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Influence of Ageing Heat Treatment on the Microstructure and Mechanical Properties of Aluminum Bronze Alloy (Cu-10%Al)

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Abstract

In this research different types of heat treatments were used to improve on the microstructure and mechanical properties of aluminum bronze alloy as a potential replacement for conventional structural materials, particularly steels. Sand casting was used in the production of the dual-phase aluminum bronze alloy with 10% aluminum content. The selected heat treatments were Solutionizing, Quenching and Ageing. The cast specimens were solutionized at 900°C for 1hr, quenched in water and then aged at temperatures of 150°C, 250°C, 350°C and 450°C and soaked for 1hr, 2hrs and 3hrs respectively at each ageing temperature. The standard heat treated specimens were subjected to mechanical tests (UTS, %E and Vicker's hardness tests). Their micrographs were equally taken using Metallurgical microscope. The results showed that the specimens aged at 350°C for 2hrs gave optimum mix of tested mechanical properties with UTS of 610MPa, %Elongation of 17.5% and Vicker's hardness value of 350Hv. Study of the microstructure showed that as ageing temperature and soaking time increased, finer agglomerates of $\alpha+\gamma_2$ phase were precipitated from the martensitic β' phase which caused the improvement on the mechanical properties of the heat treated specimens.

Keywords: Ageing heat treatment, microstructure, solutionizing, UTS, quenching, %Elongation, hardness

1. Introduction

Aluminum bronze is a type of bronze in which aluminum is the main alloying metal added to copper. 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^[5, 7]. A variety of aluminum bronzes have found industrial use, with most ranging from 5% to 11%Al by weight, the remaining mass copper, other alloying elements such as iron, nickel, manganese and silicon are sometimes added to aluminum bronze^[2]. The addition of aluminum increases the mechanical properties of the alloy by the establishment of a face-centered-cubic (F.C.C) phase which could improve the casting and hot working properties of the alloy^[1]. Aluminum bronzes have been identified as important and useful engineering materials due to their unique properties, such as high strength, excellent corrosion resistance to wear and fatigue^[3]. The self-healing surface film of aluminum oxide gives aluminum bronzes excellent corrosion resistance and the tensile strength increases with increasing β phase, hence aluminum bronze is one of the versatile wear resisting engineering materials that work under a corrosive environment with high stress^[4]. Aluminum bronze is the most tarnish-resistant Copper alloy and shows no serious deterioration in appearance and no significant loss of mechanical properties on exposure to most atmospheric conditions and hence their resistance to atmospheric corrosion combined with high strength is exploited in their use for bearing bushes in aircraft frames. It also shows low rate of oxidation at high temperatures and excellent resistance to sulphuric acid and sulphuric oxides^[6].

2. Materials and Methods

2.1 Materials

Materials and equipment used for the study include cope and drag (moulding box), rammer, venting wire, patterns, locating pins, brush, sieves, spades, bailout crucible furnace, moulding sand, pair of tongs, ladles, milling sand machine, copper wire, aluminum scrap, hacksaw and steel blade, lathe machine, grinding machine, milling machine. Heat treatment furnace, vice, Vicker's hardness testing machine, universal tensile testing machine, emery papers, etching reagent, water as quenching medium, Metallurgical microscope.

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2.2 Experimental Procedures

2.2.1 Production

Sand casting was used in the production of the aluminum bronze alloy rods. The bailout crucible furnace with refractory bricks and a crucible pot placed at the centre of the furnace was used in the melting of the Cu and Al scraps. The Cu scrap was heated to about 1083°C which is the melting temperature of Cu and then the Al scrap was charged and stirred to promote a homogenous mixture. When the melting was completed, the crucible pot was removed with the pair of tongs and hand gloves and casting into the preheated moulds was done steadily until the cavities were completely filled. The liquid alloy was allowed to solidify and cool in the mould before removal.

2.2.2 Machining

The machining operation was done using a lathe machine. This was done by clamping the ingot firmly on the lathe machine and the cutting gradually sliding along the entire length of the specimen to give the final desired shape. The specimens for the ultimate tensile strength and hardness tests were machined to the required dimensions of 250mm×30mm and 30mm×30mm respectively.

