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Effect of trace additions of iron on grain characteristics, and mechanical properties of Tin Bronze

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Abstract
The study investigated the effects of trace additions of iron on grain characteristics, electrical conductivity, and mechanical properties of tin bronze. The experimental alloys were produced with chromium 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. Hardness, tensile, and impact strength tests were performed on the cast samples. Microstructures of the specimens were also analyzed using optical microscopy. Scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) were used to characterize the cast specimens. The results indicated that iron to Cu-10wt%Sn alloy refined and modified the alloy's structure, improving the experimental alloy's tensile strength and hardness by 43.6%, and 37.1% respectively at 0.8wt% Fe content. The addition of iron led to the formation of the intermetallic phase which further contributed to the increase in tensile strength and hardness of the alloy.

Keywords: Copper, tin, iron, mechanical properties, scanning electron microscope

Introduction

Alloys of copper form an important group of materials with a wide variety of properties (Onyia *et al*., 2024) [19]. High copper alloys contain small amounts of various alloying elements such as beryllium, chromium, zirconium, tin, silver, sulfur or iron. These elements modify one or more of the basic properties of copper such as strength, creep resistance, machinability or weldability. Alloying elements also change the colour of copper from the reddish-blue to rusty-gold of bronze (Nwambu *et al*., 2017) [18]. Copper base alloys have unique compatibility with steel journal materials together with good bearing strength. Some bronzes perform well under boundary lubrication conditions (Caron, 2001) [13]. Copper alloys possess greater strength and hardness along with increased ductility as compared to copper. The increased ductility helps in the easy production of different shapes by cold forming methods such as deep drawn tubes, cartridge-cases. The corrosion resistance of copper alloys is better than that of pure copper (William, 2010) [12].

No protective treatments against corrosion are necessary with copper alloys. Slow tarnishing occurs in moist air but this is superficial (Okelekwe *et al* 2024) [5]. Copper alloys are recommended for sea water applications because of the better resistance to pitting attack than stainless steels (Kulcyk *et al*. 2012) [14]. Journal and other solid bearings, worm wheels, automobile gear selector forks and many other components where low friction and good wear resistance are required are commonly made from copper alloy castings (Stanislov *et al*., 2009) [10]. Copper and copper alloys can be chosen to give an optimum combination of strength in tension and compression, hardness, ductility and resistance to impact to suit most applications. Strengths equivalent to stainless steels are available at lower cost and, in many applications, improved corrosion resistance. Properties of copper alloys at elevated temperatures are significantly better than those of other non-ferrous metals (Nwambu *et al*. 2024; Onyia *et al*. 2024) [2, 3, 4, 5, 7, 8, 19].

Copper base alloys have been popular because of their unique compatibility with steel journal materials together with good bearing strength (Mao *et al*., 2007) [9]. Bronzes, in particular, perform well under boundary lubrication conditions. Bronzes are unquestionably the most versatile class of bearing materials, offering a broad range of properties from a wide selection of alloys and compositions (Okelekwe *et al*. 2024) [5]. Bearing bronzes offer broad ranges of strength, ductility, hardness, wear resistance, anti-seizing properties, low friction, and the ability to conform to irregularities, and tolerate dirty operating environments and contaminated lubricants (Mao *et al.*, 2007) [9]. Bearing material selection is an inevitable compromise between tribological bearing properties requiring soft materials, and mechanical strength requiring hard materials. By selecting appropriate constituents and using various alloying techniques, a wide range of materials with different properties can be realized (Stanislov *et al.*, 2009) [10].

