



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

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ABSTRACT

This paper investigates the effect of addition of Fe on the mechanical properties of aluminum Cu-10%Al bronze. Despite some of the desirable characteristics, most aluminum bronze exhibits, abysmally deficient responses in certain critical applications necessitate mechanical properties enhancement. The properties studied were tensile strength, hardness and impact strength. Universal Testing Machine (UTM) with load 50kN and Brinell tester Gunt model B 3000 (H) were utilized in the study. The specimens were prepared after using varying amounts of Fe, from 0.5-5.0% wt. to dope the aluminum bronze (Cu-10% Al) at interval of 0.5 percent. The specimens were prepared according to BS 131- 240 standards. Results show that optimum improved mechanical properties were achieved at 3.0wt% Fe addition with ultimate tensile strength (UTS) of 785MPa which represents 9.12% improvement over conventional aluminum-bronze. The alloy also demonstrated impact resilience of 87J and hardness value of 230 BHN.

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INTRODUCTION

Aluminum bronzes are a family of copper-based alloys that contain aluminum as the primary alloying element, typically in the range of 4% to 12%, according to ISO 428 specification [1] These alloys are renowned for their excellent combination of mechanical properties and corrosion resistance. The primary constituents of aluminum bronzes are copper (Cu) and aluminum (Al), but they can also include other alloying elements like iron (Fe), nickel (Ni), manganese (Mn), and silicon (Si) in varying proportions to achieve specific properties. Aluminum bronzes give a mix of chemo-mechanical properties superseding many other alloy series. This make them to be most preferred particularly for demanding applications [1] "Aluminum

bronzes are most valued for their high strength and corrosion resistance in a wide range of aggressive media" [2 , 4] They are most commonly used in applications where their resistance to corrosion makes them preferable to other engineering materials. Another notable property of aluminum bronzes are their biostatic effects. The basic properties of copper alloys are largely influenced by copper itself [3, 5] The copper component of the alloy prevents colonization of marine organisms including algae, lichens, barnacles and mussels, and therefore can be preferable to stainless steel or other non-cupric alloys in applications where such colonization would be unwanted. 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 [4,5] Aluminum bronzes are finding increasing application in chemical, petrochemical, desalination plant, marine, power generation, air- craft, automotive, iron and steel making, electrical and building industries. Foundry products achievable from the alloy are impellers, propellers, shafts, pumps and valves, water cooled compressors, non-sparking tools. Aluminum bronzes are finding increasing application in chemical, petrochemical, desalination plant, marine, power generation, aircraft, automotive, iron and steel making, electrical and building industries. Aluminum bronze castings are produced by sand, shell, die, investment and centrifugal casting [5 ,6] Aluminum bronze is a material found to exhibit a short cooling range characteristic [7], therefore its feasibility of production via sand casting technique locally and its corrosion behavior compared to conventionally produced aluminum bronze alloys need to be investigated. One of the conventional ways of producing this alloy has been via centrifugal casting [8] Sand casting technique in the production of aluminum bronze alloy is more economical and an easier route for the production of aluminum bronze alloy in developing country like Nigeria.

Their resistance to atmospheric corrosion combined with high strength is exploited, for example in their use for bearing bushes in aircraft frames. Aluminum bronze also show low rate of oxidation at high temperatures and excellent resistance to sulphuric acid, sulphur dioxide and other combustion product and are therefore used for the construction of items exposed to either or both these conditions. For example

aluminum bronzes are used very successfully for inert gas fans in oil tankers.[9] These operate under highly stressed conditions in a variable but very corrosive atmosphere containing salt-laden water vapor, sulphurous gases and carbon. Maximum corrosion resistance is provided by control of the composition. Corrosion resistance depends upon the formation of a thin protective film or layer of corrosion products which prevents or substantially slows down the rate of attack. The aluminum content of aluminum bronze impacts the ability to form very rapidly, an alumina-rich protective film which is highly protective and is not susceptible to localize breakdown and consequent pitting in the presence of chlorides. Aluminum bronzes are also very resistant to corrosion by sea water and probably find more use in sea water service than in any other environment. [10]

Virtually all metals and alloys in common use are susceptible to some extent to crevice corrosion, that is accelerated attack within or just at the edge of areas shielded by close proximity to other component or by deposits on the surface. Crevice corrosion in service is particularly objectionable when it takes the form of pitting as in stainless steels which form deep pits of very small cross section in waters of high chloride content or severe surface roughening on shafts or valve spindles in the way of bearing or seals.[11] Any crevice corrosion of aluminum bronze, however takes the form of minor selective phase dealloying, which results in little reduction of strength and practically low impairment of surface finish. Aluminum bronze are therefore, very widely used for pump shafts and for valve spindles-situations where pitting corrosion in crevices makes stainless steels unsuitable.

