

Development and Characterization of Aluminum Bronze Alloy Bush Sleeve using Horizontal Centrifugal Casting

Muhammad Nadeem Azam^{a *}, Dr. Aneela Wakeel^{2,b}

^aenr_nadeemchaudhary@yahoo.com

¹University of Engineering and Technology Taxila, Pakistan Post code 47070

² University of Engineering and Technology Taxila, Pakistan Post code 47070

Abstract

Aluminum Bronze bushing sleeves or sleeve bearings are used in the various parts of vehicles like camshaft bushing, suspensions, shock absorber, gears and strut bushes for anti-wear, anti-friction and for bearings high tensile loads. This research presents a comprehensive study on the development of Aluminum bronze bushing sleeves using horizontal centrifugal casting method. The effect of centrifugal casting parameters i.e. molds rotation speed, melt temperature, alloy composition and heat treatment optimizes mechanical properties and also microstructure of developed bushing sleeves. These bushing sleeves with desired composition have been developed by using induction furnace to reduce its import and to save foreign exchange. Different samples were casted by using horizontal centrifugal casting machine by varying parameters like rotation speed of mold and pouring temperature of melt in order to get good quality bushing sleeve. The addition of trace elements like Manganese, Iron, nickel and Zinc optimize the mechanical properties of bushing sleeves for particular application in elevating and depressing mechanism of heavy vehicles.

The developed material was characterized by using different characterization techniques like Spectroscopy (OES), wet analysis, mechanical testing, optical microscope and Scanning Electron Microscope (SEM).

Keywords: Aluminum bronze Alloy; Horizontal Centrifugal Casting; Characterization; Bush,;Sleeve

Introduction

A Bushing (sometimes termed as Bushing sleeves or Sleeve Bearings) is a mechanical part or assembly, used to isolate the vibrations between two mechanical parts either moving or stationary, hence damping the energy transmitted between the parts. [1, 2] It is most commonly used in the vehicle suspension systems, where rubber bushes (mostly synthetic rubber or polyurethane) as shown in Figure 1, are used for vibration damping, by providing separation between the parts. Bushing allows relative motion by sliding, as compared to rolling. It allows free movement of suspension parts. For example, on a bumpy ride it reduces the vibrations transmitted to the chassis of vehicles by using this rubber bushes.

Different composition and different design bushes are used depending on the nature of components and environment in which they are used, for example rubber bushes cannot be used in the harsh environment, where temperature is very high, so different material like steel and non-ferrous especially Aluminum-Bronze or other material will be used, depending upon the factors involved in the process and design these bushes keeping in view the sustainability against the particular factors involved in the process. Hence, there are different types of bushes depending upon the chemical composition and the design of the bushes.

Generally, the bushes are classified into three main types:

(1)-Rubber Bushes

They are made of a rubber tube as shown in Figure 1, with metal layers adhered to the inside wall. High stress, high torque, and high deflection make bushings a popular option for engineers. Additionally, there is the opportunity to purchase bushes that are manufactured to your specifications.



Figure 1 Rubber bushes used for reducing vibrations in vehicles chassis [2]

(2)-Steel Bushes

Steel bushings are often used in hard-working environments, as well as in oscillating and low-frequency motion, because of their high load capacity and remarkable fatigue resistance when subjected to very high temperatures.



Figure 2 Steel bushes with high load capacity and fatigue resistance

The high carbon steel and hardened steel bushings with a hardened value of 56-62 HRC are commonly used in different applications.

(3)-Aluminum Bronze Bushing Sleeves

Bronzes made from Aluminum are copper-based alloys in which Aluminum is a major alloying ingredient along with Iron, Manganese and Zinc. These alloys generally include 5-14% Aluminum. A variety of alloying elements may be added to Aluminum bronze depending on the intended usage and applications. These include but are not limited to manganese, silicon, and tin. Many heavy-duty industrial applications make use of Aluminum-Bronze bushings, such as automobiles, earthmoving equipment and pumps. [6]

Aluminum Bronze Bushes as shown in Figure 3, are used under heavy tensile and frictional loads and severe conditions rather than the steel and non-ferrous bushes. Therefore, they have vast applications in industries and are very useful in heavy vehicles where it has been used in many important assemblies like engine, elevation, depressing mechanism of heavy machinery, equipment of construction, defense and aerospace industry.