Modern engineering materials must carry high loads and simultaneously be highly reliable. Materials of choice have excellent strength and hardness, good ductility, high toughness, and excellent wear resistance (Nwambu *et al* 2017; Shankar *et al.* 2017; Watanabe *et al.* 2015) [18, 15, 16]. Cast Cu-10%Sn alloy has the basic structure which consists of cored dendrites of α + (α+ δ) eutectoid. The δ ($Cu_{31}Sn_8$) - phase is hard and brittle, decreasing the alloy's strength and ductility (Onyia *et al.* 2023; Zhao *et al.* 2017) [20, 17]. Microstructural variation in the high-strength tin bronze alloys exists over a range of levels. At the atomic and nanoscopic levels, the microstructure significantly affects an alloy's mechanical properties. The microstructure involves defect structures, hardening precipitates, and dispersed particles (Mao 2007; Stanislov, 2009) [9, 10]. It was noted that the tin bronze components failed after a longer length of use, possibly between 5000 hours. To ensure the expected service life, it has been suggested that additional alloying elements be added at specific percentage compositions. This research will look into this recommendation. The effect of iron addition on the mechanical characteristics and structure of tin bronze will be reported in this paper.

2. Materials and Methods

The base alloy for this study was produced from commercial pure copper (99.99%) and commercial pure tin (99.98%). The doped tin bronze was produced by the addition of iron 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 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 pre-determined amount of iron in powder form wrapped in aluminum foil was plunged into the molten copper and stirred. The melt was held for about 10 minutes to ensure complete dissolution of iron in the copper melt and stirred again to achieve homogeneity before pouring into preheated permanent mould and being allowed to cool to ambient temperature. Subsequently, the Cu-10wt%Sn alloys with the additives were produced by repeating the above-described procedure and introducing the different concentrations of iron (Nwambu *et al.* 2024; Ezeobi *et al.* 2024) [2, 3, 4, 5, 7, 8, 19, 8].

A tensile test was carried out on the cast specimens using a Universal Testing Machine (model WDW-10) according to ASTM E8/E8M-22 standard to determine the ultimate tensile strength and % elongation. Hardness test was carried out on 10 mm x 10 mm long cylindrical 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). 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 1200 μm). 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, 30cm^3 of hydrochloric acid, and 120cm^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)/energy dispersive spectroscopy (EDS) of the experimental alloys were carried out on the samples using a TESCAN scanning electron microscope, model number (VEGA III LMH).

3. Results and Discussion

3.1 Optical, scanning electron microscopy (SEM) and electron dispersive spectroscopy (EDS) analyses tin bronze

Figures 1.0-3.0 represent the micrographs of Cu-10wt%Sn alloy doped with alloying element (iron). This was analyzed using an optical metallurgical microscope (model: L2003A) at magnification of x 400. Figure 1.0 (a) represents the microstructure of tin bronze (Cu-10%Sn) in an as-cast condition. It indicates that the microstructure of the as-cast specimen comprise of the eutectic α-solid solution (the region where tin formed a solid solution with the copper matrix) and the intermetallic compound (Cu_3Sn) precipitates. It showed that the structure consists of coarse intermetallic compounds Cu_3Sn and $Cu_{31}Sn_8$ precipitated around dendrites of copper matrix. Figures 1.0(a)-3.0(b) show development of homogenized microstructures and disappearance of coarse intermetallic compound formed in as-cast structure. Addition of iron produced much finer grain structure, when compared with the alloy structure in as-cast condition. The equiaxed dendritic and finer grain structure observed suggests that addition of iron may increase the nucleation sites of the copper matrix during solidification (Anyafulu *et al.* 2024; Iyebeye *et al.* 2024) [7, 2, 3, 4, 6]. Large spherical grains were observed as the composition of iron increased (Figure 3b). Figures 4 to 5 show the scanning electron microcopy and EDS analysis of the alloys doped with iron. Figure 4.0 indicated uniform distribution of the intermetallic compounds of different morphology in the alloy structure. Figure 5.0 indicate the presence of six major elements which include Cu, Sn, O, C, Br and Cl etc.

