

Investigation of the effect of magnesium micro-addition on the structure and mechanical properties of tin-bronze (Cu-10%Sn) alloy

Osakwe FO, Nwaeju CC, Nnuka EE

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

Abstract

This research work investigated the effect of magnesium micro-addition on the structure and mechanical properties of tin bronze (Cu-10%Sn alloy). The properties studied were tensile strength, percentage elongation using universal tensile machine (130812), impact strength using charpy machine (U1820) and hardness using Brinell hardness tester model B 3000(H). The specimens were prepared by doping 0.2 -1.0wt% of Mg into Cu-10%Sn alloy at interval of 0.2 percent. The specimens were prepared according to BS 131-240 standards. Microstructural analysis was carried out using optical metallurgical microscope (L2003A) and scanning electron microscope (LEGALMU 11). Results obtained revealed that tensile strength and hardness of the alloy increased with increase of magnesium content up to 1wt% respectively. Impact strength and percentage elongation on the other hand, decreased with increase in magnesium content. Microstructural analysis revealed α -Cu rich phase dendrites surrounded by intermetallic compound (δ -phase). δ -phase ($\text{Cu}_{31}\text{Sn}_8$) particles formed in the interdendritic region of Cu-10%Sn-Mg alloys. The Cu-10%Sn alloy doped with micro-quantity of Mg proved to increase the hardness and tensile strength, while its ductility and impact strength were reduced and it is therefore recommended for low speed engineering applications such as rolling-mill bearing and internal combustion engines.

Keywords: microstructure, magnesium, micro-additives, mechanical properties, tin bronze

1. Introduction

Tin bronze is a type of bronze in which tin is the main alloying element added to copper. The useful range of composition is from 75 to 95%Cu and 5 to 25%Sn^[1]. Tin bronzes (Cu-Sn alloys) are comparatively hard, resist surface wear and can be cast into shapes or rolled into wires, rods and sheets very easily^[2]. The corrosion resistance of this bronze is superior to that of brass. However, tin bronzes are more expensive than the brasses and so are used only when the cheaper alloys do not suffice^[1, 2].

Cu-Sn alloys are used in high-load, low speed applications such as trunion bearings, gear bushing for road vehicles, rolling-mill bearing and internal combustion engines used for connecting rod bearing, valve guide and starters. They are also used extensively for the stressed parts of turbines, compressors, for armatures and for pumps runners' production^[1, 3, 4]. Despite these desirable characteristics, difference in mechanical properties among the tin bronzes is not great. Some contain zinc as a strengthener in partial replacement for more expensive tin. The need to overcome these obvious performance limitations is imperative to meet today's emerging technologies. The choice of method is however usually determined by cost and effectiveness. The mechanical properties of tin bronze depend on the extent to which tin and other alloying elements modify the structure. According to Nnuka (1991 and 1994), presence of alloying element in micro-quantity promotes the formation of insoluble particles which subsequently can restrict or pin dislocation motion. During solidification, micro-additives distort and deform the lattice causing interaction between dislocation and solute atom. The change in dislocation density resulting from micro-additives is

responsible for change in the structure and by implication on mechanical properties.

Magnesium has distinction of being the high taste engineering metal with specific gravity of 1.78 and highest coefficient of thermal expansion 25×10^{-6} ^[7]. Magnesium element has great effect on the mechanical properties when used as alloying element with other group of metals of the same properties^[8]. It does show an advantage over other metal system in weight reduction when section size is limited^[8, 9]. Copper has found use both as parent metal and alloying element in the development of alloy materials for various engineering applications^[10, 11]. Tin is more effective in strengthening copper than zinc, but is more expensive and has a greater detrimental effect on the electrical and thermal conductivity than zinc. Aluminium, magnesium, nickel, silicon, etc. can also be added to strengthen copper^[12]. This research work aims at modifying the structure of Cu-10%Sn alloy, by using magnesium and by impacting on the types, forms and distribution of phases within the matrix and their effects on the mechanical properties.

