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Effect of Zinc Content on the Structure and Mechanical Properties of Silicon Bronze

K. C. Nnakwo, I. U. Okeke and E. E. Nnuka

Department of Metallurgical and Materials Engineering, Nnamdi Azikiwe University, Awka, Nigeria

Corresponding author email address: kingchidiebere@yahoo.com

ABSTRACT

This research investigated the effect of zinc content on the structure and mechanical properties of silicon bronze (Cu-3wt%Si). The dopant was added in concentrations of 0.1, 0.3, 0.5, 0.8, 1 and 1.5wt%. The samples were produced using permanent die casting technique and machined to the required dimensions for the structural analysis and mechanical tests. Mechanical properties such as percentage elongation, ultimate tensile strength and Brinell hardness of the developed alloys were investigated using a 100KN JPL tensile strength tester (Model: 130812) and portable dynamic hardness testing machine (Model: DHT-6) respectively. The structural analysis was conducted using an optical metallurgical microscope (Model: L2003A) and scanning electron microscopy (SEM). Results of the structural analysis revealed that the control specimen consisted of dendrite of primary silicon and coarse intermetallic phase (Cu_3Si). The samples doped with zinc consisted of refined and modified dendritic primary silicon and intermetallic compound respectively. Mechanical tests results indicated that addition of zinc to silicon bronze improved the percentage elongation, ultimate tensile strength and hardness of the alloy significantly. The percentage elongation increased with increase in zinc content up to 1wt%. Further increase in zinc content resulted to decrease in percentage elongation with corresponding increase in hardness. It was observed that the ultimate tensile strength increased with increase in zinc content. This trend in mechanical properties was concluded to be because of the precipitation of β-phase from the α-phase as the zinc content increased to 1.5wt%.

Keywords: Intermetallic phase, primary silicon, hardness, strength, dopant

I. INTRODUCTION

The application of copper-based alloys in chemical, petroleum, automotive and power generating industries has increased significantly because of its combination of excellent properties such as corrosion resistant, ductility, malleability, non-magnetism, wear resistance, machinability; good thermal and electrical conductivities [1]. The quest for high strength engineering materials has led to the addition of other elements in trace amount to pure copper [2]. Study by Zhang et al., [3] has shown that addition of these elements to pure copper will enhance its mechanical properties, hence widens its applications. Silicon bronze is a copper-based alloy containing silicon as the major alloying element usually in the range of 3-5wt%. It is among the most widely used copper-based alloys because of its combination of corrosion resistance, strength, and formability [4]. Silicon bronze is mostly used in production of electrical conduits, valve stems, tie rods, fasteners, marine and pole-line hardware, nuts, bolts, screws, rivets, nails, and wire [5]. Ohkubo et al., [6] reported the existence of six (6) major intermetallic phases in Cu-Si alloy system at both high and room temperature. ε, γ and η'' are the room temperature intermetallic phases while α, β and κ are the high temperature intermetallic phases. Studies [7, 4, 5, 8, 9] have shown that slowly cooled silicon bronze consisted of segregated primary silicon and coarse intermetallic compound (Cu_3Si) in the alloy structure which have detrimental effect on the mechanical properties of the alloy. So, this research was aimed at investigating the effect of zinc content on the structure and mechanical properties of silicon bronze (Cu-3wt%Si).

