ISSN 2229-5518

Modification of the structure and mechanical properties of aluminum bronze (Cu-10%Al) alloy with Zirconium and Titanium

Nwambu C.N, Anyaeche I.M, Onwubiko G.C and Nnuka E.E.

Abstract - This paper examines the effect of zirconium and titanium on the structure and mechanical properties of aluminium bronze. The properties studied were tensile, hardness and impact test, universal testing machine model 50kN were used to test for tensile strength, impact strength using charpy machine model IT-30 and Brinell tester model B 3000 (H). The specimens were prepared by doping 0.5-2.5% zirconium and titanium into the aluminium bronze (Cu-10% Al) at interval of 0.5 percent. The specimens were prepared according to BS 131- 240 standards. Microstructure analysis was conducted using L2003A reflected light metallurgical microscope. Results obtained shows that tensile strength, impact strength and ductility increased respectively as dopants increased. Microstructure analysis revealed the primary α-phase, β-phase (intermetallic phases) and fine stable reinforcing kappa phase and these alterations in phases resulted in the development in the mechanical properties. Aluminum bronze doped with zirconium and titanium at 2.5% proved to increased tensile strength, ductility, impact strength, hardness and is therefore recommended for applications in engineering field.

Keywords - Aluminium bronze, zirconium and titanium addition, mechanical properties, microstructure.

1. Introduction

In recent times non-ferrous metals and alloys have become so important that technological development without them is unconceivable. Among the most important non-ferrous metals is copper with its alloys [21]. 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 [3]. The ever-present demand by the electrical industries for the worlds diminishing resources of copper has led industry to look for cheaper materials to replace the now expensive copper alloys. Whilst the metallurgist has been perfecting more ductile mild steel, the engineer has been developing more efficient methods of forming metals so that copper alloys are now only used where high electrical conductivity or suitable formability coupled with good corrosion resistance are required [6]. The copper-base alloys include brasses and bronzes, the latter being copper-rich alloys containing tin, aluminum, silicon or beryllium [7]. Aluminium bronze is a type of bronze in which aluminium is the main alloying element added to copper. It is useful in a great number of engineering structures with a variety of the alloys finding applications in different industries [1,9]. According to ISO 428 specification [2], most categories of aluminium bronze contain 4-10% wt of aluminium in addition to other alloying elements such as iron, nickel, manganese and silicon in varying proportions. The relatively higher strength of aluminum bronze compared with other copper alloys makes it more suitable for the production of forgings, plates, sheets, extruded rods and sections [3, 8]. Aluminium bronze gives a combination of chemo-mechanical properties which supersedes many other alloy series, making them preferred, particularly for critical applications [4]. Aluminium increases the mechanical properties of copper by establishing a face-centred-cubic (FCC) phase which also improves the casting and hot working properties of the base metal [5,23]. Other alloying elements example magnesium, iron, tantalum, etc. also improve the mechanical properties and modify the microstructure. Nickel and manganese improve corrosion resistance, whereas iron is a grain refiner [6, 12]. Despite these desirable characteristics, most aluminium bronze exhibit deficient response in certain critical applications such as sub-sea weapons ejection system, aircraft landing gears components and power plant facilities. The need to overcome these obvious performance limitations in aluminium bronze is imperative to meet today's emerging technologies [13]. Structure modification in aluminium bronze is accomplished through any or combination of the following processes; heat treatment, alloying and deformation. The choice of method however is usually determined by cost, and effectiveness. The mechanical properties of aluminium bronzes depend on the extent to which aluminium and other alloying elements modify the structure [18]. Hafnium and its alloy exhibit properties that provided unique technological capabilities among refractory metals. It can be used as a hardening element in cast version and also it improves weldability and corrosion resistance of cast alloys [9]. This research work aims at modifying the structure of Cu-10% Al alloy, by using Zirconium and Titanium and by impacting on the types, forms and distribution of phases within the matrix, and their effects on the mechanical properties.

