Physical and Mechanical Characterization of Aluminum Bronze (Cu-10%Al) Alloy with Tungsten

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Abstract - This paper investigates the addition of tungsten on the physical and mechanical properties of aluminium bronze. Despite some of the desirable characteristics most aluminium bronze exhibits, abysmally deficient responses in certain critical applications necessitate mechanical properties enhancement. The properties studied were electrorestivity, tensile strength, hardness and impact strength. Universal testing machine model 50kN were used to test for tensile strength, impact strength using charpy machine model IT-30 and Brinell tester model B 3000 (H). The specimens were prepared by modifying 0.5-5.0% tungsten into the aluminium bronze (Cu-10% Al) at interval of 0.5 percent. The specimens were prepared according to BS 131- 240 standards. Microstructure analysis was conducted using L2003A reflected light metallurgical microscope. Results show that optimum improved physical and mechanical properties were achieved at 3.0wt% tungsten addition with ultimate tensile strength (UTS) of 788MPa which represents 9.12% improvement over conventional aluminium-bronze. The alloy also demonstrated impact resilence of 89.27J and hardness value of 239 BHN and electrorestivity value of 5.58mm.Tungsten presence in the aluminium bronze system induced a stable reinforcing kappa phase by nucleation mechanism which resulted to enhancement of mechanical properties.

Keywords:- Aluminium-bronze, tungsten, physical and mechanical properties, microstructure.

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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 [12]. According to ISO 428 specification [13], most categories of aluminium bronze contain 4-10% wt of aluminium in addition to other alloying elements such as iron, nickel, manganese and silicon in varying proportions. 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 [4]. Aluminium bronze gives a combination of chemo-mechanical properties which supersedes many other alloy series, making them preferred, particularly for critical applications [8]. 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 [1]. 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 [15]. In recent times non-ferrous metals and alloys

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have become so important that technological development without them is unconceivable. Among the most important non-ferrous metals is copper with its alloys [5]. 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 [3]. 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 [6]. Micro alloying is a technique used to strengthen and harden metals. In this technique, the atoms of the alloying elements (impurity atoms) go into either substitutional or interstitial solid- solution, and distort the lattice structure of the solvent and offer resistance to dislocation movement. This resistance is greater with interstitial element [20]. Superior alloy with improved mechanical and corrosion properties can be obtained by addition of alloying elements in micro quantity [2]. Micro alloying technology was originally developed for micro alloyed steels. Although the amount of micro alloying elements is usually less than 1%, they lead to improved combinations of strength and ductility, weldability, toughness, and corrosion resistance [6]. Micro alloying is basically to improve the mechanical properties such as strength, hardness, rigidity, corrosion resistance and machinability, and also sometimes to improve the fluidity and other casting properties [19]. The copper-base alloys include brasses and bronzes, the latter being copper-rich alloys containing tin, aluminum, silicon or beryllium [7]. 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 [13]. 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 [18]. Kaplan and Yildiz (2003) investigated on the mechanical properties and microstructures of an aluminum bronze subjected to some physical treatments. In particular, the solidification structure, the effects of solution treatment, tempering heat treatment and mold types on the microstructure of the aluminum bronze produced in two different molds were examined.

The result showed that the heat treatments have some interesting effect on the mechanical properties, microstructures and phase transformation temperatures of the samples. It was observed that $\alpha + \beta i$ *and* $\alpha + \beta i$ phase transformation were formed depending on both the die casting and the heat treatments, but in contrast $\alpha + \beta$ phase were formed sand-casting specimen.

