Effect of chromium addition on the structure and mechanical properties of aluminium bronze (Cu-10%Al) alloy

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Abstract **- This research work investigated the effect of chromium addition on the structure and mechanical properties of aluminium bronze (Cu-10%Al alloy). The properties studied were tensile strength, yield strength, percentage of elongation using universal testing machine (FIE UTN 40) and hardness using Brinell hardness testing machine B2000 (H). The tests were conducted according to ASTM E8-16a standard. The specimens were prepared by doping 2 - 8wt% of each of the element into Cu-10%Al alloy at 2 percent interval with the help of sand casting method. Microstructural analysis was conducted by using metallurgical microscope-Dewinter Tech. Results obtained showed that hardness, yield strength, percentage of elongation and Ultimate Tensile Strength of aluminium bronze increased with increase in concentration of chromium. Microstructural analysis shows that increase in kappa phase reveals that to improve mechanical properties. Aluminium bronze doped with chromium proved to increase mechanical properties and therefore is recommended for applications in engineering industry for the production of oil industry valve fittings and marine components.**

keywords **- Sand Casting, Aluminium bronze, Chromium, microstructure, Mechanical properties**

I.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. 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. The copper-base alloys include brasses and bronzes, the latter being copper-rich alloys containing tin, aluminium, silicon or beryllium.

Aluminium bronze are copper based alloys with aluminium as the major alloying element usually in the range of 2-14% in the alloy. Other alloying elements such as iron, nickel, manganese, tin and silicon are also added to aluminium bronze depending on the intended applications. Aluminium bronze is useful in a great number of engineering structures with variety of the alloy finding their applications in different industries. They are available in both cast and wrought forms and these offer them good combination of mechanical properties and corrosion resistance. It can be classified in two kinds; the binary aluminium bronze and multi-component aluminium bronze.

Cu-Al alloys offer a combination of chemo-mechanical properties, unmatched by other series which show low rates oxidation resistance at high temperatures and excellent resistance to sulphuric acid, sulphur dioxide and other combustion products. Hence, they are used for applications where their resistance to corrosion makes them preferable to other engineering materials. These features often make aluminium bronze the first choice and sometimes the only logical choice for demanding applications. Aluminium bronzes are finding increasing used in chemical, petrochemical and desalination plants, marine, offshore and shipboard plant, power generation, aircraft, automotive and railway engineering, iron and steel making, electrical manufacturing and building industries. Foundry products achievable from the alloy are propellers, shafts, pumps and valves, water cooled compressor, non-sparking tools. In spite of these wonderful attributes posed by aluminium bronze, aluminium bronze have problem of self-annealing and embrittlement when slowly cooled at normal cooling rate. They exhibit deficient response in certain critical applications such as sub-sea weapons ejection system, aircraft landing gears component and power plant facilities. The need to overcome these obvious performance limitations is imperative to meet today's emerging technology's needs. Structural modification in aluminium 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 aluminium bronze apart from aluminium depend on the extent to which other alloying elements modify the structure. In this regard, this research aims at modifying the structure of Cu-10%Al alloy, by the addition of chromium to impact on the types, forms and distribution of phases within the matrix and their effects on the mechanical properties. Chromium is also one of the most important alloying elements. It increases the resistance to oxidation at high temperature and promotes ferritic microstructure. As a strong carbide formers, its carbide increases edge–holding property and wear resistance. It improves cutting performance due to formation of wear resistant carbides, and improvement of the tempering resistant.

II. MATERIALS AND METHOD

A. Materials and equipment

The under listed materials and equipment were used for this research work; copper scrap, aluminium scrap, chromium powder, weighing balance, crucible furnace, vernier calliper, bench vice, lath machine, electric grinding machine, hack-saw, graphite crucible pot, mixer, scoping spoon, electric blower, rammer, moulding box, hardness testing machine, universal tensile testing machine (model FIE UTN 40), emery papers of different grits, air drying machine, metallurgical microscope-Dewinter tech with digital camera.