2. Materials and Methods

2.1 Materials and equipment

The under listed materials and equipment were used for the research work; pure copper scrap (99.9%), tin powder, magnesium powder, weighing balance, crucible furnace, venire calliper, bench vice, lath machine, electric grinding machine, hack-saw, stainless steel crucible pot, mixer, scoping spoon, electric blower, rammer, moulding box, impact testing machine (U1820), hardness testing machine (A 3000 H), universal tensile testing machine (model 130812), emery papers of

different grits, air drying machine, metallurgical microscope (L 2003A), digital camera, and VEGA LMU 11 scanning electron microscope machine.

2.2 Method

a) Melting and casting of alloys

This operation was carried out to produce six separate specimens for the research work. The bailout crucible furnace with steel crucible pot was pre-heated for about 10minutes. For the control sample, 563.42g of Cu and 33.33g of Sn granules were measured out. Copper was charged into the furnace pre-set at 1150°C and heated till it melted. Tin granules were then added to the melt and stirred properly to ensure homogeneity. The alloying element (magnesium) was then introduced based on the compositions, after the control sample had been cast. The melt was manually stirred intermittently in order to ensure homogeneity and facilitate uniform distribution of the alloying element. Sand casting method was used after removal of the molten metal alloy from the furnace and carefully skimming off the dross. The molten metal was poured into the mould cavities and allowed to solidify for about 3minutes before removal from the mould.

b) Machining

The machining operation was carried out using a three jaw chuck lathe machine. The samples to be machined were firmly clamped on the machine and facing, turning and shaping operation was done on the clamped samples with the aid of a cutting tool mounted on the post of lathe machine. Eventually the required dimensions for impact, tensile and hardness test samples as well as microstructure analysis were obtained, as shown in Figures below.

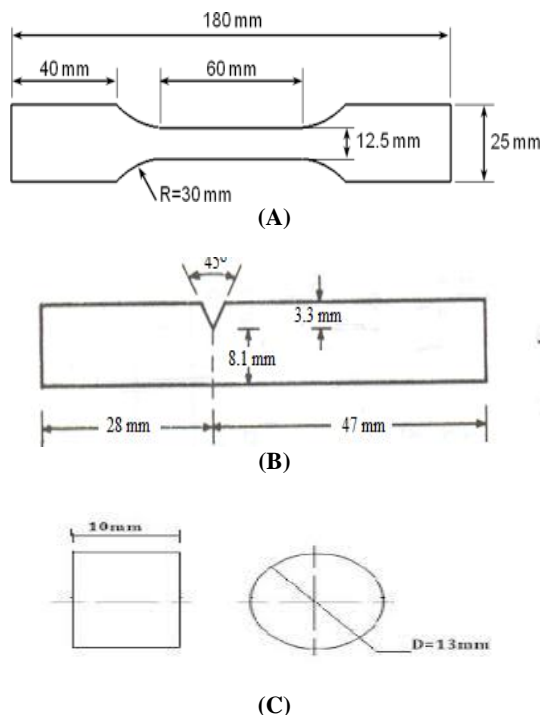


Fig 1: (a) Tensile test specimen, (b) Notch impact test specimen, (c) Hardness/microstructure specimen.

(c) Mechanical Test

The tensile strength was determined with 13081 tensile testing machine, while a Brinell hardness machine with 2.5mm diameter ball indenter and 62.5N minimum was used to determine the hardness. The equation $BHN = \frac{P}{(\frac{\pi D}{2})(D - \sqrt{D^2 - d^2})}$

was used in calculating the result of the hardness. Where BHN: is the brinell hardness number, P: is applied load (N), D: ball (indenter) diameter (mm), d: notch diameter (mm). Charpy impact test machine (U1820) was used to carry out impact strength.

(d) Microstructure examination

The microstructure of experimental specimens was studied using optical metallurgical microscope and scanning electron microscope linked with EDS analyzer. Preparation of specimens was done by grinding, polishing and etching, so that the structure can be examined using optical metallurgical microscope. The samples were ground by the use of series of emery papers in order of 220, 340, 400, 600, 800, 1000, and 1200 grits and polished using fine α -alumina powder. An iron (iii) chloride was used as the etching reagent before mounting on the microscope for microstructural examination and photographing. For SEM observation, materials were etched with hydrogen fluoride (HF). Chemical composition of materials was made by EDS (EDS analyzer Brucker Quantax) attached to the SEM using the Software thermo noran.

3. Results and Discussion

Results of ultimate tensile strength (UTS), impact strength, ductility (% elongation) and hardness responses by test specimens are displayed in Table 1 and Figures I-4 while the microstructures developed by the specimens are shown in plates 1-8.