Sami et al (2007) investigated the improvement of casting condition for some aluminum bronze alloys. They used two types of aluminum bronze alloys in order to determine the proper methods of melting and casting in two different conditions; with treating materials as (Albral 2, Lagos 50 and deoxidizing tube (E3) and without determining the effects of these conditions on mechanical properties of alloys. The alloys were (a) Aluminum bronze alloys (ABl) and (b) Nickel-aluminum bronze alloys (AB2). These alloys were produced with different melting processes and cast method. The first one was made by preparing the charge materials to be melted and then, to the cast process without using any types of additions and treatment materials. The second one was made with casting conditional control, proper techniques of casting were employed and protective layers were used to minimize the oxidation and other casting defects. The molten metals from both processes were poured into two types of moulds; sand and metal moulds, both types were in dimensions (ϴ100x250) mm. The final products of each type of alloys in each type of conditions were used to perform many types of inspections; chemical analysis, visual test, structure examinations, hardness test and tensile test. The results of all processes and inspections showed that the properties of alloys which were treated and casted in metal moulds were better than that casted in sand moulds. These alloy castings were free from shrinkage cavities, inclusions and porosities due to using suitable sequence in alloy contents melting, no overheat, reducing the melting lime, selecting non-turbulence casting method and suitable selection of pouring temperatures. The mechanical properties (hardness and ultimate tensile strength) for treated nickel-aluminum bronze alloys (T-AB2) were found to be better than that for other alloys. The current study investigates the quantity of tungsten particles weight percent addition in aluminium bronze that confers improved physical and mechanical properties that makes the material suitable for engineering applications.

2. Experimental Procedure

Materials and equipment used for this research work are: Pure copper wire, pure aluminium wire, tungsten metal powder, crucible furnace, stainless steel crucible pot, lath machine, electronic weighing balance, venire calliper, bench vice, electric grinding machine, hack-saw, mixer, scoping spoon, electric blower, rammer, moulding box, hardness testing machine, universal tensile testing machine, impact testing machine, metallurgical microscope with attended camera, etc.

2.1 Method

Melting and casting of alloys

The tungsten was sieved to remove tramps and other hard lumps to obtain smooth (homogenous) stream of particles. Further sieving of the tungsten was carried out to obtain 170-250μm fine particle size. Melting of aluminum bronze, it was placed in a crucible pot and charged into a pit furnace to be heated until molten. Then, measured proportions of fine tungsten at 0.5 to 5.0 wt% were added to the molten aluminum bronze and stirred thoroughly using a long stainless steel tong. The molten mixes were homogenised at 1100oC for 10 minutes and then cast in prepared metal moulds.

Test Specimen: Aluminium bronze alloy without tungsten as control sample was selected aside, while others containing tungsten at various weight percentage compositions were selected and machined into standard specimen.

Mechanical Test: The tensile strength were carried out with Monsanto Tensometer, while a Brinell hardness machine with 2.5mm diameter ball indenter and 62.5N minimum was used to determine the

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hardness property, Charpy impact test machine was used to carry out impact strength.

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 microstructure examination and micrographs.

Table 1: Mechanical properties of Cu-10%Al modified with Tungsten

Alloy	UTS (MPa)	Hardness (BHN)	Elongation %	Impact Strength (Joules)	e.m.f β. 10⁻⁶	ρ.10⁻⁸ mm
Cu-10%Al	431	104	28.04	64.70	5.28	9.35
Cu-10%Al+0.5W	491	115	26.41	66.13	6.08	8.91
Cu-10%Al+1.0W	549	138	24.49	69.26	6.75	8.20
Cu-10%Al+1.5W	627	156	22.56	74.37	7.16	7.48
Cu-10%Al+2.0W	683	193	19.81	78.48	7.88	6.79
Cu-10%Al+2.5W	723	229	15.96	83.63	8.37	5.03
Cu-10%Al+3.0W	788	239	12.13	89.27	8.82	4.58
Cu-10%Al+3.5W	752	224	16.10	84.89	8.48	5.39
Cu-10%Al+4.0W	711	210	18.03	80.73	8.23	6.14
Cu-10%Al+4.5W	642	208	21.00	78.54	8.08	7.03
Cu-10%Al+5.0W	606	193	25.83	73.41	7.83	8.86