2.2.3 Heat Treatment

After machining the test specimens, they were heat treated in a heat treatment furnace as follows: two test specimens were kept as control and the remaining specimens solutionized at 900°C for 1hr and then quenched in water. The quenched specimens were then aged at 150°C, 250°C, 350°C, and 450°C and held for 1hr, 2hrs and 3hrs respectively in the furnace. After each ageing temperature and holding time, the specimens were removed from the furnace and allowed to cool in air.

2.2.4 Ultimate Tensile Strength and Hardness Tests

The tensile tests were carried out using digital hydraulic universal tensile testing machine, Satec series, instron 600DX. When the load was applied on the specimen, the pressure transducer in the hydraulic system transfers the signal of reflecting voltage change into the computer system. The deformation signal is transferred to the computer through photoelectric encoder. Thus, the computer system acquires the signal of load deformation and displays test data and curves in real time. The hardness tests were carried out with a digital vicker’s tester (Hv10). Each specimen was moved close to the selected vicker’s indenter using the lever provided until it touched the indenter and a green light was shown indicating that indentation has taken place. The indented specimen was shifted closer to the microscope to measure the diagonals of the resulting indentation. Then the values were read directly on the machine. These steps were repeated until the entire specimens were tested. For each specimen, the test was conducted three times and the average value recorded.

2.2.5 Micro-Examination

A metallurgical microscope was used to analyze the microstructures of the developed alloy. Prior to this, the specimen for the microscopy was mounted and grinded using a series of emery papers of grit sizes ranging from 220µm-240µm, it was further polished with a polishing machine to remove the fine scratches to a mirror like finish. The specimens were chemically etched using iron(iii)chloride acid as etchant and then viewed with optical microscope.

3. Results and Discussion

Table 3.1 showed the ultimate tensile strength values for the solutionized and water quenched specimens as 573MPa and 650MPa respectively. The solutionized specimen has a low tensile strength value than the quenched specimen because at the solutionizing temperature of 900°C, the alloy consists entirely of the solid solution β phase which is soft and ductile and had a higher tensile strength than the as cast specimen, while water quenching from 900°C, produced a structure consisting of the martensitic phase β' which is a supersaturated solid solution that is very hard and brittle. In order to have a better combination of mechanical properties in terms of strength and ductility, the quenched specimens were aged at different temperatures and soaking times. From Table 3.2 and Fig 3.1, it was observed that the ultimate tensile strength values increased with increase in ageing temperature and soaking time. The highest ultimate tensile strength values were obtained in specimens aged at 350°C and 450°C and soaked for 2hrs, while the least ultimate tensile strength value was obtained at ageing temperature of 150°C without soaking. The corresponding UTS values are 610MPa, 605MPa and 475MPa respectively. These values were obviously higher than the value of the as cast specimen which was 455MPa indicating that the finely dispersed precipitates of α and γ_2 phases formed during the ageing heat treatment impeded dislocation movement during deformation and thereby strengthened the alloy. However, the highest UTS value of 610MPa was obtained with the specimen aged at 350°C and soaked for 2hrs. It was also observed that the UTS values decreased to 594MPa and 588MPa after the peak values of 610MPa and 605MPa at the ageing temperatures of 350°C and 450°C soaked for 3hrs respectively. These decreases were as a result of over ageing which led to the coalescence and coarsening of the finely dispersed precipitates of α and γ_2 phases.

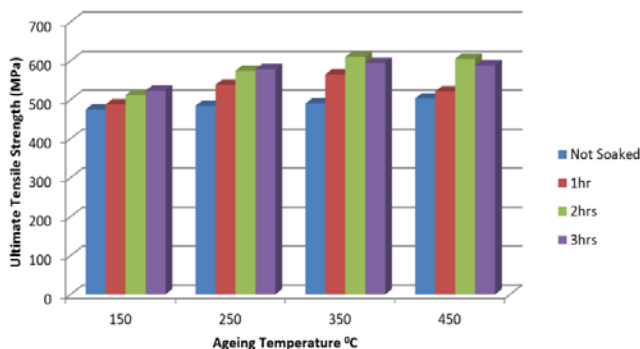


Fig 3.1: Relationship between Ultimate Tensile Strength and Aging Temp and Soaking Time