From Table 1.0 and figure 2 and 4, it was observed that the impact strength and % elongation of Cu-10%Sn alloy decreased as the composition of Mg increased. Addition of magnesium to the binary Cu-10%Sn alloy resulted in solid solution strengthening of the α -phase and formation of secondary phase (intermetallic compounds) such as Cu-CuMgSn, Cu-Mg₂Sn and Cu₂Mg-Mg₂Sn [2].

Table 1: Mechanical properties of Cu-10%Sn doped with magnesium

Sample wt%	UTS (MPa)	% Elongation	Hardness (BHN)	Impact (Joules)
Cu-10% Sn	149	15.0	135	12
Cu-10% Sn0.2%Mg	160	15.6	142	31
Cu-10% Sn0.4%Mg	165	14.5	149	22
Cu-10% Sn0.6%Mg	182	13.0	162	17
Cu-10% Sn0.8%Mg	312	4.3	285	8
Cu-10% Sn1.0%Mg	312	4.2	269	6

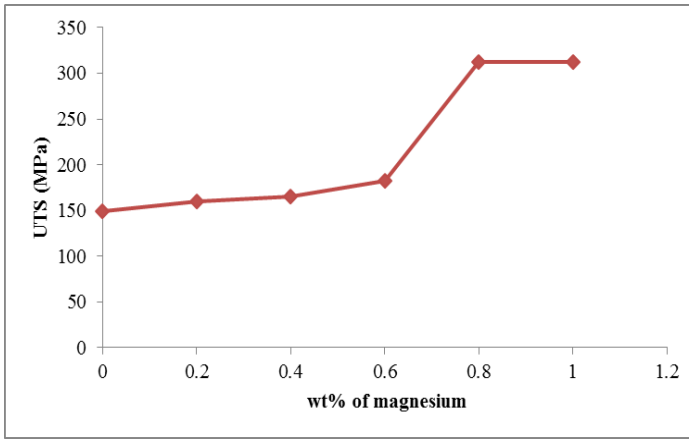


Fig 1: Effect of magnesium content on the UTS of Cu-10%Sn alloy.

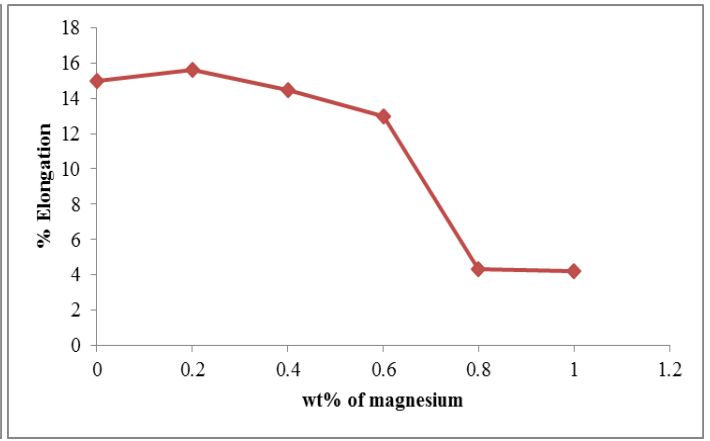


Fig 2: Effect of magnesium content on the % elongation of Cu-10%Sn alloy.

Figures 1 and 3 show that ultimate tensile strength and hardness of Cu-10%Sn alloy increased as the concentration of Mg increased. The figures indicated that the highest value were at 0.8 and 1.0wt% magnesium addition. Solid-solution strengthening effect (solution of magnesium in α -phase) caused an increase on both hardness and ultimate tensile and

decreased %elongation and impact strength as shown in Figures 1-4. When Mg content in Cu-10%Sn alloy increased, formation of hard and brittle δ -phase which has sharp edges that weaken the interdendritic region of the alloys is predominant, leading to early crack initiation and subsequent failure.