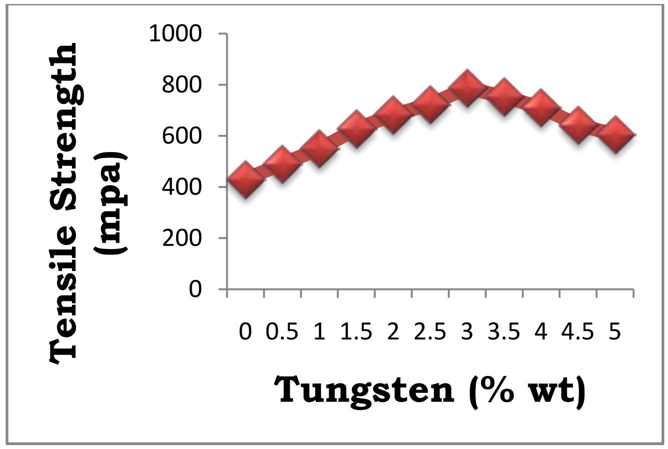

Figure 1. The effect of Tungsten composition on UTS of Cu-10%Al alloy

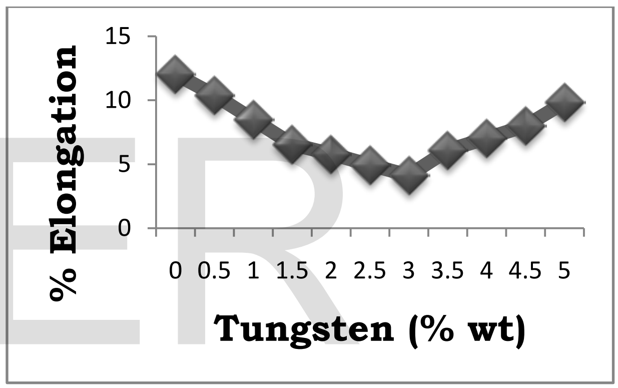

Figure 2. The effect of Tungsten composition on % Elongation of Cu-10%Al alloy.

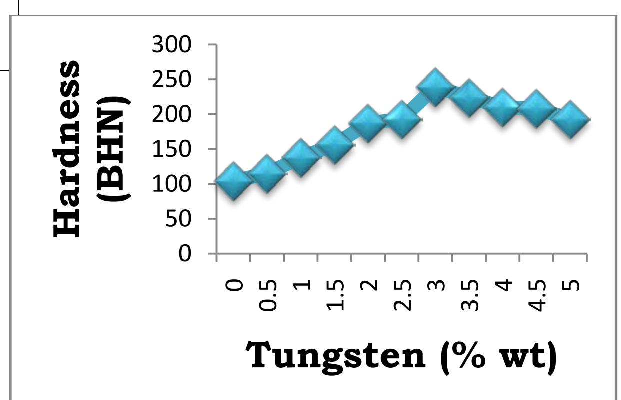

Figure 3. The effect of Tungsten composition on Hardness (BHN) of Cu-10%Al alloy.

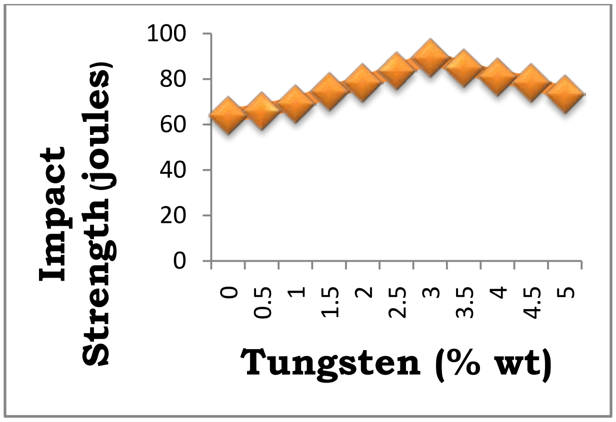

Figure 4. The effect of Tungsten composition on Impact Strength (joules) of Cu-10%Al alloy.

3. Results and Discussion

The results of the effect of tungsten additions on the physical, mechanical properties and microstructure of Cu-10%Al alloy were presented in tabular and graphical form. Table 1 and Figures 1&4 shows the variation of ultimate tensile strength, hardness strength impact strength, elongation and electrorestivity to percentage of tungsten addition to alloy while the microstructures developed by the treated alloys are shown in Plates 1-11.

