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Effect of heat treatment on tensile and compression strength of nickel aluminium bronze (Cu-10%Al-5%Ni-5%Fe)

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ABSTRACT

In this investigation two types of heat treatment solutionizing and ageing were employed to nickel-aluminium bronze (NAB alloy) containing Al, Fe and Ni as the alloying elements. Heat treatment was done to access their effect on the mechanical properties e.g. tensile and compressive strength and strain. Solutionizing temperature carried out at 850^{o}C and 900^{o}C for duration of 30 min, 60 min, 90 min and 120 min. similarly, ageing was carried out at 300^{o}C and 500^{o}C for the duration of 120 min and 180 min. The heat treated samples were subjected to water quenching in order to bring them to ambient temperature. The tensile and compressive strength and ductility of the alloy were determined in different conditions. In this case, the heat treatment was carried out in optimized conditions (temperature and duration) of solutionizing and ageing. Optimization was done based on the best combination of hardness and microstructural homogeneity attained by the samples during the heat treatment. Optimization is not included in this paper.

Keywords: NAB, Mechanical properties, tensile, compression, Solutionizing , Ageing

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INTRODUCTION

Aluminium bronze is one of the versatile wear resisting engineering materials that work under a corrosive environment with high stress [1]. As we know that Aluminium bronze that is copper based alloy contains aluminium about 5 to 12 % or sometimes up to 14% by weight with some optional alloying elements like Fe, Ni, Mn and Si etc. [2][3]. Nickel–aluminium bronze (NAB) belongs to group of aluminium bronzes. It contains 9–12 wt. % aluminium with additions of iron and nickel up to 6 wt. % [4].

Nickel-aluminum bronze is a series of copper-based alloy with additions of aluminum, nickel and iron. Combined with high strength, it shows good resistance to corrosion and wear, which makes it one of the most versatile engineering materials. It is widely used as engineering parts, such as various worm-gears, gears, bearings, dies, valves and propellers [5]. The Chemical Composition of nickel aluminum bronze are 78% Cu min, 10.0% to 11.5% Al, 3.0% to 5.0% Fe, 3.5% Mn max, 3.0% to 5.5% Ni, 0.5% max other (total)[6] .

Heat treatment increases the mechanical properties of the composites determined in tensile as well as in compression tests [7].The differences of the mechanical properties observed in the tensile test and compression test, before heat treatment, testify to the weak bonding between particles of matrix and reinforcing phase. The weak bonding could deteriorate the wear of com posites, because small particles could be pulled out from the surface by collaborating sliding element. To improve the bonding of particles the heat treatment of composites after extrusion was applied [7].

MATERIALS AND METHODS

The methodology adopted to carry out the present study essentially involved alloy preparation by melting and casting technique, its heat treatment (solutionizing and ageing) over a range of temperatures and durations, optimization of heat treatment parameters (temperature and duration), sample preparation from the alloy in as cast and heat treated conditions, characterization of mechanical properties. A schematic representation of the adopted methodology is shown below (Fig 2.1)

