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Microstructures and Physio-Mechanical Properties of Sand Cast Copper-10%Aluminium Alloys.

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Abstract
This study investigates the effect of addition of molybdenum on the microstructures, physical and mechanical properties of copper-10%aluminium alloys produced using sand casting techniques, as a potential replacement for conventional structural materials. The first approach to this research was casting a specimen with a crucible furnace. Metals were charged into the furnace according to their melting points. Molybdenum was introduced into the cast in different proportions from 1-10 wt% also a cast with zero wt% of molybdenum. After the alloying process, the specimens were sectioned, grinded, polished and etched before viewing under an optical metallographic microscope. Mechanical and physical tests were carried out on the specimens such as hardness, yield strength, tensile strength, electrical resistivity and electrical conductivity which show level of properties of each specimen. At the end of the experiments, it was concluded that the addition of molybdenum up to 7.0wt % to copper-10%aluminium alloys increases hardness, yield strength, tensile strength and electrical resistivity of copper-10% aluminum alloys and reduces its ductility and electrical conductivity.

Keywords: Copper-10%aluminium alloys, Molybdenum, Physical and Mechanical properties, Microstructure.

1. Introduction

An alloy is a substance obtained by melting together two or more components. It is also possible to produce alloys by other method such as sintering, electrolysis but the most common process is that by melting together various pure elements (Anup, 2014). Alloy made predominantly of metallic properties are metallic alloys. The general procedure in making an alloy is first to melt the metal having the higher melting point then to dissolve in it the one with lower melting point and stirring the mixture so that homogenous liquid solution is formed. When this liquid solidifies the type of structure which is produced depends largely on the relative physical and chemical properties of the two metals (Adeyemi, 2013). Pure metals are rarely used for engineering purpose except where high electrical conductivity or good corrosion resistance are required. These properties are generally of a maximum value in pure metals but such mechanical properties like tensile strength, yield strength and hardness are improved by alloying (Abdul, 2013). Aluminum bronzes are copper based alloys with aluminum as the major alloying element usually in the range 5%-14% composition in the alloy (Nwambu, 2017). Aluminum bronzes give a mix of chemo-mechanical properties superseding many other alloy series. These make them to be most preferred particularly for demanding applications (Sami, 2007). "Aluminium bronzes are most valued for their high strength and corrosion resistance in a wide range of aggressive media" (Daniel 2002). "They are most commonly used in applications where their resistance to corrosion makes them preferable to other engineering materials. The basic properties of copper alloys are largely influenced by copper itself"(Łabanowski, 2014). The presence of aluminum increase the mechanical properties of the alloy by the establishment of a face-centre-cubic (F.C.C) phase which could improve the casting and hot working properties of the alloy (Anene, 2015).Other alloying elements improve the mechanical properties and modify the microstructure. Nickel and manganese improves the corrosion resistance, whereas iron (Fe) is a grain refiner (Kaplan, 2003). Mechanical properties of bronze alloy are depending on their chemical composition, microstructure, and production condition and can be improved significantly by heat treatment (Donatus, 2012). Aluminum bronze is the most tarnish-resistant copper alloy and shows no serious deterioration in appearance and no significant loss of mechanical properties on expose to most atmospheric condition (Oh-shi, 2014). Aluminum bronze also shows low rate of oxidation at high temperature and excellent resistance to sulphuric acid, sulphur oxide and other combustion product and are therefore used for the construction of items exposed to either both of these conditions (Issac, 2010). Besides their strength, toughness, corrosion resistance in a wide range of aggressive media, wear resistance, low magnetic permeability, non-sparking characteristics, and aluminum bronzes can be readily cast, fabricated, and machined. They can also be readily welded in either cast or wrought form (Moradlou, 2011). In spite of these wonderful attributes posed by aluminum bronzes, it is surprising to know that not much work have been done on aluminum bronzes in Africa especially in Nigeria. Structural applications are mostly based on ferrous materials, steels in particular (Nnuka, 1991). Findings have shown that aluminum bronzes are fast replacing contemporary steel materials for some specific applications especially in components for marine/subsea applications. The consumption of aluminum bronzes have increased sharply in the USA. And other countries due to their property of being non-rusting in marine environment as well as also their resistance to corrosion in highly aggressive environments (Bradley, 1991). This study investigates the effect of addition of molybdenum on the physical and mechanical properties and microstructure of copper-10%aluminum alloys as a possible replacement of contemporary steel materials.

2.0 Material and methods

Materials and equipment used for this research work are: Pure copper scraps, pure aluminum scraps, molybdenum metal powder, crucible furnace, stainless steel crucible pot, lathe machine, weighing balance, venire caliper, bench vice, electric grinding machine, hack-saw, mixer, scoping spoon, electric blower, rammer, molding box, hardness testing machine, universal tensile testing machine, impact testing machine, metallurgical microscope etc.

