© 2017 IJSRSET | Volume 3 | Issue 2| Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section: Engineering and Technology

Effect of Soaking Time and Quenching Media on the Structure and Mechanical Properties of Aluminium Bronze (Cu-10%wt.Al)

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ABSTRACT

The main objective of this research was to investigate the effect of soaking time and quenching media on the structure and mechanical properties of aluminium bronze (Cu-10%wt.Al). Sand casting method was adopted in casting the samples. Standard specimens were prepared from the as-cast and heat treated samples for tensile, hardness and impact strength tests as well as microstructural analysis according to standard. The samples were solutionized at temperature of 900^{o}C for 30, 60 and 180mins and quenched in water, brine and SAE 40 respectively. The tensile, hardness and impact strength test were conducted using JPL tensile strength tester (Model: 130812), dynamic hardness tester and impact testing machine (U1820) respectively. The alloy microstructures were studied using an optical metallurgical microscope (Model: L2003A). Microstructural analysis result indicated coarse sparse distribution of $\alpha + \gamma 2$ precipitates in the as-cast specimen and presence of fine pearlite ($\alpha + \gamma 2$) in a matrix of α dominance in the heat treated specimens. The presence of coarse intermetallic compounds (β`- phase) was revealed as the soaking time increased. The obtained results indicated that heat treatment significantly improved all the tested mechanical properties except the impact strength. Optimum ultimate tensile strength and hardness values of 710MPa and 513MPa respectively were recorded for the specimen solutionized at 900^{o}C for 30 minutes and quenched in water and brine respectively. Among all the quenching media used, brine gave the best combination of mechanical properties.

Keywords: Soaking Time, Quenching Media, Solutionizing Temperature, Properties

I. INTRODUCTION

The consumption of aluminium bronzes has increased significantly in the world due to their mix of chemo-mechanical properties which supersede many other alloy series. These properties are toughness, corrosion resistance in a wide range of aggressive media and marine environment, wear resistance, low magnetic permeability, non-sparking characteristics, excellent castability, excellent machinability and weldability in either cast or wrought form [1]. These excellent properties, favourably comparing with low alloyed steels and cast irons, make aluminium bronzes one of the most versatile engineering materials [2].
Aluminium bronzes are copper based alloys with aluminium as the major alloying element usually in the range of 5% - 14% [3]. Aluminium bronzes are used for parts intended for the chemical industry, for power and electrical equipment, coins, sliding contacts, parts of bearings, shafts, bolts, sieves and high pressure flange for sub-sea weapons ejection system, clutch components for shipboard winch, propellers, landing gear components on aircraft, wear rings for hydro-turbine, impellers shafts, pumps and valves, exchanger parts, non-sparking tools and tube sheets etc [4]. Commercially, pure copper is very soft, ductile and malleable with low tensile strength, containing up to about 0.7% total impurities [3]. Various engineering applications demand high strength, therefore substantial increase in strength of pure copper is paramount in order to increase its applications. This can be obtained by alloying, heat treatment and cold working [5].

This research work was propelled by the study of Uyime et al., [6] which revealed the presence of coarse intermetallic compound (α + $\gamma 2$) in the structure of slowly cooled aluminium bronze (Cu-10%wt.Al) alloy. The structure has negative impact on the mechanical properties of the alloy. So, this experimental study is aimed at investigating the effect of soaking time and quenching media on the structure and mechanical properties of aluminium bronze alloy.

