Synthesis and wear characteristics of a copper-tin-lead alloy made via continuous casting

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Abstract

In tribological applications, alloys based on copper, tin-lead is widely employed as material for journal bearing. For copper-based alloys, bronze and brass alloys are frequently utilized as journal bearing materials. Alloys of copper, tin and lead were developed using continuous die casting process. Prepared alloy were subjected to evaluate ultimate tensile strength, hardness, compression strength and Wear strength. Furthermore, a scanning electron microscope was used to study the surface morphology of the worn surface. A fine lead distribution produced by continuous casting favors micro cracking and quick, steady wear with minimal friction, whereas a coarse microstructure produced by sand casting encourages the creation of transfer layers. Wear is slower in this instance, but the friction coefficient is significantly higher.

Key words: Lead, Tin, Bronze, Wear, Tensile Strength.

1. Introduction

Copper based alloys are widely used as bearing applications because they have Self lubrication property good corrosion and wear resistance. The effect of tin in the copper alloy will play important role on wear characteristics. Copper based tin bronze alloys were used as bearing materials to have high wear resistance, due to the influence of Tin. Also the addition of lead increases the hardness property of these types of bearing materials [1]. The leaded tin bronze bearing materials will have good machining parameters in comparison with tin bronze bearing materials. The leaded tin bronzes are most appropriate bearing material in corrosive condition, also at high temperature and high loads [2].

Leaded tin bronzes offer a good tribological characteristic in boundary lubrication environments. The tin bronze alloy contains distinct, discrete globules of lead. Lead facilitates the formation of a layer of solid lubricant when regular lubrication is absent or compromised. The lead-enriched layer keeps the sliding surfaces from coming into direct contact with one another.

Due to their high strength, high hardness, and excellent friction properties, zinc-based alloys have been used in various engineering applications and can be used as a needle bearing material. Zinc-based alloys are used as a bearing material due to their excellent physical, tribological and mechanical properties, low cost and high wear resistance. These alloys are important in high load and slow speed applications such as pins. The tribological properties of these alloys are better than bronze materials. White alloys based on lead and tin are used as a bearing material due to their frictional properties.

Rare-earth elements can be used to purify Cu melts and enhance microstructure, which enhances Cu's mechanical, as well as other physical and chemical qualities [3]. Copper alloys are generally rarely selected only for their mechanical qualities; rather, they are frequently chosen because they combine advantageous mechanical features with additional characteristics. Many factors influence and have an impact on the mechanical properties of cast alloys. To create the mixture, it can also be combined. -related variables may have an impact on the structure's and alloy's fundamental strength. Elements that becomes apparent once the metal is cast. Lead-tin bronze casting can be efficiently prevented from oxidising, its microstructure can be improved, and its resistance to wear may be increased by using traces of rare-earth metals [4].

Friction and wear are major concerns in industry and in everyday life. It is a significant source of both energy consumption and material failure. Copper-based alloy bearings have been widely utilized to resist friction and wear in various industrial applications due to their convenient reasonably good mechanical features. [5]. However, wear during service has an impact on their structural integrity and stability. In efforts to improve abrasive wear resistance, significant research has been put into developing the relationship between the mechanical characteristics of alloys and wear behaviour. In general, it was assumed that the higher the hardness, the better the alloy wear resistance [6].

According to studies conducted by Liu et al. on the wear behaviour of various polymers, abrasive wear resistance was correlated with the amount of tensile strength and elongation at break. It proved that there were other elements impacting wear behaviour in addition to hardness and tensile strength [7].

Understanding every mechanical parameter on wear behaviour is essential for achieving optimum wear performance. Bronze-based bearings were widely used in a variety of applications and were suitable for scientific investigation due to their varying mechanical properties. Cu-Sn alloys have been used as self-lubricating materials for a number of years, and powder metallurgy (PM) was the main process used to create them. The mechanical properties of copper are essential for determining whether composite materials are suitable, especially when the material is subjected to high loads and frictions. [8].

According to Xie et al., copper reinforced with fine and homogenous tin dispersoids exhibits excellent thermal and mechanical resistance at high temperatures. Their results indicate that the monotonic shear behaviour of the reflowed Cu-Sn exhibits considerable strain to failure values [9].