2. Experimental Procedure

Materials and equipment used for this research work are: Pure copper wire, pure aluminium wire, zirconium and titanium metal powder, crucible furnace, stainless steel crucible pot, lath machine, electronic weighing balance, venire calliper, bench vice, electric grinding machine, hack-saw, mixer, scoping spoon, electric blower, rammer, moulding box, hardness testing machine, universal tensile testing machine, impact testing machine, metallurgical microscope with attended camera, etc.

2.1 Method

Melting and casting of alloys: This operation was carried out to produce eleven separate specimens for the research work. The crucible furnace was preheated for about 25 minutes. For the control specimen, 153.33g of Cu and 16.67g of Al were measured out. Copper was charged into the furnace pre-set at 1200^{o}C and heated till it melted. Aluminium was then added and allowed to dissolve in the molten copper for 10-15 minutes. The modifying elements (Zirconium and Titanium) were then introduced based on compositions after the control sample had been cast.

The melt was manually stirred in order to ensure homogeneity and to facilitate uniform distribution of the modifying element. Die casting method was used after removal from the furnace and carefully skimming of the drops. The molten metal was poured into the metal cavity. The solidified castings were then removed from the cavity after 20 minutes of pouring, cleaned and ready for tests.

Test Specimen: Aluminium bronze alloy without zirconium and titanium as control sample was selected aside, while others containing zirconium and titanium at various weight percentage compositions were selected and machined into standard specimen.

Mechanical Test: The tensile strength were carried out with Monsanto Tensometer, while a Brinell hardness machine with 2.5mm diameter ball indenter and 62.5N minimum was used to determine the hardness property, Charpy impact test machine was used to carry out impact strength.

Metallography: Preparation of material was done by grinding, polishing and etching, so that the structure can be examined using optical metallurgical microscope. The specimens were grinded by the use of series of emery papers in order of 220, 500, 800, and 1200 grits and polished using fine alumina powder. An iron (iii) chloride acid was used as the etching agent before mounting on the microscope for microstructure examination and micrographs.

Table 1: Mechanical properties of Cu-10%Al modified with Zr and Ti

Alloy	Yield strength	UTS	Hardness strength	Impact Strength
Cu-10%Al	167	186	104	64.70
Cu-10%Al+0.5Ti	189	203	113	68.04
Cu-10%Al+1.0Ti	201	234	132	73.57
Cu-10%Al+1.5Ti	245	273	165	79.93
Cu-10%Al+2.0Ti	287	324	192	84.43
Cu-10%Al+2.5Ti	336	385	236	89.93
Cu-10%Al+0.5Zr	207	205	118	63.93
Cu-10%Al+1.0Zr	213	227	131	68.41
Cu-10%Al+1.5Zr	254	255	173	76.83
Cu-10%Al+2.0Zr	289	297	197	82.13
Cu-10%Al+2.5Zr	324	348	228	88.47

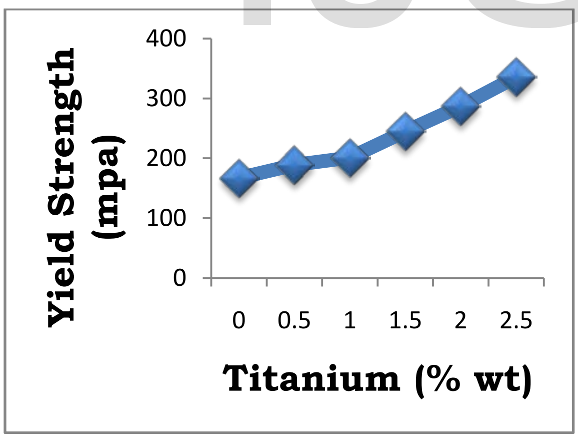

Figure 1: The effect of Titanium composition on Yielding Strength of Cu-10%Al alloy.