Table 3.1: Result of (UTS), %Elongation (%E) and Vickers Hardness Tests

Specimen Type	UTS (MPa)	%E	Vickers Hardness (Hv)
As Cast	455	40	232.5
Solutionized	573	23	305.7
Quenched	650	5	370

Also from Table 3.2 and Fig 3.2, it was observed that the percentage elongation of the aged specimens increased with increased ageing temperature and soaking time when compared with the value of the quenched specimen which was 5%. The as cast specimen has the highest percentage elongation of 40% which indicates that it is more ductile than

the heat treated specimens. Decrease in the %elongation of the aged specimens were observed at the ageing temperatures of 350°C and 450°C for 2hrs and 3hrs soaking time respectively. This was as a result of the alloy becoming stronger and harder and thus less ductile.

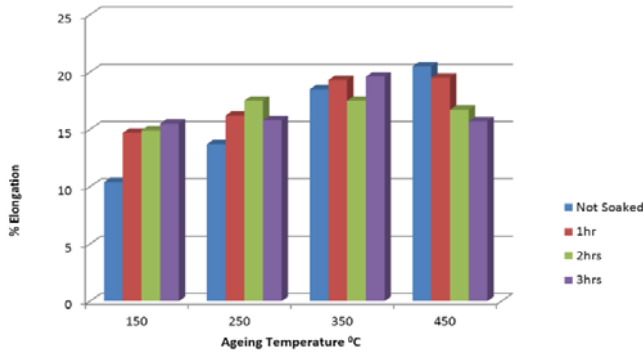


Fig 3.2: Relationship between %Elongation and Ageing Temp and Soaking Time

The results of the Vicker’s hardness test values are shown in Table 3.2 and Fig 3.3, it was observed that the hardness values increased with increased ageing temperature and soaking time confirming hardening of the aluminum bronze alloy by ageing heat treatment. The Vicker’s hardness value of as cast specimen was 232Hv, which is less than the hardness values of the heat treated specimens. The highest hardness value of 370Hv was obtained with the quenched specimen as compared with the aged specimens as a result of its martensitic structure which is hard and brittle. A study of Table 3.2 showed that specimens aged at 150°C and 250°C had less hardness values compared to the specimens aged at 350°C and 450°C. The highest hardness values of 350Hv and 345Hv for the aged specimens were obtained at ageing temperatures of 350°C and 450°C soaked for 2hrs respectively. A sharp decrease in the hardness values of the aged specimens from the peak values of 350Hv and 345Hv to 335Hv and 322Hv was observed at ageing temperatures of 350°C and 450°C soaked for 3hrs. This was as a result of over ageing which caused grain growth and the coalescence and coarsening of the fine precipitates of α and γ_2 phases.

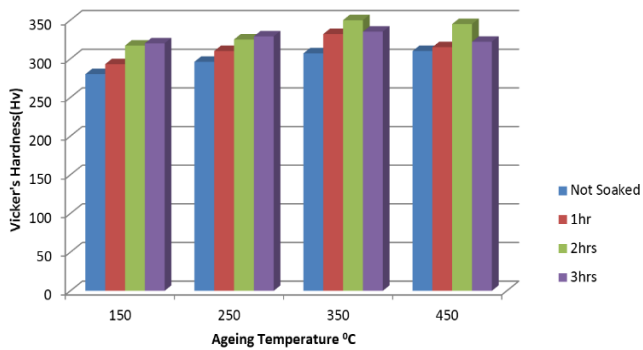


Fig 3.3: Relationship between Vicker's Hardness and Ageing Temp and Soaking Time

Table 3.2: Result of (UTS), %Elongation (%E) and Hardness Tests for Aged Specimens

Specimen Type	UTS(MPa)	%E	Vickers Hardness(Hv)
As Cast	455	40	232.5
Solutionized	573	23	305.7
Quenched	650	5	370

Ageing Temp(0c)	ST(hrs)	UTS(MPa)	%E	Vickers Hardness(Hv)
150	0	475	10.4	280
	1	488	14.7	293
	2	515	14.9	317
	3	523	15.5	320
250	0	484	13.7	296
	1	538	16.2	310
	2	574	17.5	325
	3	578	15.8	329
350	0	490	18.5	307
	1	565	19.3	332
	2	610	17.5	350
	3	594	17.6	335
450	0	503	20.5	310
	1	521	19.5	315
	2	605	16.7	345
	3	588	15.7	322