4. Physical, Mechanical properti es and microstructure

Impact energy

The dynamic strength characteristics of aluminum bronze at varied tungsten addition are shown in Figure four. Given that there is correlation between static and dynamic strength of a material, the response of the alloy under dynamic load is valid. The highest impact energy of 89.27J that fractured the specimens was obtained at 3 wt% tungsten addition in the alloy. This agrees well with literature as the impact energy of a material is structure dependent [10]. The optimum impact energy of 89.27J is high than the base value which is 64.70J. Hence, the type of microstructure developed in the alloy significantly influenced the alloy toughness responses which correspond to the fractions of coherent reinforcing precipitates present in the matrix. For instance, the best toughness supporting microstructure consisting of fine lamellar kappa precipitates was induced in the alloy at 3.0 wt% tungsten addition whereas at 4.0wt%, the precipitates appeared coarse and clustered exhibiting impact energy of 80.73J. Similar microstructural features developed at both 4.5 wt% and 5.0 wt% tungsten contents further diminish the alloy impact strength. This gave rise to the low impact energy of 78.54J and 73.41J respectively.

Elongation (Ductility) and Electrorestivity

Figure three shows the alloy's response with respect to its percentage elongation under deformation. The curve is slightly showing reduction in elongation as tungsten addition increases and as well as the electrorestivity. This trend is an indication that the alloy ductility was influenced by the amount of tungsten in its matrix. Generally, the extent of linear stretch a material suffers is a measure of its formability since the phenomenon incorporates both elastic and plastic deformation responses [3]. However, percent elongation is majorly influenced by the strain-hardening capacity of an alloy in which the material's micro-constituents suffered significant flow before dislocation tangle sets-in. In the present study, the combination of clustered precipitates, coupled with the presence of other intermetallics (Fe-Al) dispersed at the grain boundaries must have sustantially impaired the alloy ductility with tungsten addition. Notwithstanding, the inducement of fine lamellar kappa precipitates within fine needle-like alpha matrix supports ductility exhibited by the alloy at tungsten addition.

Ultimate Tensile Strength

Figure one illustrates the tensile strength of aluminium bronze at different 0-5.0 wt% tungsten addition. The flow curve is indicating an optimum ultimate tensile strength of 788MPa at 3.0 wt % tungsten addition which is about 9.12 percent above the tensile strength of base aluminium-bronze which is usually in the range of 431MPa. The tensile strength flow curve pattern must have been due to the different microstructures developed in the alloy at varying amount of tungsten addition. The inducement of varying fractions of kappa (κ) precipitates in alpha (α) aluminium matrix, their morphology and size significantly influenced the alloys response under tensile load. This is in line with the work of Oh-Ishi and Mcnelly (2004) that also made similar observation. The kappa precipitates, being a stable and coherent secondary phase in the matrix provided substantial level of impediment to dislocation motion which increased the alloy strength in proportion to the amount of fine lamellar kappa precipitates present. Gradual decrease in strength from 752-606 MPa, was observed as tungsten content increased from 3.5-5.0 wt% while the minimum value of 606MPa was exhibited at 5.0 wt%. The development of coarse kappa reinforcing precipitates at 3.5 wt% tungsten additions was responsible for decrease in UTS and clustering of the precipitates at 4.0 wt% and 5.0 wt% tungsten additions further compromise the reinforcing influence of the precipitates.

Hardness

The surface strength of the alloy in term of ability to resist wear and indentation at varying amount of tungsten addition is illustrated in Figure three. It is evident that the extent of hardness induced in the alloy is determined by the proportion of hard and fine lamellar kappa (κ) precipitates present in the matrix of each specimen. The control specimen exhibited the least hardness value of 104BHN due to the absence of requisite reinforcing phase in its structure. This might have paved the way for the precipitation of a rather deleterious and soft gamma () phase within the matrix as tungsten was not added to the system. However, the preponderance of fine kappa precipitates in higher amounts above the soft needle-like alpha grains that were induced at 3.0 wt% tungsten addition support modest increase in hardness value of 239BHN.