Table 1: Cu-10%Al alloy chemical composition (wt%)

Cu	Al	Fe	Ca	K	S	Cl	O	C
89.69	9.67	0.08	0.04	0.03	0.07	<0.01	<0.01	0.4

The chemical compositions of the materials used in this research are given in terms of weight composition and are presented in table 1.

2.1 Experimental Procedures

2.1.1 Melting and casting of alloys

Sand casting was used to produce eleven separate samples based on its advantages of low cost, ease of use and flexibility in the production of alloys with pre-selected composition of 1.0 to 10% of molybdenum content. The crucible furnace was preheated for about 15 minutes. Copper was charged into the furnace pre-set at 1200 ^{o}C and heated till it melted. Aluminum was dissolved inside the molten metal. The modifying element (molybdenum) was introduced based on varying compositions after the control sample had been cast. The melt was manually stirred in order to ensure homogeneity and to facilitate uniform distribution of the alloying element before casting, machining and mechanical testing took place.

2.1.2 Mechanical Test Samples

Copper-10%aluminium alloy samples were machined as per ASTM E8M-04 standards for mechanical properties test. The figures below show the test preparation.

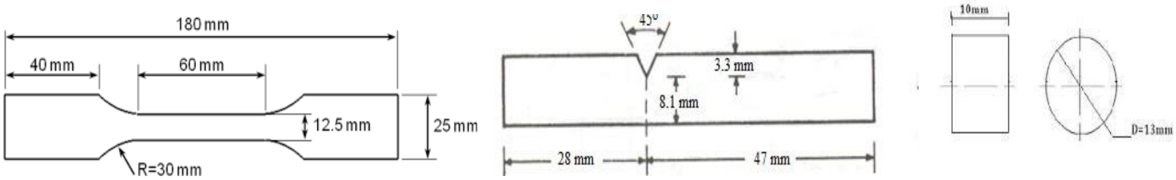

Fig: (i) Tensile test specimen (ii) Notch impact test specimen, (iii) Hardness/microstructure specimen

2.1.3. Mechanical Properties Test:

The ultimate tensile strength was tested on Instron (Model 600DX) universal testing machine while a Brinell hardness machine with 2.5mm diameter ball indenter and 62.5N minimum was used to determine the hardness property. Charpy impact test machine was used to carry out impact strength.

2.1.4. Physical Properties Analysis

Electrical conductivity is the reciprocal of electrical resistivity, and measures a material's ability to conduct an electric current. It is represented by the Greek letter σ (sigma) while resistivity is represented by the Greek letter ρ (rho). A multimeter device was used to measure the resistance of the rod.

$$\rho = R\,\frac{A}{L} \tag{1}$$

R = is the electrical resistance of a uniform specimen of the material, L= is the length of the piece of material, A = is the cross-sectional area of the specimen

$$\text{Electrical Conductivity} = \frac{1}{\text{Resistivity}} \tag{2}$$

2.1.5. Structural Analysis

Structural analysis was conducted at Metallurgical Training Institute (MTI), Onitsha and Sheda Science and Technology Abuja using optical metallurgical microscope (Model: L2003A), scanning electron microscope (LEO-430i) and energy dispersive spectroscopy (LINK-ISIS-300). Preparation of material was done by grinding, polishing and etching, so that the structure can be examined using optical metallurgical microscope. The specimens were grinded by the use of series of emery papers in order of 220, 500, 800, and 1200 grits and polished using fine alumina powder. An iron (iii) chloride acid was used as the etching agent before mounting on the microscope for microstructure examination and micrographs.

3.0 Results and Discussions

Table 2 represents the mechanical and physical properties test results carried out on the alloy samples.

Table 2: Mechanical and Physical properties test results

Alloy	**Yield Strength (MPa)**	**Ultimate Tensile Strength (Mpa)**	**Hardness BHN**	**Elongation %**	**Impact Strength (Joules)**	**Resistivity ρ (Ω·m). $\times 10^{-8}$**	**Conductivity σ S/m $\times 10^{7}$**
Cu-10%Al	167	331	104	36.04	42.34	5.28	9.35
Cu-10%Al+1.0Mo	223	407	137	24.38	35.63	6.83	8.15
Cu-10%Al+2.0Mo	295	466	188	22.32	32.45	8.22	6.49
Cu-10%Al+3.0Mo	352	504	267	20.48	30.42	9.43	4.49
Cu-10%Al+4.0Mo	398	545	296	17.46	27.88	9.83	4.14
Cu-10%Al+5.0Mo	432	582	335	15.64	26.56	12.75	3.86
Cu-10%Al+6.0Mo	483	607	357	15.38	26.13	13.83	3.23
Cu-10%Al+7.0Mo	525	626	371	15.02	25.35	14.92	2.69
Cu-10%Al+8.0Mo	518	584	367	16.48	26.42	14.43	2.49
Cu-10%Al+9.0Mo	478	555	346	18.46	28.38	12.83	3.14
Cu-10%Al+10.Mo	452	549	335	20.64	30.58	11.75	4.26

3.1 Mechanical Properties Analysis

Figures 1 & 2 represents the mechanical properties of the alloy samples.