3.1 Microstructure

The differences in the microstructures of the specimens resulting from different ageing temperatures and soaking times affected the mechanical properties of the test specimens. The micrographs are shown in plates 1 to 19. From plate 1, which is the control specimen (as cast) of Cu-10%Al bronze alloy, it was observed that the microstructure consists of large coarse interconnected intermetallic Cu_9Al_4 compound and $\alpha+\gamma_2$ phases. This particular plate exhibits the lowest mechanical properties in terms of tensile strength and hardness because of its coarse microstructure.

Microstructural examinations reveal that the structures of the heat treated specimens were quite different from the control specimen. Plate 2 shows the microstructure of the specimen solutionized at 900°C and soaked for 1hr and cooled in air. The micrograph reveals the formation of fine $\alpha+\gamma_2$ phases and Cu_9Al_4 compound which showed modified structure from the as cast specimen and hence improved mechanical properties as shown in Tables 4.1 and 4.2

Plate 3 shows the microstructure of the specimen solutionized at 900°C, held for 1hr and water quenched. It was observed that the coarse intermetallic Cu_9Al_4 compound in the as cast specimen was transformed into dendritic, acicular martensite β' phase structure. The formation of this martensitic β' phase made the quenched specimen very hard and brittle and thus undesirable for engineering structures.

Plates 4-19 show the microstructure of specimens aged at different temperatures and soaking time after quenching. From the above plates, it was observed that $\alpha+\gamma_2$ eutectoid phase precipitated from the martensitic β' phase structure. As ageing temperature and soaking time increased, finer agglomerates of the phases $\alpha+\gamma_2$ were precipitated out which caused the improved mechanical properties of the aged specimens over the as cast and quenched specimens. Plates 14 and 18, as observed had the finest precipitate of $\alpha+\gamma_2$ phases which were associated to their having highest mechanical properties (tensile strength, impact strength and hardness).

Plates 15 and 19 are the micrographs of the specimens aged at 350°C and 450°C soaked for 3hrs respectively. From the experimental results, these specimens had reduced strengths and hardness values from the peak values, and from their micrographs, the reduced strengths and hardness values were caused by, grain growth which led to coalescence and coarsening of the $\alpha+\gamma_2$ phase precipitates and thus soften the alloys.

