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Unveiling manganese effects on the hardness and electrical resistivity of Cu-20wt%Zn-xMn alloy

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Abstract
This paper focuses on the effects of manganese contents on hardness and electrical resistivity of Cu-20wt%Zn-xMn alloy. Manganese was added in concentrations of (x: 0.1, 0.3, and 0.5wt%). The samples were produced by permanent die casting and machined to the required dimensions for the structural analysis and mechanical tests. Physical and mechanical properties studied were electrical resistivity and Brinell hardness respectively. Standard equipment was used to study the structure and calculate the hardness and electrical resistivity of the developed alloy. The results of the structural analysis showed that the control specimen consisted predominantly of coarse and needle-like α-phase of zinc in copper (Cu_3Zn). The samples doped with manganese consisted of refined dendrites of α-phase with patches of secondary phase. Physical and mechanical tests results indicated that addition of manganese to alpha brass increased the hardness and electrical resistivity respectively. The value increase recorded for electrical resistivity and Brinell hardness were from $0.74 \times 10^7 \Omega m$ to $1.32 \times 10^7 \Omega m$ and 124HB to 150HB respectively.
Keywords: Alpha-brass, Hardness, Structure, Manganese, Electrical resistivity

1.0 Introduction

Brasses are copper base alloys containing zinc as the major alloying element. This brass in most cases contains minor additive elements knowingly or as impurities hence widening the area of application of the alloy. These additives or impurity elements act as refiners (Mn, Fe, Al, Sn, Ti, Be), some of which are insoluble (Pb, S, Zn), and helps in corrosion resistance (Sn, Cr, Al) with other properties like reducing dezincification, shrinkage, cracks and increases fluidity, ductility, workability, wear resistance, and strength (Akhyar et al., 2019; Edward et al., 2017; Imam et al., 2018). While improving the mechanical properties of copper alloys, electrical conductivity which is the most important properties of copper is sacrificed (Nnakwo, 2019; Nnakwo et al., 2019a; Nnakwo et al., 2019b; Nnakwo et al., 2020; Nnakwo et al., 2021; Nnakwo et al., 2022). This property as traded by alloying tailored the applications of copper to where high strengths and impact energy are needed but retained to some extend electrical conductivity (Haruhiko et al., 2011; Nnakwo et al., 2017; Nnakwo and Nnuka, 2018). Some of these alloying elements form solid solubility or intermetallic compounds that alter the structure of brass thereby shifting the proportion of alpha, beta, or gamma phase.

This strengthening effect tends to improve the mechanical properties as it was attributed to reduction in grain size, modulus effects, and to interfacial or surface energy (Khan & Azam, 2015; Rajab & Osama, 2014; Youxiong et al., 2014). Previous research (Imam et al., 2018) showed that adding up to 3.48wt% of Mn to Cu-29Zn alloy consist of refined single α-phase with improved mechanical properties. Similar grain refinement was observed by adding 0.3-2.0wt% Si to Cu-10Zn, 0.5wt%Si to 60Cu-39.5Zn and 0.1wt% Co to Cu-10Zn-1.5Si alloys which resulted to increased strength and hardness with reduction in elongation. On the contrary, it was observed that the addition of 0.5wt% Mn to Cu-39Zn-1.1Pb-0.45Fe and adding Mn up to 5 % to Cu-15Zn increased the elongation (0vat et al., 2012). Addition of 0.05-0.2wt%Zr to Cu-30Zn increased the hardness value from 102HV to 185HV but reduced the wear rate from 12.3 x 10-6 cm3/min. to 5.66 x 10- 6 cm3/min (0.20%wt Zr) (Ali & Nawal, 2018). Other element like Sn, Bi, Ti, Fe showed refined structure and improved mechanical properties with minor addition on high zinc brasses (Moustafa, 2016).

The main objective of this research is to develop a brass alloy of moderate zinc content with improved hardness and electrical resistivity by manganese addition as minor additions of manganese have not been studied on electrical resistivity. The studied brass will be used as material in electrical terminals, automotive coolers, heat exchanger, plugs, lamp fittings, locks, ship forging products, tubes, valves, decorative hardware and architecture.

