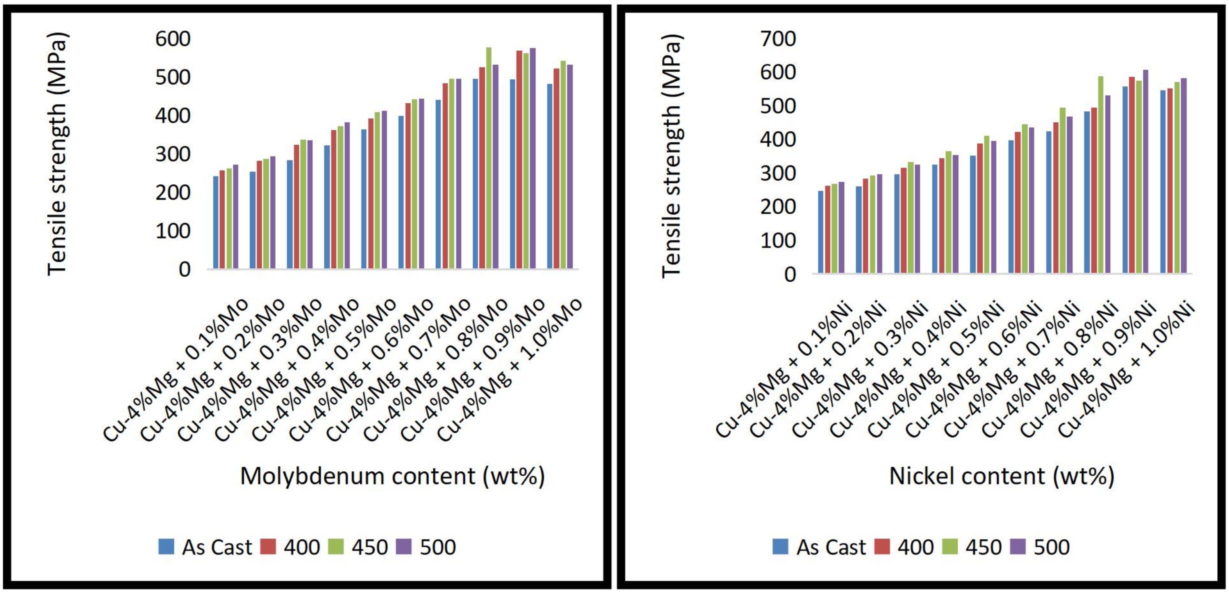

Fig. 5.0: Effect of dopant content on the ultimate tensile strength of Cu-4wt%Mg alloy at different solutionizing temperatures.