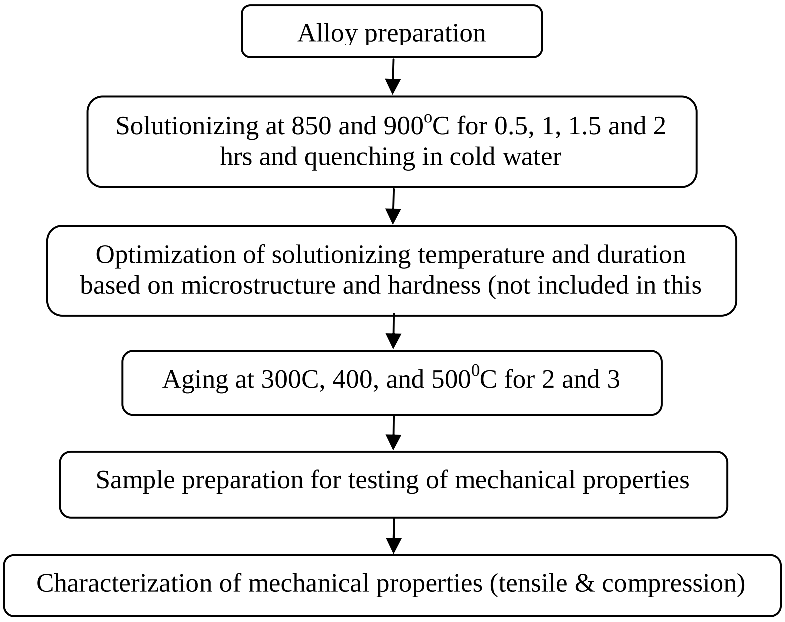


Fig: 2.1 – Flowchart of methodology adopted

2.1 EXPERIMENTAL WORK

2.1.1 Alloy preparation

The Al bronze with a nominal composition of Cu-10Al-5Fe-5Ni was synthesized using liquid metallurgy route. The process started with the preparation of the charge containing required quantities of different elements like Cu, Al, Ni and Fe. Cu pieces were charged in a graphite crucible and melted employing an oil-fired furnace. The melt surface was covered with flux (Albral) and other alloying elements were added to the melt (maintained at 1170^{o}C) gradually. Care was taken to add the lower melting elements like Al to add at latter stages of melting with a view to reduce losses through vaporization. The melt was stirred manually for some time to facilitate dissolution of the alloying elements. After cleaning the melt surface, pouring was carried out in permanent moulds in the form of 14 mm diameter, 150 mm long cylindrical rods (Fig 2.2). In order to hold the solidification structure differences of die casting specimens at the minimum, the die molds have been used after being subjected to preheating at 450–500^{o}C.

2.2 Heat treatment

The heat treatment cycle employed in this investigation consisted of solutionizing and artificial ageing done in an electric heat treatment furnace (Fig 2.3).

2.2.1 Solutionizing

In order to further improve the mechanical properties of cast alloy (NAB) can be heat treated. The alloy was investigated in both as cast and heat-treated conditions. The solutionizing was done at different combinations of temperatures and times. solutionizing was carried at 850 and 900^{o}C, for 0.5, 1, 1.5 and 2 hrs, respectively. Water quenching was employed to bring the heat treated samples to ambient temperature after the solutionizing. There are eight specimens (A-H) taken for solutionizing as summarized below in Table 2.1

2.2.2 Aging

In order to determine the role of the aging, the samples subjected to ageing that were prior solutionized at 900^{o}C for 1.5 hrs. the specimens were aged at three temperature e.g. 300, 400 and 500^{o}C for 2 and 3hrs, respectively. Water quenching was employed to bring the heat treated samples to ambient temperature after the solutionizing. There are six specimens (AA-AF) taken for ageing as summarized below in Table 2.2

Table 2.1: Solutionizing time & temperature of as -cast nickel-aluminum bronze

Sample no.	Temperature	Time	Quenching medium
A	850 ^{0}C	0.5 hr.	Water
B	850 ^{0}C	1.0 hr.	Water
C	850 ^{0}C	1.5 hrs.	Water
D	850 ^{0}C	2.0 hrs.	Water
E	900 ^{0}C	0.5 hr.	Water
F	900 ^{0}C	1.0 hr.	Water
G	900 ^{0}C	1.5 hrs.	Water
H	900 ^{0}C	2.0 hrs.	Water

Table 2.2: Ageing time & temperature of solutionized nickel-aluminum bronze

Sample no.	Temperature	Time	Quenching medium
AA	300 ^{0}C	2 hrs.	Water
AB	300 ^{0}C	3 hrs.	Water
AC	400 ^{0}C	2 hrs.	Water
AD	400 ^{0}C	3 hrs.	Water
AE	500 ^{0}C	2 hrs.	Water
AF	500 ^{0}C	3 hrs.	Water

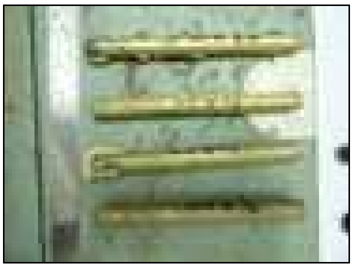


Fig: 2.2 – As-cast cylindrical rod of NAB

Fig: 2.3 – Electric heat treatment furnace

Fig: 2.4 – Electric heat treatment furnace

2.3 Tensile test

2.3.1 Preparation of test specimen

Tensile specimens with a gauge diameter of 4mm, gauge length of 20 mm, shoulder diameter10 mm and gripping length 15 mm (Fig 2.5) were prepared from NAB alloy in both as cast and heat-treated conditions.