Various researches have been conducted on the effect of heat treatment techniques on the structure and mechanical properties of aluminium bronze. Uyime et al [6] revealed that normalizing gave the optimum mix of tested mechanical properties with ultimate tensile strength value of 325MPa, elongation of around 60% and Rockwell hardness values of 46.5 - 63.7 HRc. Jinquan et al [7] established that heat treatment under 1GPa refined the microstructure; however, it showed little effect on composition of phases and hardness. Praveen and Prabhash, [8] indicated that heat treated alloy attained superior tensile strength and elongation as compared to that in the as-cast condition. The study of Praveen and Prabhash, [8] revealed that aged samples attained higher hardness and tensile strength than the solutionized specimens while their elongation tended to follow a reverse trend. The compressive strength of the heat treated alloy samples was less than that of the as-cast alloy while the aged samples attained higher strength compared to the solutionized ones. Mechanical characterization of aluminium bronze-iron granules composite was investigated by Sekunowo et al., [1]. Cast samples of the alloy contained varied amount of iron from 2-10 wt%. The samples were homogenized at 1100^{o}C for 10minutes in order to relieve the as-cast structures. The results showed that optimum mechanical properties were achieved at 4 wt% Fe addition with ultimate tensile strength (UTS) of 643.8MPa which represented 10.1% improvement over conventional aluminium bronze. The alloy also demonstrated impact resilience of 83.9J and micro-hardness value of 88.7HRB. Prabhash and Praveen, [9] revealed that the hardness of heat treated alloy increased after solutionizing and ageing treatments compared to the as cast one. Also, the samples aged at 400^{o}C for 3 hrs attained the highest hardness. Abdul and Praven, [10] indicated that as-cast Cu-Al-Fe alloy specimens showed granular structure consisting of primary α, eutectoid α+$\gamma 2$ and Fe rich phase. The study revealed that solutionizing heat treatment led to microstructural homogenization by way of the elimination of the dendrite structure and dissolution of the eutectoid phase and other micro-constituents to form the single phase structure consisting of β. This was followed by the formation of the β' martensite, retained β and α. Ageing brought about the transformation of the martensite and other microconstituents into the eutectoid phase [10]. The specimens that were solutionized at 850^{o}C for 2hrs obtained the highest hardness in the category of solutionized specimens while ageing at 300^{o}C for 2 hrs offered maximum hardness amongst the aged specimens. The as-cast specimens obtained the highest compressive strength and strain followed by the heat treated ones while the trend reversed for tensile properties.

The effects of production methods on the microstructure and mechanical properties of aluminium bronze were studied by Kaplan and Yildiz, [11]. The solidification structure, the effects of solution treatment, tempering heat treatment and mould types on the microstructure of the aluminium bronze produced in two different moulds were examined. The results of the study showed that the metallographic structure of aluminium bronze was heterogeneous in the preheated die casting specimen before the treatments, but homogenous in the sand casting. It was observed that the structure of the sand mould casting contained fine rounded grains along outermost cross section and lengthwise inclined column grains towards inside and big grains at the innermost section. Considering such grain structure, it was suggested that die mould before casting should be preheated up to 450–500°C to annul the negative effects of the heterogeneous solidification structure of the material. Peter et al [12] indicated that the structure of the rapidly cooled aluminium bronze specimens was fine, consisted of α-phase grains and the α+ κ eutectoid while the structure of the annealed specimens consists of α grains and coarse eutectoid regions with κ_{III}-type precipitates. Maximum hardness was obtained by quenching and ageing at 400°C and this was attributed to the dispersion of fine particles of κ in the martensitic (β') phase. Peter et al., [12] revealed that upon annealing, with subsequent air cooling, the fraction of $\gamma 2$ increased which resulted to the increased hardness of the alloy. Increasing the annealing temperature led to the increase in the size of α grains and the size of the eutectoid areas between them.

II. MATERIALS AND METHOD

Copper and aluminium wires of 99.9% and 99.8% purity respectively, water, SAE 40 and brine were the materials used for this experimental study. Copper and aluminium wires were used as the base materials while water, SAE 40 and brine were used as the quenching media. Equipment used were weighing balance, bailout crucible furnace, stirrer, venire calliper, bench vice, lath machine, electric grinding machine, hack saw, forceps, muffle furnace, emery paper of grits sizes, rotary ultrafine polishing cloth, polycrystalline diamond suspension, ethanol solvent, etchants (acidified ferric chloride), air-gun drying machine, metallurgical microscope, impact testing machine, universal hardness testing machine and universal tensile testing machine were used for this research work.