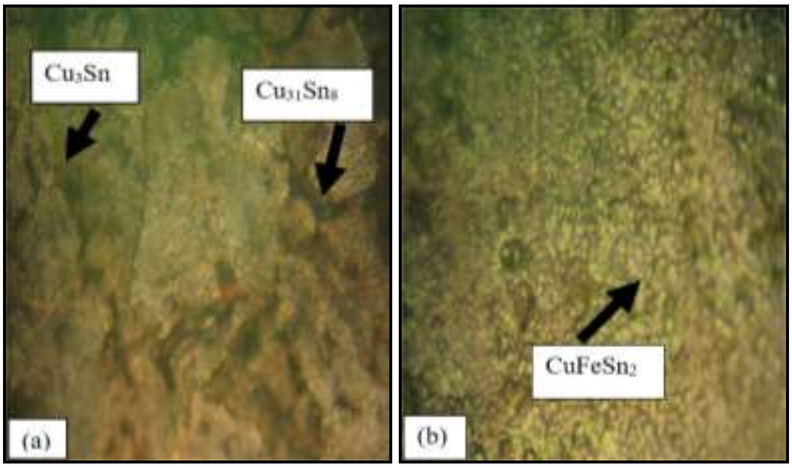

Fig 1: Micrograph of Cu-10wt%Sn alloy (Control) and Cu-10%Sn-0.2%Fe alloy

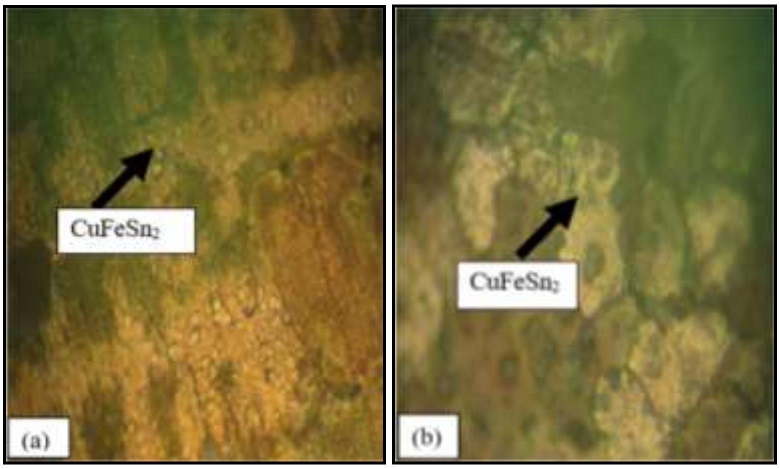

Fig 2: Micrograph of Cu-10%Sn-0.4%Fe alloy and Cu-10%Sn-0.6%Fe alloy