Figure 3 Aluminum bronze bushes developed through horizontal centrifugal casting machine

Material Selection In the experimental practice, the goal was to cast hollow cylinder of aluminum bronze by horizontal centrifugal casting process. Melt Treatment carried out in induction furnace and melt treatment covers three methods: Covering fluxes, Degassing Tablet and Deoxidizing tubes. The fluxes are used for purpose of cleaning, covering, shielding the metal from the oxygen, and slag thickening. ALBRAL is mostly used for aluminum bronzes. Degassing is usually required to remove dissolved hydrogen from the molten metal at elevated temperature.

Melt Treatment

The composition of Aluminum Bronze Alloy used to Aluminum Bronze Bushing is shown in Table 1:

Table 1: The chemical composition of Aluminum bronze bush

% Cu	%Al	%Fe	%Mn	%Zn	%Ni
83.55	9.70	3.25	2.2	0.45	0.17



Figure 4 Developed Aluminum bronze bush sleeve

Raw Material

The planning was done to produce the desired component Aluminum bronze alloy in induction furnace. Induction furnace process is basically a melting or recycling process not refining process. Therefore for development of the desired composition alloy can only be achieved by using good grade raw materials. Following raw materials were arranged i.e. Copper ingot 99.9%, Aluminum ingot 99.9 %, Ferro-manganese copper master alloy; Zinc Ingot, degassing, fluxing and deoxidizing agents.

Induction furnace of 200 Kilograms capacity was used for melting of raw material. Raw and melting temperature was kept under constant monitoring with the help of thermocouple. The melting of raw materials was started at 1100 and gradually increases to 1200 degree centigrade. All major alloying addition in the furnace had been carried out just before pouring the prepared melt into the ladle. Degassing and grain refinement completed before going to casting into horizontal centrifugal casting machine.

Horizontal Centrifugal Casting

In a genuine centrifugal casting technique, the mould is spun around its own axis while it is being cast. For a simple cylindrical or tubular item, this is the most effective approach of dealing with it. As shown in figure 4, the thickness of the cylinder is computed based on the amount of metal that has been utilized.. It is possible to use the centrifugal force of the spinning mold to achieve the desired form and wall thickness instead of the spinning mold.

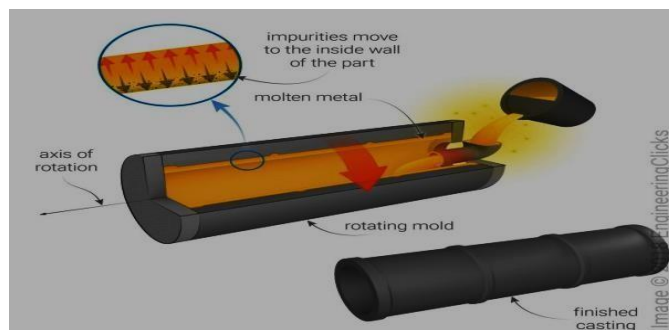


Figure 5 Schematic HCC

Because of the porous nature of the metal and the presence of impurities, the solidification process begins on the exterior surface of the mold. The bore of the device may need to be machined to remove the cemented component. The centrifugal casting process is the ideal choice if you want a high-density casting product. Even though aluminum bronze has a higher rotational speed requirement than tin bronze or gun metal, fast cooling rates induce surface cracking, which should be avoided when using aluminum bronze.