Sand casting method was adopted for producing the samples for this experimental study. The mass by weight of the materials to be melted was calculated in order to obtain the alloy of the composition Cu-10%wt.Al and measured using the weighing balance. The bailout crucible furnace was preheated for two minutes after which the calculated amount of pure copper wire was charged into the furnace. When the copper metal attained its melting temperature at 1083^{o}C, it was superheated to 1150^{o}C to ease casting. Then, weighed amount of aluminium metal was added to the copper melt. After five minutes, the aluminium dissolved and the melt was stirred vigorously to ensure homogeneity. The melt was poured into the mould cavity of dimension 250mm by 16mm and allowed to solidify. The solidified castings were then removed from the mould, cleaned, cut, machined to the required dimension using lathe machine and stored for mechanical tests.

The chemical composition of the alloy produced was determined using energy dispersive X-ray fluorescence (EDXRF) and the result is presented in Table 1.

Table 1: Chemical composition of the developed aluminium bronze

Elements	Composition by weight (%wt)
Cu	89.950
Al	9.963
Si	0.040
Fe	0.020
Mg	0.010
Zn	0.001
Mn	0.002
Pb	0.004

With the aid of a muffle heat treatment furnace, the machined specimens were heat treated at solutionizing temperature of 900^{o}C for 30, 60 and 180 minutes and quenched in water, brine and SAE 40 respectively. The specimens were arranged in the furnace in such a way as to allow uniform circulation of hot air to all the specimens. After the completion of the quench, the specimens were removed from the various media and sanding was done after each quench to maintain a consistent surface finish of the specimen throughout the experiments.

III. RESULTS AND DISCUSSION

Plates 1-10 represent the microstructure of aluminium bronze (Cu-10%wt.Al) in as cast and heat treated conditions.

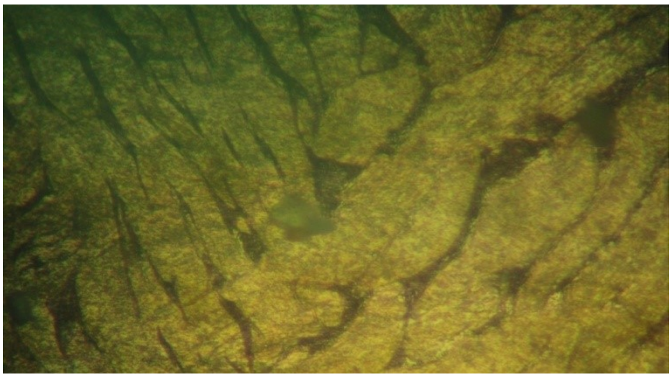

Plate 1. Micrograph of as-cast aluminium bronze (Cu-10%Al)

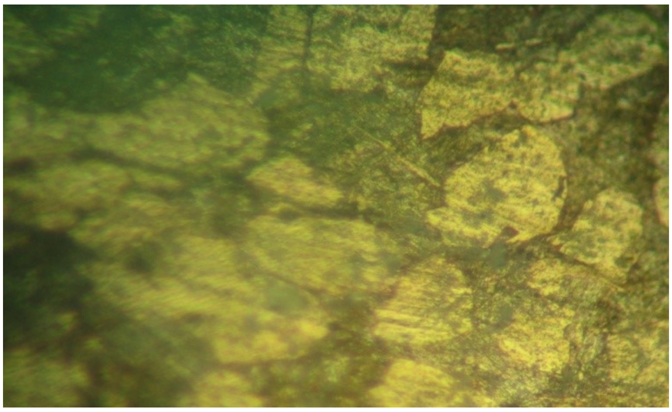

Plate 2. Micrograph of aluminium bronze soaked for 30 minutes and quenched in Water

Plate 3. Micrograph of aluminium bronze soaked for 30 minutes and quenched in SAE 40