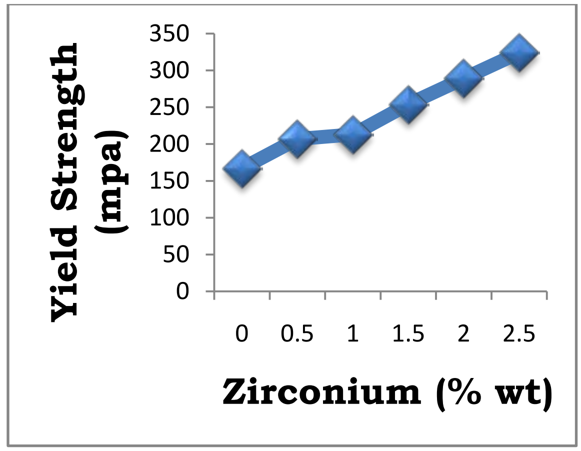

Figure 2: The effect of Zirconium composition on Yielding Strength of Cu-10%Al alloy.

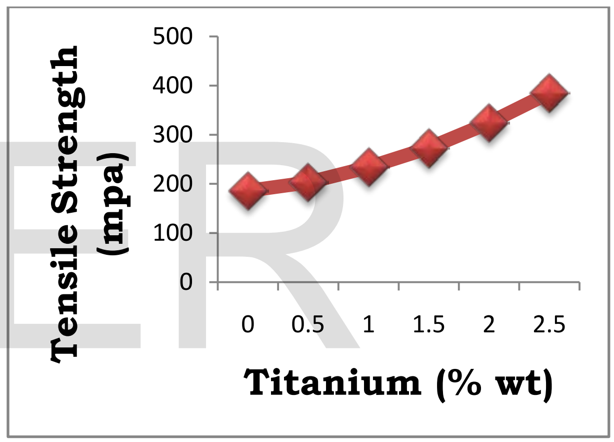

Figure 3: The effect of Titanium composition on UTS of Cu-10%Al alloy.

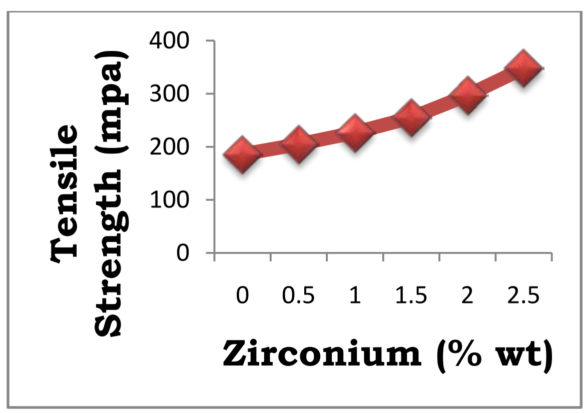

Figure 4: The effect of Zirconium composition on UTS of Cu-10%Al alloy.

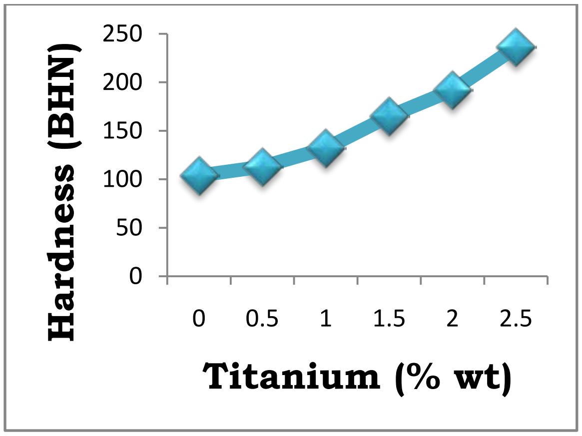

Figure 5: The effect of Titanium composition on Hardness (BHN) of Cu-10%Al alloy.

