

## Effect of niobium addition on the structure and mechanical properties of aluminum bronze (Cu-10%Al) alloy

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### Abstract

This paper investigated the effect of niobium on the structure and mechanical properties of aluminium bronze. The properties studied were ductility, tensile and yield strengths, using universal testing machine model 50kN, impact strength using charpy machine model IT-30 and Brinell tester model B 3000 (H). The specimens were prepared by doping 1- 10% niobium into aluminium into the aluminium bronze (Cu-10% Al) at interval of one percent. The specimens were prepared according to BS 131-240 standards. Microstructural analysis was conducted using L2003A reflected light metallurgical microscope. Results obtained shows that tensile strength, yield strength, impact strength and ductility increased by 10% respectively. 1% niobium shows increased in hardness result. Microstructural analysis revealed the primary  $\alpha$ -phase,  $\beta$ -phase (intermetallic phases) and fine stable reinforcing kappa phase and these phases resulted to the enhanced mechanical properties. Aluminium bronze doped with niobium proved to increased strength, ductility, and impact strength and reduces hardness and is therefore recommended for applications in engineering and allied industry.

**Keywords:** microstructure, Niobium additives, Structure, Aluminium bronze.

### 1. Introduction

Aluminium bronze is a type of bronze in which aluminium 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 [1]. According to ISO 428 specification [2], most categories of aluminium bronze contain 4-10% wt % aluminium in addition to other alloying elements such as iron, nickel, manganese and silicon in varying proportions. The relatively higher strength of aluminium bronze compared with other copper alloys makes it more suitable for the production of forgings, plates, sheets, extruded rods and sections [3, 8]. Aluminium bronze gives a combination of chemo-mechanical properties which supersedes many other alloy series, making them preferred, particularly for critical applications [4]. Aluminium 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 [5]. 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 aluminium 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 aluminium bronze is imperative to meet today's emerging technologies. Structure 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 bronzes depend on the extent to

which aluminium and other alloying elements modify the structure.

Niobium 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 of cast alloys [9]. This research work aims at modifying the structure of Cu-10% Al alloy, by using niobium and by impacting on the types, forms and distribution of phases within the matrix, and their effects on the mechanical properties.

### 2. Materials and Method

#### 2.1 Materials and equipment

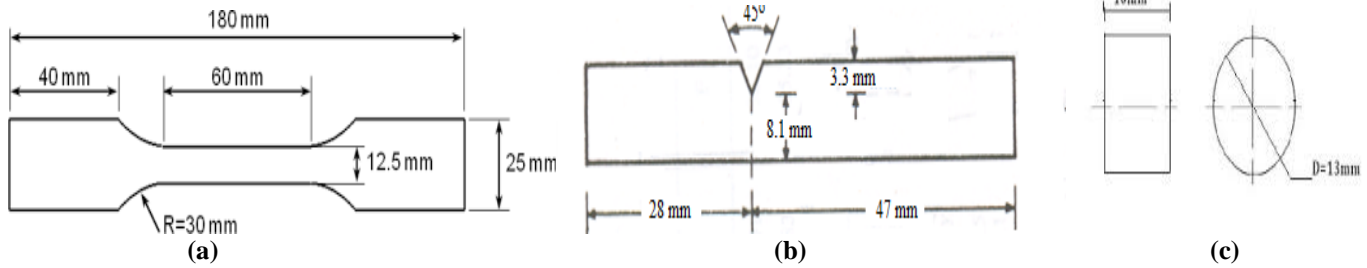
The under listed materials and equipment were used for the research work: Pure copper scraps, pure aluminium scraps, niobium metal powder, weighing balance, crucible furnace, venire calliper, bench vice, lath machine, electric grinding machine, hack-saw, stainless steel crucible pot, mixer, scoping spoon, electric blower, rammer, moulding box, impact testing machine, hardness testing machine, universal tensile testing machine, metallurgical microscope with attended camera, etc.