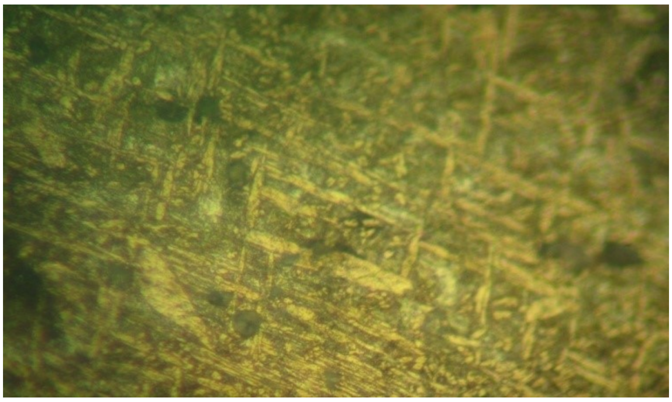

Plate 4. Micrograph of aluminium bronze soaked for 30 minutes and quenched in Brine

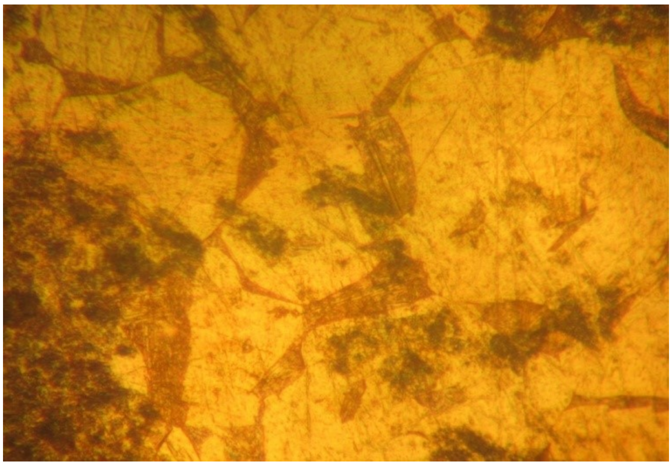

Plate 5. Micrograph of aluminium bronze soaked for 60 minutes and quenched in Water

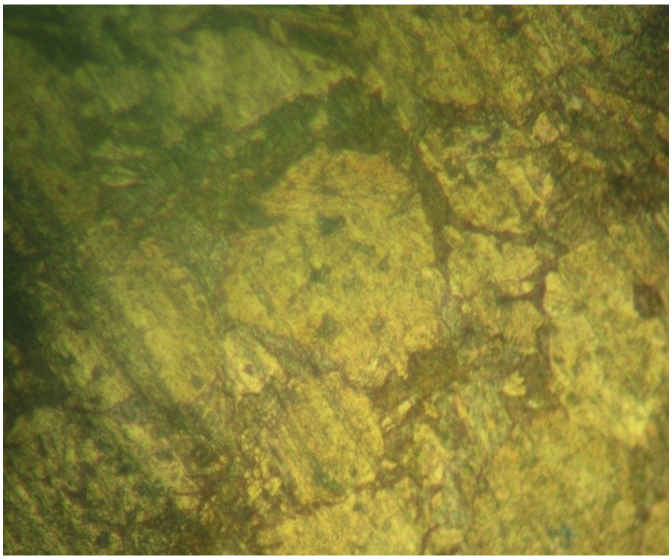

Plate 6. Micrograph of aluminium bronze soaked for 60 minutes and quenched in SAE 40

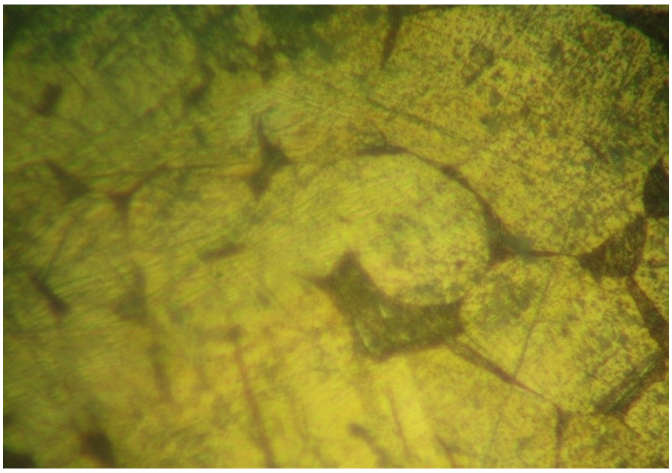

Plate 7. Micrograph of aluminium bronze soaked for 60 minutes and quenched in Brine