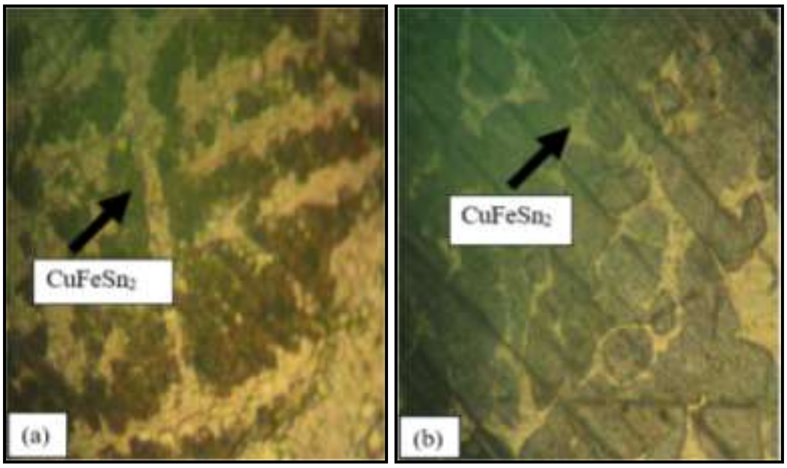

Fig 3: Micrograph of Cu-10%Sn-0.8%Fe alloy and Cu-10%Sn-1%Fe alloy

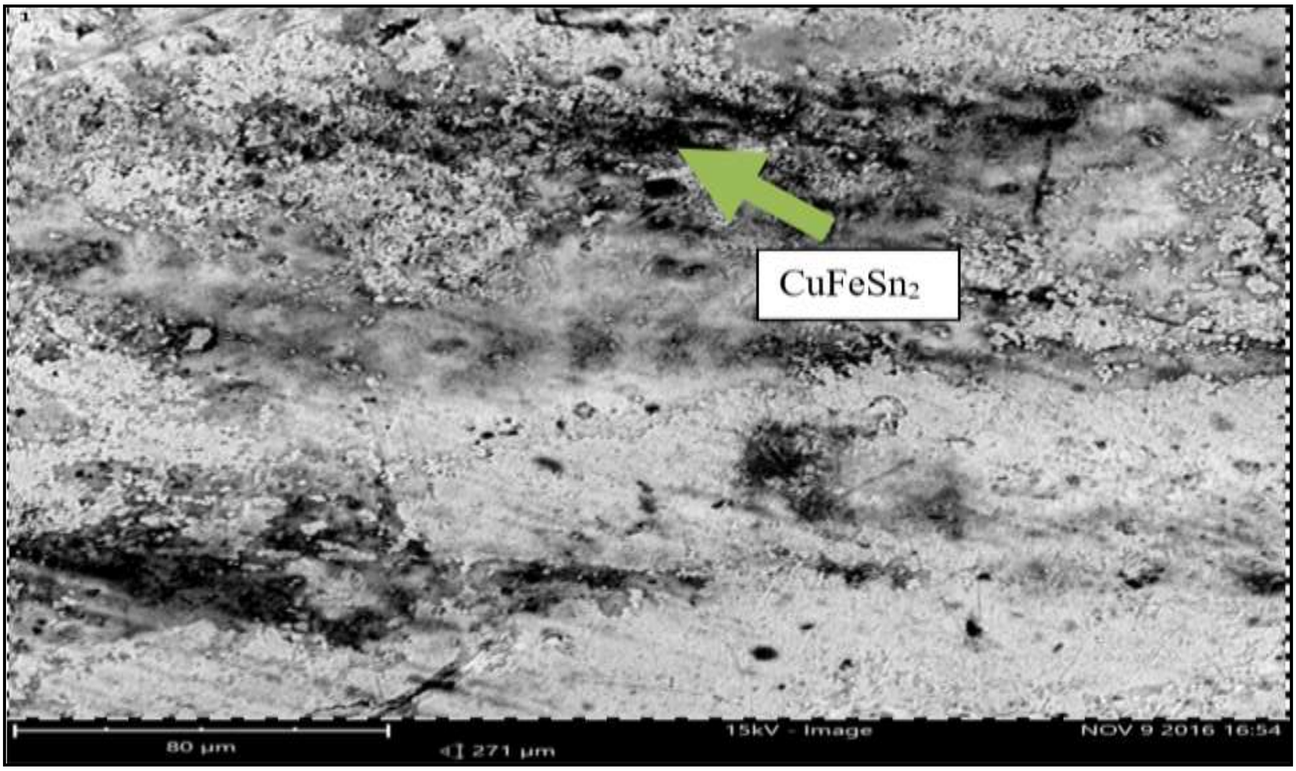

Fig 4: Micrograph (SEM) of Cu-10%Sn-0.8%Fe alloy.