Study by Mattern et al., [7] on the influence of silicon content and rapid quenching on the phase formation of Cu–Si alloys revealed different meta-stable phases on the quenched samples, which were dependent on the chemical composition. The study revealed the presence of high temperature phases, η, σ and κ in the alloy structure at room temperature. Rapid quenching suppressed the formation of the room temperature phase ε. Ketut et al., [4] investigated the effect of silicon content on the mechanical and acoustical properties of silicon bronze alloys for musical instruments. The results of the study indicated that the mechanical properties and damping capacity of Cu-Si were higher than Cu-20wt%Sn alloy. Puathawee et al., [8] investigated the effect of silicon and tin addition on the microstructure and microhardness of Cu-Si-Zn alloy. The study established that the hardness of 60Cu-0.5Si-39.5Zn alloy was 123.4 Hv. The hardness of the alloy increased with increase in silicon content. Moreover, the addition of tin together with silicon increased the amount of beta (β) phase and uniform dispersive gamma (γ) phase. Božića et al., [9] revealed in the study of the microstructure and micro-hardness of Cu-Ti and Cu-Ti-Si alloys the presence of fine, dispersed primary $TiSi_2$ particles and high super saturated solid solution in the rapidly solidified Cu-1.2Ti-3$TiSi_2$ powder. The microstructure of the studied alloys was not completely homogenous but rather exhibited the presence of homogenous fluctuations in the range of 5-10µm. Maximum hardness was obtained by Cu-1.2Ti-3$TiSi_2$ powder, owing to the primary $TiSi_2$ dispersoides formed during atomization. The study revealed that high strengthening of the Cu-Ti-$TiSi_2$ powder by ageing treatment was because of the simultaneous influence of the following factors: The development of the nodular structure, precipitation of metastable Cu_4Ti and the presence of primary $TiSi_2$ dispersed phase particles.

II. MATERIALS AND METHOD

The copper and silicon used as the base materials for this research were 99.99 and 99.98% pure respectively. The dopant was added in concentrations of 0.1, 0.3, 0.5, 0.8, 1 and 1.5wt%. Permanent die casting technique was adopted for producing the alloys samples used for this research. The required amount of pure copper wire was melted in a bailout crucible furnace and the predetermined amount of silicon powder wrapped in an aluminium foil was added to the melt and stirred vigorously to ensure homogeneity. The mixture was superheated and the control sample was cast. The remaining melt was doped with different concentrations of zinc and cast. The cast samples were machined to the required dimension and stored for the mechanical tests.

III. RESULTS AND DISCUSSION

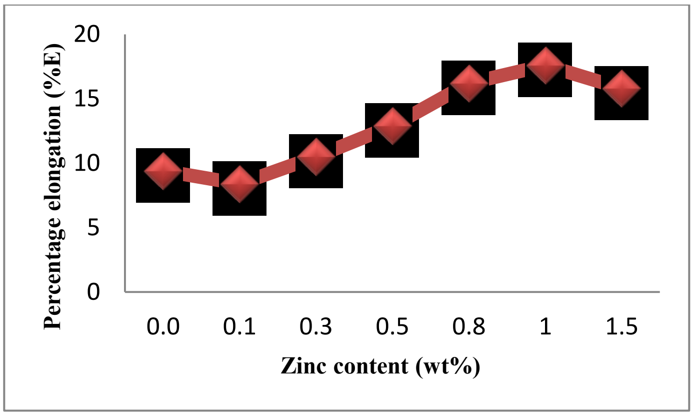

Figure 1: Effect of zinc content on the percentage elongation of silicon bronze

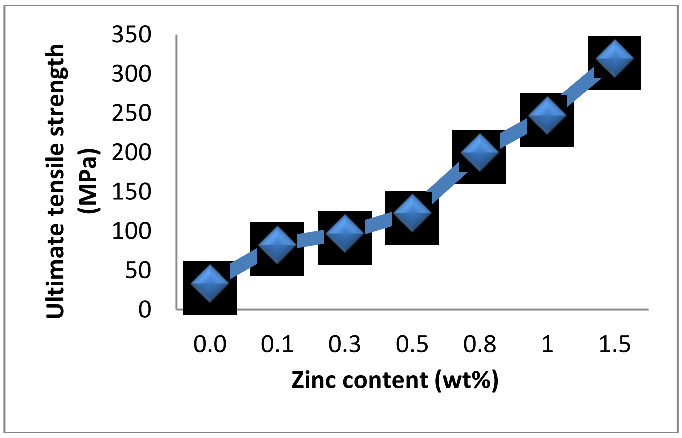

Figure 2: Effect of zinc content on the ultimate tensile strength of silicon bronze