2.0 Material and methods

The materials utilized in this experimental study included copper wire, zinc granules, and manganese powder, each with a percentage purity of 99.6%, 99.5%, and 99.3%, respectively. The predetermined quantities of these materials were calculated using weight percent calculations and measured with an electronic compact scale. For the control sample (Cu-20wt%Zn), 404g of copper was charged into the preheated bailout crucible furnace and heated until melting was achieved. Subsequently, 105g of pure zinc granules were introduced into the melt and stirred to ensure homogeneity. An additional 4g of copper and 5g of zinc were added to compensate for percentage oxidation losses during heating. The mixture was stirred for 15 seconds to achieve complete dissolution of the zinc metal. The prepared permanent mould was preheated to a temperature of 200oC. The melt was poured into the preheated permanent mould and allowed to cool to ambient temperature. The Cu-20wt%Zn-xMn alloys were developed by repeating the same procedure with manganese additions in concentrations of 0.1, 0.3, and 0.5wt%. The resulting alloys were then stored for machining. Samples for microstructure, electrical resistivity, and hardness were machined to international standards. The surface morphology of the developed Cu-20wt%Zn-xMn alloys was analyzed using an optical metallurgical microscope (OM) and scanning electron microscopy (SEM) after prior grinding, polishing, and etching processes. The hardness value of Cu-20wt%Zn-xMn was recorded from a portable hardness tester while electrical resistivity was evaluated from ohm's experiment using ohm's equation

$$R = V/I \tag{1}$$

$$\rho = RA/L \tag{2}$$

where R is resistance of the specimen to the flow of electricity (Ω), V is voltage passing through the specimen (V), I is current passing through the specimen (A), ρ is resistivity (Ω-m), A is the area of the specimen (m^2), and L is the length of the specimen (m).

3.0 Results and Discussions

Figures 1 and 2 illustrate the variations in hardness and electrical resistivity of Cu–20Zn–xMn with increasing concentrations of manganese. The experimental results indicated that the Cu–20Zn base alloy recorded electrical resistivity and hardness of 0.74 x 10^{-7}Ωm and 124 BHN, respectively. The electrical resistivity and hardness of the developed alloy were increased by 51.4% and 3.2%, respectively after incorporating about 0.1wt% manganese into the Cu–20Zn alloy. This could be attributed to the refining effect of manganese in Cu-Zn binary alloy and formation of hard secondary phase in the alloy structure as evidenced in the OM and SEM images (Fig. 3). The electrical resistivity and hardness of Cu–20Zn–xMn alloy increased from 1.12 x 10^{-7}Ωm to 1.22 x 10^{-7}Ωm and from 128 BHN to 137 BHN, respectively after increasing the manganese concentration from 0.1wt% to 0.3wt%. Figures 3b-e shows clearly that the addition of manganese significantly refined the grain structure of the parent alloy, forming dendrites of the α-phase with an intermetallic compound (Cu_2ZnMn). This refinement and increased solubility of manganese in the copper matrix increased the mean free path of electrons and electron scattering points, leading to an increase in the electrical resistivity of the alloy. Both the electrical resistivity and hardness increased progressively with increasing manganese content reaching maximum values of 1.32 x 10^{7}Ωm and 150 HB, respectively at 0.5wt%Mn addition. The change in morphology, characterized by refined dendrites and the presence of the intermetallic phase increased the grain boundary areas, leading to intense dislocation motion impediment and increase in the hardness of the alloy.