Leaded tin bronzes, like other copper-based alloys, are preferred as important components in bearing and bushing systems. Tin provides the majority of the strength capabilities in those alloys, whereas lead, which is present in the microstructure as an insoluble, soft second phase, provides strong anti-frictional properties. These alloys may also include zinc, nickel, and other elements. Commercial leaded tin bronzes include varying percentages of various components to fit a specific use [10].

Jabinth and Selvakumar investigated the frictional properties of pure copper both before and after reinforcement with different amounts of vanadium and graphene and concluded that progressively mixed compounds increased the wear resistance. [11].

Leaded tin bronze alloy was used in the manufacture of bearings, particularly for high load circumstances. Bearing fails unexpectedly during service. To solve this issue, the influence of lead in copper and tin alloys was investigated in this work. Mechanical qualities such as tensile strength and tribological parameters such as specific wear rate and coefficient of friction were thoroughly examined. Also, the mechanism of lead in friction materials minimising Cu damage was studied.

2.Materials and Methods

In the current work, a semi-continuous casting technique was used to create a huge ingot of a leaded tin bronze alloy .The casting machine operated at a speed of 42 mm/min, and the cooling crystallizer's water pressure was 0.02 MPa during the casting operation. Before rolling, the surface temperature of work piece A was approximately 1000 °C. A shaft of 45mm diameter and 1000 mm lengths are cut and shaft is processed from leaded tin bronze using continuous die casting process**.** The method for producing continuous cast shapes involves pouring molten metal into a vertical mould with the ability to quickly cool the metal to the point of solidification. With better physical qualities than sand castings, the metal solidifies with a thin, uniform grain structure thanks to the quick cooling in the mould. The cast-shaped bar is trimmed to the required length once it has set. The chemical compositions of bearing materials used in the experiments were given in Table 1.

Tensile, hardness test and microstructural analysis were performed using ASTM standards. Chemical composition of continuous casted part is obtained using optical emission spectrometer. The INSTRON-5967(Norwood, MA, USA) Universal testing equipment was used to perform tensile, test on prepared samples. The materials were characterised using scanning electron microscopy and energy dispersive spectroscopy (EDS) analysis using VEGAS TESCAN, Scanning electron Microscope. Four samples were evaluated to determine the alloy's performance.

Table 1.Chemical composition of Continuous casted bearing material

Material	Cu	Zn	Pb	Sn	P	Mn	Fe	Ni	Si
Percentage	76.9	0.62	14.4	6.53	0.06	<0.002	0.035	1.23	0.007

Figure 1.Continuous casted part.

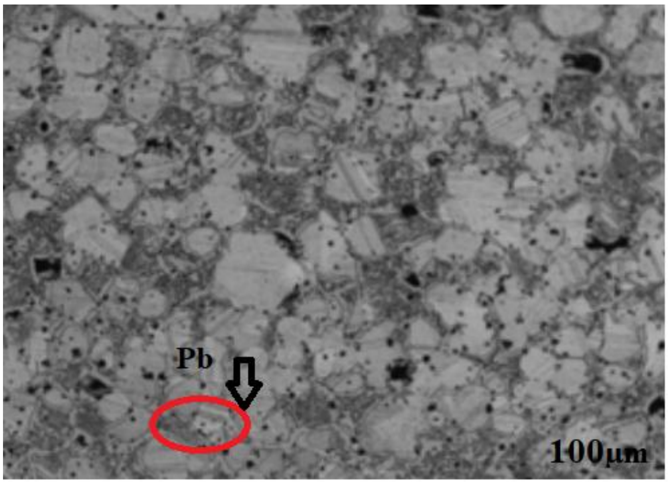


Figure.2 SEM image of Casted copper, tin-lead alloy.