CONCLUSION

The processing of aluminium bronze for enhanced physical and mechanical properties through the addition of tungsten was investigated. The presence of tungsten particles in the alloy significantly influenced the microstructure which affected the alloy properties. In summary, the overall results of this study show that:

- Optimum combination of UTS, ductility impact toughness and hardness are attainable with 3.0 wt% of tungsten addition which is superior to the base aluminium-bronze alloy. Fine lamellar and coherent kappa phase can be evolved in aluminium-bronze using tungsten particles without quenching or fast cooling process as stated by Cenoz (2010). The aluminium bronze-tungsten alloy developed is recommended for application as structural members in automobiles, aerospace and allied engineering facilities.

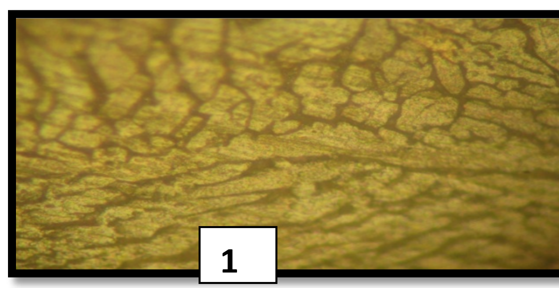

Plate 1: Micrograph of Cu-10%Al(x400)

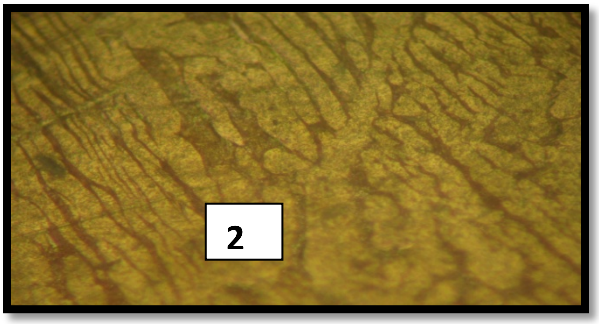

Plate 2: Micrograph of Cu-10%Al +0.5%W(x400)

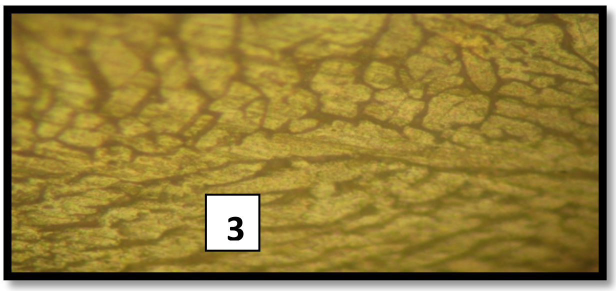

Plate 3: Micrograph of Cu-10%Al +1.0%W(x400)

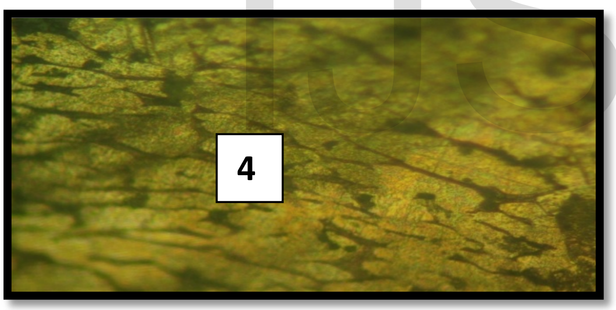

Plate 4: Micrograph of Cu-10%Al +1.5%W(x400)

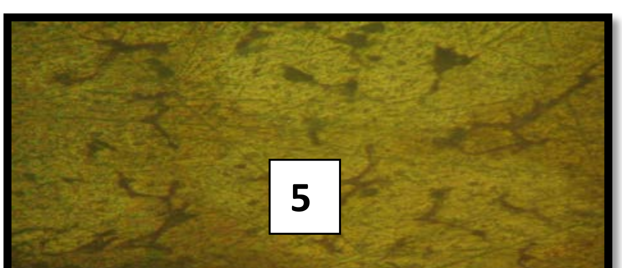

Plate 5: Micrograph of Cu-10%Al +2.0%W(x400)