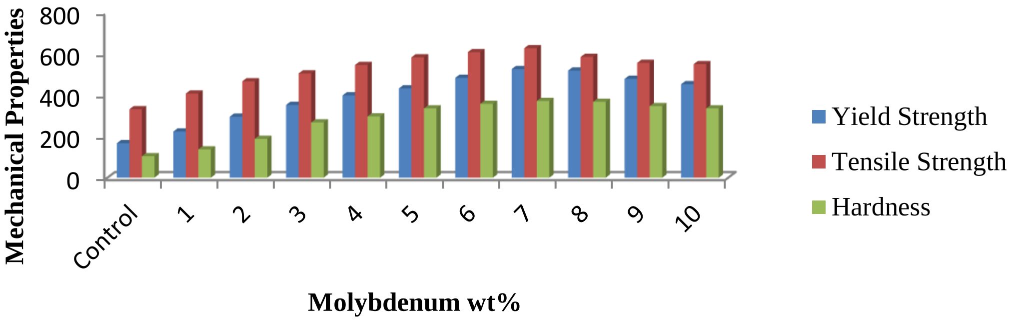

Figure 1; effects of molybdenum composition on properties of Cu-10%Al alloy

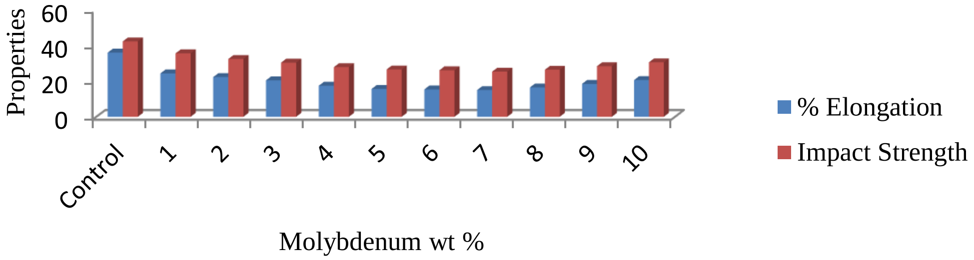

Figure 2; effects of molybdenum composition on properties of Cu-10%Al alloy

Table 2 and figures 1 &2 depicts mechanical properties test results of treated samples with molybdenum. It was observed that hardness, yield and tensile strength increased as composition of molybdenum increased while percentage elongation decreases. This treatment significantly improved the hardness, yield and tensile strength properties of the alloys particularly in the sample containing 7.0% composition of molybdenum as compared to base alloy or the sample with zero % composition of molybdenum though with significant reduction in ductility. Addition of this modifying element to copper- aluminum alloys decreases the solubility of aluminum in copper matrix. This developed a structure that will substitute a compressive stress in the copper lattice which retarded the movement of dislocation and made the alloy to have a good combination of mechanical properties.

3.2 Physical Properties Analysis

Figure 3 represents the correlation between resistivity and electrical conductivity of the alloy samples.

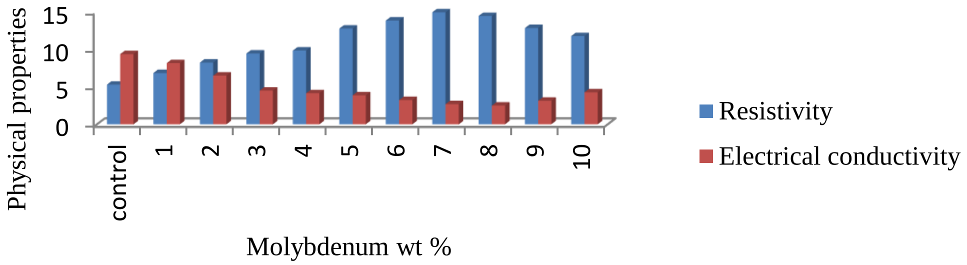

Figure 3; effects of molybdenum composition on properties of Cu-10%Al alloy

Table 2 and figure 3 showed that as molybdenum composition increases in the alloy samples, electrical resistivity increases as well while electrical conductivity decreased in almost all the alloys cast thus, agreeing with the known principle that resistivity of a metal is increased by even a small amount of impurity**.** The increase in resistivity as a result of doping element of Cu-Al alloys is probably connected with lattice defects induced by the doping elements (Nwankwo, 2015).