Metal failures in service are often caused by the combined influence of



corrosion and mechanical factors, the most common being stressed corrosion, which occurs under the simultaneous action of high tensile stress and an appropriate corrosive environment and corrosion fatigue which occurs under cyclic stressing in a corrosive environment. High resistance to stress corrosion cracking is an important reason why aluminum bronze is being used by the British Navy for under water fastenings. High resistance to corrosion fatigue is essential for marine propellers and it is principally for that reason that most large propellers are made from nickel aluminum bronze. This materials is quite outstanding in resistance to corrosion fatigue in sea water, been much superior to high tensile brass or to stainless steels.[12] Manganese aluminum bronze, which is also used for large propellers, also has high corrosion fatigue strength though somewhat inferior to nickel aluminum bronze. Turbulent water flow conditions can cause local erosion of the protective films on which alloys depend for their corrosion resistance and result in localized deep attack by combination of corrosive and erosive action. The corrosion/erosion resistance of the aluminum bronze is substantially higher than that of the brasses and similar to that of 70/30 copper-nickel which is generally recognized to be one of the alloys most resistant to this type of attack.

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 [18]. Kaplan and Yildiz investigated 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 moulds 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 is 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 in sand casted specimen. Sami et al [19] investigated the improvement of casting condition for some aluminum bronze 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 aluminum bronze that confers improved physical and mechanical properties that makes the material suitable for engineering applications.

MATERIALS AND METHODS

Materials

Materials and equipment used for this research work are: pure copper wire, pure aluminum wire, tungsten metal powder, crucible furnace, stainless steel crucible pot. Lathe machine, electronic weighing balance, venire caliper, 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, and metallurgical microscope with attended camera.

Methods

Melting and Casting of the Alloys

The iron filings were grinded and sieved to remove tramps and other hard lumps to obtain smooth (homogeneous) stream of particles. Further sieving of the filings was carried out to obtain 170-250 μ m fine particle size. It was placed in a crucible pot and charged into a pit furnace and heated until molten. Then, measured proportions of fine Fe at 0.5 to 5.0 wt% were added to the molten aluminum bronze and stirred thoroughly using long stainless steel tong. The molten mixes were homogenized at 1100 $^{\circ}$ C for 10 minutes and the cast in metal moulds.

Test Specimen: Aluminum bronze alloy without addition of Fe as control sample was selected aside, while others containing Fe at various weight percentage

compositions were selected and machined into standard specimen.

Mechanical Test: The tensile strength were carried out with the Universal Testing Machine (UTM), while a Brinell hardness machine (Gunt) with 2.5mm diameter ball indenter and 62.5N minimum load was used to determine the hardness property, charpy impact test machine was used to carry out impact strength. After the tensile strength tests, percentage elongation was determined for each of the samples.

RESULTS AND DISCUSSION:

The results of the effect of adding Fe to the aluminum bronze are shown in Table 1 and Figures 1-4. The results show the variation of Tensile Strength, Impact Strength, Hardness and percentage elongation of the specimens under vary percentage of Fe addition.

Table 1: Variation in mechanical properties with increased Fe (wt) addition

S/N	Alloy	Fe Addition (wt)	Tensile Strength (MPa)	Hardness (BHN)	Impact (J)	% Elongation
1	Cu-10Al	-	425	98	62	27
2	Cu-10Al	0.5	481	105	65.3	26.2
3	Cu-10Al	1.0	536	130	68.1	23.5
4	Cu-10Al	1.5	617	148	71.02	32
5	Cu-10Al	2.0	678	188	75.1	18.9
6	Cu-10Al	2.5	715	215	84.2	16
7	Cu-10Al	3.0	775	220	87.1	12.2
8	Cu-10Al	3.5	755	226	84.7	15.7
9	Cu-10Al	4.0	760	215	80.04	17
10	Cu-10Al	4.5	715	210	77.1	22
11	Cu-10Al	5.0	650	189	72.2	24.6