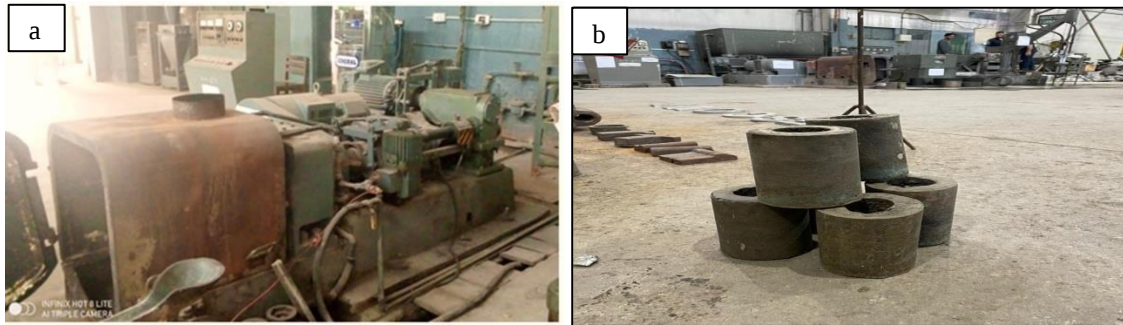


Figure.(6a and b) Horizontal centrifugal casting machine and developed sleeves blanks

Several factors have an impact on the quality of centrifugal castings. The rotating velocity, pouring temperature, pouring velocity, and mold temperature are all critical process factors. The melt treatment that is employed during the melting of the charge influences the quality of the casting as well as the casting itself.

Approximately 140mm outer diameter is provided by the mold, which is constructed of mild steel. The mold is 170mm in length and 100mm in width on the interior. During the casting practice, initially cracks observed in developed sleeves. But keep changing the parameters like RPM,s, temperature and controlling the cooling rate , the developed samples produced were free of defects especially the crack in the sleeves which was observed during horizontal centrifugal casting.

The ideal mold rotation for this centrifugal casting was as under:

Table 2: HCC process parameters

Sample NO's	RPM	Melting Temperature
D1 & D2	1100	1200
D3 & D4	1150	1150
D5 & D6	1200	1150

All developed Aluminum bronze sleeves samples were further characterized by using advance characterization tools. Developed 6* samples of bushing sleeves comprises 2* bushes set by keeping above mentioned table's process parameters and marked as D1, D2, D3, D4, D5 & D6.

Characterization Results and discussions

Spectroscopy Analysis

The composition of developed samples was analyzed by using spectrometer and further the wet analysis was being carried out to confirm the elemental composition.

Table 3: Chemical analysis of Developed samples

%Cu	%Al	%Ni	%Fe	%Mn	%Zn
83.55	9.70	0.17	3.25	2.20	0.45

Aluminum is the major alloying element beside other trace elements like Manganese, Nickel, Ferrous and Zinc that are also play alloying elements role and optimize inherent properties like bearing heavy tensile loads along with shocking, frictional and abrasion loads as compared traditional market sleeves. The mechanical properties of Aluminum bronze alloys have been significantly increased by the addition of other alloying elements in varying percentage ranges of Mg and Ni elements [4] [5]. The developed bushes are basically manufactured for heavy tensile load bearing applications especially in elevation and depressing mechanism of heavy track vehicles of defence, aerospace and construction machinery.

Hardness

The hardness of developed Aluminum bronze bushing sleeves as cast and heat treated was determined by universal hardness tester FH-12. To see heat treatment effect, the solution treatment followed with water quenching of the developed samples D3, D4 and then aged the developed samples to a temperature of 400 degree centigrade .The hardness values are given as under in result table 4:

Table 4: The hardness of developed Aluminum bronze alloy bushes in HB by using Universal hardness tester

Nomenclature	Observed Value Hardness (HB)
SAMPLE D1	150
SAMPLE D2	156
SAMPLE D3(HT)	228
SAMPLE D4(HT)	213
SAMPLE D5	156
SAMPLE D6	168

Tensile Strength

Tensile strength and percentage elongation test of developed Aluminum bronze alloy bushings samples was carried by using Universal hardness testing machine. Tensile sample prepared as per ASTM standard E-8.