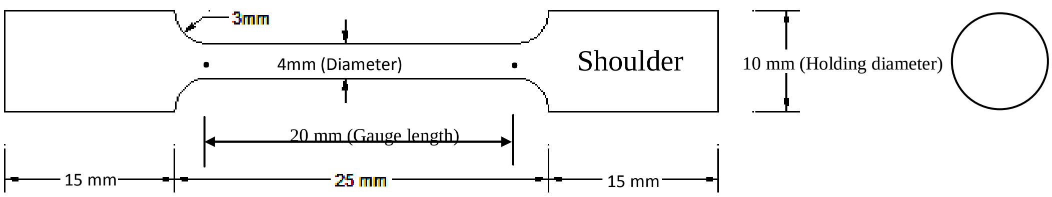


Fig: 2.5 - Test specimen for tensile test with actual dimensions

Fig: 2.6 - Test specimen of as cast Nickel Aluminium Bronze

A standard dumbbell-shaped test specimen is prepared for tensile test (Fig 2.6). It has enlarged ends or shoulders for gripping (Fig 2.5). The important part of the specimen is the gage section. The cross-sectional area of the gage section is reduced relative to that of the remainder of the specimen so that deformation and failure will be localized in this region. The gage length is the region over which measurements are made and is centered within the reduced section. The distances between the ends of the gage section and the shoulders should be great enough so that the larger ends do not constrain deformation within the gage section, and the gage length should be great relative to its diameter. To avoid end effects from the shoulders, the length of the transition region should be at least as great as the diameter, and the total length of the reduced section should be at least four times the diameter.

The sample usually is made into multiple "specimens" for testing. Test samples must be prepared properly to achieve accurate results. Test specimens must be made carefully, with attention to several details. The specimen axis must be properly aligned with the material rolling direction. The dimensions of the specimen must be held within the allowable tolerances. Each specimen must be identified as belonging to the original sample. If total elongation is to be measured after the specimen breaks, the gage length must be marked on the reduced section of the bar prior to testing.

2.3.2 Test procedure

Tensile tests were performed on round specimens having 4 mm gauge diameter and 20 mm gauge length at a strain rate of 4×10^{-3} s^{-1}. An average of two observations has been considered in this study. The equipment used for carrying out the tensile was an Instron make universal testing machine (Fig 2.4). Tensile test was carried out at room temperature.

The test set-up requires that equipment be properly matched to the test at hand. There are three requirements of the testing machine: force capacity sufficient to break the specimens to be tested; control of test speed (or strain rate or load rate), as required by the test specification; and precision and accuracy sufficient to obtain and record properly the load and extension information generated by the test. The grips must properly fit the specimens and they must have sufficient force capacity so that they are not sliped during testing.A tensile test involves mounting the specimen in a machine and subjecting it to tension. The tensile force is recorded as a function of the increase in gage length. As a result we get a stress-starin curve. Engineering stress, or nominal stress, s, is defined as $s = F/A_{o.}$ where F is the tensile force and A_o is the initial cross-sectional area of the gage section. Engineering strain, or nominal strain, e, is defined as $e = \Delta L/L_0$ where L_0 is the initial gage length and ΔL is the change in gage length ($L - L_0$).

2.4 Compression test

2.4.1 Preparation of test specimen

Cylindrical specimens (size: 10 mm diameter and 15 mm long) were used for conducting compression tests. Specimens for compression test were taken from the as cast sample. Specimens having large *L/D* ratios should be avoided to prevent buckling and shearing modes of deformation (Fig: 2.7)

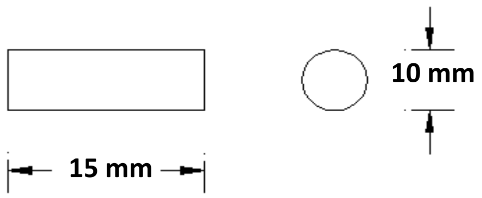


Fig: 2.7 – Specimen for Compression test

2.4.2 Test procedure

Cylindrical specimens were used for conducting compression tests at a strain rate of 10^{-3} s^{-1}. The equipment used for carrying out the tensile and compression tests was an Instron make universal testing machine (Fig 2.4). The specimen is placed between compressive plates parallel to the surface. The specimen is then compressed at a uniform rate. The maximum load is recorded along with stress-strain data. An extensometer attached to the front of the fixture is used to determine modulus.

The compressive strength of a material is that value of uniaxial compressive stress reached when the material fails completely. The compressive strength is usually obtained experimentally by means of a compressive test. The apparatus used for this experiment is the same as that used in a tensile test. However, rather than applying a uniaxial tensile load, a uniaxial compressive load is applied.