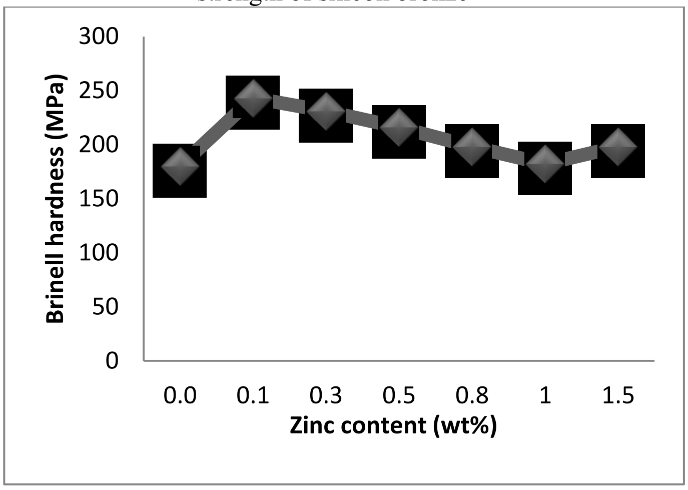

Figure 3: Effect of zinc content on the hardness of silicon bronze

Figures 1-3 show the effect of zinc contents on the percentage elongation, ultimate tensile strength and hardness of silicon bronze. Analysis of Figures 1-3 shows clearly that addition of zinc to Cu-3wt%Si alloy increased the percentage elongation, ultimate tensile strength and hardness of the alloy significantly. Figure 1 showed that the percentage elongation of Cu-3%wtSi-Zn alloy increased with increase in zinc content up to 1wt%. Further increase in zinc content resulted to decrease in percentage elongation. It was also observed in Figure 3 that the hardness of the alloy decreased with increase in zinc content up to 1wt%, after which it began to increase. This was attributed to the precipitation of β-phase in the alloy structure as evidenced in Figure 11. Different trend was observed in the ultimate tensile strength as it increased spontaneously with increase in zinc content. This was because of the presence of coherent α-β phase evenly distributed in the alloy structure.