#### 2.2 Method

**a) Melting and casting of alloys:** This operation was carried out to produce eleven separate specimens for the research work. The crucible furnace was preheated for about 15 minutes. For the control specimen, 153.33g of Cu and 16.67g of Al were measured out. Copper was charged into the furnace pre- set at 1150 °C and heated till it melted. Aluminium was then added and allowed to dissolve in the molten copper for 5 minutes. The alloying element (niobium) was then introduced based on compositions after the control sample had been cast.

The melt was manually stirred order to ensure homogeneity and to facilitate uniform distribution of the alloying element. Sand casting method was used after removal from the furnace and carefully skimming of the drops. The molten metal was poured into the mould cavity. The solidified casting were then removed from the mould after 2 minutes of pouring, cleaned and stored for tests.

**b) Test Specimen:** Aluminium bronze alloy without niobium as sample was selected aside, while others at various weight percentage compositions were selected and machined into standard specimen, see figures below.



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

**(c) Mechanical Test:** The tensile strength was determined with Monsanto Tensometer, while a Brinell hardness machine with 2.5mm diameter ball indenter and 62.5N minimum was used to determine the hardness property. This equation  $BHN = \frac{P}{\left(\frac{D}{2}\right)^2 - \left(\frac{d}{2}\right)^2}$  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 was used to carry out impact strength.

**(d) Metallography:** 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 microstructural examination and micrographs.

**3. Results and Discussion**

Results of the ultimate tensile strength (UTS), impact strength, ductility and hardness responses by test specimens are displayed in Table 1 and Figures 1-4 while the microstructures developed by the specimens are shown in Plates 1-11. Plate 2-11 show the microstructures of Cu-10% Al alloy doped with 1-10wt % niobium respectively. Apart from

different intermetallics, two major phases were revealed under the optical microscopes via:  $\alpha$ -phase and  $\beta$ -phase. The  $\alpha$ -phase increased in size as the composition of niobium increases. This led to the formation of fine lamellar form of kappa ( $\kappa$ ) precipitates present in the microstructures.  $\beta$ -phase decreased in size as the weight percentage composition of niobium increased thereby allowing little or no  $\gamma_2$  phase to precipitate. Presence of sparse distribution of kappa precipitates in the predominated  $\alpha + \gamma_2$  matrix caused smaller grains to emerge in increasing quantity creating smaller lattice distance thereby resulting to improvement of mechanical properties. Plate 11 shows the effect of 10wt% niobium addition on the Cu-10%Al alloy. The amount of the fine lamellar kappa phase within the matrix increased compared to plates (5 and 6) where fewer kappa phase was observed. The presence of more niobium in the system led to increased nucleation sites for the transformation which suppressed the formation of  $\beta$ -phase within the copper lattice, and increased the barrier dislocation movement.

From plate 1 which is the control specimen, it was observed that the microstructure consists of large coarse interconnected intermetallic  $Cu_9Al_4$  compound and  $\alpha + \gamma_2$  phases. This alloy exhibit the lowest mechanical properties in terms of tensile strength, impact strength, ductility and hardness because of the coarse microstructure