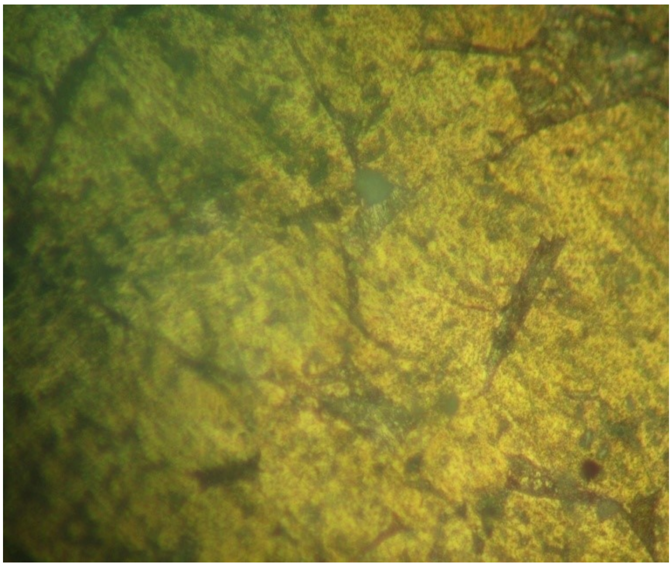

Plate 8. Micrograph of aluminium bronze soaked for 180mins and quenched in Water

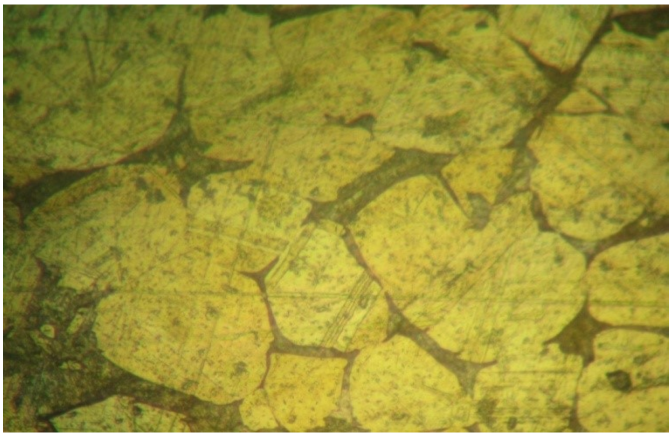

Plate 9. Micrograph of aluminium bronze soaked for 180mins and quenched in SAE 40

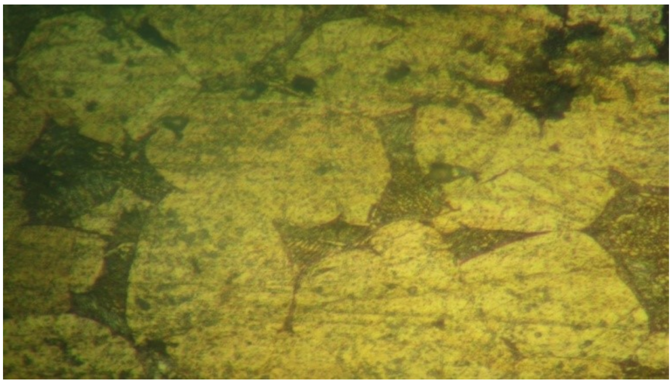

Plate 10. Micrograph of aluminium bronze soaked for 180mins and quenched in Brine

