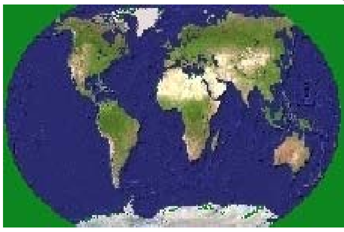

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Effect of ageing time and temperature on the mechanical properties of aluminum bronze alloy

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Abstract

In this research different types of heat treatments were used to improve on the 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℃ for 1hr, quenched in water and then aged at temperatures of 150℃, 250℃, 350℃ and 450℃ and soaked for 1hr, 2hrs and 3hrs respectively at each ageing temperature. The standard heat treated specimens were subjected to mechanical tests (Impact strength and Yield strength tests). Their micrographs were equally taken using Metallurgical microscope. The results showed that the specimens aged at 350℃ for 1hr and 2hrs gave optimum mix of tested mechanical properties with impact strength of 30J and yield strength of 480MPa respectively. 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, quenching, impact strength, and yield strength

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 srap, 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℃ 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 impact strength and yield strength tests were machined to the required dimensions of 5.5cm×1.0cm×1.0cm and 250mm×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℃ for 1hr and then quenched in water. The quenched specimens were then aged at 150℃, 250℃, 350℃, and 450℃ 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 Yield Strength and Impact strength 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 impact strength specimens were cut to a standard size of 5.5cm ×1.0cm×1.0cm, and a V-notch was made using go-no-go gauge. The carpy tong was used to place the prepared specimen on the machine and impact testing machine hammer was suspended by a hanger provided. The gauge was adjusted to zero position and the hammer lever released to hit the specimen in position. The energy absorbed was read from the gauge in joules. This process was repeated for all the specimens and their absorbed energy values recorded. 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.

3.0 Results and Discussion

From Table 3.1 and Fig 3.2, it was observed that the yield strength values increased with increased ageing temperatures and soaking time. As cast specimen has yield strength of 310MPa which was far less than the yield strengths of all the heat treated specimens. The quenched specimen has the highest yield strength of 516MPa compared to the solutionized and aged specimens which was as a result of its martensitic structure that is very hard. The highest yield strength of 480MPa was obtained at ageing temperature of 350ºC for 2hrs, after which the yield strength decreased to 465MPa at the ageing temperature of 350ºC for 3hrs due to the over ageing of the alloy.

The results of the impact toughness values are shown in Table 3.1 and Fig 3.1. From the result, it was observed that the impact values of the aged specimens increased with increased ageing temperature and soaking time. The quenched specimen has energy absorption of 21J, which is smaller compared to the values of the aged specimens. This means that the quenched specimen is less ductile, hence more brittle and therefore low energy of absorption than the aged specimens. The highest impact value of 82J was obtained with the as cast specimen showing it has the maximum ductility compared to the heat treated specimens. Highest impact values of 30J and 29J for the aged specimens were observed at ageing temperatures of 350ºC and 450ºC soaked for 1hr respectively. The result also showed that the impact energy values increased at the lower ageing temperatures of 150ºC and 250ºC as the soaking increased while at the higher ageing temperatures of 350ºC and 450ºC, the impact energy values decreased as the soaking time increased. This decrease was as a result of over ageing which made the crystals to grow larger and became soft.

Table 3.1 Result of Impact Strength and Yield Strength Tests

Specimen Type	Impact Strength (J)	Yield Strength (MPa)
As Cast	82	310
Solutionized	35	405
Quenched	21	516

Ageing Temp(0c)	ST(hrs)	Impact Strength(J)	Yield Strength(MPa)
150	0	23	355
	1	26	360
	2	27	405
	3	25	412
250	0	24	371
	1	28	415
	2	26	452
	3	28	435
350	0	28	375
	1	30	460
	2	26	480
	3	25	465
450	0	29	395
	1	29	410
	2	25	467
	3	23	450