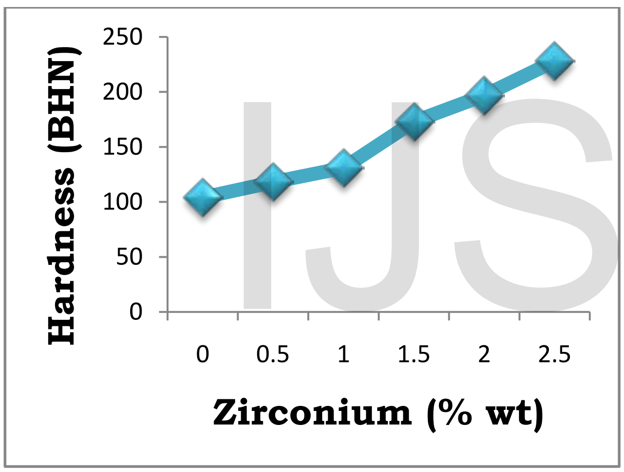

Figure 6: The effect of Zirconium composition on Hardness (BHN) of Cu-10%Al alloy.

3. Results and Discussion

The results of the effect of zirconium and titanium additions on the structure and mechanical properties of Cu-10%Al alloy were presented in tabular and graphical form. Table 1 and Figures 1&6 shows the variation of yield strength, ultimate tensile strength, hardness strength and impact strength to percentage of modifiers addition to alloys while the microstructures developed by the treated alloys are shown in Plates 1-11.

4. Mechanical properties

It was observed from the results that were obtained in this study that mechanical properties increases with increase of compositions of zirconium and titanium but values of alloys treated with titanium were higher than the values from zirconium samples. However, samples modified with titanium possessed better mechanical properties than samples modified with zirconium. The explanation is that titanium and zirconium hampers the eutectoid decomposition. The β-phase is kept, and the structure became fine-grained. Figures 1-6 have shown that with simultaneous addition of titanium and zirconium to the Cu-10%Al alloy system, it improves the mechanical properties of these alloys.

5. Microstructure examination

From plate 1 which is the control specimen, it was observed that the microstructure consists of large coarse interconnected intermetallic Cu9Al4 compound and α+ phases. This alloy exhibits the lowest mechanical properties in terms of yield strength, tensile strength, impact strength, ductility and hardness because of the coarse microstructure. Plates 2-11 show the microstructures of Cu-10% Al alloy

ISSN 2229-5518

modified with 0.5-2.5wt % of modifying element respectively. Apart from different intermetallics, two major phases were revealed under the optical microscopes via: α-phase and ß-phase. The α-phase increased in size as the composition of titanium and zirconium increases. This led to the formation of fine lamellar form of kappa (k) precipitates present in the microstructures. ß-phase decreased in size as the weight percentage composition of zirconium and titanium increased thereby allowing little or no phase to precipitate. Presence of sparse distribution of kappa precipitates in the predominated α + matrix caused smaller grains to emerge in increasing quantity creating smaller lattice distance thereby resulting to improvement of mechanical properties. Plate 6 and 11 shows the effect of 2.5wt% zirconium and titanium addition on the Cu-10%Al alloy. The amount of the fine lamellar kappa phase within the matrix increased compared to plates (2 and 7) where fewer kappa phase was observed. The presence of more modifiers in the system led to increased nucleation sites for the transformation which suppressed the formation of ß-phase within the copper lattice, and increased the barrier dislocation movement.