Microstructures

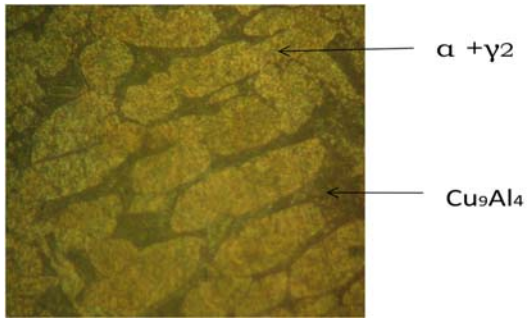


Plate 1: As cast specimen

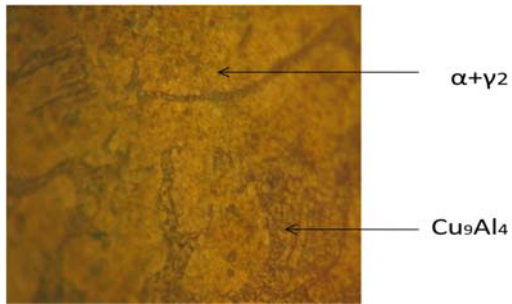


Plate 2: Solutionized specimen

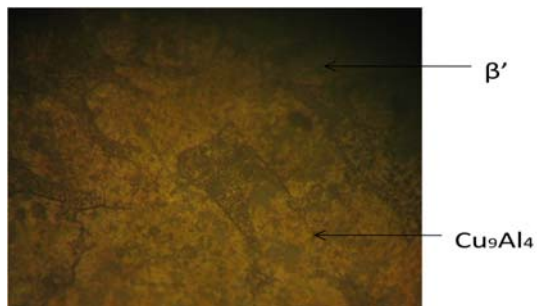


Plate 3: Quenched specimen

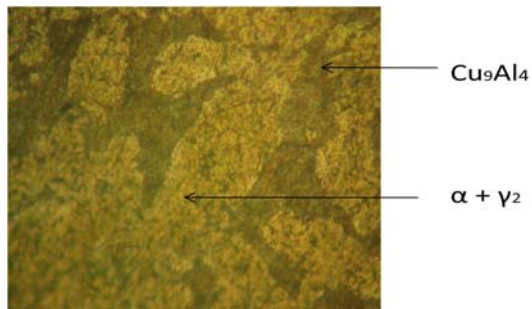


Plate 4: Specimen aged at 150°C without soaking.

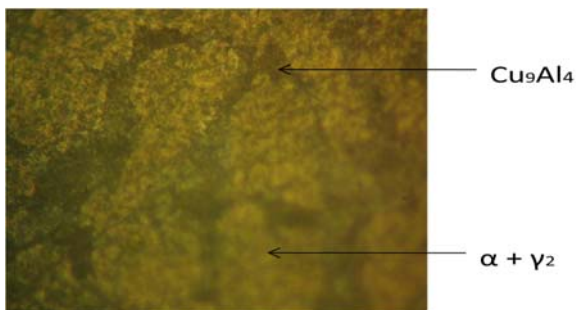


Plate 5: Specimen aged at 150°C for 1hr.

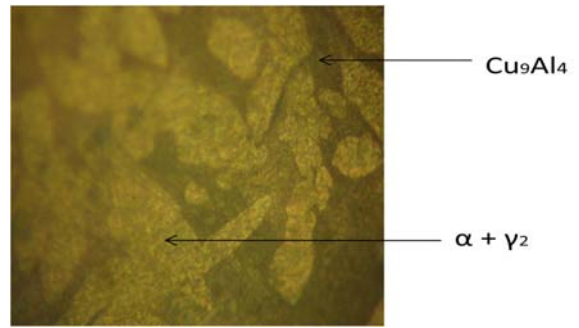


Plate 6: specimen aged at 150°C for 2hrs

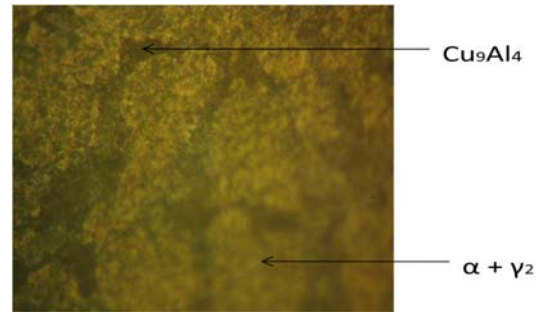


Plate 7: Specimen aged at 150°C for 3hrs.

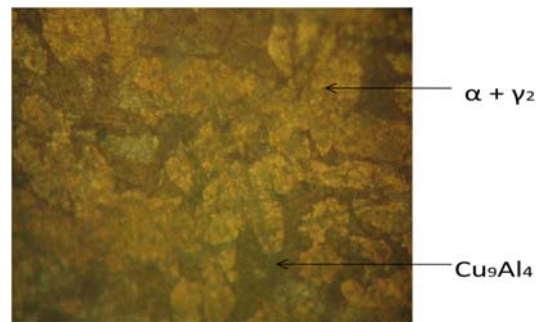


Plate 8: Specimen aged at 250°C without soaking.

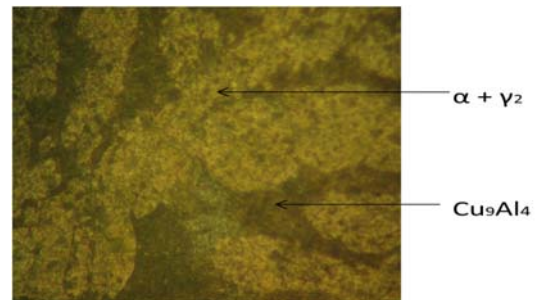


Plate 9: Specimen aged at 250°C for 1hr.