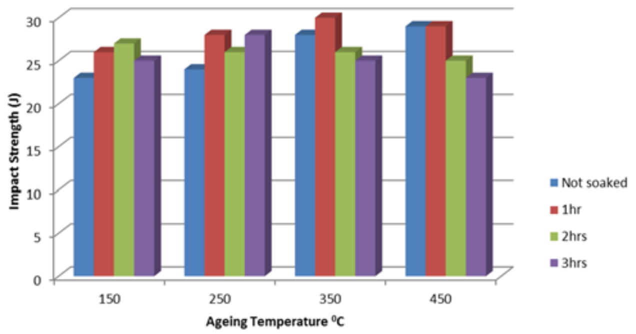

Fig 3.1 Relationship between Impact Strength and Ageing Temp and Soaking Time

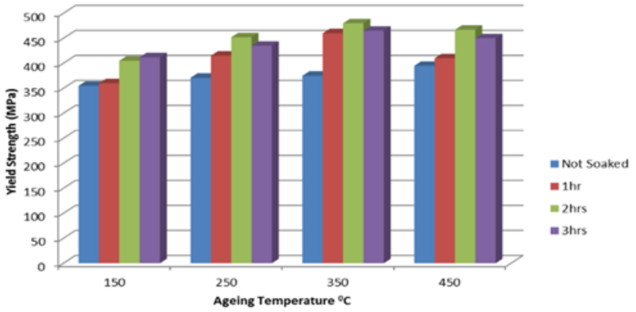

Fig 3.2 Relationship between Yield Strength and Ageing Temp and Soaking Time

Microstructures

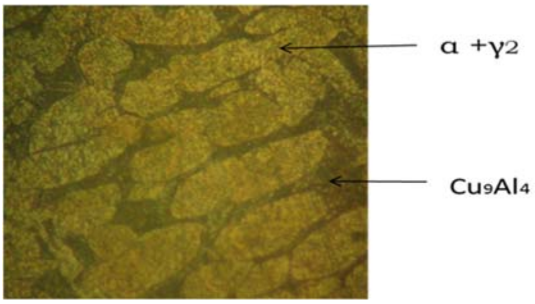

Plate1: As cast specimen

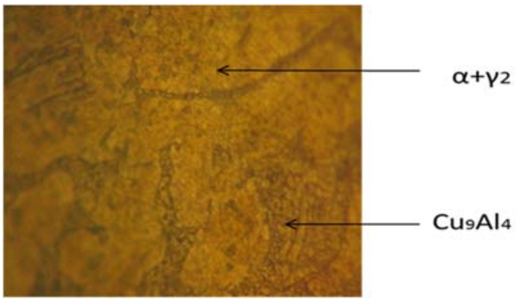

Plate 2: Solutionized specimen

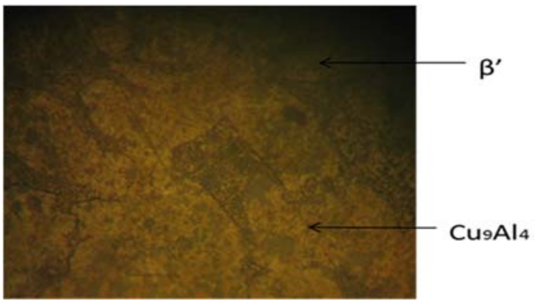

Plate3: Quenched specimen

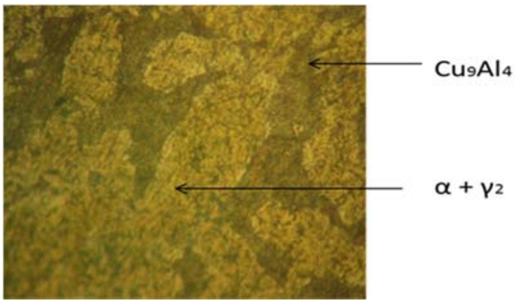

Plate 4: Specimen aged at 150^{o}C without soaking

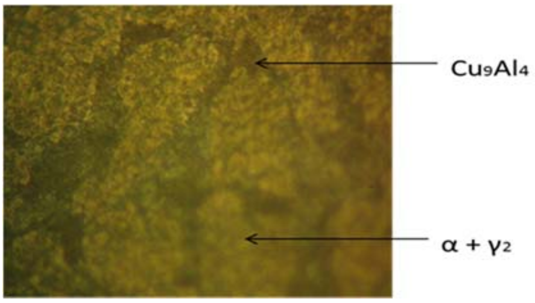

Plate 5: Specimen aged at 150^{o}C for 1hr

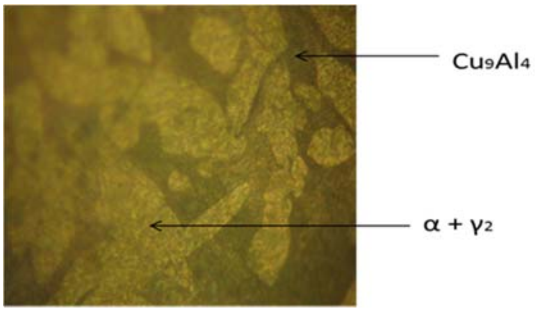

Plate 6: specimen aged at 150°C for 2hrs

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 yield strength and impact strength than the as cast alloy and solutionized specimens.

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