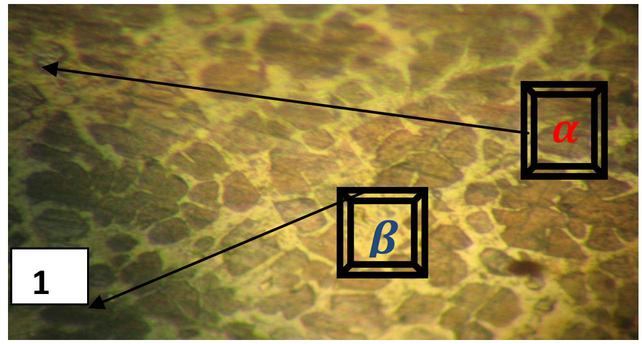

Plate 1: Micrograph of Cu-10%Al (x400)

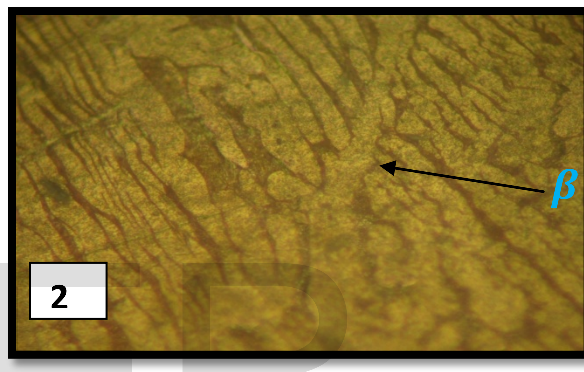

Plate 2: Micrograph of Cu-10%Al +0.5%Ti (x400)

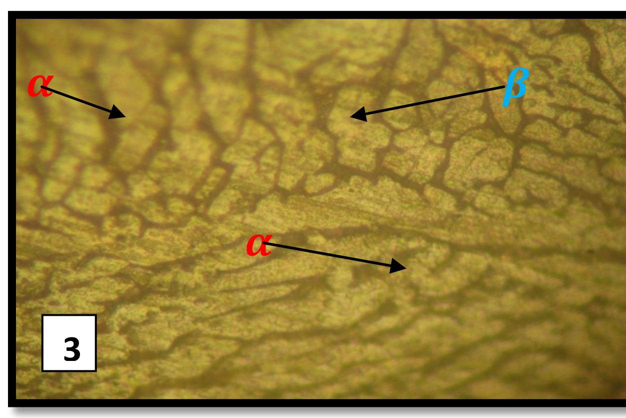

Plate 3: Micrograph of Cu-10%Al +1.0%Ti(x400)

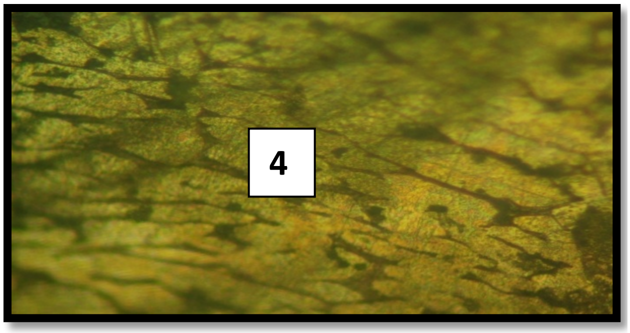

Plate 4: Micrograph of Cu-10%Al +1.5%Ti(x400)

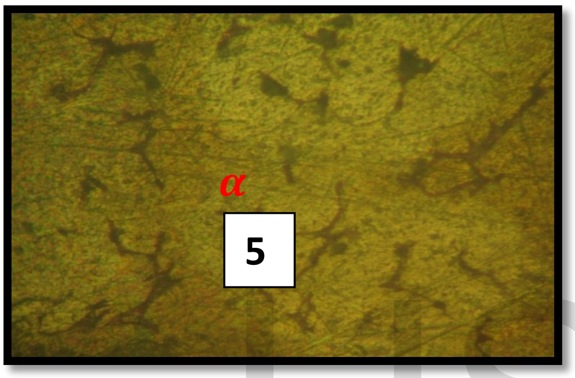

Plate 5: Micrograph of Cu-10%Al +2.0%Ti(x400)