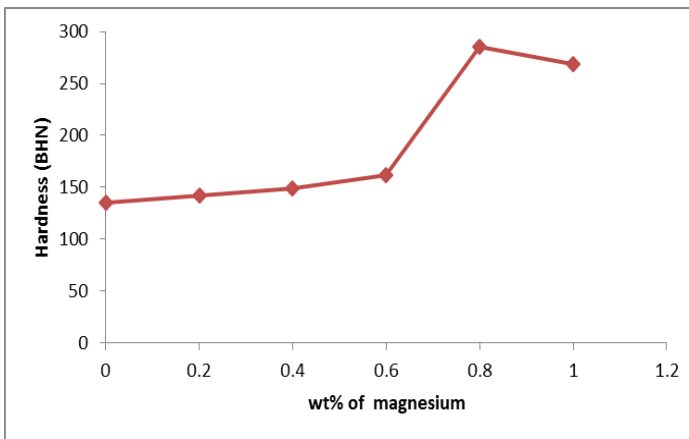


Fig 3: Effect of magnesium content on the hardness of Cu-10%Sn alloy

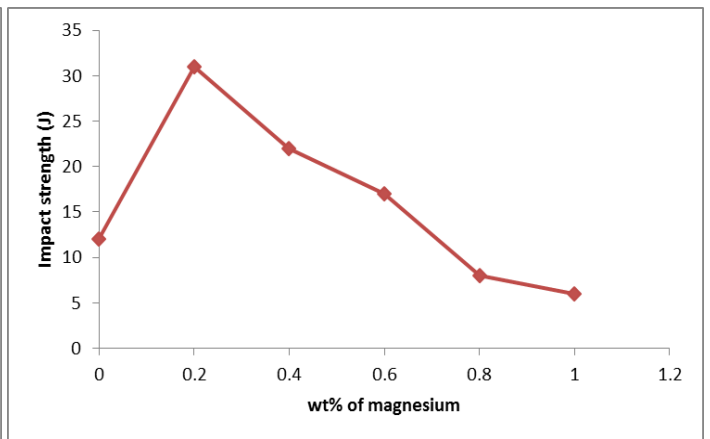


Fig 4: Effect of magnesium content on the impact strength of Cu-10%Sn alloy

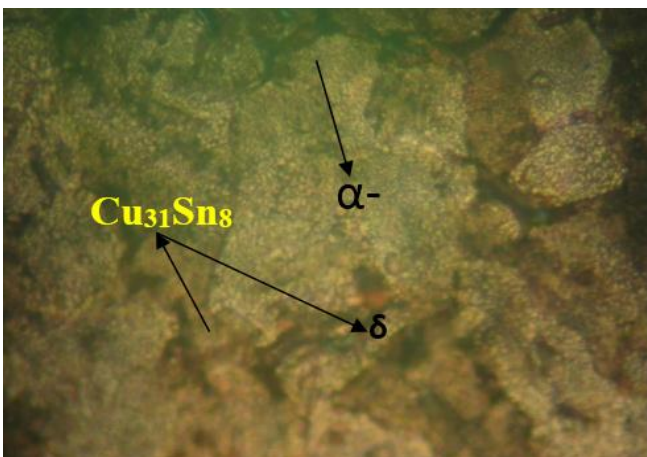


Plate 1: Micrograph of Cu-10%Sn (control)

