IDEAL INTERNATIONAL JOURNAL of IGBO SCHOLARS FORUM, NIGERIA. Volume 4 No 2, September, 2017

Effects of chromium on the structural sensitive properties of locally produced copper-10%aluminium alloys.

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Abstract:

This research work examines the effects of chromium on the structural sensitive properties of copper-10%aluminium alloys produced using local techniques, as a potential replacement for conventional structural materials. The first approach to this research was melting and casting samples with a crucible furnace and sand-casting technique. Metals were charged into the furnace according to their melting points. Chromium was introduced into the cast in different proportions from 1-10wt% also a cast with 0wt% of chromium. After the homogenization of the alloys, the samples were sectioned, grinded, polished and etched before viewing under an optical metallographic microscope. Mechanical tests were carried out on the samples such as yield strength, hardness and tensile strength which show level of hardness, yield strength and ductility of each sample. At the end of the experiments, it was concluded that the addition of chromium to copper-10%aluminium increases both hardness, yield and tensile strength of copper-10%aluminium alloy and reduces its ductility.

KEYWORDS: Copper-10%aluminium, Chromium, Microstructure, Tensile and Yield Strength, Hardness, Microscope.

Introduction

In recent times non-ferrous metals and alloys have become so important that technological development without them is unconceivable. Among the most important non-ferrous metals is copper with its alloys. Copper excels among other non-ferrous metals because of its high electrical conductivity, high thermal conductivity, high corrosion resistance, good ductility and malleability, and reasonable tensile strength [2]. The ever-present demand by the electrical industries for the worlds diminishing resources of copper has led industry to look for cheaper materials to replace the now expensive copper alloys. Whilst the metallurgist has been perfecting more ductile mild steel, the engineer has been developing more efficient methods of forming metals so that copper alloys are now only used where high electrical conductivity or suitable formability coupled with good corrosion resistance are required [13]. The copper-base alloys include brasses and bronzes, the latter being copper-rich alloys containing either tin, aluminum, silicon or beryllium [1,3]. Aluminum bronze is a type of bronze in which aluminum is the main alloying element added to copper. It is useful in a great number of engineering structures with a variety of the alloys finding applications in different industries [10]. Aluminum bronze is a type of bronze in which aluminum is the main alloying metal added to copper. A variety of aluminum bronze of different composition have found industrial use, with most ranging from 5% to 11% aluminum by weight, the remaining mass copper, other alloying element such as iron nickel, manganese and silicon are also sometime added to aluminum bronze [5]. The relatively higher strength of aluminum bronze compared with other copper alloys makes it more suitable for the production of forgings, plates, sheets, extruded rods and sections [3, 8]. Aluminum bronze gives a combination of chemo-mechanical properties which supersedes many other alloy series, making them preferred, particularly for critical applications [4]. Aluminum increases the mechanical properties of copper by establishing a face-centred-cubic (FCC) phase which also improves the casting and hot working properties of the base metal [14]. Other alloying elements example magnesium, iron, tantalum, etc. also improve the mechanical properties and modify the microstructure. Nickel and manganese improve corrosion resistance, whereas iron is a grain refiner [6]. Despite these desirable characteristics, most aluminum bronze exhibit deficient response in certain critical applications such as sub-sea weapons ejection system, aircraft landing gears components and power plant facilities. The need to overcome these obvious performance limitations in aluminum bronze is imperative to meet today’s emerging technologies [20]. Structure modification in aluminum bronze is accomplished through any or combination of the following processes; heat treatment, alloying and deformation. The choice of method however is usually determined by cost and effectiveness. The mechanical properties of aluminum bronzes depend on the extent to which aluminum and other alloying elements modify the structure [19, 15]. Hafnium and its alloy exhibit properties that provided unique technological capabilities among refractory metals. It can be used as a hardening element in cast version and also it improves weldability and corrosion resistance of cast alloys [9]. In spite of these wonderful attributes posed by aluminium bronzes, it is surprising to know that not much work have been done on aluminium bronzes in Africa especially in Nigeria. Structural applications are mostly based on ferrous materials, steels in particular [7]. Findings have shown that aluminium bronzes are fast replacing contemporary steel materials for some specific applications especially in components for marine or subsea applications. The consumption of aluminium 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. Aluminium bronze alloy construction for basic oxygen and electric arc furnace hoods, roofs and side vents was identified as a viable alternative for carbon steel construction for these equipments. The use of aluminium alloy was found to be as much as five times the life of comparable carbon steel [6]. This research work examines the effect of chromium on the structural sensitive properties of copper-10%aluminium alloys produced using local techniques, as a potential replacement for conventional structural materials.