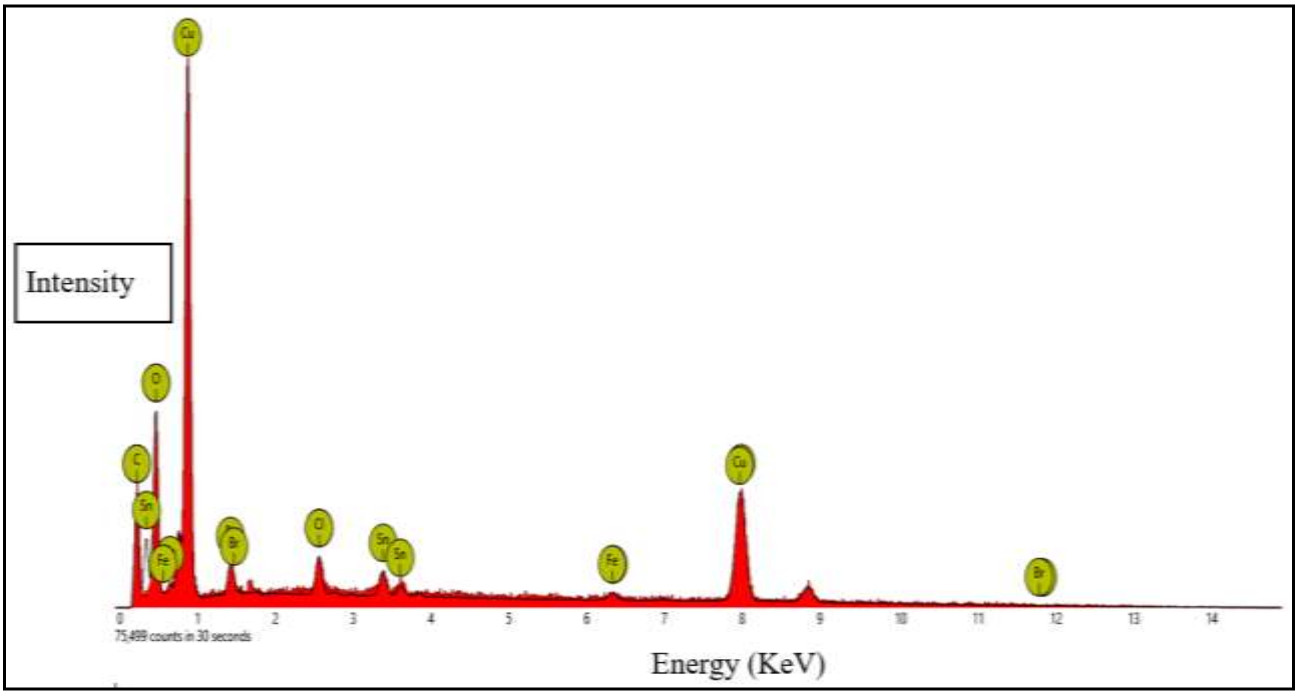

Fig 5: EDS spectrum of Cu-10%Sn-0.8%Fe alloy.

3.2 Mechanical properties and conductivity of Cu-10wt%Sn alloy

Figures 6-8 show the effect of iron addition on the mechanical properties: –tensile strength, hardness, and impact strength of the alloy. It is observed from the Figures that the ultimate tensile strength and hardness increased with increasing concentration of iron up to 0.8% before decreasing with further increase in concentration of the additive. The addition of 0.8wt% Fe to Cu-10wt%Sn alloy resulted to improvement in the ultimate tensile strength and hardness of the experimental alloy by 43.6%, and 37.1% respectively. Maximum ultimate tensile strength and hardness values obtained were 262MPa, and 238 HRB at 0.8wt%Fe content respectively. The addition of 0.1wt%Fe to Cu-10wt%Sn resulted in improvement in the impact strength of the alloy by 65.34% respectively. The decrease in the strength and hardness of the alloys at high iron concentrations was attributed to coarsening of the grains (Nwambu *et al*. 2024; Okelekwe *et al*. 2024) [2, 3, 4, 5, 7, 8, 19, 5]. The improvement in the strength and hardness of the alloys was attributed to the presence of refined and modified intermetallic phases in the structure of the alloys (Osakwe *et al*. 2024) [2, 3, 4, 5, 7, 8, 19].