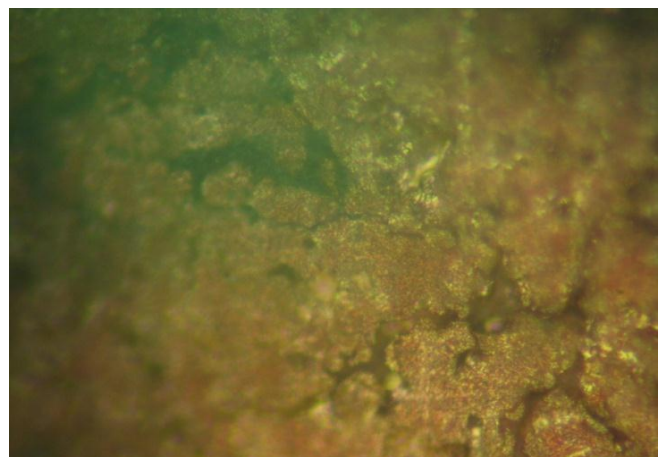


Plate 2: Cu-10%Sn + 0.2%Mg

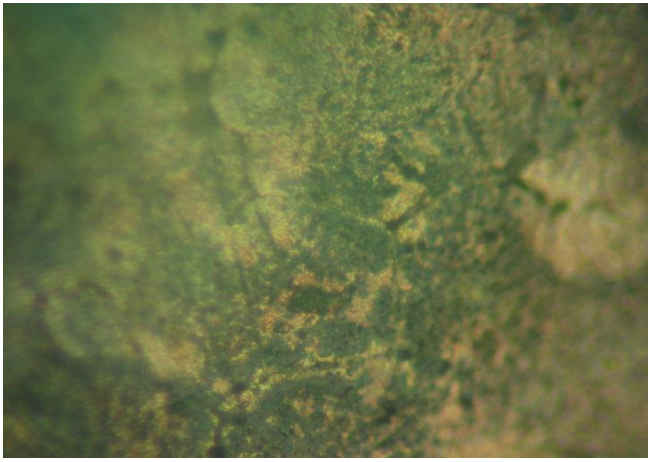


Plate 3: Cu-10%Sn + 0.4%Mg

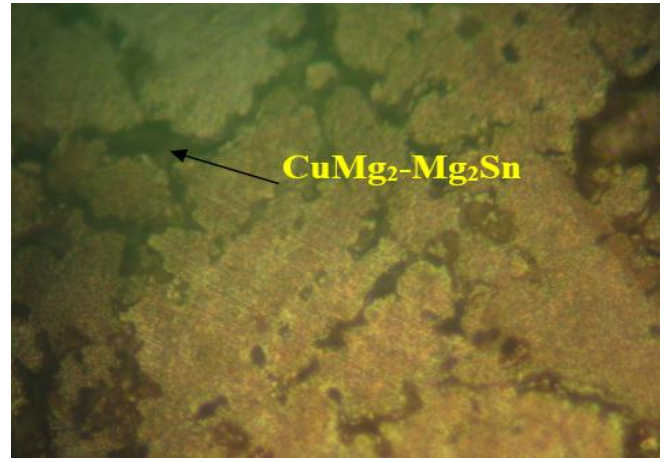


Plate 4: Cu-10%Sn + 0.6%Mg

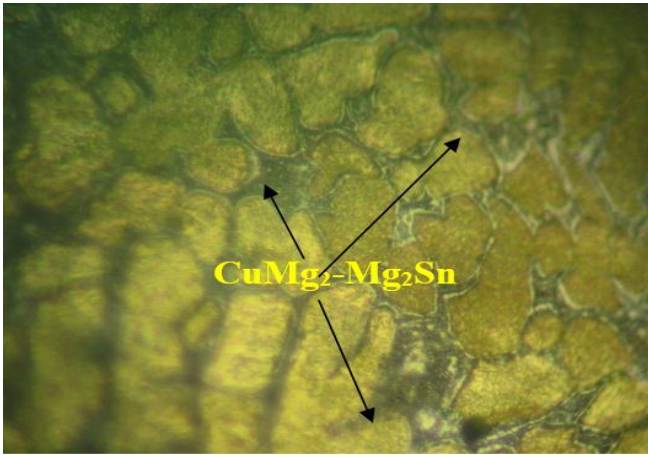


Plate 5: Cu-10%Sn + 0.8%Mg

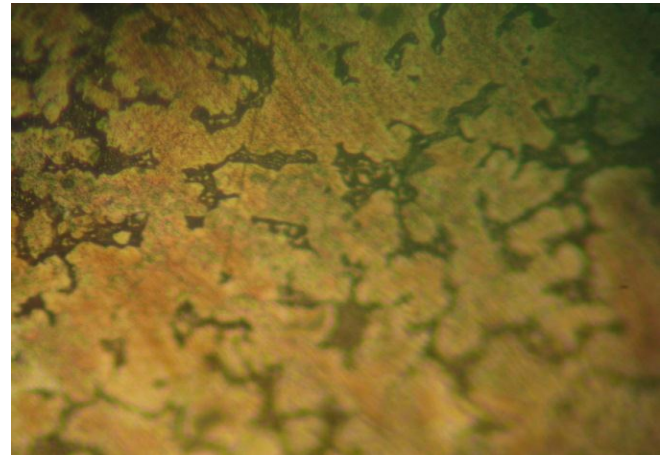


Plate 6: Cu-10%Sn + 1.0%Mg

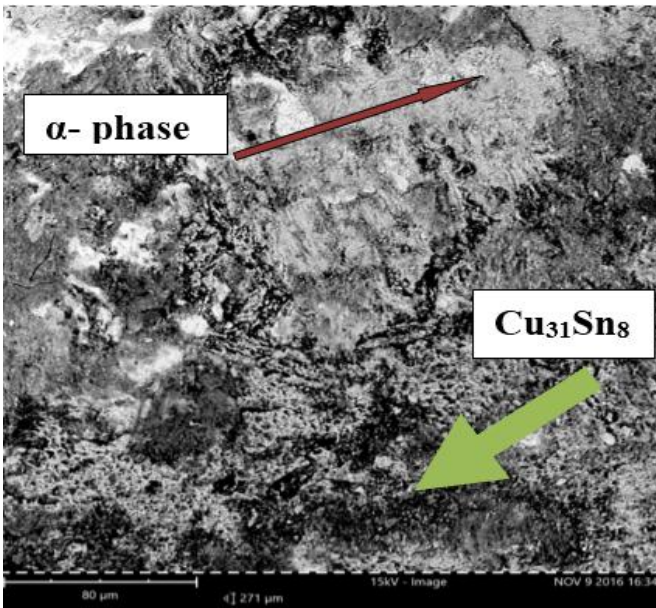


Plate 7: SEM micrograph of Cu-10%Sn alloy (Control)