3.3 Structural Analysis

The micrographs of the alloy samples are shown in plates 1 to 11.

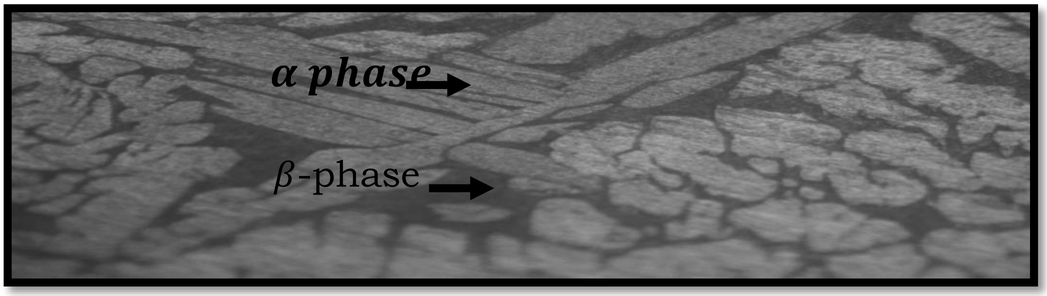

Plate 1: Micrograph of Cu-10%Al (base alloy) (x400)

Plate 2: Micrograph of Cu-10%Al+1.0%wt of Mo (x400)

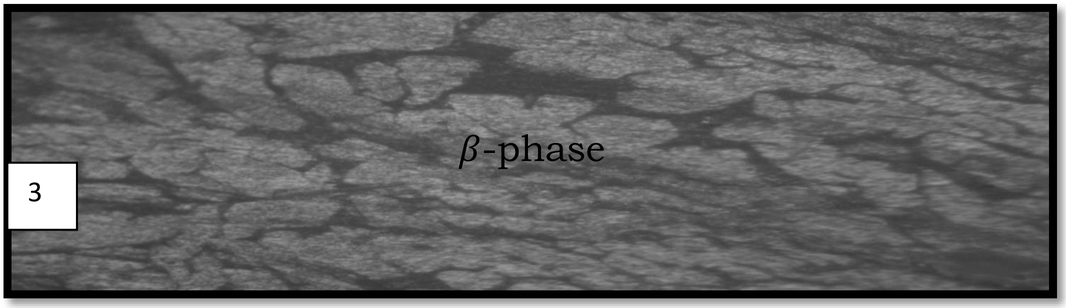

Plate 3: Micrograph of Cu-10%Al+2.0%wt of Mo (x400)

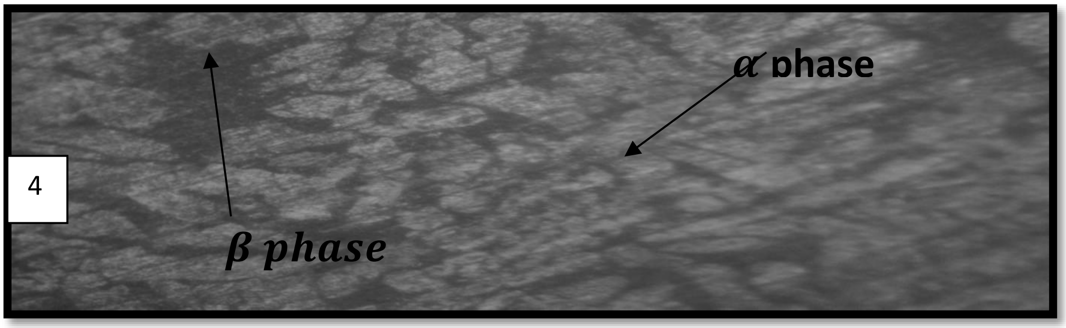

Plate 4: Micrograph of Cu-10%Al+3.0%wt of Mo (x400)

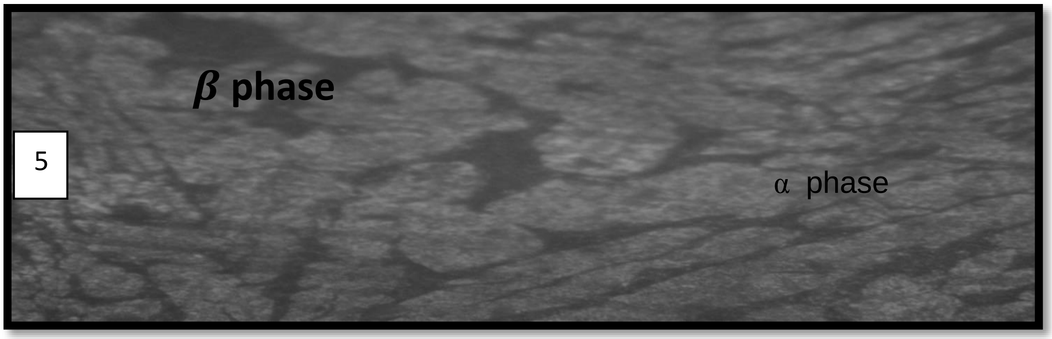

Plate 5: Micrograph of Cu-10%Al+4.0%wt of Mo (x400)