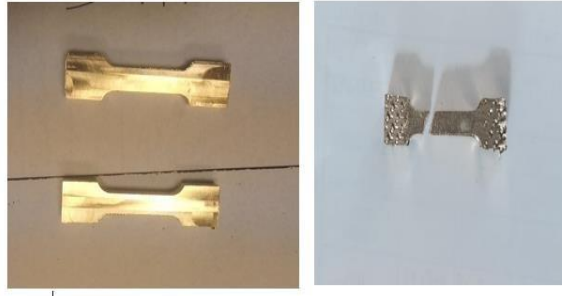


Figure 7 tensile strength and percent elongation

The developed samples of aluminum bronze sleeve have good tensile strength and elongation percentage. The tensile strength values were increased after heat treatment of the developed alloy with decrease in percentage elongation where martensitic structure formed during heat treatment. The values of tensile strength and elongation are as under given in the table 5:

Table 5: The tensile strength of developed Aluminum bronze bush

Nomenclature	Actual tensile strength (KG/MM ²)	Elongation [%]
D1	62	14
D2	65.2	12
D3	68	5.2
D4	66	6
D5	64	12
D6	62	13

Impact Toughness

Impact testing can perform according to ASTM E-23.



Figure 8 V-notch impact test sample

The Charpy Izod toughness tester was used to determine the impact toughness of developed samples of Aluminum bronze bushings. The results of samples are given as under table 5

Table 6: Impact toughness

Nomenclature	Observed Impact Toughness (KG-M/CM ²)
D1	4.6
D2	5.4
D3(HT)	2.5
D4(HT)	2.8
D5	4.5
D6	5.0

Optical Microscopy

The optical microscopic analysis of developed samples by using Versamet II showed two major phases i.e. alpha phase with Copper and reinforced beta phase having Aluminum and other alloying elements like Fe, Mn, Ni and Zn traces in the matrix of alpha phase. The copper content in this phase is in the range of 80-85% and aluminum content is typically ranges in the 8-10.5%. Aluminum rich phase within the matrix are regions enriched with Aluminum and other trace elements like Mn and Iron. The higher concentration of Aluminum is responsible for increasing corrosion resistance and few other unique properties[4, 5]. This phase forms small discrete particles or dendritic structures within the matrix of copper. Besides specific alloy composition, the small amount of Mn, Iron and Zinc as trace elements are also present in the bushing sleeves which contribute various properties such as hardness, strength and resistance to wear corrosion, Casting fluidity [7] [6].

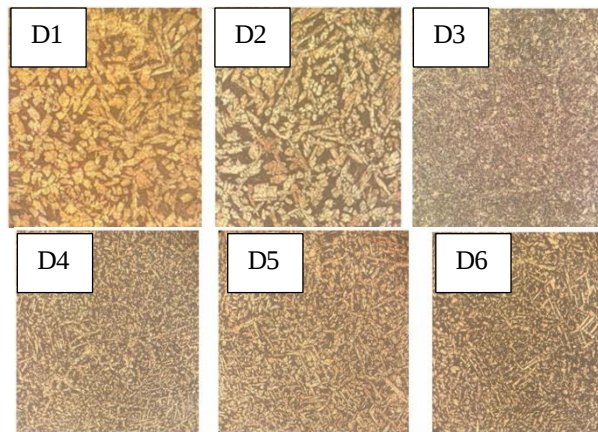


Figure 9 The microstructures by optical microscopy of the developed Aluminum bronze samples at 400x

The results of microscopy showed that alpha precipitates of Aluminum, Mn and iron in the matrix of Cu of developed bushing sleeves [8]. The finer grain structure contributes to improved mechanical properties. When the RPM,s of the centrifugal casting machine is kept at low speed, the grain size of the precipitates formed are coarsened grains and by increasing the RPM,s of the machine these precipitates in the beta region of matrix of Copper becomes fine and size of the grains decreases and dispersed equiaxed throughout the whole microstructure of the developed Aluminum bronze bushing sleeves and it contributes higher mechanical strength and other properties. The impact of the mould speed RPM,S of the horizontal centrifugal casting machine can be clearly be seen in microstructure of all Developed samples.