Materials and Equipments

Materials and equipment used for this research work are: Pure copper scraps, pure aluminum scraps, chromium metal powder, crucible furnace, stainless steel crucible pot, lath 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

Experimental Procedures

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 chromium 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 (chromium) 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.

Mechanical Test Samples

Copper-10%aluminium alloy without chromium as control sample was selected aside while others containing chromium at various weight p ercentage compositions were selected and machined as per ASTM E8M-04 standards. see figures below.

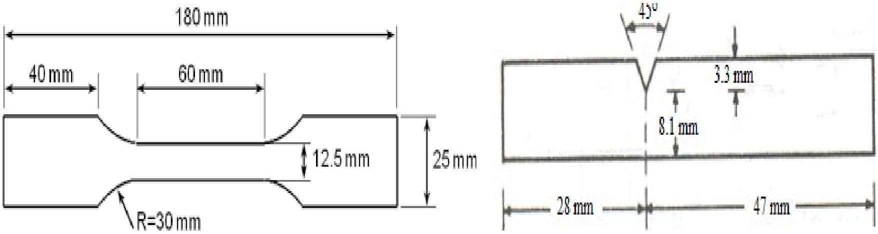


Fig: (i) Tensile test specimen (ii) Notch impact test specime n, (iii) Hardness/microstructure specimen.

Mechanical 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.

Structural Analysis

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.

Results and Discussion

Table 2: Mechanical properties test results

Alloy	Yield Strength (MPa)	Ultimate Tensile Strength (Mpa)	Hardness (Hv)	Elongation %
10%Al (control)	167	331	104	36.04
10%Al+1.0Cr	228	385	129	24.64
10%Al+2.0Cr	298	433	181	23.16
10%Al+3.0Cr	381	484	247	21.56
10%Al+4.0Cr	416	529	293	18.46
10%Al+5.0Cr	441	586	330	15.64
10%Al+6.0Cr	478	605	349	15.14
10%Al+7.0Cr	518	623	381	14.86
10%Al+8.0Cr	488	574	364	17.76
10%Al+9.0Cr	456	549	343	20.46
10%Al+10Cr	441	516	330	16.84

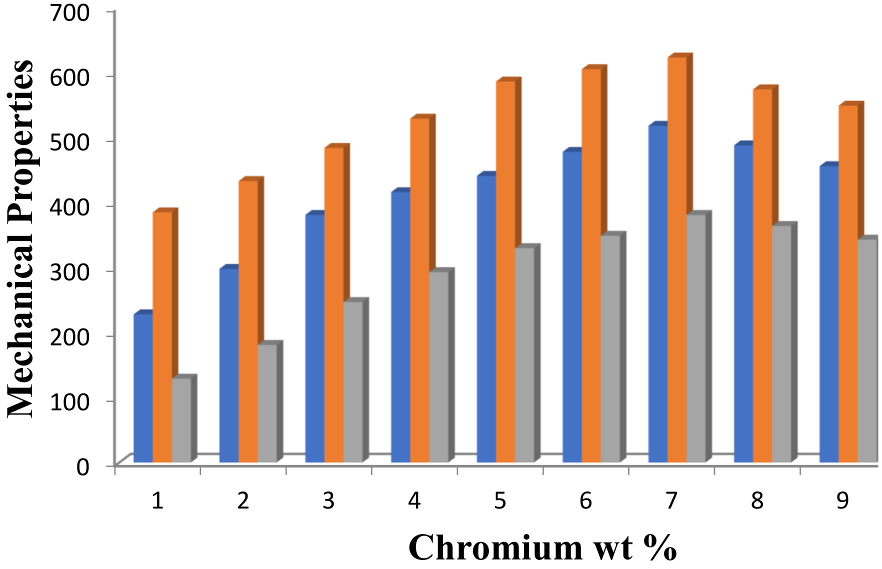


Figure 1; effect of chromium composition on properties of Cu-10%Al alloy.