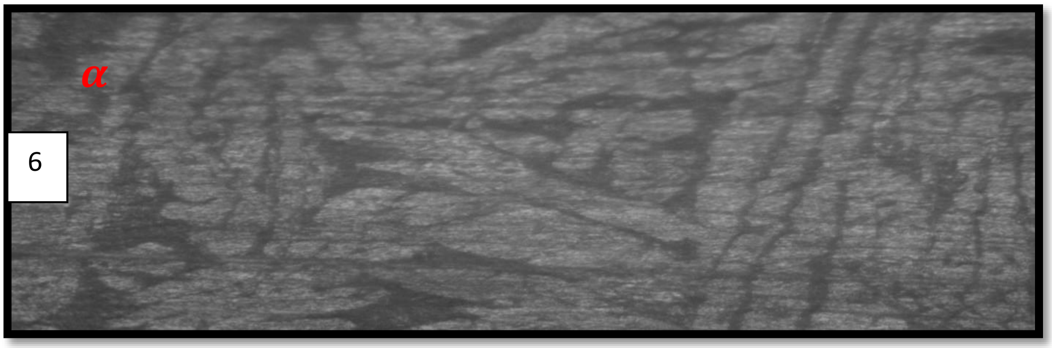

Plate 6: Micrograph of Cu-10%Al+5.0% wt of Mo (x400)

Plate 7: Micrograph of Cu-10%Al+6.0 %wt of Mo (x400)

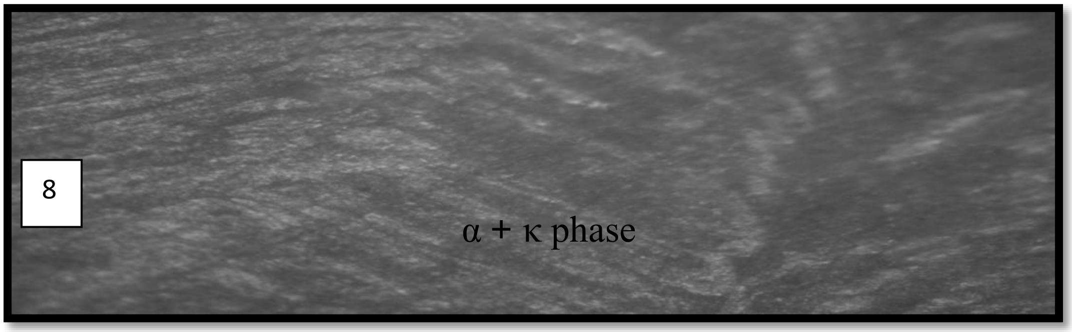

Plate 8: Micrograph of Cu-10%Al+7.0% wt of Mo (x400)

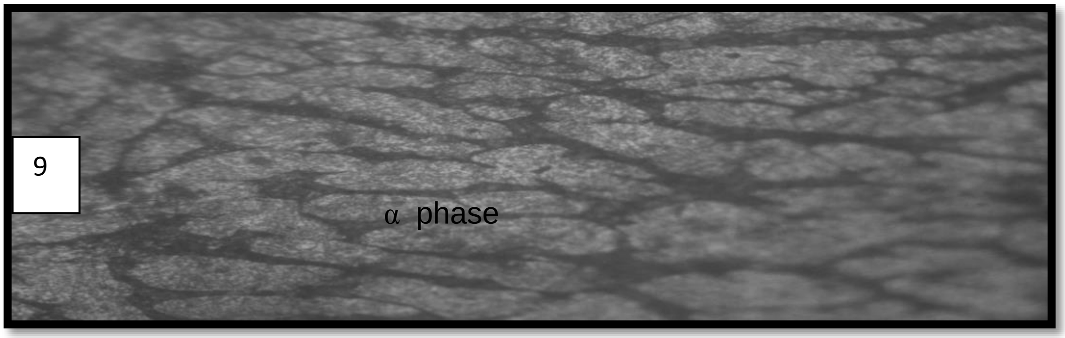

Plate 9: Micrograph of Cu-10%Al+8.0%wt of Mo (x400)