Similarly when the heat treatment of developed samples was being carried out the dendrites of alpha Aluminum, Mn and Fe dispersed equiaxed and in finer grain size exhibiting higher mechanical strength of developed samples D3, D4. Moreover the horizontal centrifugal casting technique proved to be effective in achieving uniform grain distribution and minimized the porosity within the bushing sleeves which further led it to better mechanical and other inherent properties like wear, corrosion and fatigue.

Scanning Electron Microscopy

Scanning electron microscopy of these developed aluminum bronze bushing sleeves reveal information about grain size, phase distribution and surface defects. The SEM images of aluminum bronze bushing showed average grain size which influences the mechanical properties like hardness, tensile strength and other properties. Smaller grain size results in improving mechanical properties due to higher density of the grain boundaries [9, 10]. The phase distribution showed the different phases of Copper [8], Aluminum and other alloying elements and also reveals arrangements and distribution of these phases aiding in understanding the alloy's composition and potential performance characteristics.

Surface defects can also be encompassed by irregularities, imperfections and anomalies on

the material's surface which identifies crucial defects and access the materials reliability and potential failure.

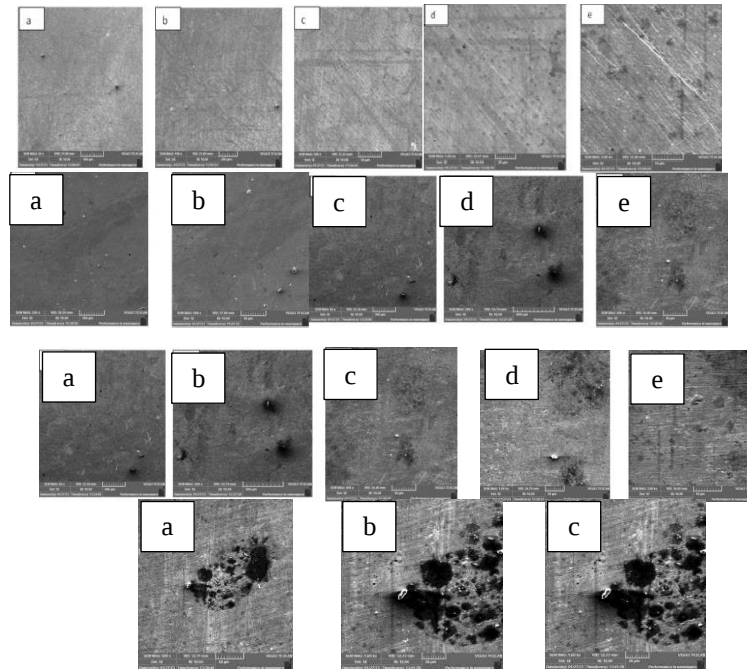


Fig 7: SEM images of developed sample of Aluminum Bronze

The topography and morphology studied of developed Aluminum bush alloy in SEM also showed a sound casting except a non-metallic inclusion in one developed sample D5 which is often results due to negligence while foundry practice. Therefore proper melt temperature, mold rotation speed, degassing, pouring and all other foundry parameters may reduce and eliminate these sorts of defects.

CONCLUSIONS

The Aluminum bronze alloy bush sleeves with desired chemical composition have been developed by using horizontal centrifugal casting machine. Alloying addition of trace elements like Mn, Fe, Ni and Zn along with controlled process parameters of Horizontal Centrifugal Casting i.e. RPM (rotation speed of mold) and temperature during casting have been kept in continuous monitoring which results into defects free and a sound bushing sleeves. When the mold rotation speed increased, it precipitates into finer grain size and vice versa and also it results in positive change trend in mechanical properties of developed samples. The characterization results of all developed samples such as hardness, tensile and impact values are all within the specified limits of Aluminum bronze bush sleeves. The alloying addition of these elements in the aluminum bronze bushing sleeves which inherent

anti wear anti-corrosion, low fatigue, machinability, casting fluidity and high tensile strength property which is useful in elevating and depressing mechanism of tracked vehicles.