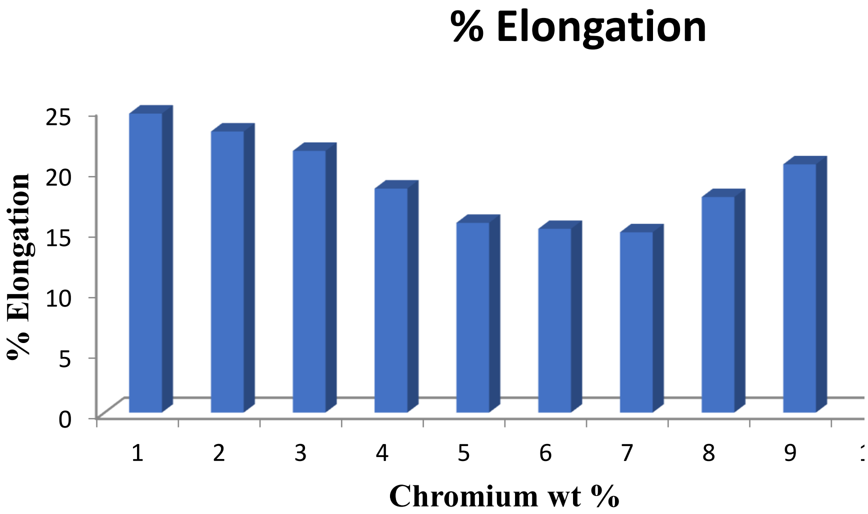


Figure 2; effect of chromium composition on properties of Cu-10%Al alloy.

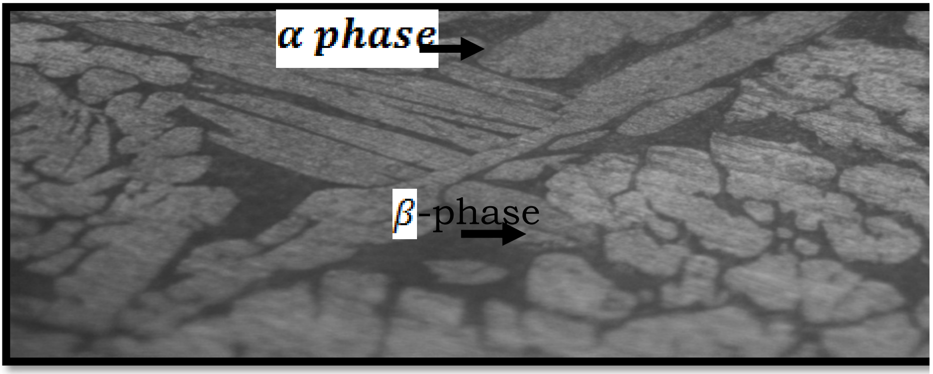


Plate 1: Micrograph of Cu-10%Al (x400)

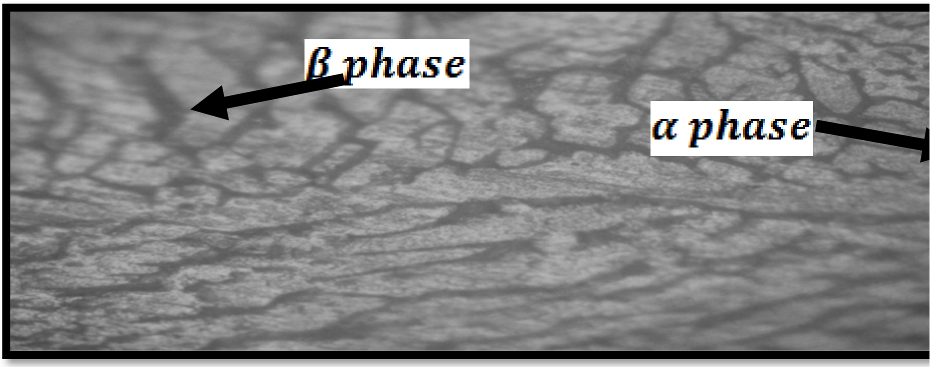


Plate 2: Micrograph of Cu-10%Al +4.0%Cr (x400)