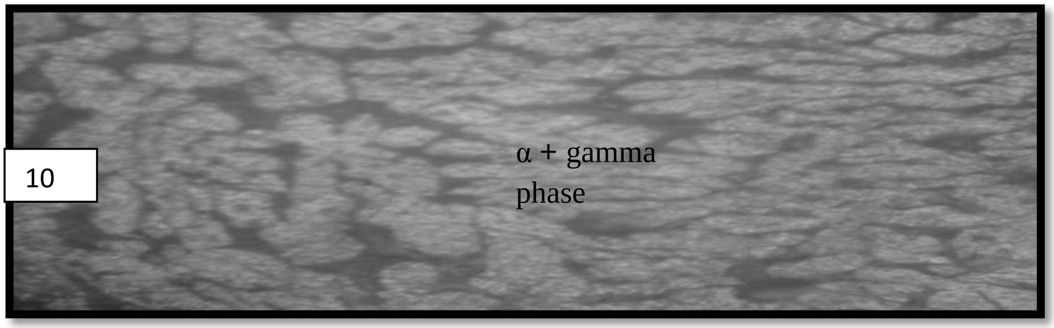

Plate 10: Micrograph of Cu-10%Al+9.0 %wt of Mo (x400)

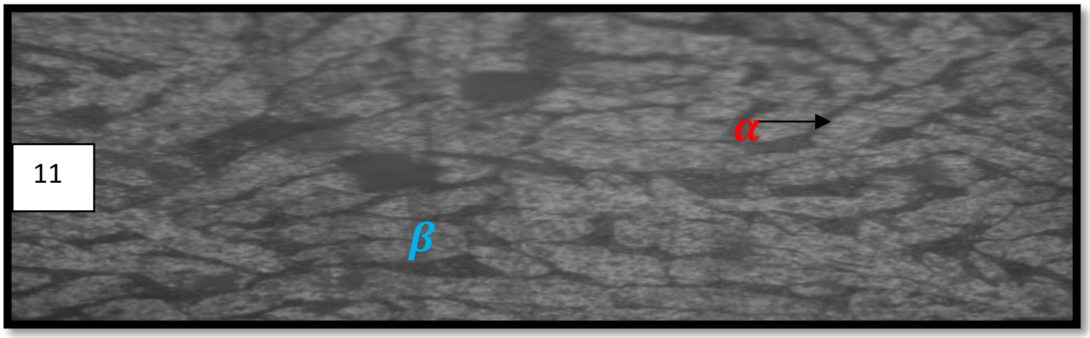

Plate 11: Micrograph of Cu-10%Al+10%wt of Mo (x400)

From plate 1, which is the control specimen (base alloy) of Cu-10%Al bronze alloy, it was observed that the microstructure consists of large coarse interconnected intermetallic Cu_9Al_4 compound and $\alpha+\gamma_2$ phases. This particular plate exhibits the lowest mechanical and physical properties because of its coarse microstructure. Plates 2 to 11 shows the microstructure of Cu-10%Al alloy treated with (1.0 to 10) wt% of molybdenum element. Molybdenum stabilized the β- phase and hence increased toughness and strength. The microstructure showed that molybdenum increased the quantity of α-phase in Cu-10%Al alloy system. Presence of sparse distribution of kappa precipitates in the predominated α + k caused smaller grains to increase in the microstructure which enhanced mechanical properties of the alloy.

3.4. Structural analysis were also done with scanning electron microscope (SEM) and energy dispersive spectroscopy (EDS) to identify the phases and elements present and their peaks as presented in plates 12-15.