B. Method

The methodology adopted to carry out these research essentially involved alloy preparation by melting and casting techniques. The alloying element chromium were added in concentration of 2-8% by weight to molten Cu-10%Al alloy, stirred and sand cast. Subsequently, specimens obtained from the casting were subjected to machining and mechanical test such as ultimate tensile strength, yield strength, hardness and ductility. The microstructure of the samples was also studied using, metallurgical microscope.

III. EXPERIMENTAL PROCEDURE

A. Alloy preparation

The sequence of operations followed to obtain the studied specimens and mechanical test samples include; the use of calculated quantities of copper scrap, aluminium scrap, chromium powder. The materials were weighed out in their appropriate proportions respectively using a weighing balance. Sand mould was prepared and used for the casting of the specimens. Meanwhile, impurities such as metals, hard lumps, stones etc. were removed from the moulding sand using 500µm and 400µm sieves to obtained fine and uniformly distributed grain size. The sand was mixed well in a sand mixing machine with the addition of a little quantity of water to ensure uniform distribution of the ingredients. The foundry floor was cleared of dirty and floor board was put in place. Some moulding sands were sprinkled on the floorboard surface and then patterns were introduced. Sand was introduced and rammed; the ingate runner and risers, plumbago (painting materials), rammers etc. were used to prepare the mould. The patterns were removed and the cavities created were repaired. The pattern removal was done slowly to prevent mould damage. After the pattern was removed and mould repaired, ash was then sprinkled on the cavities to enhance easy flow of the molten metal inside. The furnace used for the melting operation is a pit type crucible furnace with a graphite crucible pot of maximum controlled temperature of about 1500$_o$C. Prior to charging of metal into the furnace, the crucible pot was removed and properly cleaned to avoid contamination by other material inclusion.

B. Melting and Casting of alloys

This operation was carried out to produce five specimens for the mechanical and microstructural analysis. The pit type crucible furnace with graphite crucible pot was pre-heated for about 10minutes. Cu and Al were weighed out. Copper was charged into the furnace pre-set at 1500$_o$C and heated till it melted. Aluminium was then allowed to dissolve in the molten copper for 6minutes and stirred properly to ensure homogeneity. The alloying element chromium were then introduced separately into the melt (Cu-10%Al) based on the compositions, after the control sample had been cast. The melt was manually stirred intermittently in order to ensure homogeneity and facilitate uniformity in the distribution of alloying element. Then molten metal was poured into the mould cavities and allowed to solidify for about 30minutes before removal from the mould.

C. 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 operations were done on the clamped samples with the aid of a cutting tool mounted on the post of lathe machine. Eventually the required dimensions for tensile and hardness test samples as well as microstructure analysis were obtained.

D. Tensile test

The tensile test was conducted using universal testing machine (FIE UTN 40) at room temperature. Specimens for this test were machined to a dumbbell shape which is the required standard specifications so as to fit the grips as shown in Figure 1. The testing process started with the specimen labelled 1 and continued on to 5. The specimens were placed each between the two grips, these held the specimen in place, gradually force is applied on the work piece till it fractured. Different values of force and extension were obtained and recorded. Hence, the specimen were tested to determined their ultimate tensile strength, ductility (%elongation) and yield strength. These properties determined were tabulated in Table 1.