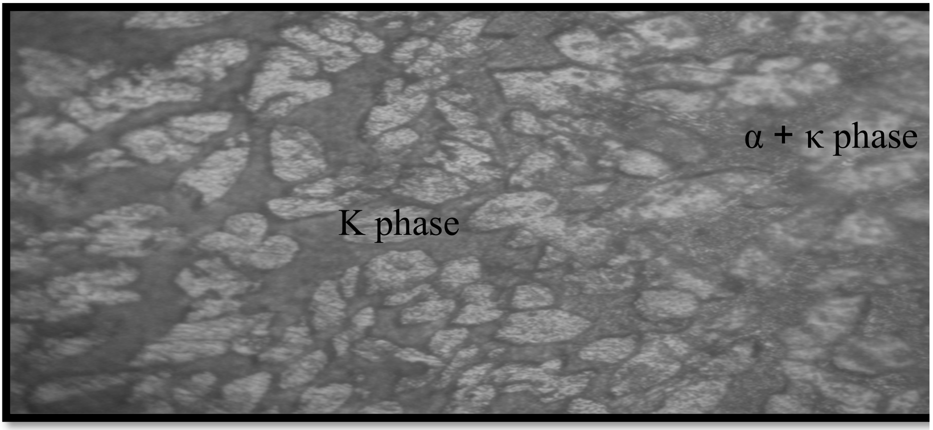


Plate 3: Micrograph of Cu-10%Al +6.0%Cr (x400)

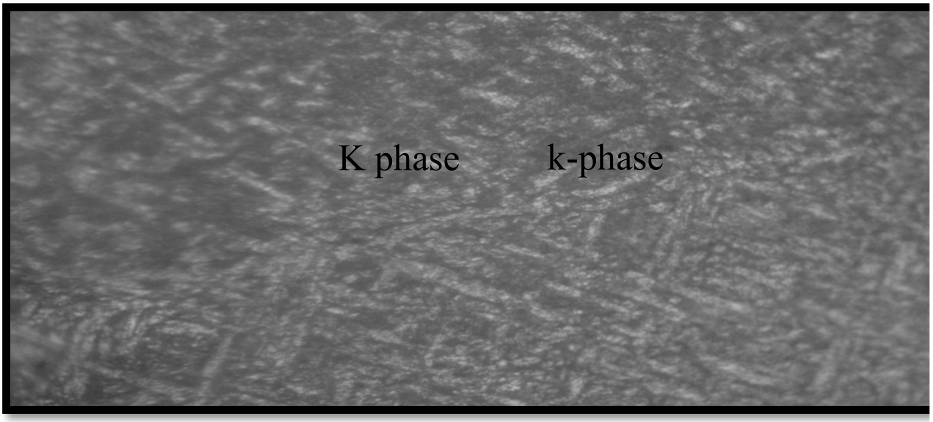


Plate 4: Micrograph of Cu-10%Al +7.0%Cr (x400)

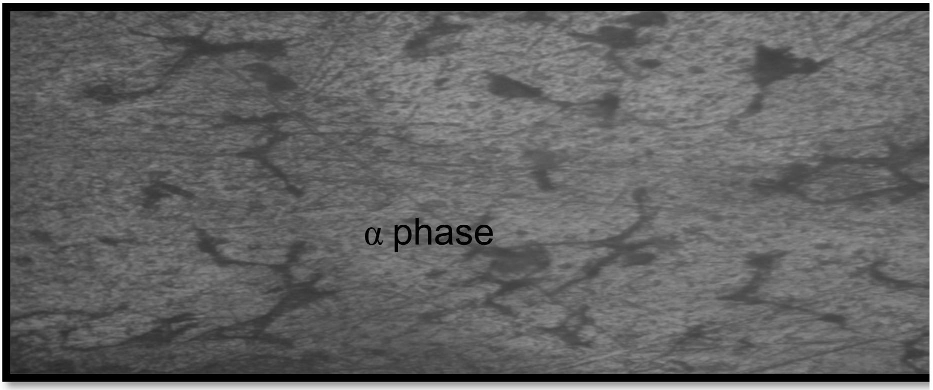
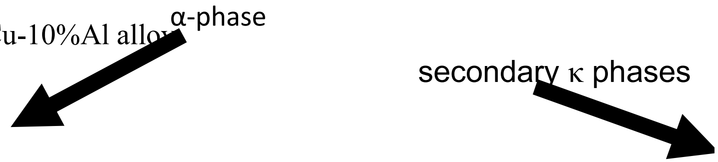


Plate 5: Micrograph of Cu-10%Al +8.0%Cr (x400)