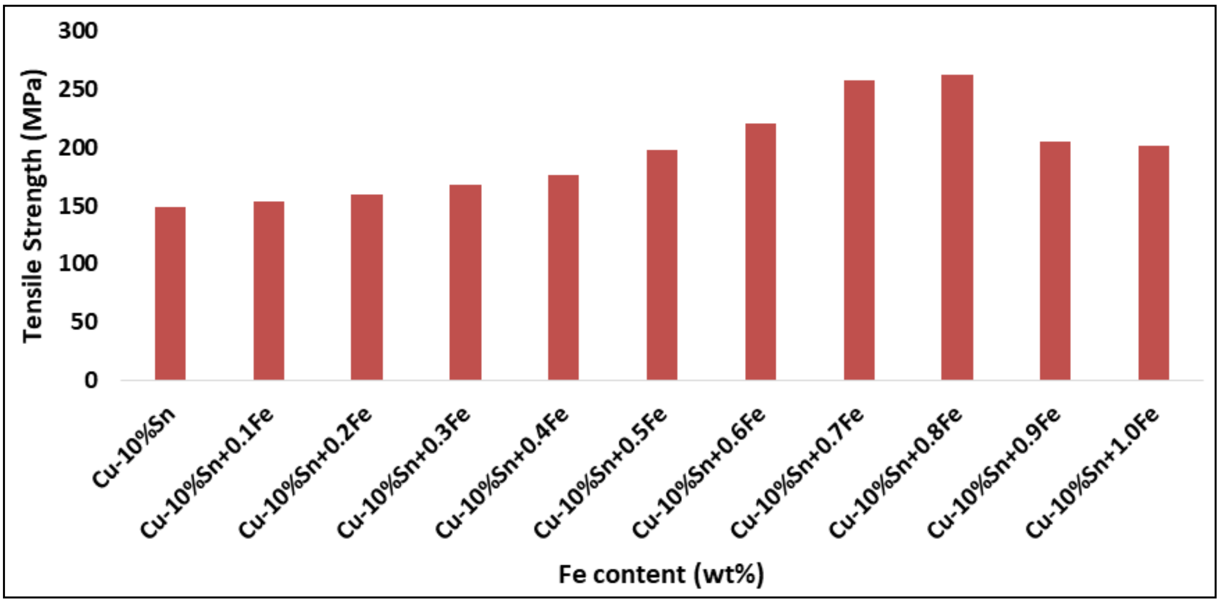

Fig 6: Effect of iron content on the ultimate tensile strength of Cu-10wt%Sn alloy.

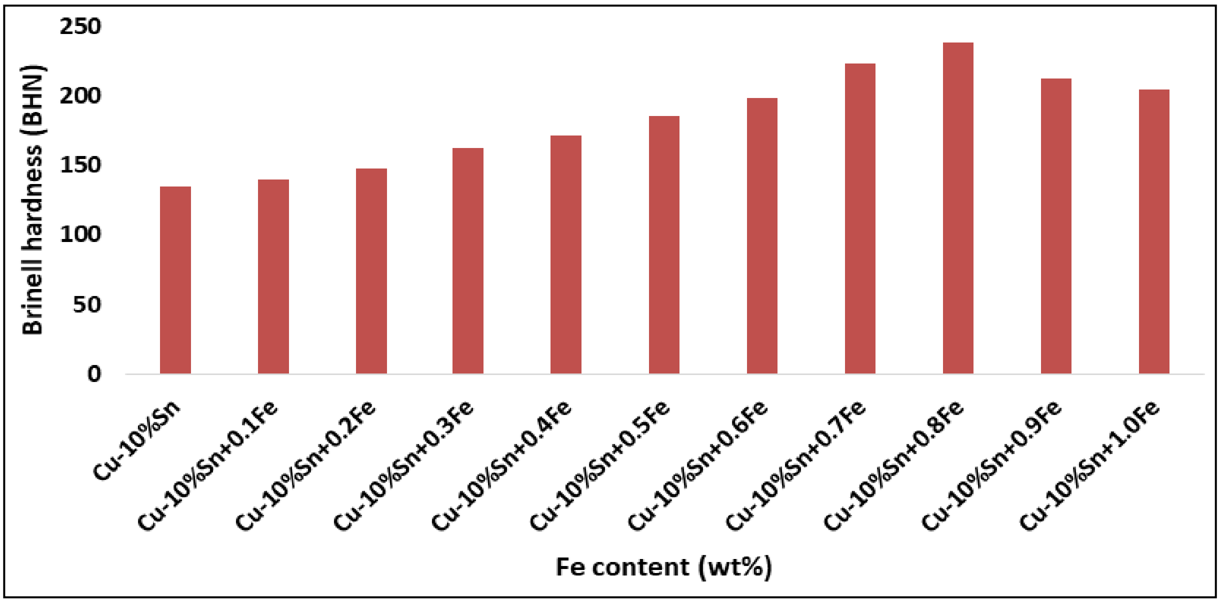

Fig 7: Effect of iron content on the hardness of Cu-10wt%Sn alloy.