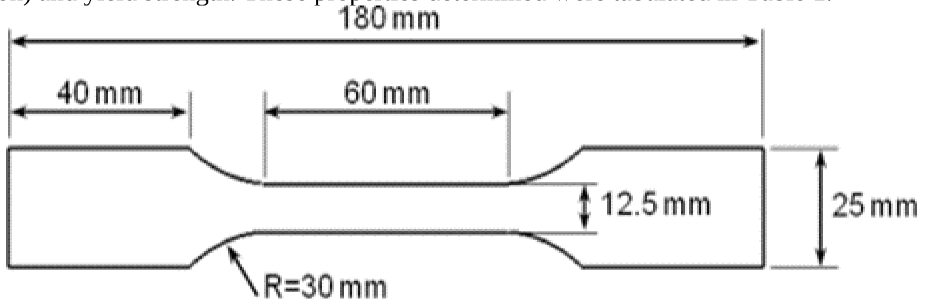

Figure 1: Tensile test specimens

E. Hardness Test

This test was conducted using a Brinell testing machine model B2000 (H). The specimen each 20mm in diameter were polished, placed on an adjusting table below the control panel separately, the table was raised to the focus of the microscope which helped to determine the exact spot for indentation. On pushing the start button on, the microscope returned automatically to its resting position and the spherical indenter was carefully placed on the specimen surface. A specified force was applied and maintained for about 15seconds after which the indenter bounced back to its formal position. The indentation was clearly seen on the monitor of the Brinell testing machine, the diameter of the indentation was obtained by placing four metric lines on the edges of the indentation using hand control knob. The diameter obtained and the force applied was used by the machine to calculate the Brinell hardness of the work piece. Brinell hardness result was displayed on the bottom left hand corner of the monitor. Three indentations were taken on each specimen and the mean was obtained.

F. Microstructural examination

The microstructure of the experimental specimen was studied using metallurgical microscope. In the process, a cubic sample was cut from each of the 5 cast samples. The samples were ground by the use of series of emery papers of different grits with decreasing coarseness from 220, 340, 400, 600, 800, 1000 and 1200 grades and polished using fine α-alumina powder. The specimens were washed thoroughly and dried using the oven dryer. After drying, the specimen were inserted into potassium dichromate which was the etching reagent for about 10-15 seconds and layers of the specimens were attacked chemically until the polished surface were slightly discoloured or dull in appearance. The etched specimens were washed in water to stop the etching action. The specimens were dried and viewed under a high power electron microscope with a magnification(x100, x400) for microstructure analysis and micrographs showing the different morphologies of the cast alloy were taken.

IV. RESULTS AND DISCUSSION

Results of ultimate tensile strength (UTS), ductility (% elongation) and hardness responses by the test specimens are displayed in Table 1 and Figures 2-5 while the microstructures developed by the specimens are shown in plates 1-5. From Table 1 and Figure 2, it could be observed that addition of all the elements within the studied range of composition improved ultimate tensile strength as compared to the control sample (Cu-10%Al). It can further be seen that the rate of increase varied with increase in concentration of the alloying element. Steady increase in UTS of Cu- 10%Al alloy was observed as the composition of chromium increased from 2-8%. Highest ultimate tensile strength value of 151.49MPa in this regard was recorded when 8wt% chromium was added to Cu-10%Al alloy.

Table1. Mechanical properties of Cu-10%Al doped with chromium

Sample Type	UTS (MPa)	Yield Strength (MPa)	Elongation (%)	Hardness (BHN)
Cu+10%Al	79.85	67.08	2.08	99.25
(Cu+10%Al) + 2%Cr	104.75	93.46	0.70	119.02
(Cu+10%Al) + 4%Cr	122.51	112.09	3.10	127.87
(Cu+10%Al) + 6%Cr	140.48	123.94	3.58	144.82
(Cu+10%Al) + 8%Cr	151.49	139.99	4.02	158.24