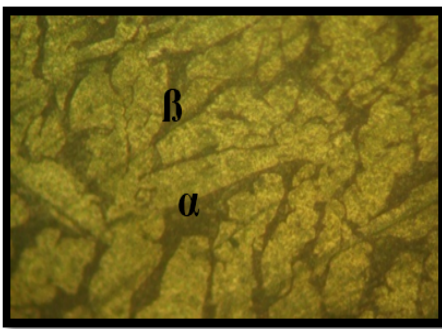


Plate 4

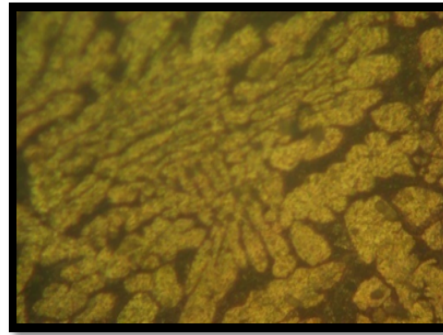


Plate 5

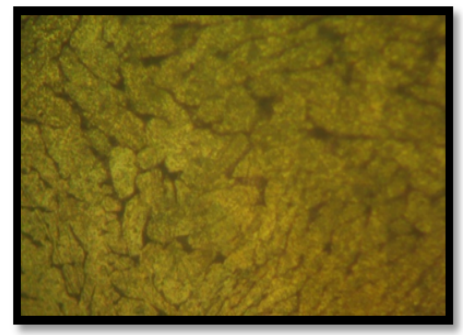


Plate 6

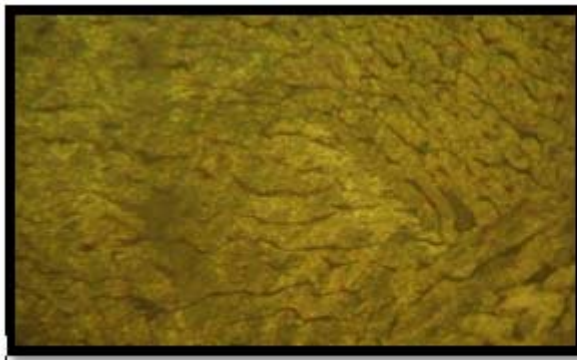
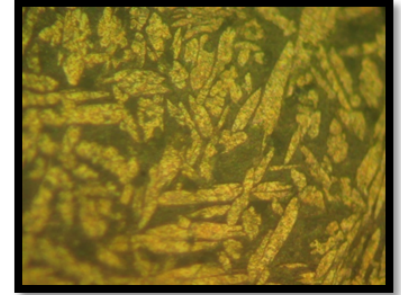
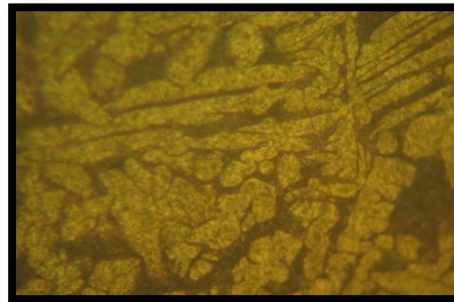
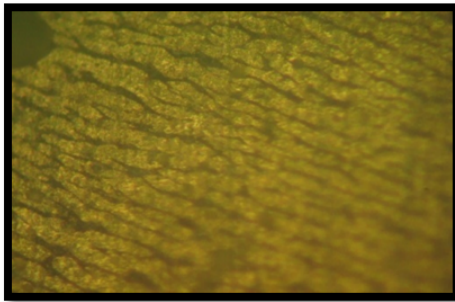


Plate 10

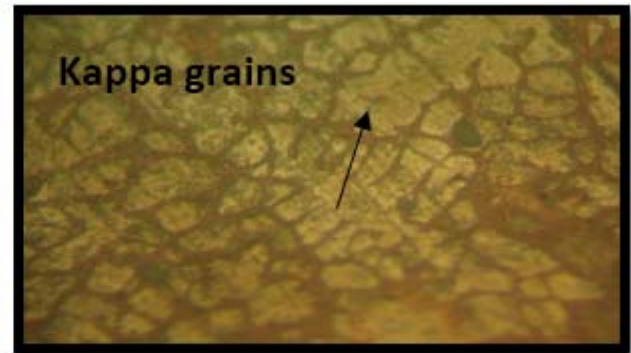


Plate 11

Note: Aluminium- bronze morphologies with/without niobium metal at (1) 0% (2) 1% (3) 2% (4) 3% (5) 4% (6) 5% (7) 6% (8) 7% (9) 8% (10) 9% (11) 10%