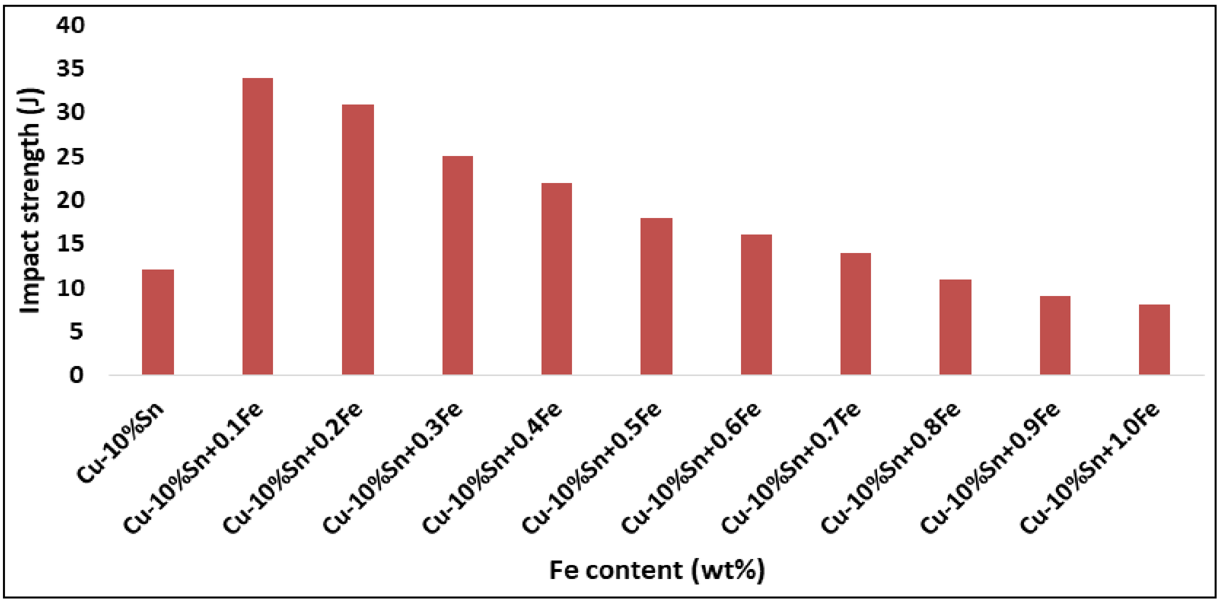

Fig 8: Effect of iron content on the impact strength of Cu-10wt%Sn alloy.

4. Conclusions

The effect of iron content on the structure, and mechanical properties of Cu-10wt%Sn alloy has been investigated. The following conclusions can be made from the experimental results and theoretical analysis:

- The mechanical properties of Cu-Sn-x alloy are dependent on the concentration of the alloying elements and the structure of the developed alloy.
- The deoxidizing and grains refining effect of iron led to the optimum impact energy observed in the alloy doped with iron.
- The increased tensile strength and hardness noted in the doped alloy were due to simultaneous formation of intermetallic compounds and a decrease in grain size and dendritic structure.