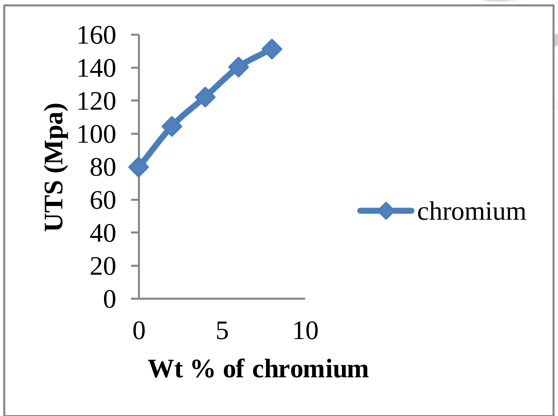

Figure 2: Effect of chromium content on the UTS of Cu-10%Al alloy

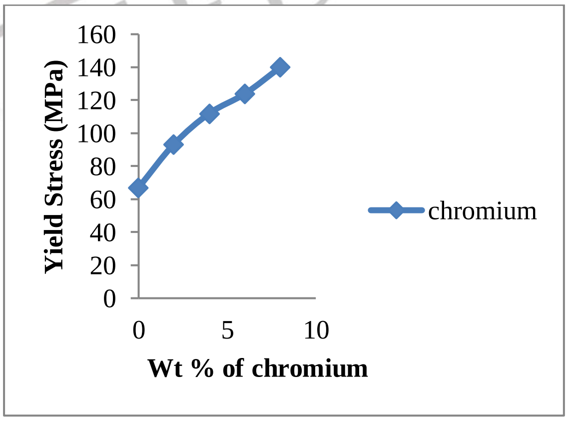

Figure 3: Effect of chromium content on the yield strength of Cu-10%Al alloy

In figure 3, the yield strength of alloy was gradually increased as the composition of chromium is increased. The highest yield stress value is 139.99MPa at 8% chromium is added to aluminium bronze alloy.

In Figure 4, ductility is increased by applying load. It was observed that percentage elongation of Cu-10%Al which is the control sample was higher than that doped with chromium. The %elongation of Cu-10%Al alloy increased as the composition of chromium increased. When percentage composition of chromium increased, the α-phase present in the microstructure increased. This led to formation of kappa-phase. β - phase decreased both in size and quantity thereby allowing little or no gamma 2 (γ2) phase to form. The presence of kappa-phase in the structure (Plate 4 and 5) suppressed the formation of γ2-phase within the matrix and promote the transition of copper matrix from brittle to ductile on addition of chromium.

In figure 5, hardness value increased based on the alloying element chromium is incrased. The highest hardness value is 158.24BHN at 8% of chromium is added to Cu-10%Al alloy.

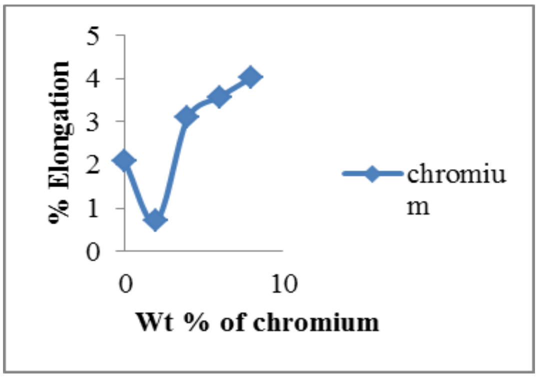

Figure 4: Effect of chromium content on the %elongation Cu-10%Al alloy

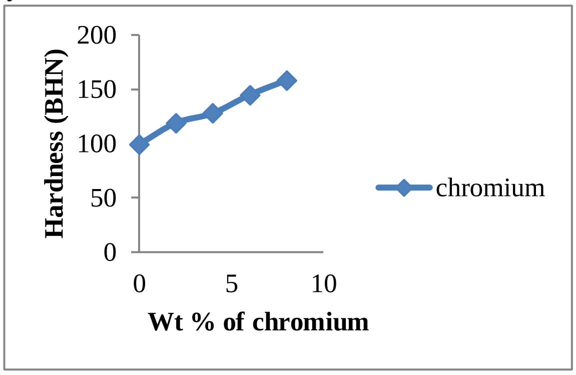

Figure 5: Effect of chromium content on the hardness of Cu-10%Al alloy

Plate 1 to 5 represent the microstructure of aluminium bronze alloy doped with chromium of 2-8wt%. There are three phases formed such as α-phase, β-phase and α + γ2 phase. The α-phase is the region where Al formed solid solution with copper matrix while α+γ2 phase is the intermetallic compound. The intermetallic compound exists in the form of plate like, precipitate through the α-solution from the grain boundaries. This phase is a hard and brittle compound which has a complicated lattice. The eutectoid α+γ2 phase transformed into β-phase.