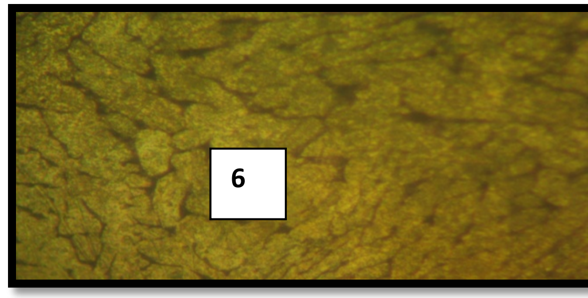

Plate 6: Micrograph of Cu-10%Al+2.5%W.(x400)

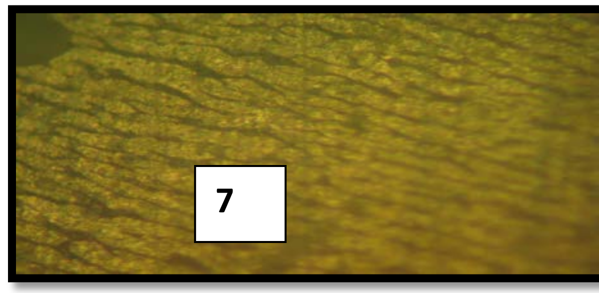

Plate 7: Micrograph of Cu-10%Al+3.0%W(x400)

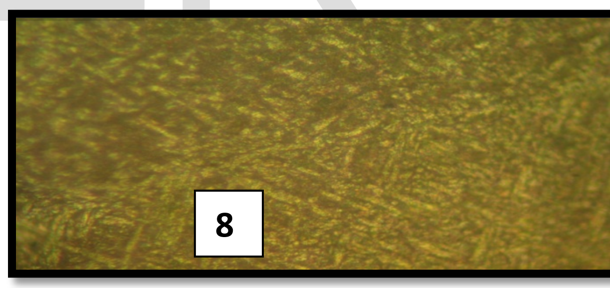

Plate 8: Micrograph of Cu-10%Al +3.5%W(x400)

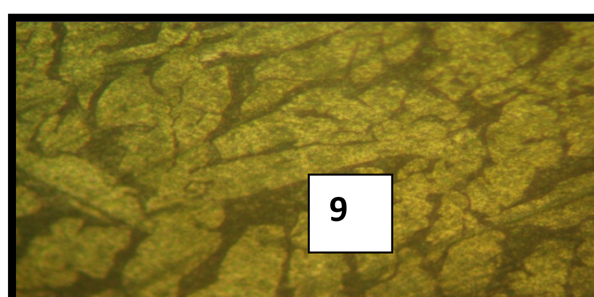

Plate 9: Micrograph of Cu-

10%Al+4.0%W(x400)

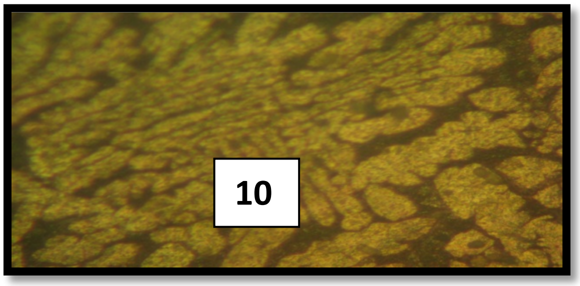

Plate 10: Micrograph of Cu-10%Al+4.5%W(x400)

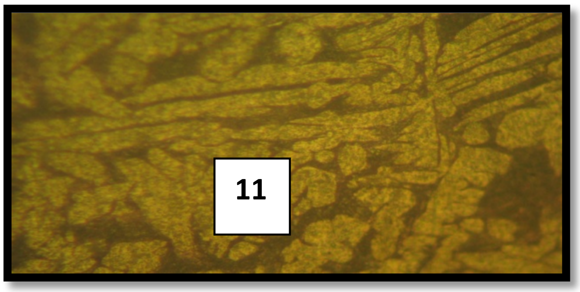

Plate 11: Micrograph of Cu-10%Al+5.0%W(x400)

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