Microstructural and Mechanical behaviour of Nickel Aluminum Bronze alloys

Prabhakar Kuppahalli\textsuperscript{1}, R. Keshavamurthy\textsuperscript{2}, P. Sriram\textsuperscript{3}, J.T Kavya\textsuperscript{4}

\textsuperscript{1}Professor, Department of Mechanical Engineering, Dayananda Sagar College of Engineering (DSCE), Bengaluru-560078, Karnataka, India, Research Scholar Dr. Premachandra Sagar Center for Advanced Materials affiliated to Mangalore University, Dept. of Materials Science. prabhakar123kuppa@gmail.com

\textsuperscript{2}Professor Department of Mechanical Engineering, Dayananda Sagar College of Engineering (DSCE), Bengaluru-560078, Karnataka, India. keshavamurthy.r@gmail.com

\textsuperscript{3}Chairman, RAPSRI Engineering Products Company Limited, Harohalli II Phase, Kanakapura Taluk, Ramanagar District – 562112, Karnataka, India. sriram.p@rapsri.com

\textsuperscript{4}Assistant Professor, Department of Automobile Engineering, Dayananda Sagar College of Engineering (DSCE), Bengaluru-560078, Karnataka, India. jtkavyamce@gmail.com

Abstract. The present investigation reports on microstructure and mechanical characterization of permanent and shell moulded Nickel Aluminum Bronze alloy Castings (NAB) (AB2) melted in Medium Frequency coreless Induction furnace. The mechanical properties studied consisted of Tensile strength, Yield Strength, ductility on one hand, Optical microscopy and grain size measurements on the other. Effect of zirconium addition on the microstructure and mechanical characteristics of Permanent and shell moulded castings have been studied. The results of this investigation reveal that microstructures consisted of dispersed particles in the matrix of copper solid solution both in permanent and shell moulded castings. Shell moulded castings exhibited extensive grain refinement compared to Permanent moulded castings. Very high values of Tensile Strength, Yield strength and Elongation values are obtained for the Nickel Aluminum Bronze alloys. Shell moulded castings have exhibited superior mechanical properties than Permanent moulded castings in all the characteristic / property values obtained.

Keywords: Nickel Aluminum Bronze, Microstructure, Permanent Mould, Shell Mould, Induction furnace, Mechanical Properties, Grain size.

1. Introduction
Copper and its alloys have gained prominence due to their good physical and mechanical properties. Among the physical properties mention may be made a good electrical, thermal conductivity and corrosion resistance. Among the mechanical properties their tensile strength, yield strength, ductility and hardness. Designers have been selecting copper base alloys from times immemorial as bearing materials as the structure is ideal for mating surfaces. The traditional copper alloys are copper tin bronzes, leaded tin bronzes, Aluminum Bronzes and Manganese bronzes. The selection depends on functional conditions of load and lubrication.

There are four Aluminum Bronze Cast alloys, the high strength Nickel-Aluminum Bronze which is by far the most popular sand cast alloy. This is a low Manganese Alloy with Manganese contents upto 3%. The lower strength,(low-Nickel) Aluminum Bronze used mostly in die casting. The low
magnetic permeability Aluminum Silicon Bronze, the high Manganese Aluminum Bronzes (upto 15% Manganese) mostly as an alternative to Nickel-Aluminum bronze in ship propellers.

For the purposes of present investigation only the AB2(NAB) alloy which is a low Manganese alloy is used. NAB is a binary copper-Aluminum system with alloying additions of Nickel and Iron. Copper Development Association’s General guidelines for main application of NAB(2) includes Aerospace, Architecture, Marine-Defence, Marine-Commercial Offshore oil/gas petrochemical, Desalination and Water Condenser System [1].

Peter Slama, Jaromir Dloutiy, Michal Kover [2] discussed exhaustively on the effects of heat treatment to microstructure and mechanical properties of Aluminium Bronze%. They resorted to annealing, quenching and aging treatments on a CuAl10Ni5Fe4 alloy and used light and scanning electron microscopy for their observations. The presence of alpha and kappa phases and their effects on the mechanical properties were studied. Further with the help of DSC and EBSD techniques the presence of gamma 2 in the microstructure was established. Also they compared the results with the data of CuAl14Fe5 Aluminum Bronze and found out the presence beta+Gamma 2 phase which gave high hardness and wear resistance to the material. Fig 1(a) and Fig 1 (b) both the diagrams have been taken from the work of Peter Slama, Jaromir Dloutiy, Michal Kover [2].