In plate 1 the microstructure shows dendritic of alpha grains in a matrix of beta phase. In plate 2 the microstructure shows acicular alpha grains in a matrix of beta phase. The microstructure shows that α-phase increased in size as the composition of chromium increases. This significantly led to the formation of fine lamellar form of kappa precipitates present in the microstructure. The combined effect of Cu-10%Al and chromium suppressed the formation of α+γ 2 – phase and produced kappa-phase. The kappa-phase precipitating through the α-region has a pronounced effect on the properties of aluminium bronze and considerably increased mechanical properties. The presence of sparse distribution of kappa- precipitates in predominance of α+γ2 causes smaller grains to emerge in increasing quantity thereby creating smaller lattice distance which resulted in the improvement of mechanical properties.

Thus, chromium improved ductility, UTS, yield strength and hardness in composition of 2-8wt%. The amount of kappa phase within the matrix increased in plate 4 and 5. Few kappa phases only present in plate 2 and 3. This is an indication that presence of more chromium in the system led to increased nucleation sites for the transformation which suppressed the formation of β-phase within the copper lattice, and increased the barrier for dislocation movement.

plate 1

plate 2

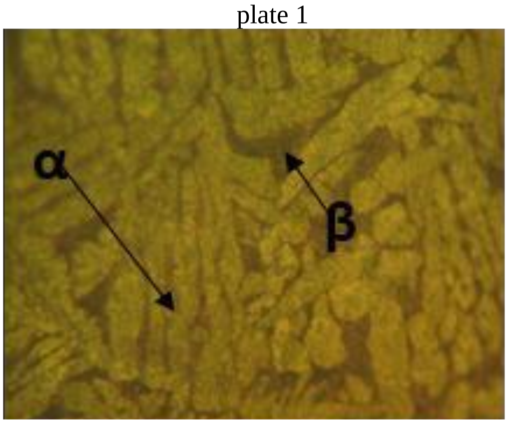

plate 4

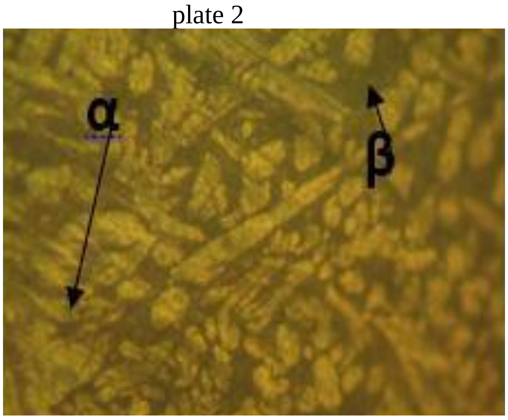

Plate 3

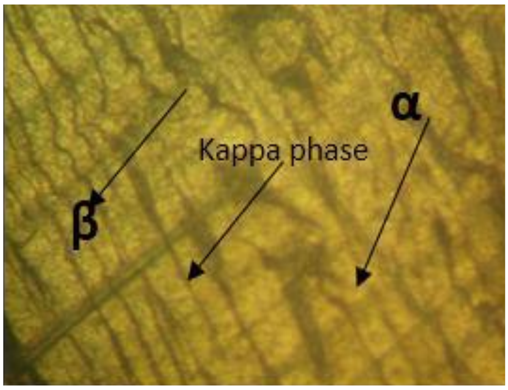

Plate 5

Figure 6: Aluminium bronze morphologies with or without chromium at (1) 0% (2) 2% (3) 4% (4) 6% (5) 8%

V. CONCLUSION

The effect of chromium addition on the structure and mechanical properties of aluminium bronze (Cu-10%Al alloy) has been discussed in detail. The research works has shown that aluminium bronze had improved mechanical properties when doped with chromium. Addition of refractory metal (chromium) increased mechanical properties of aluminium bronze. The phases obtained by casting aluminium bronze in a sand mould are α, β, α+γ2, kappa phase. Increasing chromium content of alloy up to 8wt% will increase UTS, yield strength, hardness and ductility. By increasing the compositions of the alloying elements, the mechanical properties of aluminium bronze improved which is attributable to change in microstructure of the alloy. Aluminium bronze alloyed with chromium (refractory metal) is recommended for making marine fasteners, oil and chemical industry as valve fittings, aerospace landing gear components, welding clamps and bearing bushes.

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