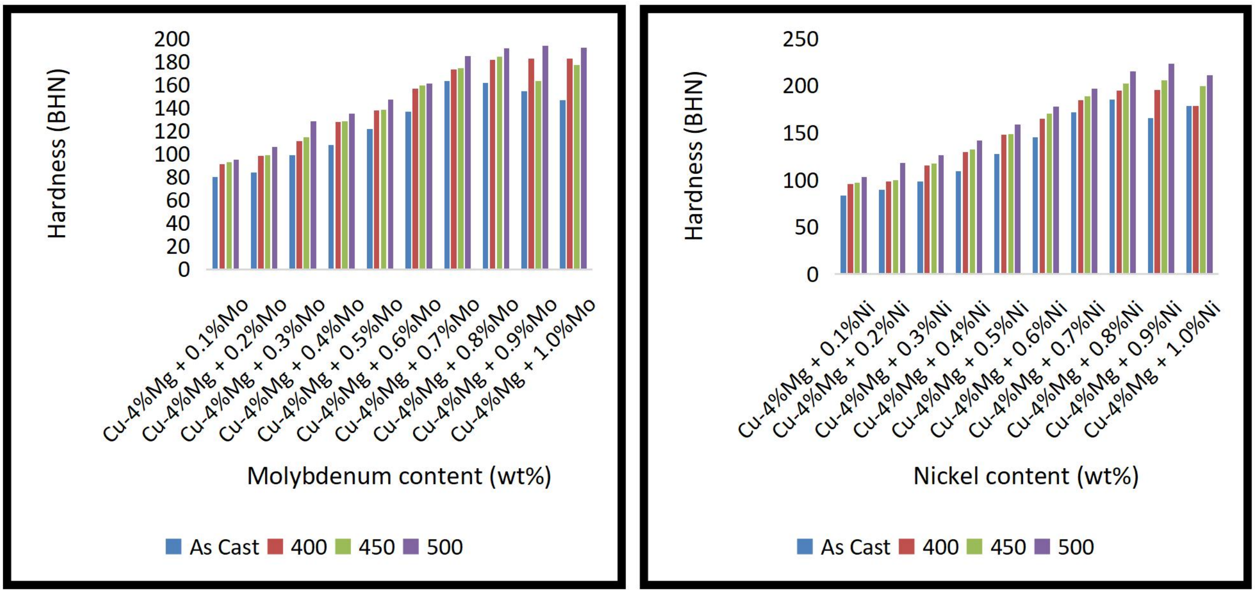

Fig. 6.0: Effect of dopant content on the hardness of Cu-4wt%Mg alloy at different solutionizing temperatures.

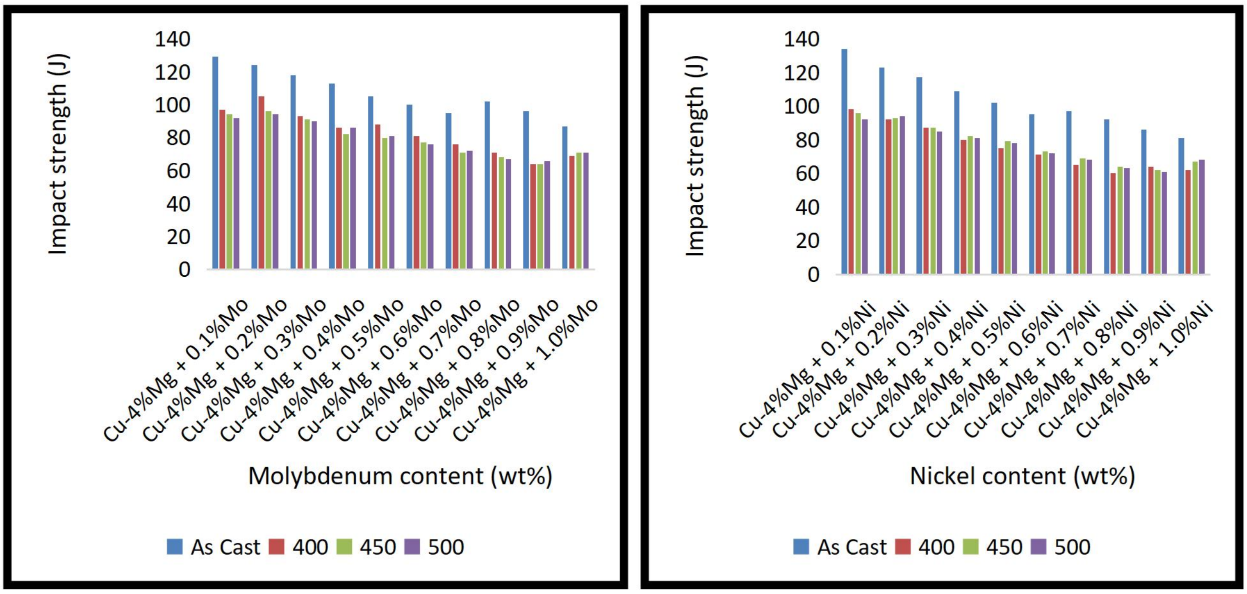

Fig. 7.0: Effect of dopant content on the impact strength of Cu-4wt%Mg alloy at different solutionizing temperatures.

IV. CONCLUSION

It has been experimentally investigated how the homogenization heat treatment affects the mechanical properties and grain features of copper-magnesium alloy. Additionally, the effects of nickel and molybdenum additions on Cu-4wt%Mg alloys' microstructure, tensile strength, impact strength, and hardness were examined. The study's findings showed that adding nickel and molybdenum to Cu-4wt%Mg alloy greatly enhanced its mechanical qualities, with nickel being especially useful in this respect. Nevertheless, the alloy compositions respond differently to homogenization heat treatment; Cu-4wt%Mg exhibits increases in mechanical characteristics whereas grain coarsening causes decreases. To optimize the heat treatment procedures for particular alloy compositions and applications, more investigation could be required.

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