The Effect of Varying the Composition of Phosphorus on the Microstructure and Mechanical Properties of Tin-Bronze Alloys

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ABSTRACT: *An investigation was carried out to assess the effect of phosphorus addition on copper- tin alloys. However, the effect of an increase in phosphorus above 0.25% has received little or no attention. Much effort has been expended only to study the effect of phosphorus as a deoxidizing agent on copper and its alloys. In this study, a new approach of casting phosphorus tin-bronze using an improvised vacuum crucible pots, made of clay mould was adopted. This method offers low cost and consumes less energy. The various microstructures that result from the slow cooling rate during the casting process enhance mechanical properties and were carefully examined. It was observed that the hardness and tensile strength increases as phosphorous content is increased from 0.1% to 1.0%. An optimum value of 0.9% phosphorus was obtained with corresponding hardness and tensile strength of 140HB and 912.26MPa respectively.*

KEYWORDS: *Deoxidizing, microstructure, tin-bronze.*

I. INTRODUCTION

Phosphor bronze is characterized by high tensile strength, good corrosion and resistance to wear, high mechanical load and excellent elastic properties. It also possesses good castability and machinability. Phosphorus improves soundness and cleanliness of casting, which causes improvement in strength and ductility [6, 4, 2]. During the last two decades, many materials have been cast successfully using various methods including horizontal continuous casting, vacuum casting and strip casting techniques; for stainless steel, high silicon-steel, as well as copper and copper alloys. It is believed that these casting processes are suitable for producing bronze and phosphorus bronze plate without experiencing low productivity [5, 2]. Thus, the retention of as little as 0.1% phosphorus further increases the strength and hardness of the alloy [4, 1, 7].

Due to these advantages, phosphorus bronze is widely used for high-load, high speed, spring, condenser tube, gears, marine fitting, diaphragms, bellows, lock-washers and cotter pins applications, as well as poorly lubricated bearings in corrosive environments. The structure and proprieties of alloy depend on melting and casting conditions, which influences the alloy crystallization [3, 5].

Many types of castings can be used for copper and its alloys, such as sand, shell, investment, permanent mold, chemical sand, centrifugal and die casting. The technological specifications for casting processes are the most important factors to obtain good results [3, 6, 4, 9]. In this study, the effect on microstructure and mechanical properties by increasing phosphorus content in as-cast tin-bronze alloys using an improvised vacuum crucible pots is presented.

II. MATERIALS AND METHOD

II.1 Materials: Tin bronzes may conveniently be divided into two groups: low-tin bronzes and high-tin bronzes. Low-tin bronzes are those in which the tin content is less than 17%. This is the maximum theoretical limit of the solubility of tin in the copper-rich solid solution. In practice, the usual limit of solid solution is nearer to 14%, although it is rare to find a bronze with this tin content in a homogeneous single phase [3, 9]. In this study, a low tin-bronze was selected as the experimental alloy and Table 1 shows its chemical composition.

Table 1.0: Composition of the investigated phosphorus-bronze alloy

Samples (%wt)	Cu	Sn	P
A	95	5.0	0.0
B	95	4.9	0.1
C	95	4.8	0.2
D	95	4.7	0.3
E	95	4.6	0.4
F	95	4.5	0.5
G	95	4.4	0.6
H	95	4.3	0.7
I	95	4.2	0.8
J	95	4.1	0.9
K	95	4.0	1.0
L	92	6.5	1.5
M	92	6.0	2.0
N	92	5.5	2.5
O	92	5.0	3.0
P	92	4.5	3.5
Q	92	4.0	4.0
R	92	3.5	4.5
S	92	3.0	5.0

II.2 Casting Technique : Clay is one of the most widely used ceramic raw materials which are found naturally in great abundance, often used as mined without any further processing. When mixed in the appropriate proportions, clay and water form a plastic mass that is very amenable to shaping [6]. The formed piece is dried to remove some of the moisture and fired at an elevated temperature to improve its mechanical strength.

In this study, an improvised clay molded vacuum crucible pots of 5mm thickness was employed. The crucible pots consist of the melting and the casting sections. Each sample was charged in each of the crucible pots and sun-dried for 72hours. The preliminary study performed revealed that the crucible pot attains a temperature of 1850°C before adequate heat can be transferred to melt the sample. With this knowledge, each sample in the crucible pot was heated to a temperature of 1850°C, after which the cast alloys in rod forms were obtained.

II.3 Etching and Surface preparation : Micro-structural analysis is used in research studies to determine the micro-structural changes that occur as a result of varying parameters such as composition, heat treatment or processing steps [8, 7]. An optical metallurgical microscope was employed to carry out the metallographic analyses on the selected specimens. The analyses capture a square shape of approximately 3mm x 3mm of the specimen. All samples were prepared by grinding and polished with silicon carbide gel in the order 220, 320, 400 and 600 grit sizes. Optical examination was performed prior to etching with 2% alcoholic ferric chloride solution, to identify inclusions, porosity, and other casting defects.