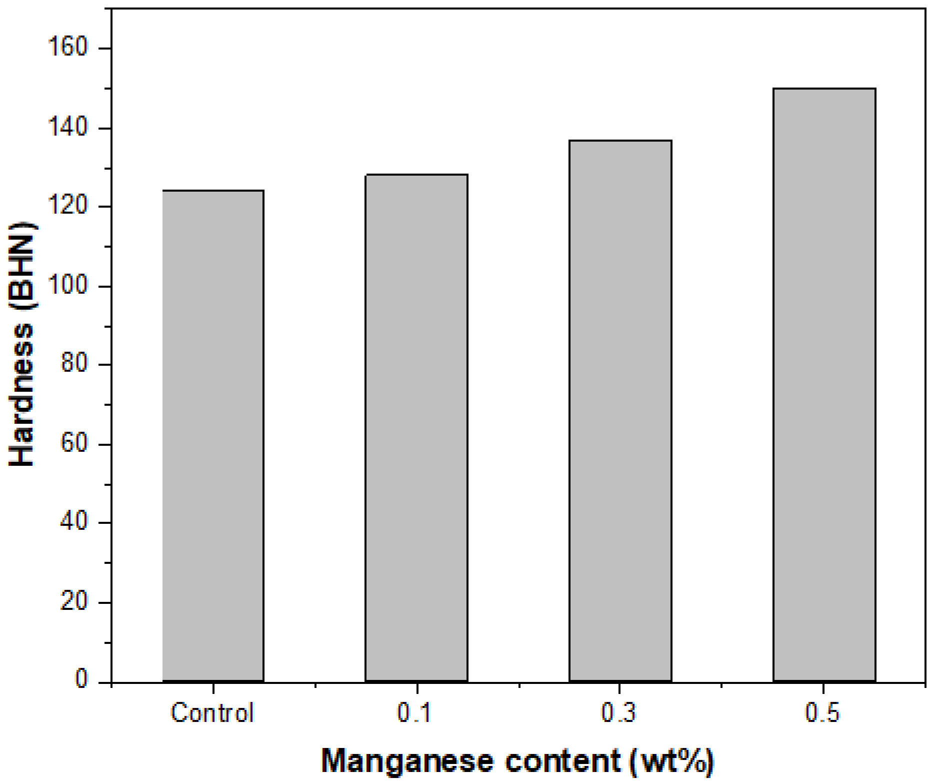

Figure 1: Effect of manganese content on the hardness of Cu-20wt%Zn alloy

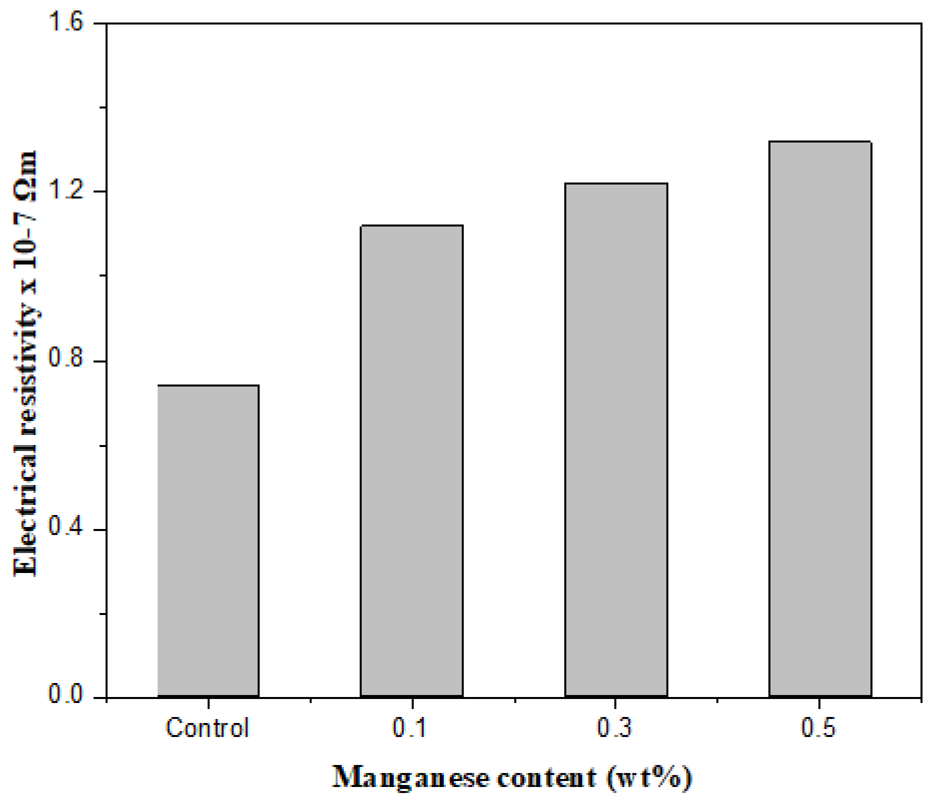

Figure 2: Effect of manganese content on the electrical resistivity of Cu-20wt%Zn alloy