RESULTS AND DISCUSSION

3.1 Tensile strength

Fig 4.1 shows tensile stress versus strain plots for the samples in as cast heat treated conditions. The stress increased with strain prior to specimen fracture. The mechanical properties of the samples in as cast and optimized heat treated (solutionized and aged) conditions are shown in Fig. 4.2. The tensile strength of the aged samples was the highest while that of the as cast one the minimum, solutionized alloy showing an intermediate response. As far as elongation is concerned, it was the highest for the solutionized samples whereas that of the as cast one the least; the elongation of the solutionized samples lied in between the two.

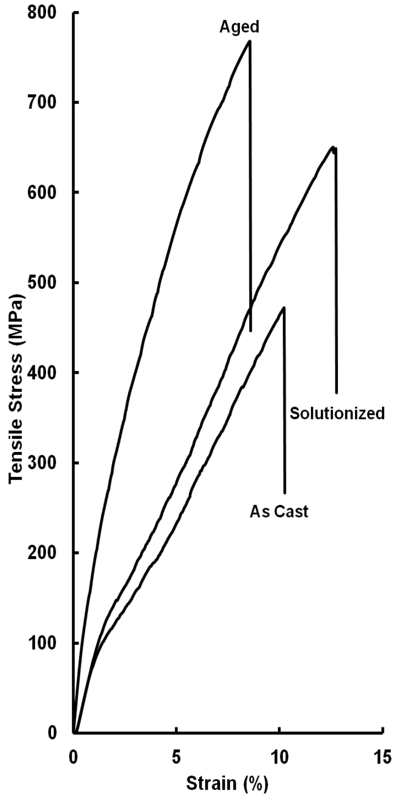


Fig: 3.1(left) - Tensile stress-strain plots of the bronze samples in as cast and heat treated conditions [solutionized: solutionizing at 900°C for 1.5 hrs, Aged: ageing at 500°C for 2 hrs]

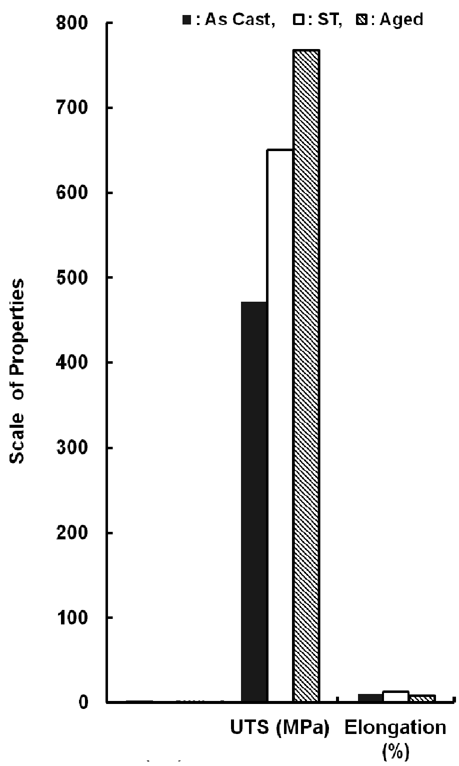
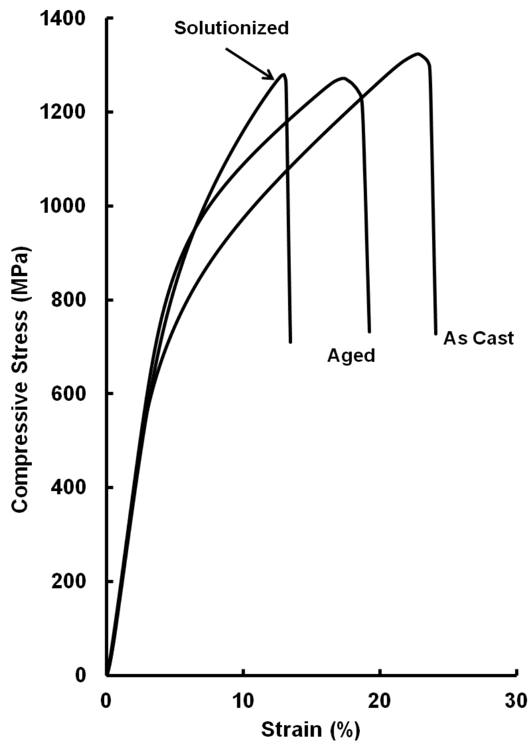