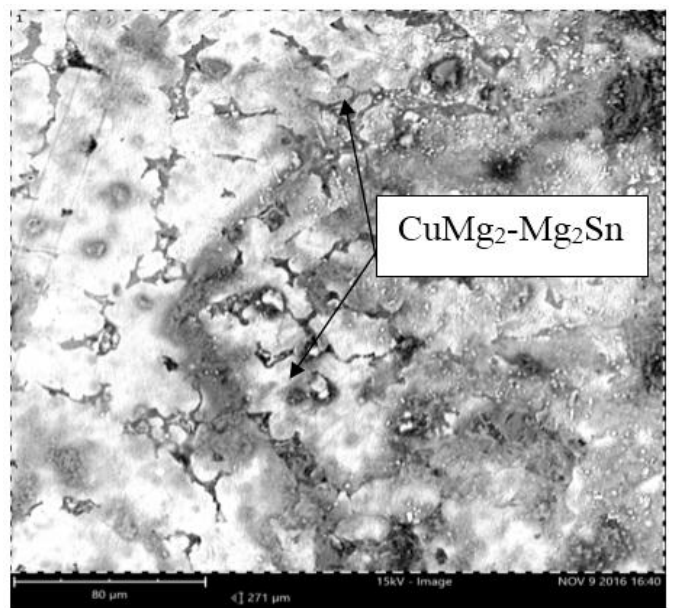


Plate 8: SEM micrograph Cu-10%Sn+0.8%Mg alloy

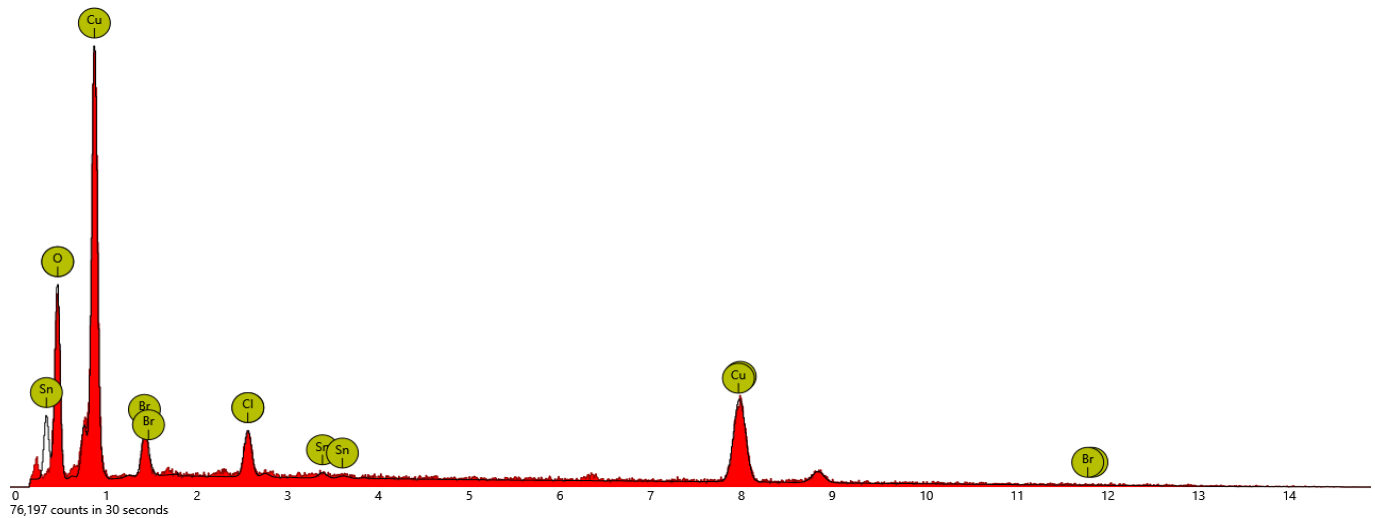


Fig 5: EDS spectra of Cu-10%Sn alloy (control)

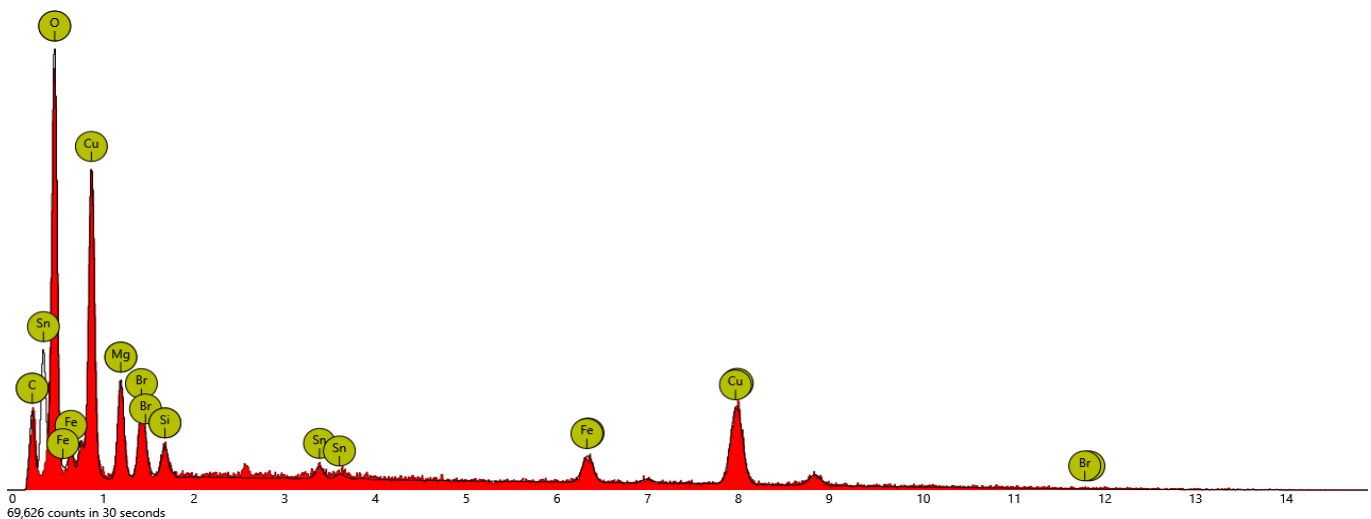


Fig 6: EDS spectra of Cu-10%Sn-0.8%Mg alloy

Plates 1-8 represent the micrographs of Cu-10%Sn and Cu-10%Sn doped with magnesium of 0.2wt% - 1.0wt% concentrations. The micrograph and scanning electron micrograph of the control specimen (Cu-10%Sn alloy) shown in plate 1 and 7 respectively, revealed that the microstructure of the specimen comprised of the eutectic α -solid solution (the region where copper formed a solid solution with the tin matrix, which is the grey region in SEM morphology) and the δ - phase which is the dark region in SEM micrographs). The intermetallic compound existed in the form of coarse needle-like precipitate from the α -phase through grain boundaries.