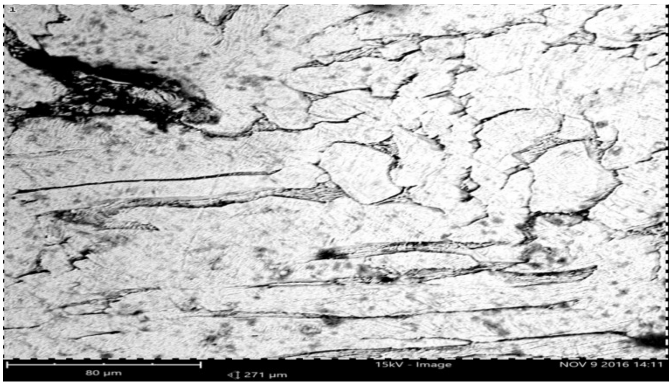

Plate 11. Micrograph (SEM) of Cu-10%Al (As-cast)

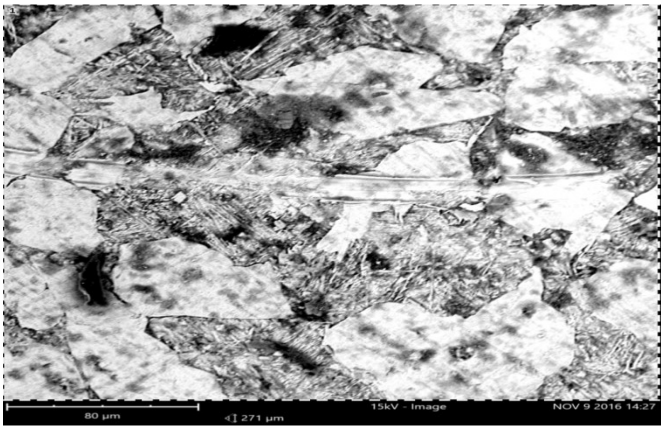

Plate 12. Micrograph (SEM) of aluminium bronze soaked for 30 minutes and quenched in Water

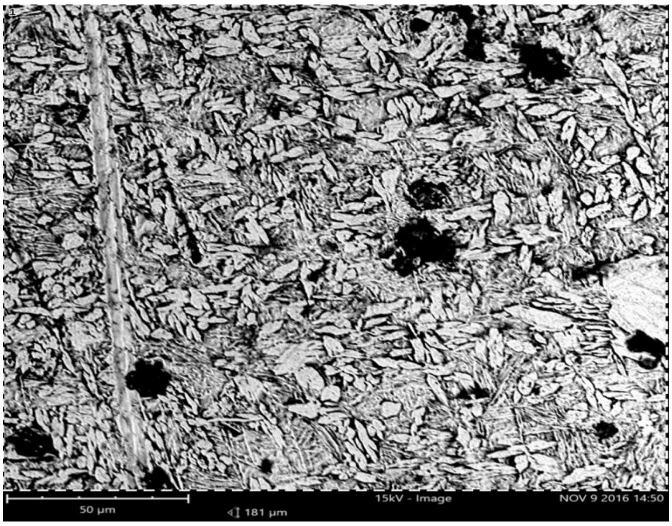

Plate 13. Micrograph (SEM) of aluminium bronze soaked for 30 minutes and quenched in Brine

Plate 1 represents the microstructure of aluminium bronze (Cu-10%wt.Al) in as cast condition. It was indicated that the microstructure comprised of coarse needle-like precipitates of primary α-phase and eutectoid $\alpha+\gamma 2$, evenly distributed in the alloy matrix. The specimens quenched in water showed finer grains to compare with the specimens quenched in brine and SAE40. More homogenized and very fine grains were indicated at 30 minutes soaking time. Increasing the soaking time from 30 minutes to 180 minutes at the said solutionizing temperature (900^{o}C) resulted to the formation of coarse grains in the alloy structure.

The micrographs of aluminium bronze solution heat treated at 900^{o}C, soaked for 30mins, 60mins and 180mins and quenched in water, brine and SAE40 are presented in Plates 2-10. The micrographs revealed greater extents of microstructural homogenization along with coarsening of the intermetallic compounds as the soaking time increased.

Plates 11-13 represent the scanning electron microscopy analysis of the control and heat treated specimens. The micrograph of the control specimen revealed the presence of evenly distributed needle-like precipitates of intermetallic compound (Plate 11). The morphology of the intermetallic compound of the heat treated specimens changed from needle-like to plate-like form as evidenced in Plates 12 and 13. Plates 12 and 13 revealed an increased amount of α-phase co-existing with plate-like intermetallic compound.