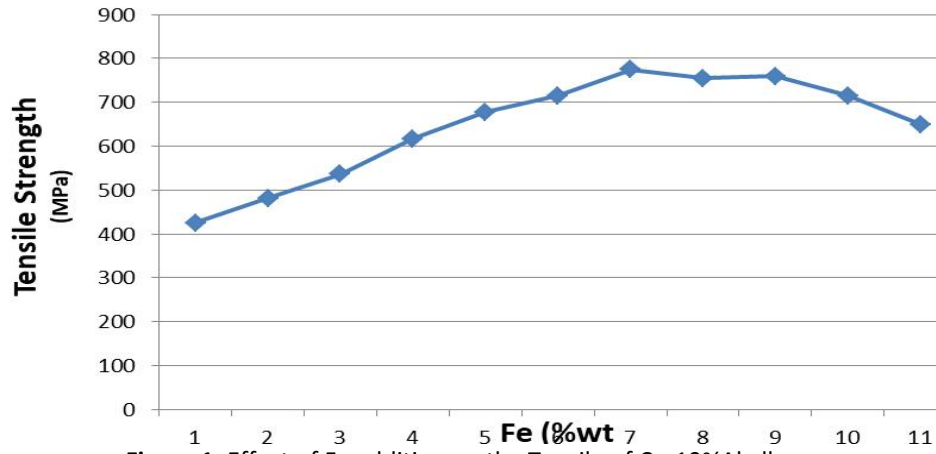


Figure 1: Effect of Fe addition on the Tensile of Cu-10%Al alloy

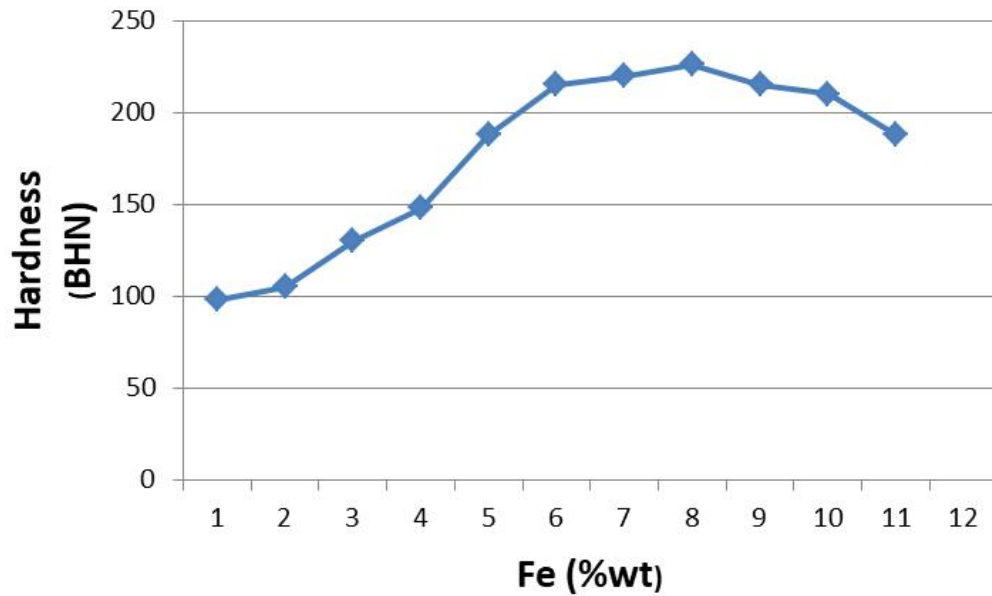


Figure 2: Effect of Fe addition on the Hardness of Cu-10%Al alloy

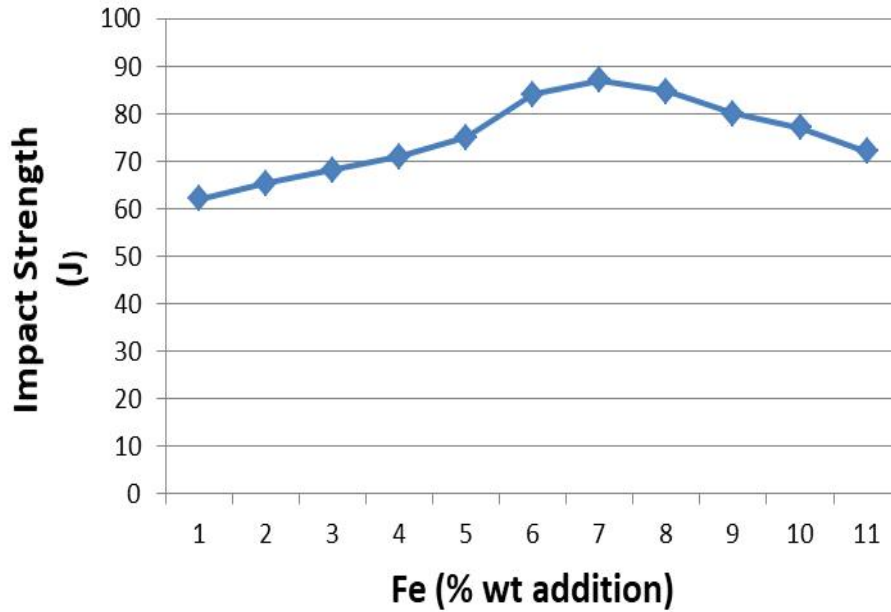


Figure 3: Effect of Fe addition on the Impact Strength of Cu-10%Al alloy

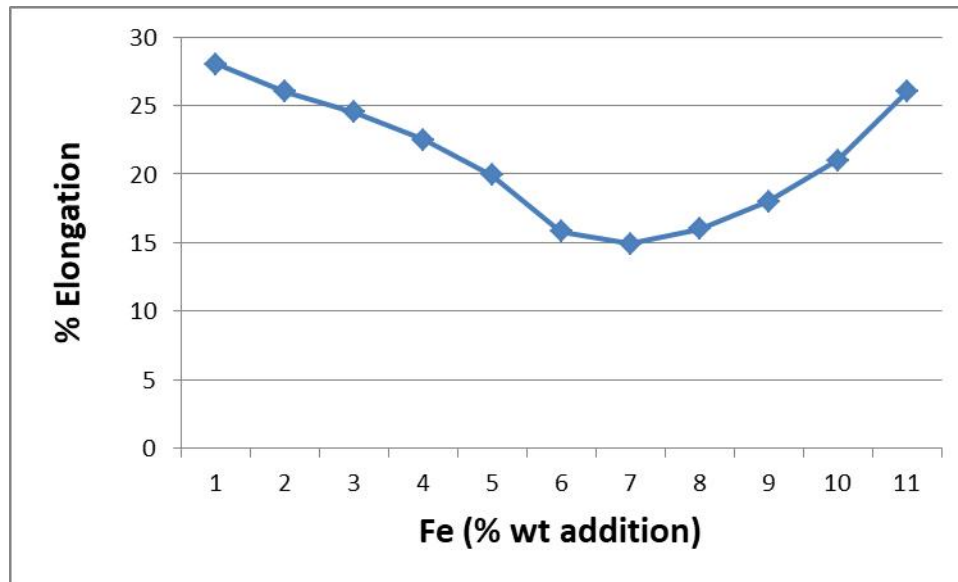


Figure 4: Effect of Fe addition on the % Elongation of Cu-10%Al alloy



The result of Tensile Strength indicates an optimum tensile strength of 785Mpa at 3.0 wt% Fe addition which is about 9.12 percent above the tensile strength of base aluminum-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 Fe addition. The inducement of varying fractions of kappa (κ) precipitates in alpha (α) aluminum matrix, their morphology and size significantly influenced the alloys response under tensile load. This is in line with the work of Ohishi and Menelly that also made similar observation. The Hardness of the alloy in terms of ability to resist wear and indentation at varying amount of Fe addition is illustrated in Figure 2. 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 98BHN 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. 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 226BHN. 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 87J that fractured the specimens was obtained at 3 wt% Fe 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 higher than the base value which is 62 J. Hence, the type of microstructure developed in the

alloy significantly influenced the alloys toughness responses which correspond to the fractions of coherent reinforcing precipitates present in the matrix.

Figure 3 shows the alloy's response to its percentage elongation under deformation. The curve is slightly showing reduction in elongation as Fe addition increases and as well as the electrostivity. This trend is an indication that the alloy ductility was influenced by the amount of Fe 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. However, percent elongation is majorly influenced by the strain hardening capacity of an alloy in which the materials micro-constituents suffered significant flow before dislocation tangle sets-in. in the present study, the combination if clustered precipitates, coupled with the presence of other intermetallic (Fe-Al) dispersed at the grain boundaries must have substantially impaired the alloy ductility. Notwithstanding, the inducement of fine lamellar kappa precipitates within fine needle-like alpha matrix supports ductility exhibited by the alloy at Fe addition

CONCLUSION

The processing of aluminum bronze for enhanced physical and mechanical properties through the addition of Fe was investigated. Results of this study show that: optimum combination of UTS, ductility impact toughness and harness are attainable with 3.0 wt% of Fe addition which is superior to the base aluminum-bronze alloy. Fine lamellar and coherent kappa phase can be evolved in aluminum-bronze using Fe particles without quenching or fast cooling process as stated Cenoz. The aluminum bronze-tungsten alloy developed is recommended for application



as structural members in automobiles, aerospace and allied engineering facilities.

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