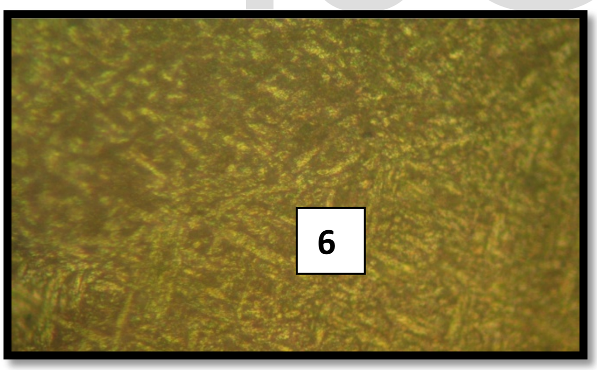

Plate 6: Micrograph of Cu-10%Al +2.5%Ti(x400)

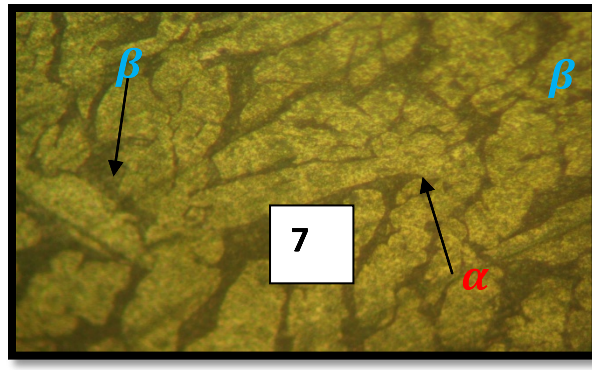

Plate 7: Micrograph of Cu-10%Al+0.5%Zr. (x400)

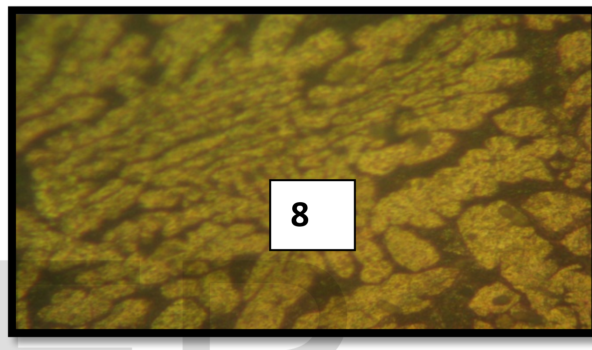

Plate 8: Micrograph of Cu-10%Al+1.0%Zr. (x400)

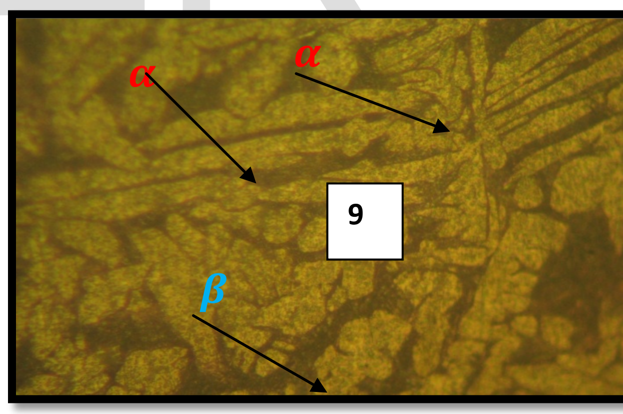

Plate 9: Micrograph of Cu-10%Al+1.5%Zr. (x400)

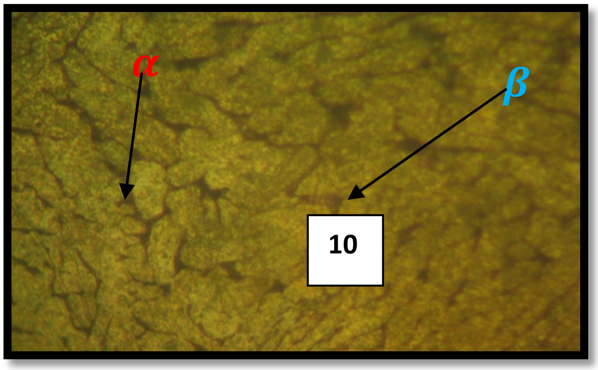

Plate 10: Micrograph of Cu-10%Al+2.0%Zr.(x400)