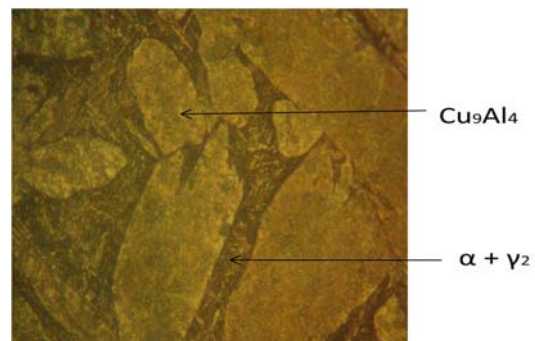


Plate 10: Specimen aged at 250°C for 2hrs.

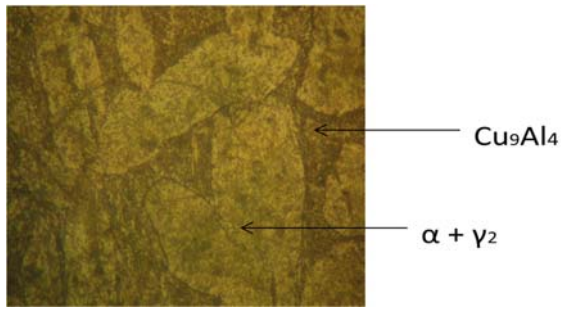


Plate 11: Specimen aged at 250°C for 3hrs

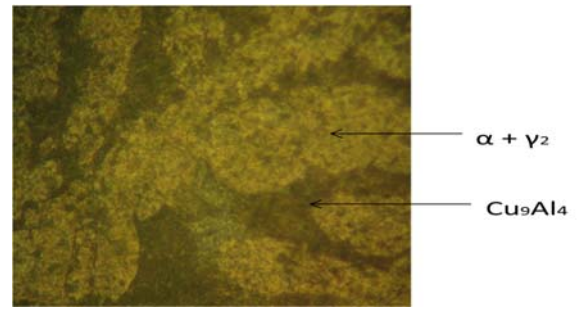


Plate 16: Specimen aged at 450°C without soaking.

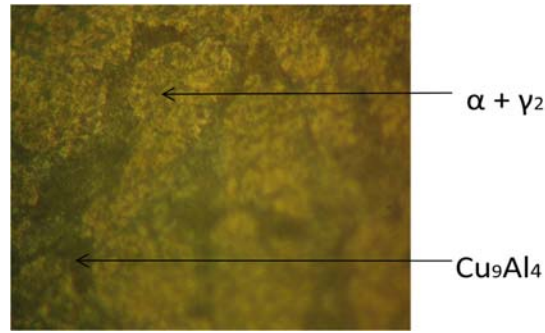


Plate 12: Specimen aged at 350°C without soaking.