Table 1: Mechanical properties of Cu-10%Al doped with niobium

Sample wt%	UTS (MPa)	Yield strength	% elongation	Hardness (BHN)	Impact (joules )
0	144	98	9.30	103	15.1
1	478	281	10.70	118	23.0
2	535	306	12.2	115	24.0
3	647	328	13.17	112	24.2
4	680	337	13.92	108	25.1
5	713	362	14.02	107	26.0
6	745	397	14.35	107	26.0
7	801	438	14.90	105	30.0
8	867	457	15.25	104	31.2
9	915	498	15.60	103	32.0
10	973	515	16.25	105	32.0

Figure 1, 2 and 3 show that ultimate tensile strength, percentage elongation and impact strength of Cu-10%Al alloy increased as the concentration of niobium increased. The figures indicated that the highest values were observed at 10wt% niobium addition. This corroborates the work of

Nnuka (1991) and Ohi-ishi (2004) that also made similar observations. The kappa precipitates are soft, stable and coherent secondary phase in the copper matrix and provided substantial level of impediments to dislocation motion, hence the improvement on the mechanical properties.

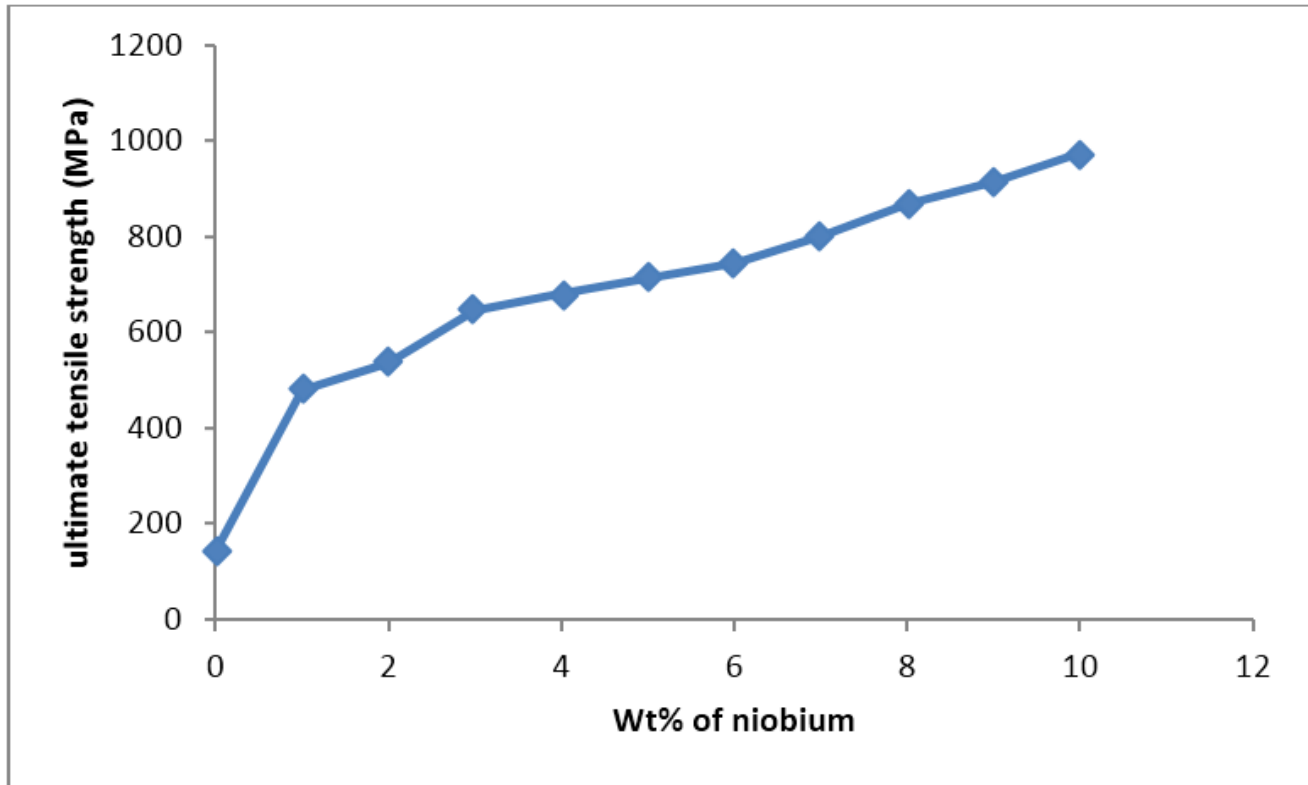
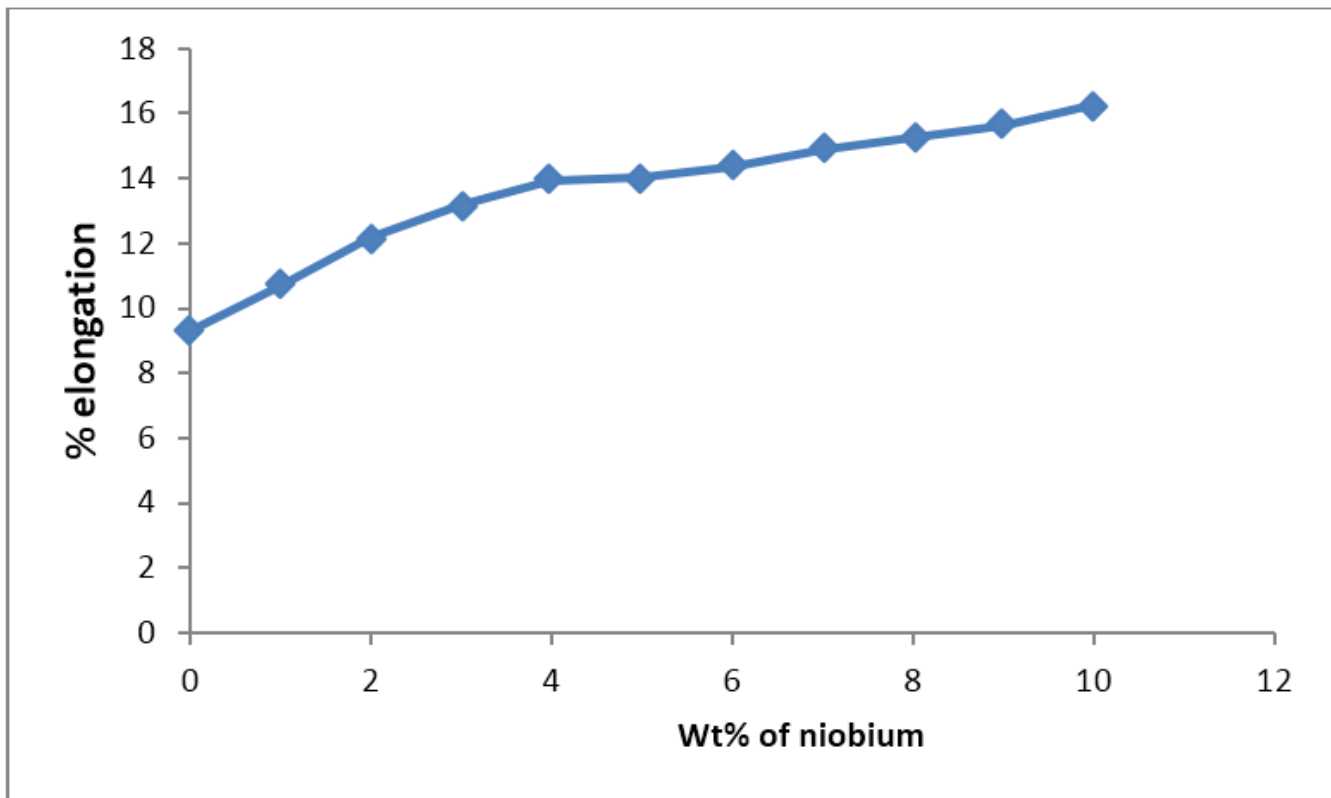
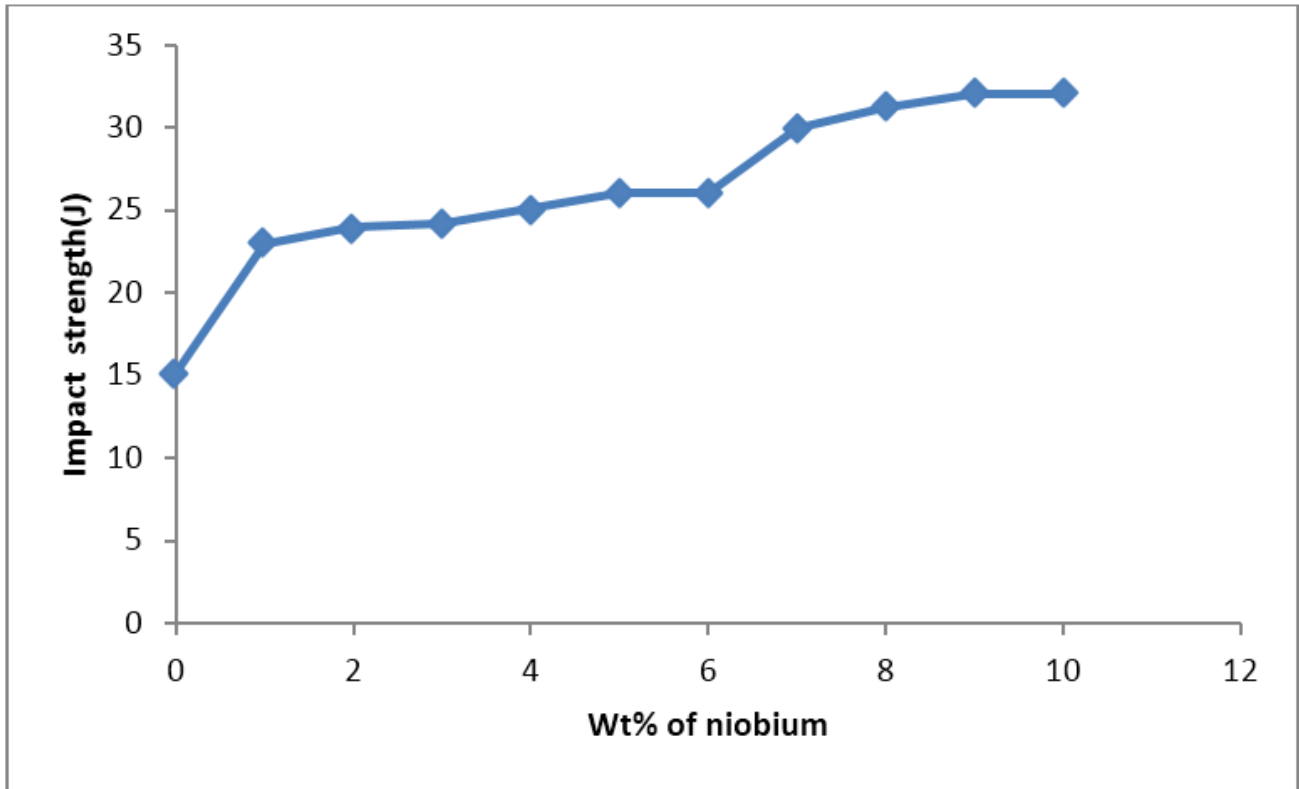