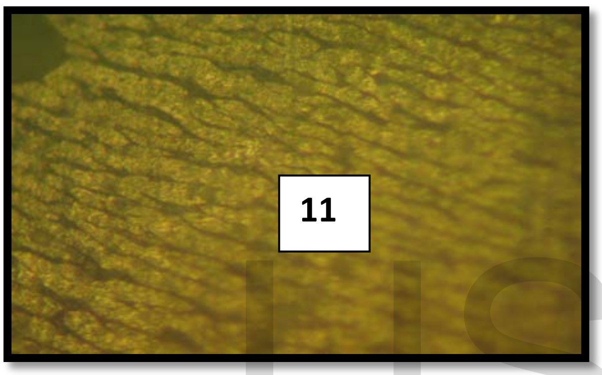

Plate 11: Micrograph of Cu-10%Al+2.5%Zr. (x400)

REFERENCES

[1] Aaltonen, P. Kelemetti, K. and Hanninen, H. (1985). Effect of tempering on corrosion and mechanical properties of cast aluminium bronzes. *Journals of Metallurgy, p. 233-242.*

[2] Abdul Amir, H. Abubakar, M. Huda Dhia, J. Sam Sin Yan, Jasin Hilo, N. Ali-Taminui, Redah, I. and Ahmed, A. (2013). Corrosion of nickel – aluminum bronze alloy in aerated 0.1M sodium chloride solution under hydrodynamic condition. *International Journal of Electrochemical Science, Vol.8, P.4571-4582*.

[3] Adeyemi, G. Oluwadare, B. S. and Olanipekun, K. O. (2013). The investigation on the effect of addition of magnesium on the microstructure and mechanical properties of aluminium bronze. *International Journal of Engineering Science Invention, ISSN: 2319-6719, Vol. 2, No. 11, p. 1-13.*

[4] Ahmed, Z. and Dvani, P. (1975). The effect of alloying addition on the optimisation of corrosion resistance and mechanical properties of alpha and beta aluminium bronze. *Paper from 6th International Congress on Metallic Corrosion, Books Sydney, p.28,* Aluminum Bronze Family: www.morganbronze.com

[5] Anup, R. P. (2014). Mechanical properties and microstructural investigation of aluminium bronze by centrifugal casting process. *Department of Mechanical Engineering, Ganpat University, p.1-83.*

[6] Bukola, J. B. Micheal, O. B. and Joseph, O. B. (2013). Corrosion characteristics of as-cast aluminium bronze alloy in selected aggressive media. *Journals of Minerals Characterization and Engineering, Vol. 1, p. 245-249.*

[7] Cenoz, I. (2010). Metallography of aluminium bronze alloy as cast in permanent iron die. *Scientific Paper, UDC. 620.186.669.715, MJoM Vol.16 (2), p.115-122.*

[8] Copper Development Association, (2000). Resistance to wear of aluminium bronzes. *CDA Publication No.126.*

[9] Donatus, U. Joseph, A. O. Itopa, M. (2012). Mechanical propertiesa and microstructure of

locally produced aluminium bronze alloys. *Journal of Minerals and Materials Characterization and Engineering, Vol. 11, p. 1020-1026.*

[10] Eli, G. and Menachem, B. (1988). Phase transformation in permanent mould cast aluminium bronze. *Journal of Materials Science, Vol.23,No.10,p.3558-3562.* *doi:10.1007/BF00540495*

[11] Gronostajski, Z. (2001). The effect of phase transformation on the limit strain of aluminium bronze. *Journals of Achievements in Mechanical and Materials Engineering, Vol.3, p.225-228.*