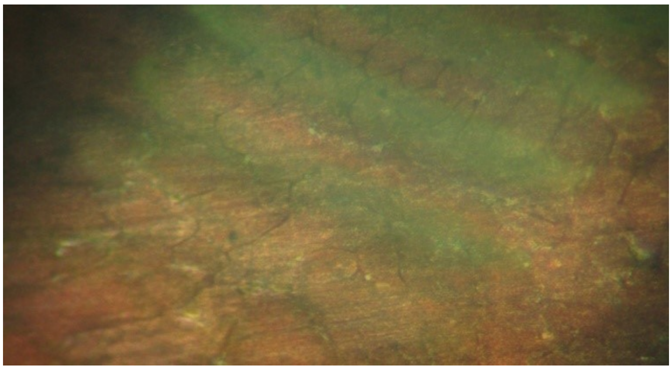

Figure 4: Micrograph of Cu-3wt%Si alloy

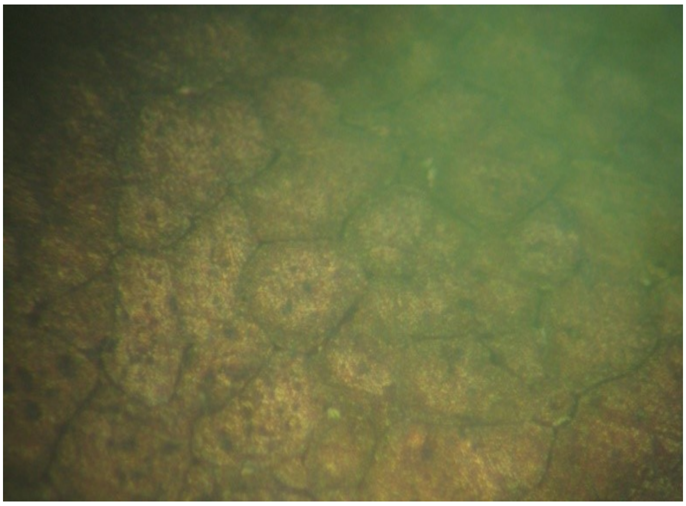

Figure 5. Micrograph of Cu-3wt%Si-0.1wt%Zn alloy

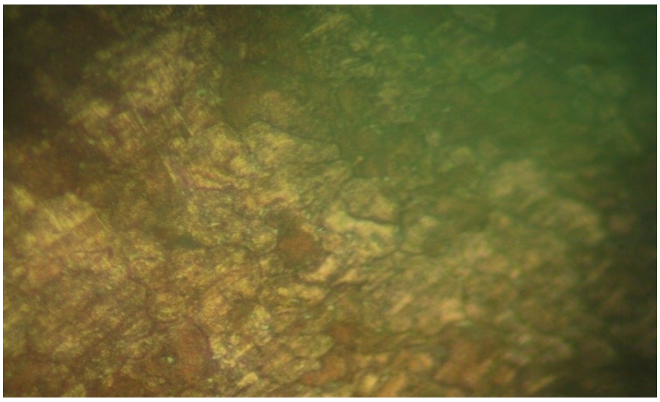

Figure 6. Micrograph of Cu-3wt%Si-0.5wt%Zn alloy

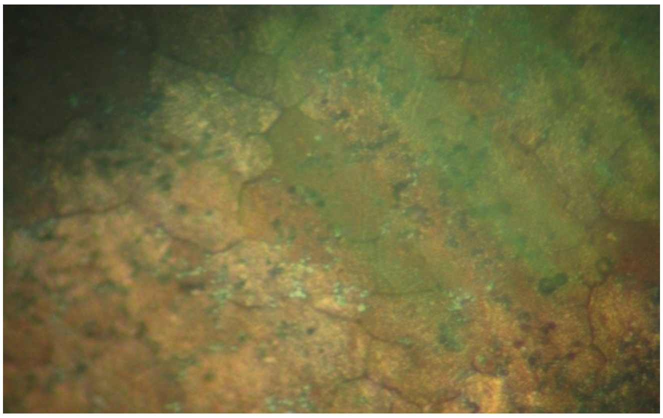

Figure 7. Micrograph of Cu-3wt%Si-1wt%Zn alloy

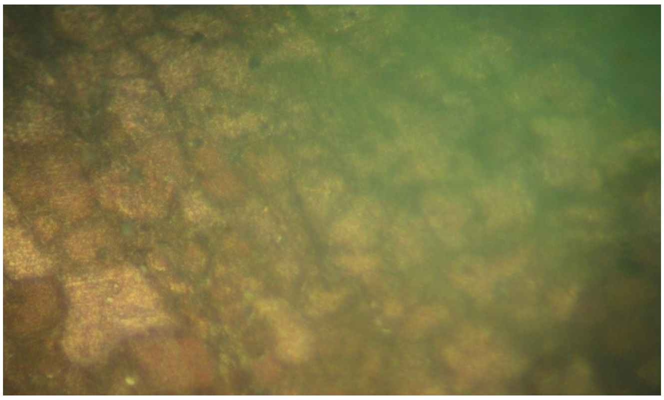

Figure 8. Micrograph of Cu-3wt%Si-1.5wt%Zn alloy

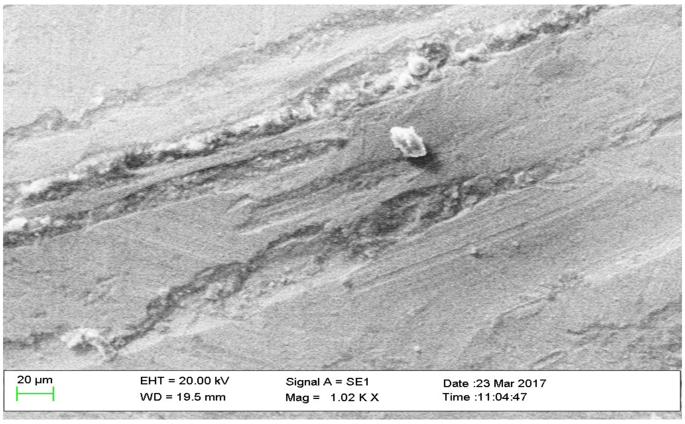

Figure 9: Micrograph (SEM) of Cu-3wt%Si alloy

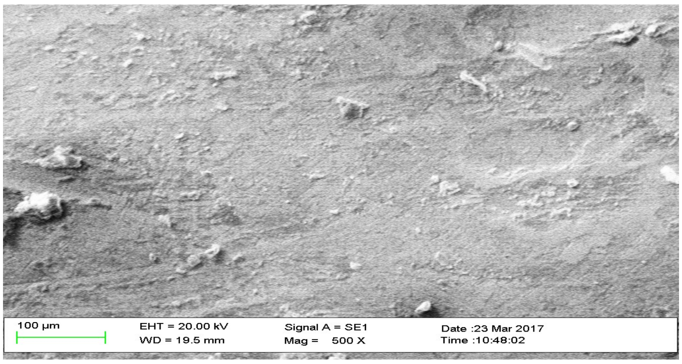

Figure 10: Micrograph (SEM) of Cu-3wt%Si-1wt%Zn alloy

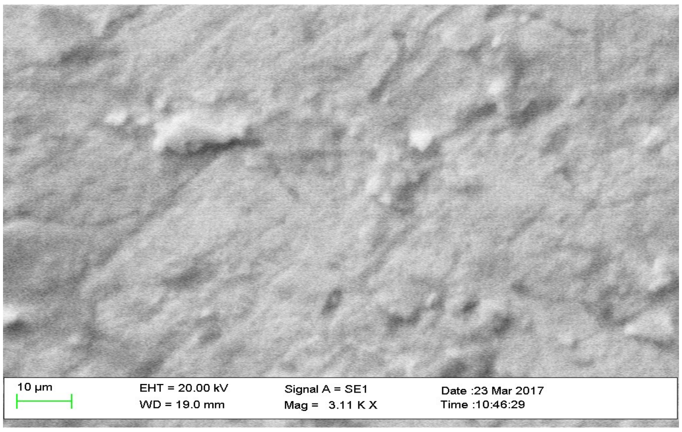

Figure 11: Micrograph (SEM) of Cu-3wt%Si-1.5wt%Zn alloy

The optical and scanning electron microscopy analyses of Cu-3wt%Si are presented in Figures 4 and 9 respectively. A detailed analysis of the surface morphology revealed the presence of segregated primary silicon and coarse Cu_3Si intermetallic phase. Figures 5-8 and 10-11 show the structural analysis of silicon bronze doped with zinc of different concentrations. The micrographs revealed the presence of α-copper solid solution containing silicon and zinc. Analysis of Figures 5-8 and 10-11 showed clearly that addition of zinc slightly decreased the size of the dendritic primary silicon and hence resulted to increased percentage elongation, ultimate tensile strength and hardness of the alloy. The volume of the α-phase increased with increase in zinc concentration up to 1% by weight. At 1.5wt% zinc addition, the β-phase precipitated out of the α-phase and hence caused a systematic increase in hardness and ultimate tensile strength with corresponding decrease in percentage elongation.

IV. CONCLUSION

The effect of zinc on the structure and mechanical properties of silicon bronze was investigated using standard techniques. From the results of the analysis, the following conclusions were drawn:

1. The presence of dendritic primary silicon in Cu-Si alloy system contributed to its moderate ultimate tensile strength and hardness with corresponding very low percentage elongation.
2. The significant improvement in the percentage elongation, ultimate tensile strength and hardness of the doped silicon bronze was attributed to the decrease in size, refinement and modification of the dendritic primary silicon in the alloy structure.
3. The decrease in percentage elongation of Cu-3wt%Si-Zn alloy at 1.5wt% zinc addition was attributed to the presence of α-β phase in the alloy structure.
4. The increased hardness observed in Cu-3wt%Si-Zn alloy at 1.5wt% zinc content was attributed to the precipitation of β phase from the α-phase in the alloy structure.

V. ACKNOWLEDGEMENT

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