Plate 6: SEM of Cu-10%Al alloy



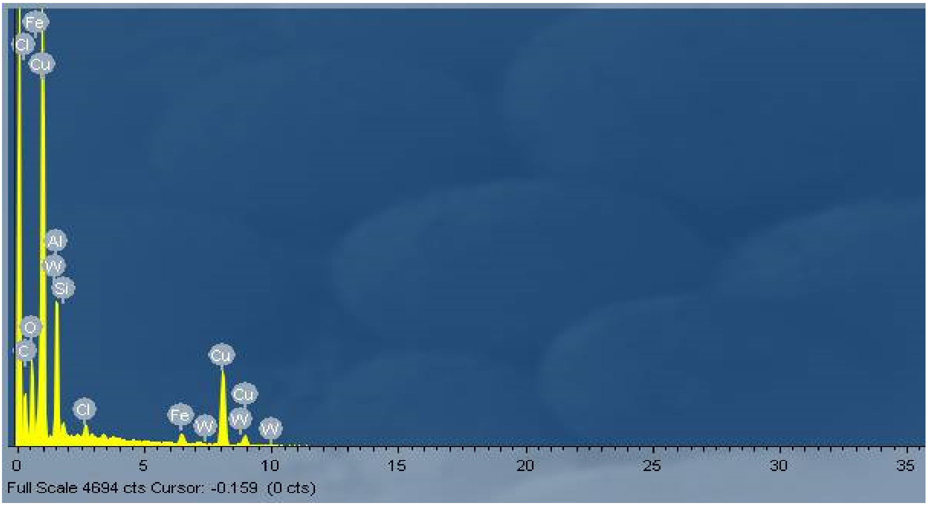


Figure 3: EDX of Cu-10%Al alloy

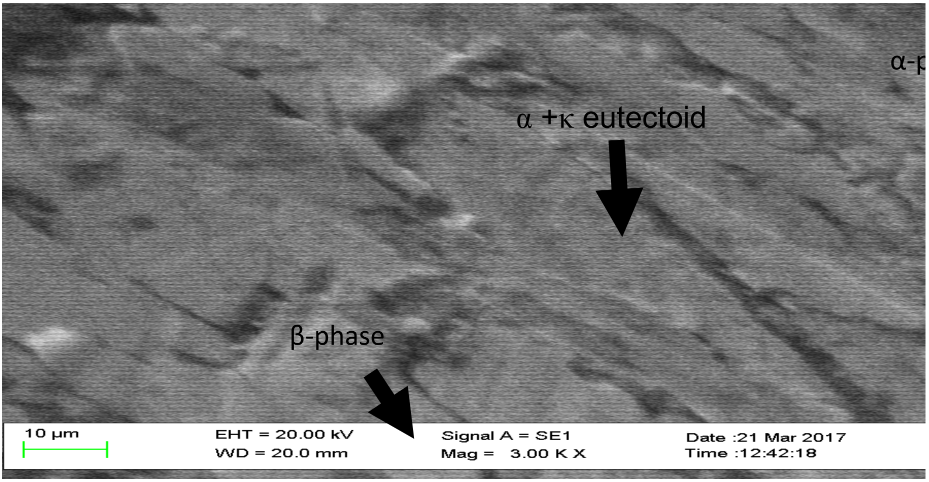


Plate 7: SEM of Cu-10%Al alloy with Cr

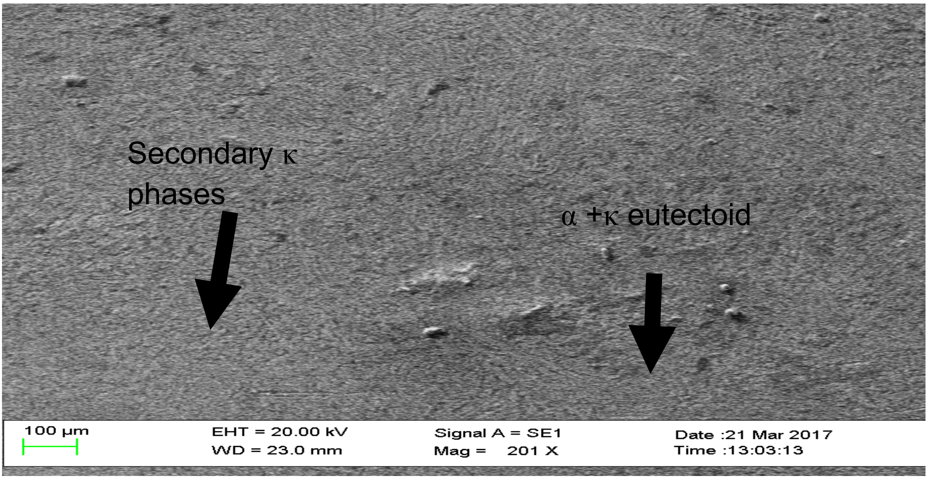


Plate 8: SEM of Cu-10%Al alloy with Cr

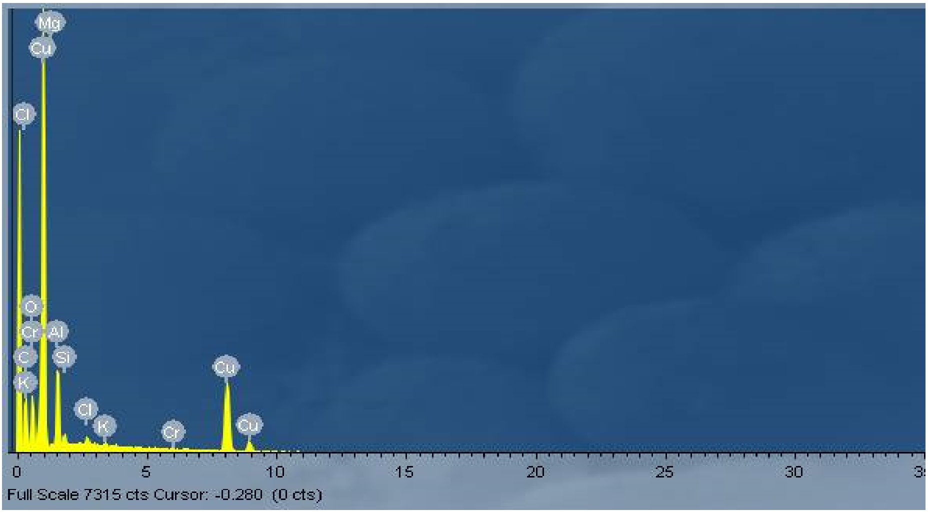


Figure 4: EDX of Cu-10%Al alloy with Cr

Results of the mechanical properties responses by test samples are displayed in Table 1 and Figures 1&2, it was observed that as composition of chromium increased the mechanical properties (hardness, yield and tensile strength) increased while percentage elongation decrease. This treatment significantly improved the hardness, yield and tensile properties of the alloys particularly in the sample containing 7.0% composition of chromium as compared to the sample with zero % composition of chromium though with significant reduction in ductility (elongation). This was probably due to the transformation of the β-phase present in the structure to produce structures of $\alpha + k$ eutectoid in a matrix of α dominance. This structure has no clear area of stress concentration but rather has lamellar shape and processes better combination of mechanical properties. It was observed that after the peak values at 7.0% of chromium composition, yield strength, tensile strength and hardness decreased and elongation increased because of the coarsening of the finely dispersed precipitates as the their content increased.

Structural Analysis with SEM AND EDX

The microstructures developed by the samples are shown in Plates 1 to 8. From plate 1 which is the control sample, it was observed that the microstructure consists of large coarse interconnected intermetallic Cu9Al4 compound and α+ gamma phases. This alloy exhibits the