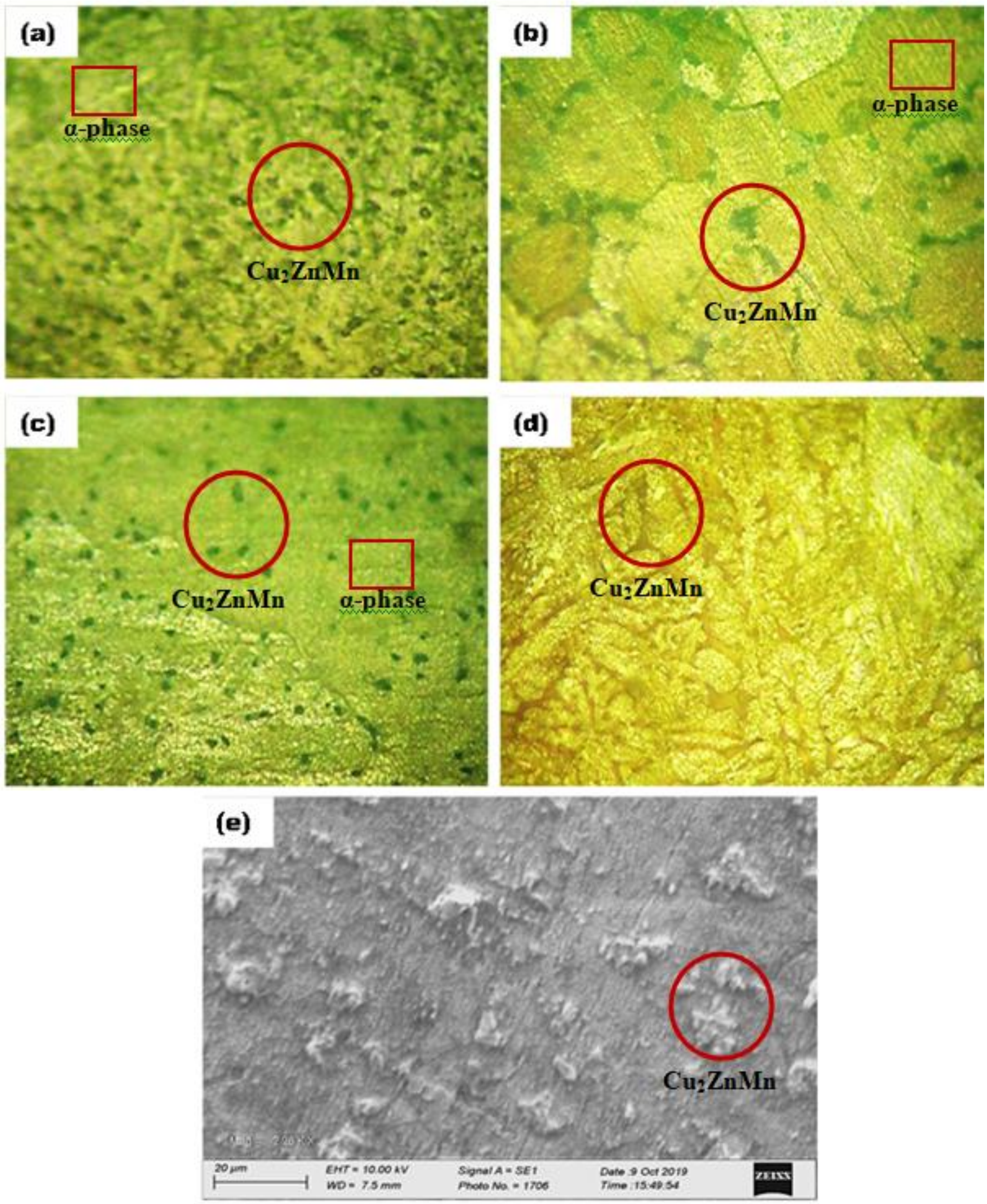

Figure 3: Optical micrograph (a) Cu-20Zn (b) Cu-20Zn-0.1Mn (c) Cu-20Zn-0.3Mn (d) Cu-20Zn-0.5Mn (e) SEM of Cu-20Zn-0.5Mn.

4.0. Conclusion

The effect of manganese content on hardness and electrical resistivity of Cu-20wt%Zn-xMn alloy has been investigated using standard engineering techniques. The following conclusions were drawn from the results of the study.

- The structure of Cu-20wt%Zn alloy showed needle-like α-grains while Cu-20wt%Zn-xMn alloy showed refined and modified dendrites of α-phase with patches of second phase (Cu_2ZnMn) dispersed in the alloy matrix.
- The electrical resistivity of Cu-20wt%Zn-xMn increased with increase in manganese concentration from 0.74 x $10^7\Omega$m to 1.32 x $10^7\Omega$m.
- Brinell hardness increased from 124HB to 150HB at manganese concentration of 0.5wt% which indicated that reduction in grain size influenced hardness.
- The structure and mechanical properties of the studied alloy were sensitive to increase in manganese concentration.

5.0 Recommendation

- Further studies should be carried out on thermo-mechanical processing on the doped Cu-20Zn-xMn.
- Further studies should be carried out to investigate the effects of Equal Channel Angular Pressing (ECAP), severe plastic deformation, and aging heat treatment on the grain characteristics of Cu-20wt%Zn-xMn ternary alloys.

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