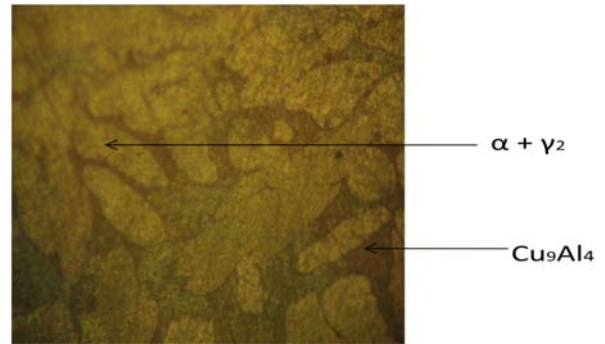


Plate 17: Specimen aged at 450°C for 1hr

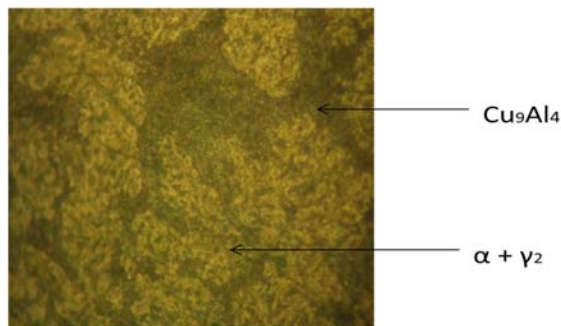


Plate 13: Specimen aged at 350°C for 1hr

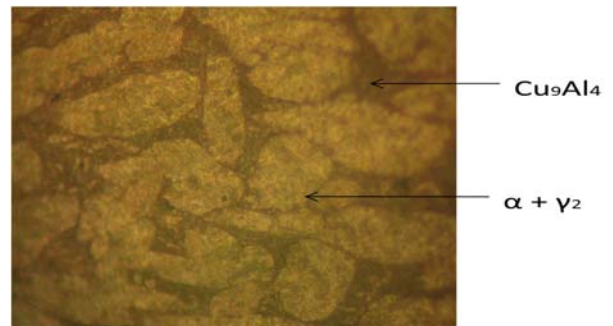


Plate 18: Specimen aged at 450°C for 2hrs

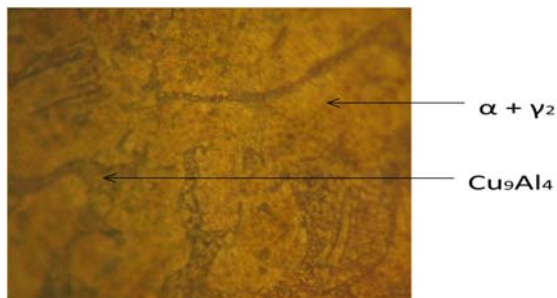


Plate 14: Specimen aged at 350°C for 2hrs

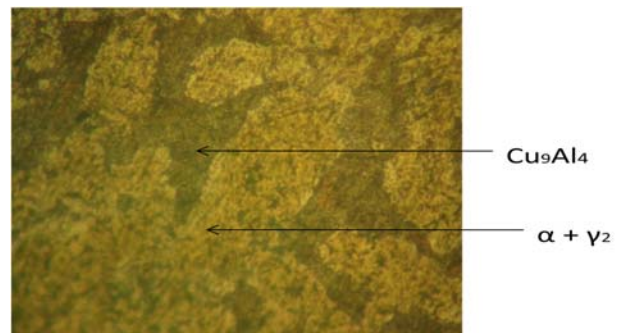


Plate 19: Specimen aged 450°C for 3hrs.

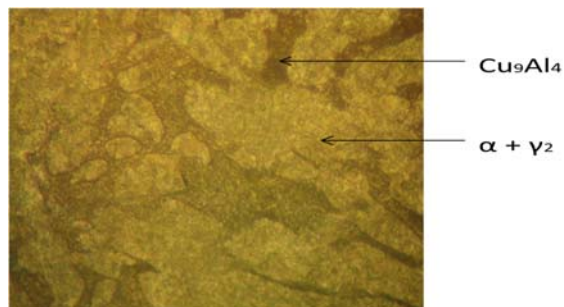


Plate 15: Specimen aged at 350°C for 3hrs

4. Conclusion

From the research, the following conclusions were drawn based on the experimental results:

1. Solutionizing the as cast alloy at 900°C for 1hr produced a homogeneous solid solution β phase which impacted better mechanical properties than the Cu_9Al_4 intermetallic compound of the as cast alloy.
2. Water quenching the alloys from the solutionization temperature of 900°C transformed all the β phase into β' phase structure which is a supersaturated solid solution that is harder and more brittle than the as cast alloy.

3. Ageing heat treatment transformed the martensitic β' phase into finely dispersed precipitates of α and γ_2 phases which have better combination of mechanical properties in terms of tensile strength and hardness than the as cast alloy, quenched, and solutionized specimens.

References

1. Copper Development Association Publication (1992). No 94.
2. Haggins, R.A, (2004). Engineering metallurgy part 1, 6th ed. pp 462-463.
3. <http://www.CDA.org.uk/megabz/corr/pub81/default.htm>
4. Mustafa Yarar, Yahya Altunpak (2009). Materials and Design,30-878-884
5. Smith, W.F (1993). Structure and properties of Engineering alloys, second edition, MCGraw-Hill, ISB 0-07-59172-5.
6. Wharton, J.A, Bank, R.C, Kear, G, Wood, R.J.K, Stoke, K.R & Walsh, F.C (2005). The corrosion of nickel aluminum bronze in seawater corrosion science, pp3336-3367.
7. William, F. Smith & Javad Hashemi (2006). Foundations of materials science and Engineering, 4th ed, Mc Graw Hill.