III. EXPERIMENTAL STUDY

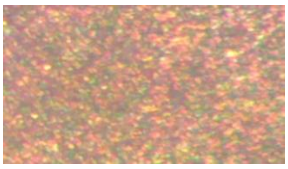
III.1 Brinell Hardness measurement : In order to determine the variation of hardness based on casting technique, *Leitz 8299 micro-hardness tester* was used to perform the micro-hardness tests of the cast samples. A load 250Kg was used for indentation on the polished samples for 15 seconds. The indentation was square shaped. Diagonal length of square was measured by a scale attached on the microscope.

III.2 Tensile Strength Measurement : The tensile tests were performed using a *Monsanto Tensometer* tensile testing machine, equipped with a data acquisition system for recording the strain and load. The strain was measured with a strain gauge and extensometer attached at the center of each specimen (giving a very precise measurement but limited to the elastic region of the cast specimens).

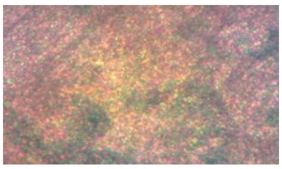
IV. RESULTS AND DISCUSSIONS

IV.1 Microstructure Analysis : Fig 1.0 below shows the variation of microstructure as phosphorus content increases. The residual phosphorus may be sufficient to be present as copper-phosphide which appears dark-blue in the microstructures at the initial stage. It may easily be distinguished from cuprous oxide by the fact that the latter is translucent with a copper reflection in the centre. There are no traces of porosity and the grain structure is lightly delineated (as the percentage of phosphorus increases up 0.9%) by the use of alcoholic ferric chloride etchant. These microstructures consist of regularly shaped primary grains of eutectic. The eutectoid constituent is made up of two phases, alpha (the copper-rich solid solution of tin in copper) and delta (an intermetallic compound of fixed composition). The constituent of the eutectic has become absorbed by the primary grains and is not visible as separate particles up to 0.7% phosphorus. A blue-grey colour began to set in as the percentage of phosphorus increases from 0.1% to about 0.7% and later appeared bright-red.

In addition, the vacuum casting employed enabled the phosphorus to be evenly dispersed, thus producing fine grains which appear within the region of the cast samples and improve the mechanical properties of alloys. As the percentage of phosphorus increases from 1.0 to 2.5%, the secondary phases (intermetallics boundaries) exist, indicates the coarse dendrite structure of the matrix compound (Fe-P) having bright-red contrast and precipitated at the grain boundaries.


Sample A


Sample B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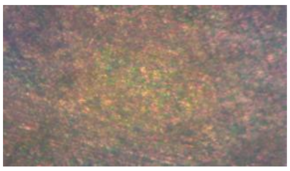
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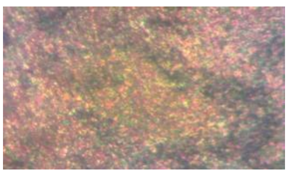
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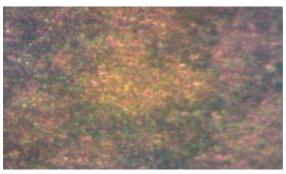
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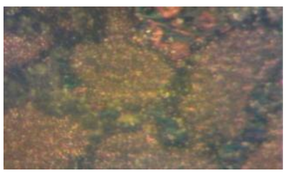
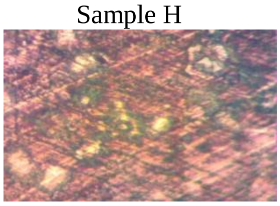

Sample H


Sample I


Sample J


Sample K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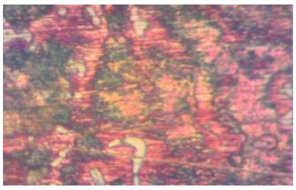
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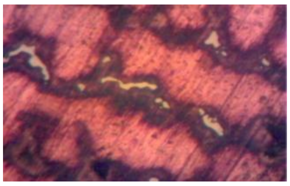
Sample N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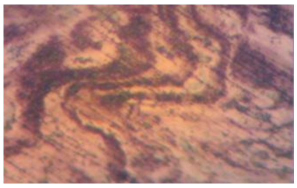
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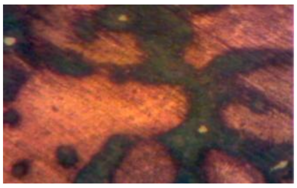
Sample Q


Sample R

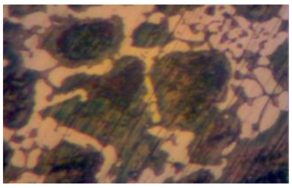
Sample S

Fig 1.0: The microstructure of the as-cast phosphorus bronze

IV.2 Results of Mechanical Testing: In this study, it was observed that at 0.1-0.2%P, the material is very hard and strong with low level of ductility. As the percentage of phosphorus increases from 0.3-1.5%, the materials become harder and tough due to the formation of grain boundary edges, thus experiences high level of ductility (long plastic deformation before fracture). Table 2 below shows the variation in the considered mechanical properties in the samples