Fig: 3.2(right) - Typical mechanical (hardness and tensile) properties of the bronze samples in as cast and heat treated conditions [ST: solutionizing at 900°C for 1.5 hrs, Aged: ageing at 500°C for 2 hrs]

3.2 Compressive strength

Fig 4.3 represents the compressive stress plotted as a function of strain for the as cast, solution treated and aged samples. In this case, the stress increased with strain. The rate of increase in stress was high initially. This was followed by a lower rate of increase in stress with strain, attainment of maximum stress and specimen fracture. Fig 4.4 shows mechanical properties of the samples in the as cast and optimized heat treated (solutionized and aged) conditions. The heat treated (solutionized and aged) alloy samples attained inferior strength and reduction in height compared to their as cast version (Fig. 4.3 & 4.4). Further, the heat treated samples displayed comparable strength while the as cast samples attained maximum reduction in height followed by that of the aged and solutionized samples.



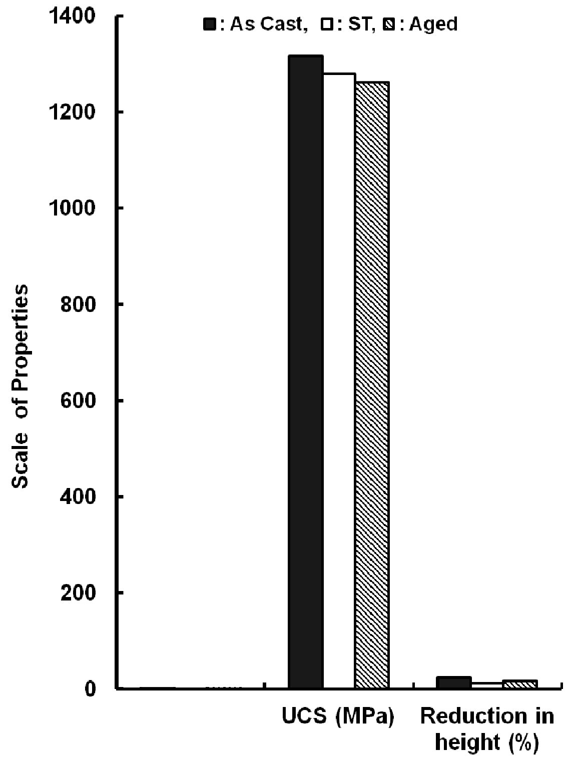


Fig: 3.3- Compressive stress-strain plots of the bronze samples in as cast and heat treated conditions [solutionized: solutionizing at 900^{o}C for 1.5 hrs, Aged: ageing at 500^{o}C for 2 hrs]

Fig: 3.4- Typical mechanical (compression) properties of the bronze samples in as cast and heat treated conditions [ST: solutionizing at 900^{o}C for 1.5 hrs, Aged: ageing at 500^{o}C for 2 hrs]

CONCLUSION

This chapter presents conclusions arrived at based on the results obtained and observations made in this investigation. The conclusions relate to the mechanical properties such as tensile and compressive properties brought about by heat treatment involving solutionizing and ageing and corresponding changes in. Following are the conclusions drawn:

1.The tensile stress increased with strain. The rate of increase in stress was high initially. This was followed by a lower rate of increase in stress with strain, attainment of maximum stress and specimen fracture. The heat treated alloy attained superior tensile strength and elongation as compared to that in the as cast condition. The aged samples attained higher hardness and tensile strength than those of the solutionized samples while their elongation tended to follow a reverse trend.

2. During compression loading, higher stress was recorded with increasing strain prior to specimen failure. In this case, the rate of increase in stress was high initially. This was followed by a reduction in the rate of increase in stress and ultimately specimen fracture. Moreover, the compressive strength of the heat treated alloy samples was

somewhat inferior to that of the as cast alloy while the aged samples attained higher strength compared to that of the solutionized ones. Reduction in height was the maximum for the as cast alloy followed by that of the solutionized and aged samples.

3. The study suggests the mechanical properties of the samples to be affected by heat treatment significantly. The type (solutionizing and ageing) and parameters (temperature and duration) of heat treatment also affected the characteristics of the sample to a considerable extent. Accordingly, it emerges from the study that it is possible to obtain desired combinations of properties through optimizing the heat treatment type and parameters.

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