The results of the mechanical properties of aluminium bronze solutionized at 900°C, soaked for different times (30, 60 and 180minutes) and quenched in water, brine and SAE 40 respectively are presented in Figures 1-4.

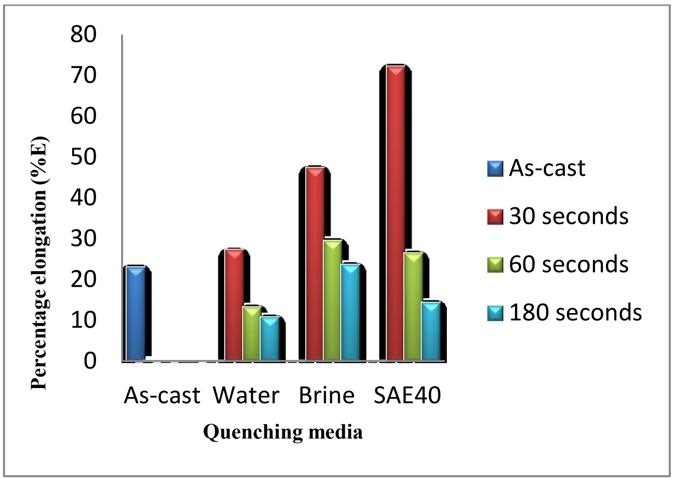

Figure 1. Effect of soaking time and quenching media on the percentage elongation of aluminium bronze

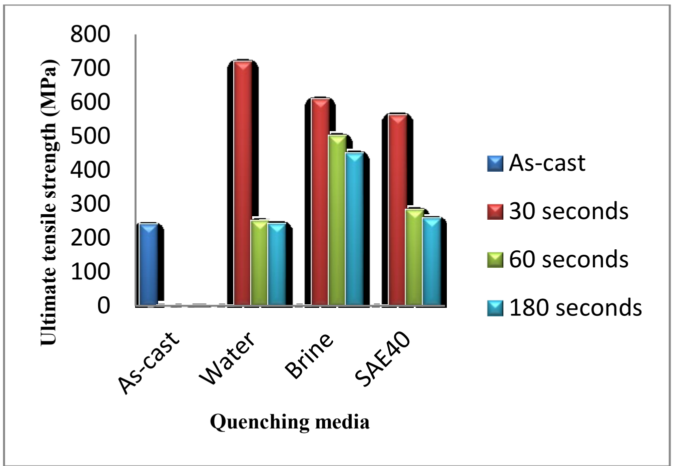

Figure 2. Effect of soaking time and quenching media on the ultimate tensile strength of aluminium bronze

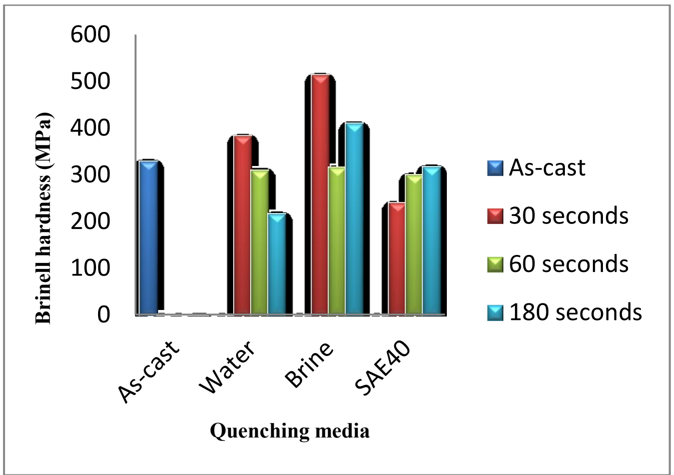

Figure 3. Effect of soaking time and quenching media on the hardness of aluminium bronze