lowest mechanical properties in terms of yield strength, tensile strength, hardness and elongation because of the coarse microstructure. Plate 2 to 8 show the microstructures of Copper-10%aluminium alloy treated with 1-10wt % chromium respectively. Apart from different intermetallic compounds, three major phases were revealed under the optical microscopes, scanning electron microscopy: α-phase, ß-phase and α +κ eutectoid while figure 3 &4 of EDX reveals the elements present in the alloy and their peak. The α-phase increased in size as the composition of chromium increases. This led to the formation of fine lamellar form of kappa (k) precipitates present in the microstructures. Beta-phase decreased in size as the weight percentage composition of chromium increased thereby allowing little or no phase to precipitate. 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 mechanical properties. The amount of the fine lamellar kappa phase within the matrix increased compared to plates (1&2) where fewer kappa phase was observed.

Conclusion

- It was observed from experiments that addition of chromium to copper-10%aluminium alloys stabilizes the beta phase, suppresses formation of gamma phase and brought about refinement in the alloys structure.
- 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 10wt% chromium content.
- Specimen that contains 7.0wt% composition of chromium gave the highest values of mechanical properties with ultimate tensile strength in the range of 623MPa, yield strength of 518MPa, elongation of around 14.86% and hardness values of 381BHN. This agrees with Adeyemi, et.al (2013) that addition of modifying elements like magnesium will increase the mechanical properties of aluminum bronze.

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