5. References

1. Avner SH. Introduction to Physical Metallurgy. 2nd ed. New York: McGraw-Hill Book Company; c1974.
2. Iyebeye KO, Nwambu CN, Nnuka EE. Investigating the effects of Lanthanum and Tin additions on the structure and physic-mechanical properties of Cu-30% Zn Alloy. UNIZIK Journal of Engineering and Applied Sciences. 2024;3(2):735-755.
3. Nwambu CN, Ekwedigwe CM, Iyebeye KO, Osakwe FO. Mechanical Behaviors of Copper-Aluminium-Titanium Alloy. UNIZIK Journal of Engineering and Applied Sciences. 2024;3(2):685-690.
4. Nwambu CN, Iyebeye KO, Ekwedigwe CM, Osakwe FO. Effect of Dopants Particulates on the Structure and Mechanical Properties of Copper-12wt% Aluminium Alloy. UNIZIK Journal of Engineering and Applied Sciences. 2024;3(2):675-684.
5. Okelekwe NM, Nwambu CN, Nnuka EE. Influence of chromium addition on the microstructural and mechanical properties of copper-magnesium alloys. UNIZIK Journal of Engineering and Applied Sciences. 2024;3(2):699-708.
6. Osakwe FO, Ekwedigwe CM, Iyebeye KO. Structure and Mechanical Properties of Doped Cu 10wt%Sn Alloy. Advance Journal of Science, Engineering and Technology. 2024;9(9):63-74.
7. Anyafulu UV, Ekwedigwe CM, Nwambu CN, Nnuka EE. Effect of Bismuth and Lead on the Mechanical Properties of Aluminium-4% Copper Alloy. UNIZIK Journal of Engineering and Applied Sciences. 2024;3(2):691-698.
8. Ezeobi UE, Nwambu CN, Nnuka EE. Influence of heat treatment parameters on mechanical properties and microstructure of Cu-10wt% Si-2wt% Ni alloy. UNIZIK Journal of Engineering and Applied Sciences. 2024;3(2):666-674.
9. Mao T, Bian X, Xue X, Zhang Y, Guo J, Sun B. Correlation between viscosity of molten Cu–Sn alloys and phase diagram. Physica B. 2007;387:1-5.
10. Stanislov SN, Irina BM, Oleg DN. Handbook of Non-Ferrous Metal Powders. 2009:331-68.
11. Vijendra S. Physical Metallurgy. Delhi: Standard Publishers Distributors; c2010.
12. William DNJ. Metallurgy of Copper Based Alloys. Copper Development Association, Inc.; 2010:1-3.
13. Caron RN. Copper: Alloying. In: Encyclopedia of Materials: Science and Technology. 2nd ed. Elsevier; c2001. p. 1652-1660.
14. Kulczyk M, Skiba J, Przybysz S, Pachla W, Bazarnik P, Lewandowska M. High strength silicon bronze (C65500) obtained by hydrostatic extrusion. Archives of Metallurgy and Materials. 2012;57(3):859-862.
15. Shankar KV, Sellamuthu R. Determination on the effect of tin content on microstructure, hardness, optimum aging temperature and aging time for spinodal bronze alloys cast in metal mold. International Journal of Metalcasting. 2017;11(2):189-194.
16. Watanabe C, Takeshita S, Monzen R. Effects of small addition of Ti on strength and microstructure of a Cu-Ni-Si alloy. Metallurgical and Materials Transactions A. 2015;46(6):2469-2475.
17. Zhao C, Zhang W, Wang Z, Li D, Luo Z, Yang C, Zhang D. Improving the mechanical properties of Cu-15Ni-8Sn alloys by addition of titanium. Materials. 2017;10(9):1038. doi:10.3390/ma10091038.
18. Nwambu CN, Anyaeche IM, Tsetim TT, Nnuka EE. Physical and mechanical characterization of aluminum bronze (Cu-10% Al) alloy with tungsten. International Journal of Scientific & Engineering Research. 2017;8(1).
19. Onyia CW, Nnuka EE, Nwambu CN. Influence of chromium on the structure and physic-mechanical properties of Cu-3wt% Si alloys. UNIZIK Journal of Engineering and Applied Sciences. 2024;3(1):400-408.
20. Onyia CW, Nnuka EE, Nwambu CN, Ekwedigwe CM. Effect of Titanium Content on the Structure, Electrical Conductivity and Mechanical Properties of Cu-3wt% Si Alloys. Open Access Library Journal. 2023;10(12):1-14.