![Phase Diagrams](image)

**Figure 1.** (a) vertical section of the phase diagram of Ni-Al-Br with 5% Ni and 5%Fe  
(b) vertical section of phase diagram of Cu-Al-Fe at 3% Fe

Nwambu C N Anyaechel I. M, Onwubiko G. C and Nnuka E. E [3] studied the effects of Zirconium and Titanium taken as modifiers on Tensile strength, hardness and impact properties of a Cu-10%Aluminum alloy. Results obtained showed that tensile strength, impact strength and ductility increased respectively as dopants (viz Zirconium and Titanium) increased. Microstructural analysis revealed the primary alpha phase, intermetallic phases and fine stable reinforcing kappa phase and these alterations in phases resulted in the development in mechanical properties.
The work of Labanowski, T. Olkowski[4] on a CuAl10Fe5Ni5 alloy used in making marine propellers has shown the presence of Iron rich kappa phase precipitates in the microstructures and its effect on mechanical properties of alloy. Depending on the presence of small or large globular precipitate of kappa phase its effect on tensile strength and ductility is known. Further they infer that the chemical composition of the alloy, Fe-Ni ratio, cooling rate and casting technology all have effects on shape of kappa particles.

Prabash Jain, Praveen Kumar Nigam[5] studied the effect of heat treatment on Cu-10Al-5Ni-5Fe alloy on microstructure and hardness. They used solutionising at 850°C, 900°C for different durations of time and aging at 300°C and 500°C for the same variables and found out that aging at 400°C for 3 hours gave the highest hardness.

In the light of the above, the objective of this investigation has been to synthesize NAB(AB2) alloy by coreless Induction furnace of medium frequency and cast them in both permanent and shell moulds. Characterisation of this alloy was carried out by Microstructural observations by optical microscopy, grain size measurements and Hardness studies. Unlike in various studies earlier on this alloy, efforts have been made to compare the permanent mould cast and shell mould cast NAB alloy for all its characteristics. There is no mention in the literature of comparison of the properties of this alloy by the two casting methods (PM & SM) and this has been the special feature of this investigation.

2. Experimental Details
The melting of Nickel Aluminum Bronze alloy was done in a 300kg capacity, 175kw, M/s Inductotherm, Coreless Induction furnace with lining material of Alumina ramming mass. The charging sequences of melting, degassing, dross cleaning and duplexing were strictly followed as per a detailed procedure laid down for the production of Nickel Aluminum Bronze alloy. The gas content was checked in a reduced pressure gas test apparatus and the density in the densitic equipment. Castings were obtained with both permanent and shell moulds. Microstructural evaluations were carried out at M/s Advanced Metallurgical Laboratories, Bengaluru using OLYMPUS Microscope BX51NI with Clemex Image Analyser, Grain size determinations were made as per ASTM E 112-2013 using the same Microscope. Tensile test was conducted as per ASTM B 148-1978 using a 50KN machine model. Heat treatment of Nickel Aluminum Bronze alloy was carried out at 950°C for 60 minutes and quenching in water. Ageing temperature adopted was 650°C for 2 hours and air cooled. The furnace used was an electric resistance furnace with kanthal heaters from four sides range upto 1200°C, Accuracy +/-5°C make AFML.

| Table1. Chemical Composition of AB2 (NAB) alloy. |
| Elements | Actual |
| Cu       | 82     |
| Al       | 8.65   |
| Fe       | 4.04   |
| Ni       | 3.92   |
| Zn       | 0.236  |
| Sn       | 0.213  |
| Sb       | 0.152  |
| Si       | 0.105  |
| Pb       | 0.062  |
| Cr       | 0.061  |
| Mn       | 0.047  |
| Bi       | 0.014  |
| Zr       | 0.011  |
| S        | 0.006  |
| P        | 0.005  |
| Mg       | 0.003  |
| Be       | 0.000  |
3. Results and Discussion