Heat treatment effect also has been studied of developed samples which appreciable increases the hardness and tensile strength with decrease in its ductility and also eventually fall in the values of impact strength of developed samples. Heat treatment of developed alloy composition results in achieving next high tensile grade bushing sleeves which was developed by addition of extra alloying addition of manganese, iron and other trace elements. Heat treated samples of developed alloy showed martensitic and bainite structure which can be seen during the optical microscopy of the developed samples D3 and D4. The dendritic reinforced alloying elements dissolved equaled in the matrix of Copper results in high hardness and tensile strength.

Microscopy has been carried out by using optical microscope which showed two phases alpha phase having Copper and beta phase reinforced with aluminum and other trace elements equiaxed distribution of atoms in the matrix of Copper alpha phase. By increasing mold rotation speed , melt temperature the grain size gets finer and also results in optimization in mechanical properties.

The topography and morphology studied of developed Aluminum bush alloy in SEM also showed a sound casting bushing sleeves have defect free structure. Topographic studied revealed that some inclusions i.e. non-metallic or porosity in the morphology which could affect the quality of the developed sleeve and also its performance.

The indigenously development of these Aluminum bronze bushes help us in developing these bushes locally which reduces our dependency on the import of these items from foreign countries.

It also help the country and especially the defence industry of Pakistan in saving of huge foreign exchange.

Literature References

- [1] P. Beeley, *Foundry technology*: Elsevier, 2001.
- [2] P. S. Patel and J. V. Patel, "A review of tribological and mechanical investigation of aluminum bronze C95500 cast by horizontal centrifugal casting," 2019.
- [3] B. U. Odoni, F. O. EDOZIUNO, C. C. NWAEJU, and R. O. Akaluzia, "Experimental analysis, predictive modelling and optimization of some physical and mechanical properties of aluminium 6063 alloy based composites reinforced with corn cob ash," *Journal of Materials and Engineering Structures «JMES»*, vol. 7, pp. 451-465, 2020.
- [4] T. A. Elkholy, "Journal of American Science," *Journal of American Science*, vol. 7, 2011.
- [5] A. Imah, S. Ekenyem, C. Ogbu, G. Ewa, and E. Nnuka, "Effects of Nickel on the Structure and Mechanical Properties of Aluminum Bronze (Cu-10wt% Al)."
- [6] J. Kim, J. Kim, and C. Pyo, "Comparison of mechanical properties of Ni-Al-Bronze alloy fabricated through wire arc additive manufacturing with Ni-Al-Bronze alloy fabricated through casting," *Metals*, vol. 10, p. 1164, 2020.
- [7] S. Ilangovan, "Study of microstructure, hardness and wear properties of sand cast Cu-4Ni-6Sn bronze alloy," *Journal of Engineering Science and Technology*, vol. 10, pp. 526-532, 2015.
- [8] V. K. Sharma, R. Singh, and R. Chaudhary, "Experimental study of tribological behavior of casted aluminium-bronze," *Materials Today: Proceedings*, vol. 5, pp. 28008-28017, 2018.
- [9] E. Culpan and G. Rose, "Microstructural characterization of cast nickel aluminium bronze," *Journal of materials science*, vol. 13, pp. 1647-1657, 1978.
- [10] F. Hasan, A. Jahanafrooz, G. Lorimer, and N. Ridley, "The morphology, crystallography, and chemistry of phases in as-cast nickel-aluminum bronze," *Metallurgical Transactions A*, vol. 13, pp. 1337-1345, 1982.