Fig 1: Effect of niobium content on the UTS of Cu-10%Al alloy.



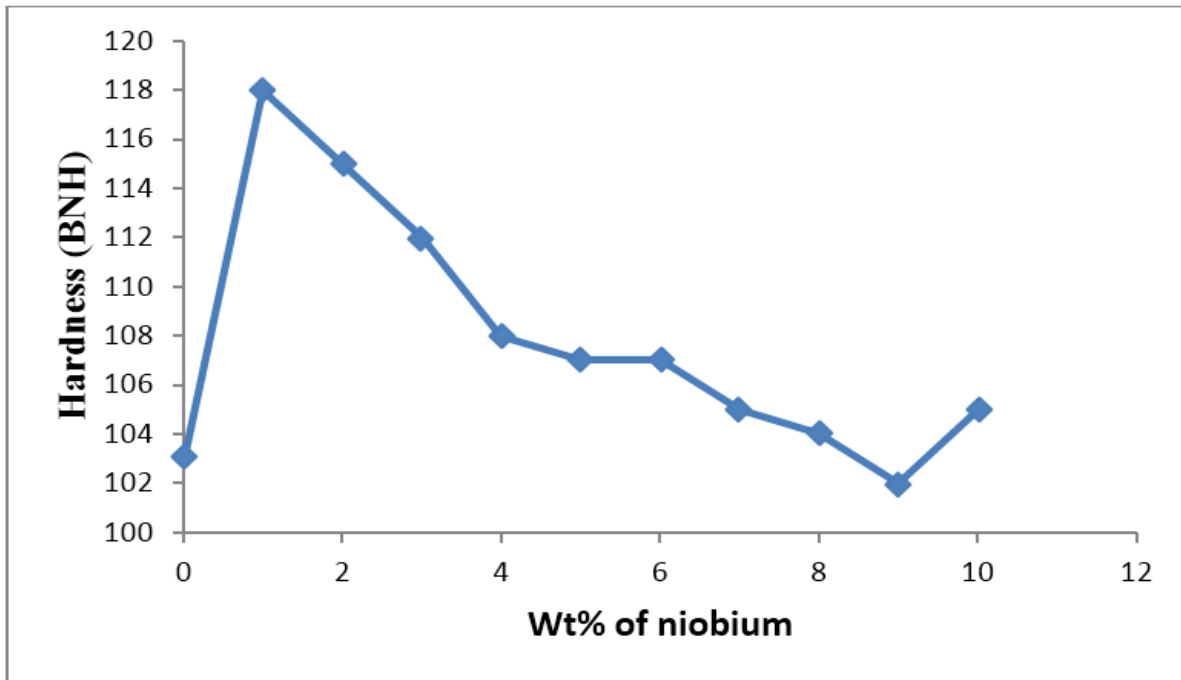
**Figure. 2:** Effect of niobium content on the % elongation of Cu-10%Al alloy



**Fig 3:** Effect of niobium content on the impact strength of Cu-10%Al alloy

Figure 4 also revealed that hardness of Cu-10%Al doped with niobium decreased as the composition of niobium increased. This was duly observed from 1-5wt% niobium addition. From 6-10wt%, an increase in hardness value was noted. The trend is an indication that extent of hardness induced in the alloy was determined by the proportion of  $\beta$ -phase present. Plates 2-

4 show the formation of  $\beta$ -phase with smaller quantity of alpha grains. The  $\beta$ -phase is harder and more brittle than the  $\alpha$ -phase.



**Fig 4:** Effect of niobium content on the hardness of Cu-10%Al alloy

#### 4. Conclusion and recommendation

This research work has shown that addition of niobium to aluminium bronze enhanced improvement of the mechanical properties. In summary, the overall results of this study have shown that aluminium bronze had an improved mechanical properties and structure when doped with niobium (refractory metal). The high value of UTS, yield strength, ductility and impact strength, reduces the cause of failure in engineering designs and construction.

As the concentration of the alloying element increased,  $\alpha$ -phase precipitated through the process of nucleation and growth to form fine lamellar kappa grains. Hence, these grains provided substantial level of impediments to dislocation movement, thus improved the mechanical properties.

Aluminium bronze alloyed with niobium is recommended to be used as a substitute for making propeller in sea-going vessel, landing gear component of aircraft as against aluminium bronze alloyed with silicon.

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