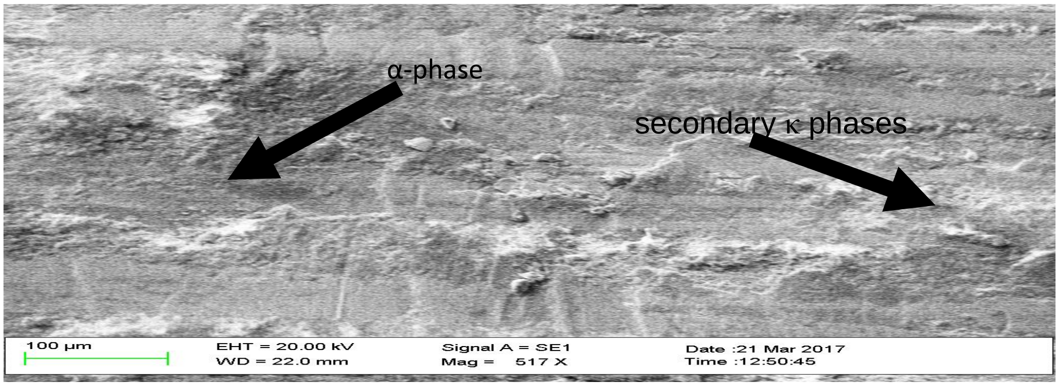

Plate 12: SEM of Cu-10%Al alloy

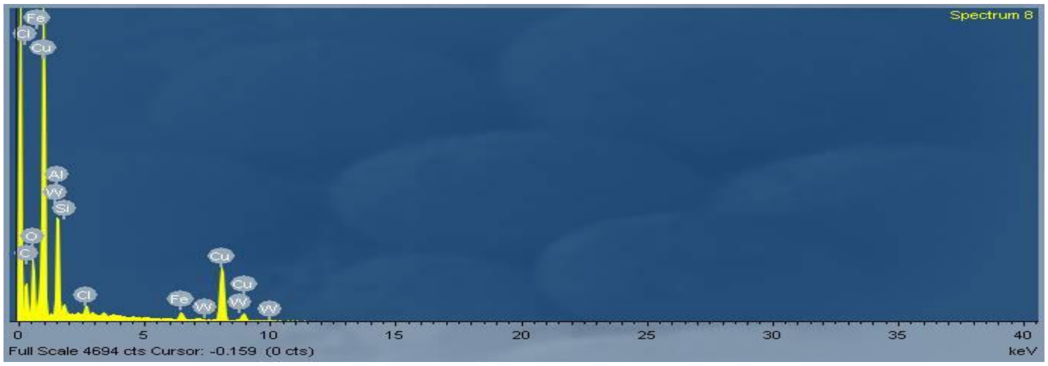

Figure 4: EDX of Cu-10%Al alloy (base alloy)