Table 2.0: Variation in the mechanical properties of the samples

Samples (wt %)	Hardness (HB)	Tensile Strength (MPa)	Elongation (%)
95Cu-5Sn	107	520.18	12.00
95Cu-4.9Sn-0.1P	112	542.05	18.00
95Cu-4.8Sn-0.2P	121	565.38	25.00
95Cu-4.7Sn-0.3P	128	590.22	38.80
95Cu-4.6Sn-0.4P	133	616.75	38.40
95Cu-4.5Sn-0.5P	138	631.39	49.16
95Cu-4.4Sn-0.6P	140	707.98	46.18
95Cu-4.3Sn-0.7P	140	780.55	24.00
95Cu-4.2Sn-0.8P	140	821.13	33.87
95Cu-4.1Sn-0.9P	140	912.26	12.70
95Cu-4.0Sn-1.0P	136	864.88	27.31
92Cu-6.5Sn-1.5P	112	761.39	20.80
92Cu-6.0Sn-2.0P	101	691.42	27.60
92Cu-5.5Sn-2.5P	90.7	592.79	5.75
92Cu-5.0Sn-3.0P	81.3	577.59	22.92
92Cu-4.5Sn-3.5P	72.4	561.78	25.00
92Cu-4.0Sn-4.0P	65.5	530.93	26.42
92Cu-3.5Sn-4.5P	59.5	509.69	17.69
92Cu-3.0Sn-5.0P	51.9	499.55	12.40

This tendency can be identified in the microstructure as an indication of small grain sizes results in the improvement of hardness and tensile strength. At about 2.0-5.0%P, the materials experiences little plastic deformation due to a few reductions in cross-section (necking), reduces the hardness of the materials further. It is observed from the plot that the peak hardness increases with phosphorus content. Also it is to be noted that the magnitude of the peak hardness observed is marginally different, due to varying phosphorus content.

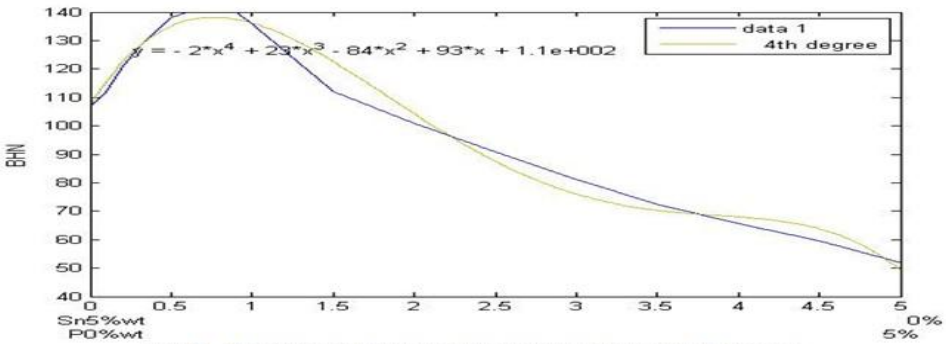

Fig 2: Variation of Hardness with percentage Tin and Phosphorus

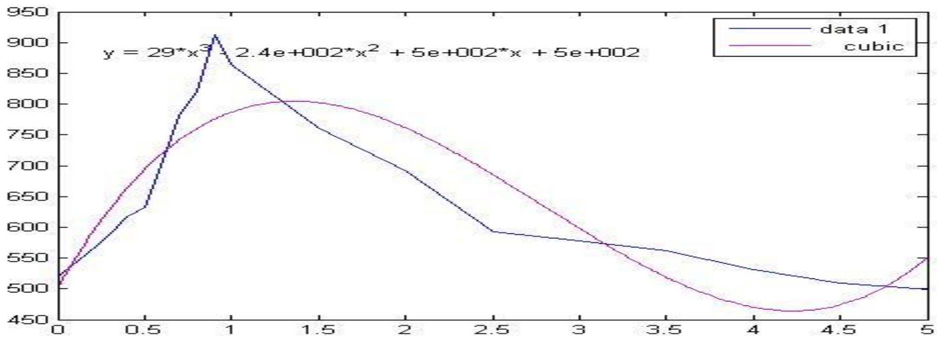

Fig 3: Variation of Tensile strength with percentage Phosphorus

V. CONCLUSIONS

In this study, microstructural characterization of phosphorus tin-copper alloys was carried out and the results obtained are given as follows:

(i) The microstructure of sample J, with composition 95Cu4.1Sn0.9P (%wt) revealed a complete homogenous eutectic structure and the grains are evenly distributed.

(ii) Similarly, sample J also gives an optimum hardness and tensile strength of 140HB and 912.26MPa.

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