[12] Hassan, F. Iqbal, J. and Ridley, N. (1985). Microstructure of as-cast aluminium bronze containing iron. *Journals of Materials Science and Technology, Vol.1, No.4, p. 321-315.*

[13] Haydar, A. Al-Ethar, H. Alihobi, H. and Halahazim, A. (2014). Effect of graphite on mechanical and machining properties of aluminium bronze. *International Journal of Mechanical Engineering and Technology (IJMET), ISSN 0976-06359(online), Vol.5, p.189-199.*

[14] Hong, Y. Yugui, Z. and Zhiming, Y. (2009). Cavitation erosion corrosion behaviour of manganese- nickel-aluminium bronze in comparison with manganese brass. *Journals of Materials Science Technology, Vol. 25, No. 6, p. 758-765.*

[15] Pisarek BP. The crystallization of aluminium bronze with addition of Si, Cr, Mo, and/ or W. Archives of materials science and engineering, 2007; 28(8):461-466.

[16] Vin C. Aluminium bronze part 1 and 11. Metallurgy of copper and cooper alloys. Copper Development Association. 2002, 1-20.

[17] Kear G, Barkeer BD, Stokes KR, Walsh FC. Electrochemistry of non-age 90-1o copper-nickel alloy (UNSC70610)./ Electrochemica Aga, 2007; 52(7):2343-2351.

[18] Kenth GB. Mechael KB. Engineering material properties and selection. Sixth Edition, Pentice- Hall lnc. Upper Sdalle River New Jessy 07458. 1999, 570-594.

[19] Adeyemi GJ, Olwadare BS, Olanipekun, KO. The investigation on the effect of addition of magnesium on the microstructure and mechanical properties of aluminium bronze. International Journal of Engineering Science Invention. ISSN: 2319-6719, 2013; 2 (11):1-13.

[20] Sekunowo OI, Adeosun SO, Lawal GI, Balogun SA. Mechanical characteristics of aluminium bronze iron – granules composites. International Journals of Scientific & Technology Research ISSN 2277-8616. 2013; 2(4):174-184.

[21] Nnuka EE. The effect of micro-additives on the quality and distribution pattern of the secondary phase in aluminium copper alloy system. The Nigeria Engineer, 1991; 26(3):30-37.

[22] Oh-shi K, Mc Nelly TR. Microstructural modification of cast nickel aluminium bronze. Metallurgical and Materials Transactions, 2004;

35(9):2951-2961.

[23] R. E. Smallman, R. J. Bishop, Modern Physical Metallurgy and Materials Engineering, Science, process, applications, Sixth Edition, Butterworth- Heinemann, Linacre House, Jordan Hill, Oxford OX28DP, 225 Wildwood Avenue, Woburn, MA 01801-2041, 1999.

[24] U. K. Korzunin, V. P. Razshtupkin, B. I. Matjuhin, Study of the microstructure of non ferrous alloys, Materialovedenie, Omsk, 2008, 20.

[25] Kay Geels, Metallographic and Materialogr aphic Specimen Preparation, Light Microscopy, Image Analysis and Hardness Testing, Printed in U.S.A, ASTM, No. MNL46, 2007.

[26] M. Jablonska, A. Jasik, A. Hanc, *Archives of Materials Science and Engeneering*, **29**(1), 16 (2008).

[27] H. J Meigh, Cast and wrought aluminum bronzes– properties, processes and structure, Institute of Materials, London, 2000.

[28] R. Vl. Gavrilova, R. I. Petkov* Researches on the structure and properties of heat treated, nickel alloyed, molybdenum modified aluminum bronze, *University of Chemical Technology and Metallurgy – Sofia; Faculty of Metallurgy and Material Science, 1756 Sofia, blvd. Kl. Ochridski, Bulgarian Chemical Communications, Volume 45, Number 4 (pp. 644–648) 2013*