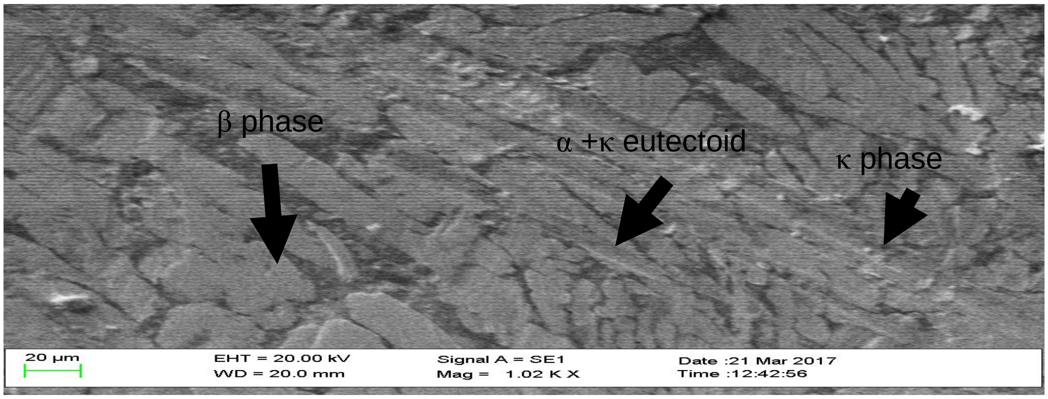

Plate 13; SEM of Cu-Al alloy with 6wt% of Mo

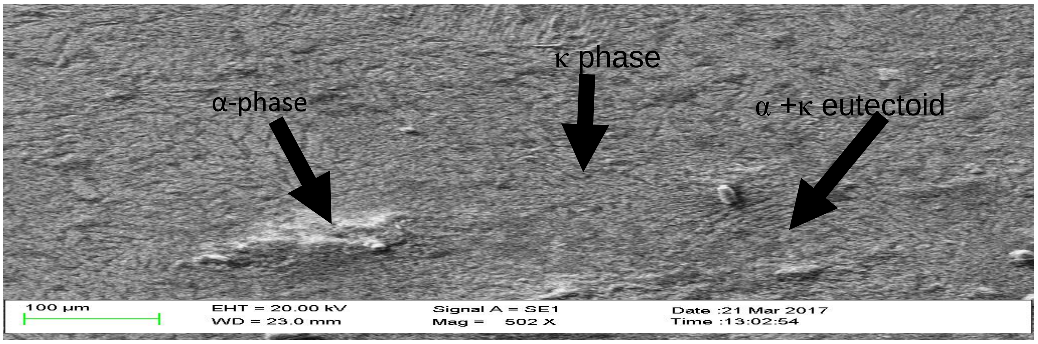

Plate 14; SEM of Cu-Al alloy with 8wt% of Mo

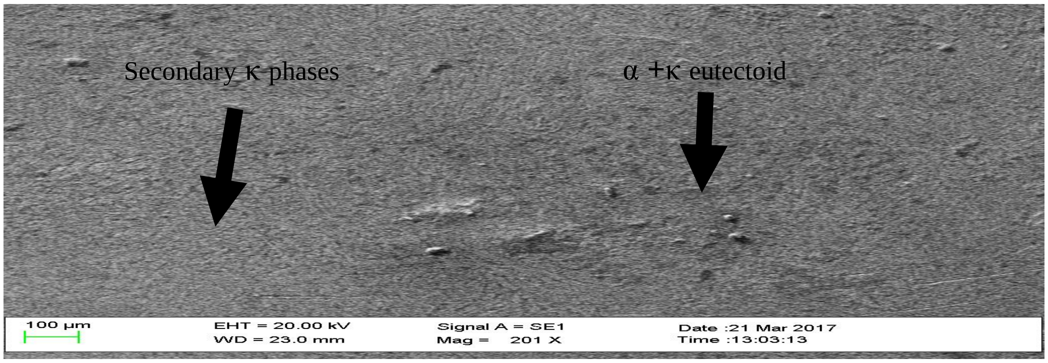

Plate 15: SEM of Cu-10%Al alloy with 7.0wt% of Mo

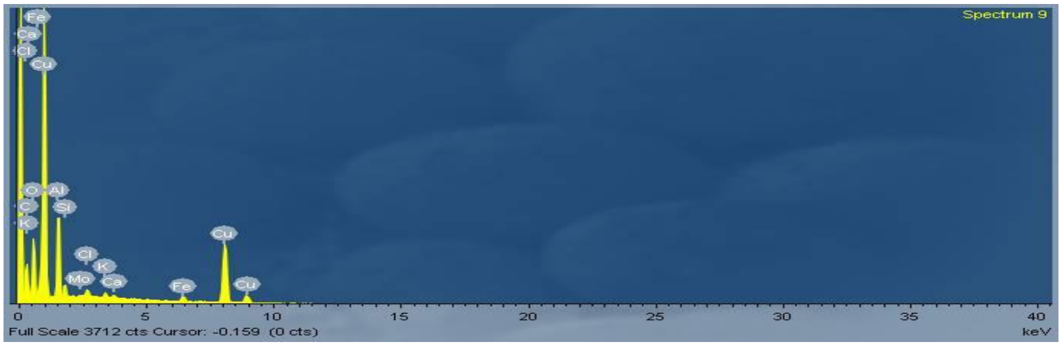

Figure 5; EDX of Cu-10Al alloy with 7.0wt% of Mo

Plates 12 to 15 showed scanning electron microscopes which revealed the phases present while figure 4&5 of EDX revealed the elements present and their peaks. Four major phases were revealed under the optical microscopes the α-phase, ß-phase, k-phase and α +κ eutectoid while EDX depicts the elements present in the alloy such as Cu, Al, Fe, Ca, K, S, Cl, O, C and Mo and their peaks. The α-phase increased in size as the composition of molybdenum increased. Gamma phase became suppressed while beta-phase was stabilized and that brought about precipitation of kappa phase. The presence of sparse distribution of kappa precipitates in the predominated α + matrix caused smaller grains to emerge in increasing quantity creating smaller lattice distance thereby resulting to improvement of the mechanical properties.

4.0. Conclusion

This study has shown that copper-10%aluminium alloys with improved mechanical properties and microstructures as compared to conventionally used structural alloys can be produced locally. Sand casting was found effective base on its advantages of low cost, ease of use and flexibility in the local production of the binary alloys with carefully selected composition of 1 to 10% molybdenum content. It was noted from experiments carried out that addition of molybdenum to copper-10%aluminium alloys stabilizes the beta phase, suppresses formation of gamma phase and brought about refinement in the alloys structure. Sample that contains 7.0% composition of molybdenum gave the highest values of tested mechanical properties with ultimate tensile strength in the range of 626MPa, yield strength of 525MPa and hardness values of 371BHN, the high value of mechanical properties of copper-10% aluminum alloys reduces the cause of failure in engineering designs and constructions. This agrees with Adeyemi, et.al (2013) that addition of modifying elements like magnesium will increase the mechanical properties of aluminum bronze which can be used in a substitute for propeller of a sea-going vessel. The results of physical properties test showed increasing electrical resistivity led to decreasing electrical conductivity unlike metal conductors, meaning that high resistance electrical motors could be made from this type of alloy.

5.0 Recommendation

These developed alloys modified with Mo should be used for making component (propeller) in sea-going vessel because of their high values of mechanical properties as obtained in this study.

The improved copper-aluminum alloys have high tensile strength, hardness and yield strength, they are recommended for use in military application and aerospace industries.

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