From plates 2-6, the analysed microstructure contained primary copper-dendrites and substantial amount of different intermetallic phases constituents varied in shapes, size and distribution. They are located at the grain boundary of α -Cu and form dendritic network (plate 5 and 8). The number and size of δ -phase particles increased with magnesium content of the alloys. This acted as a load bearing phase, producing hardening effects and increased wear resistance in the alloy [11]. Plate 8, Figures 5 and 6 showed the SEM micrographs of Cu-10%Sn-0.8%Mg with the corresponding EDS-spectra of intermetallic observed in the cast-tin bronze. The EDS analysis indicated the oval particles as Cu_3Sn . Beside Cu_3Sn phase, another Sn-containing phase ($\text{CuMg}_2\text{-Mg}_2\text{Sn}$) was observed

(plate 8). In addition, the Sn-containing intermetallic nucleating as dark grey rod with needle-like was observed. Also, it was observed in plate 8 that the spread of intermetallic phases in the alloy matrix were vigorous, which further explained why an increase in Mg concentration increased ultimate tensile strength and hardness and decreased ductility and impact strength with increase in concentration of Mg in the studied alloy.

4. Conclusions and Recommendation

This research work has shown that micro-addition of magnesium to tin bronze resulted in the improvement of certain mechanical properties. The increased in UTS and hardness observed in the doped alloy were as a result of simultaneous formation β -phases (Intermetallic compounds) which therefore caused decrease in grain size and dendritic structure. The following conclusions are therefore made from the research:

- When Mg content increased, secondary phases like $\text{Cu}_2\text{Mg-MgSn}$, Cu-CuMgSn and $\text{Cu}_2\text{Mg-Mg}_2\text{Sn}$ were formed in the interdendritic region of Cu-10%Sn alloying thereby causing an increase in the hardness value.
- For effective ductility and impact strength, micro-addition of magnesium to Cu-10%Sn alloy should be recommended for low speed engineering application.

- Tin bronze alloyed with magnesium in micro-percentage can be recommended for low speed applications such as trunion bearing, gear bushing for road vehicles, rolling-mill bearing and internal combustion engines.

5. Acknowledgement

The authors wish to acknowledge the technical assistance of the staff of Delta State Polytechnic, Ogwashi-uku and National Metallurgical Training Institute, Onitsha, for making available their equipment for this research.

6. References

1. Stanislov SN, Irina BM, Oleg DN. Handbook of Non-Ferrous Metal Powders, 2009; pp. 331-368.
2. 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.
3. Skočovský P. Designing Materials [in Slovak] (1st edition), EDIS, ISBN 80-7100- 608-4, Žilina, Slovak republic, 2000.
4. Skočovský P. Material Sciences for the Fields of Mechanical Engineering [in Slovak] (2nd edition), EDIS, ISBN 80-8070-593-3, Žilina, Slovak republic, 2006.
5. Nnuka EE. The Effect of Micro Additives on the Quality and Distribution Pattern of the Secondary Phase in Aluminium-Copper Alloy System. *The Nigerian Engineer*. 1991; 26(3):30-37.
6. Nnuka EE. Effect of Dopants on the Structure and Properties of Aluminium and some of its Alloys. *JAST*. 1994; 4(2):145-153.
7. Kenneth GB, Micheal KB. Engineering Materials properties and Selection. Sixth edition, prentice- Hall Inc. Upper saddle River New Jersey, 1999; 07458:570-594
8. Yaro SA, Agigbodion VS. The Effect of Copper on the mechanical Properties of Al-Si-Fe alloy. *International Research Journal Science and Technology (REJEST)*. 2009; 3(2):58-57.
9. Adeyemi G, Oluwadare BS, Olamipekum KO. The investigation on the effect of addition of magnesium on the microstructure and mechanical properties of aluminium bronze. *International Journal of Engineering Science Invesion*. ISSN:2319-6719, 2013; 2(11):1-13.
10. Venkala Ranga Reddy D. Microalloying of advanced Al-Zn-Mg-Cu Alloy. *Metal World Technology*. 2008; Pp. 16-17
11. Nwaeju CC, Odo JU, Jisieke SC, Edoziuno FO. Effects of copper addition on the structure and mechanical properties of Al-4%Zn alloy. *International Journal of Scientific Research Engineering & Technology (IJSRET)*. ISSN: 2278-0882. 2016; 5(1):43-48.
12. <http://www.metweb.com/reference/copper-alloy.aspx> Alloying Elements Effects on Properties of Copper Alloys.