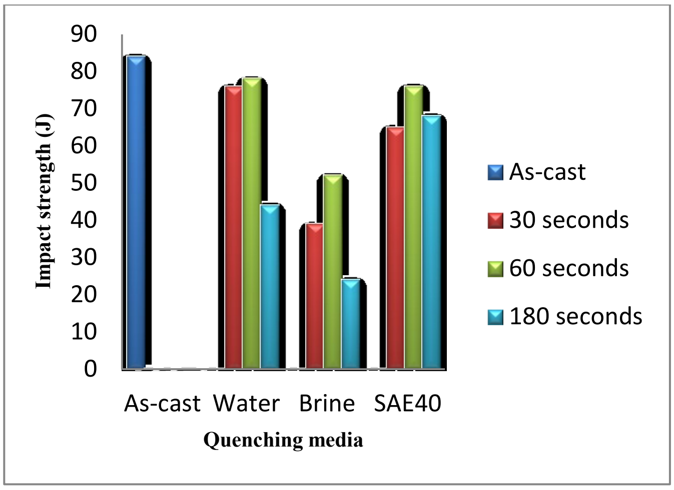

Figure 4. Effect of soaking time and quenching media on the impact strength of aluminium bronze

Figures 1-4 represent the effect of soaking time and quenching media on the percentage elongation, ultimate tensile strength, hardness and impact strength of aluminium bronze solutionized at 900°C. Figures 1-3 showed that heat treatment had significant effect on the tested mechanical properties of the alloys studied. Maximum percentage elongation and ultimate tensile strength were evidenced on the specimen soaked for 30 minutes and quenched in SAE 40 and water respectively. It was also noted in Figures 1-2 that the percentage elongation and ultimate tensile strength of the specimen quenched in water, brine and SAE 40 decreased with increase in soaking time. Figure 3 indicated that the specimen quenched in water showed an increase in hardness at 30 minutes soaking time, while the specimens quenched in brine showed an increased hardness at soaking time of 30 minutes and 180 minutes. The hardness values of all the specimens quenched in SAE 40 were less than the one in as-cast condition (Figure 3). The impact strength of all the heat treated specimens was less than that of the as-cast specimen (Figure 4). Figure 4 showed that the impact strength of the specimens quenched in water, brine and SAE 40 respectively, increased as the soaking time increased to 60 minutes after which it decreased with increase in soaking time.

IV. CONCLUSION

The effect of soaking time and quenching media on the structure and mechanical properties of Cu-10%wt.Al alloy has been studied and the following conclusions were drawn:

a. The structure and mechanical properties of aluminium bronze were greatly controlled by the heat treatment parameters such as the soaking time and quenching medium of the treatments.
b. Finer primary α- phase resulted to an improved ultimate tensile strength of the alloy while coarser primary α grains reduced the strength and ductility significantly despite identical hardness values.
c. Among all the quenching media used, brine gave the best combination of mechanical properties.
d. The ultimate tensile strength of aluminium bronze in as-cast condition increased from 240MPa to 710MPa when the alloy was solutionized at 900^oC for 30 minutes and quenched in water.
e. Maximum hardness value of 513MPa was obtained in the specimen solutionized at 900^oC for 30 minutes and quenched in brine.
f. Formation of coarse sparse distribution of $\alpha+\gamma2$ precipitates in the structure of as-cast aluminium bronze resulted to high hardness and low ductility of the alloy.

V. RECOMMENDATIONS

a. Shorter soaking time is highly recommended at high solutionizing temperature (900^oC) in order to avoid formation of coarse intermetallic compound which greatly reduced the mechanical properties of the alloy.
b. Brine is highly recommended as the best quenching medium as it produced alloy with suitable structure and good combination of mechanical properties.
c. When ultimate tensile strength and hardness are highly demanded in an engineering component made of aluminium bronze, a solutionizing temperature of 900^oC at soaking time of 30 minutes is highly recommended.

VI. ACKNOWLEDGEMENT

The authors are grateful to the management of Cutix Cable Plc, Nnewi, Nigeria for their assistance in provision of the materials and testing of the developed alloys.

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