Typical microstructures of the Chill Cast (permanent mould), Shell Cast samples are shown in figures 2, 4, 6, 8 and figures 3, 5, 7, 9 respectively. The Shell Cast structure in fig.3 shows fine needle shaped particles in a coarse grained (Beta) phase. The relative slow cooling in Permanent moulds is reflected by the Coarseness of (Beta) grains and the lower Mechanical Properties. Fig.3 shows fine needles in a mixture of Coarse and fine grained beta phase in the Shell moulded specimens. The higher mechanical properties of Shell moulded samples can be due to the refinement of grains. The higher ductility and hardness values in Shell moulded Specimens is due to the very fine grained microstructure. The fine grained structure is due to the very fast solidification achieved during Shell moulding.

Figure 2. NAB Chill Cast

Figure 3. NAB Shell Mould

Figure 4. NAB+HT Chill Cast

Figure 5. NAB+Zr Shell Mould

Figure 6. NAB+Zr Chill Cast

Figure 7. NAB+Zr Shell Mould

Figure 8. NAB+Zr+HT Chill Cast

Figure 9. NAB+Zr+HT Shell Mould
Heat treatment of Ni-Al-Br samples has resulted in greater homogeneity in their microstructure and general refinement of the grains. The presence of dendritic structure was noticed in the cast material which is not there after heat treatment procedure. Further the presence of kappa phase which is a combination of Fe₃Al and NiAl precipitates is seen in the microstructure and this is more true heat treated version of the samples. Aging of the samples during heat treatment has resulted in the formation of martensitic structure (beta’) and this has enhanced the strength of the material in shell moulded samples which can be inferred from the fig.10, 11 and 12. From all these observations it is realized the increase in alpha phase and alpha+ gamma 2 phase decreases the strength of the materials but the presence of the kappa phase enhances the same.

![Graph 1](image1.png)

**Figure 10.** Variation of Grain size.

![Graph 2](image2.png)

**Figure 11.** Variation of ultimate tensile strength

![Graph 3](image3.png)

**Figure 12.** Variation of Ductility
Solutionising and aging and the parameters used in them like the temperature and time have definite effects on the properties of the material. The increase in strength of shell moulded castings can be explained by the presence of small kappa phase precipitates and the increase in kappa phase size precipitates has resulted in reduced elongation of the material.

4. Conclusions
Increasing number of small κ-phase (kappa) precipitates, decreasing content of alpha phase have resulted in improvement in tensile strength of shell moulded castings compared to permanent moulded castings. Also the effect of grain refiner Zirconium in the alloy has modified the structure and enhanced the strength levels in these castings.

5. References
[1] Designing Aluminum-Bronze castings 1983, Copper Development Association publication no.81, pp-2-18.
[2] Peter Slama, Jaromir Dlouy and Michal Kover 2014 Influence of Heat treatment on the microstructure and Mechanical Properties of ALuminum Bronze, Materials and Technology, 48(4) PP599-604.
[3] Nwambu C. N, Anyaech. I. M, Onwubiko. G. C and Nnuka. E. E 2017 Modification of the structure and Mechanical properties of ALuminum Bronze (Cu-10%Al ) alloy with Zirconium and Titanium, International Journal of Scientific and Engineering Research, Volume 8, Issue 1, P1048-1057.
[4] J. Labanowski, T. Olkowski 2014 Effect of Microstructure on Mechanical Properties of BA1055 Bronze Castings, Archives of Foundry Engineering Vol14, Issue 2PP 73-78.
[5] Prabhash Jain, Praveen Kumar Nigam Influence of Heat treatment on Microstructure and hardness of nickel Aluminum Bronze (Cu-10Al-5Ni-5Fe)
[6] Piaseaczny, L &Rogwski, K. 2006 Modeling of Mechanical properties from blade section thickness of the ship propeller sand casting, Conference Marine Transport, University of Catalunia, Barcelona , PP515-520.
[7] Sokolov, N.N, Lazarenko, S. P. &Zuravlev, 1971 Aluminum bronze Propellers, Leningrad: Sudostroenie.

Acknowledgments
The authors of this paper would like to thank Dr. C P S Prakash, Principal DSCE for his kind permission to submit this paper and to Mr. R Krishnamurthy, Research Engineer RAPSRI Engineering Products ltd. Harohalli for his able assistance in preparing the samples.