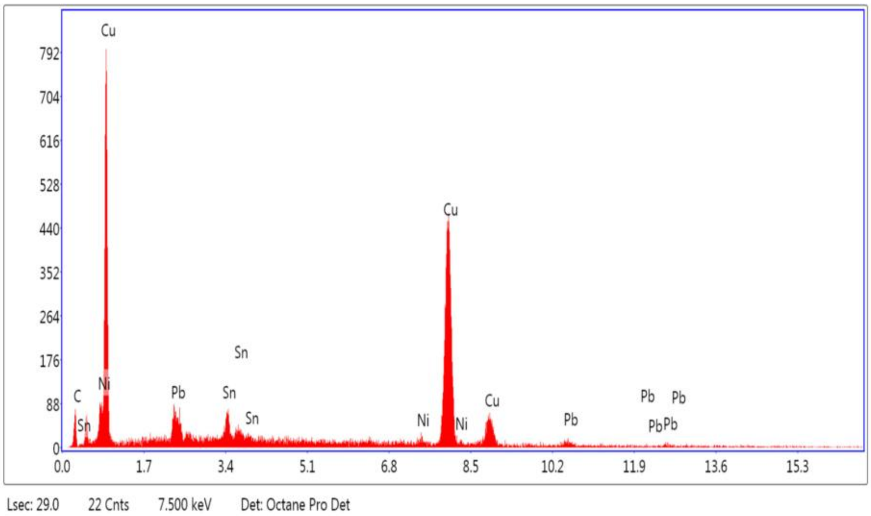


Figure 3. EDAX image of Casted copper, tin-lead alloy

Figure.3 Depicts the EDS data of a CuPbSn alloy with white irregular particles in the structure that are lead particles, as well as the diffraction data shown by the arrow. Energy-dispersive X-ray spectroscopy is used to perform an elemental analysis or chemical characterisation of a material (table 2).This particular form of X-ray fluorescence spectroscopy explores over the electromagnetic radiation interacts with a sample by examining at the X-rays that are produced when charged particles strike the sample.

Table 2: EDS analysis results of Casted copper, tin-lead alloy

Element	**Weight %**	**Atomic %**
C K	21.02	59.31
PbM	2.27	0.37
SnL	2.70	0.77
NiK	1.55	0.89
CuK	72.47	38.66

3.Results and discussions:

3.1Tensile test:

Sample were prepared as per ASTM E8 standards to evaluate tensile strength (diameter of 12.52mm) and the results obtauined are plotted as shown in figure 4.

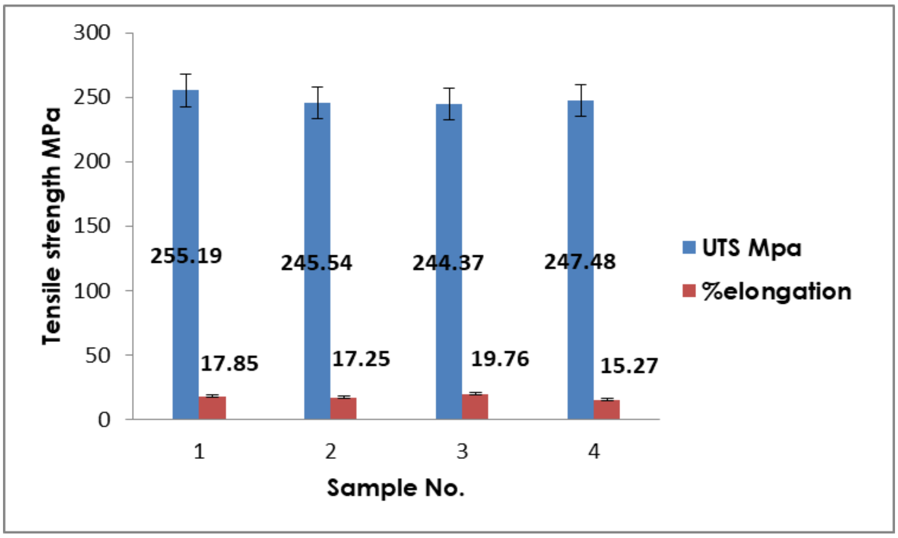


Figure 4.UltimateTensile strength Mpa and % percentage elonagtion of Casted copper, tin-lead alloy samples.

From the results it is observed that Tensile strength 255.19 N/mm2, and elongation observed is19.72 %.four samples with same standards were prepared and tested for tensile strength.As can be seen in Figure 4, after accounting for the standard deviation of the experimental findings, there was no significant variance in the tensile strength of the copper, aluminium, and tin-lead alloy.

3.2 Hardness Test:

The macro-hardness of the materials was tested using a 310 HBS-3000 Brinell hardness tester. The following are the hardness test results. The hardness value of the prepared specimen was tested using a 1/16" ball indenter on a "B" scale. The initial load of 3Kg and the major load of 100Kg were applied to all four samples, yielding an average Rockwell Hardness Number (RHN) of 25.75.

Sn alloys are largely formed of a soft Sn matrix with the formation of hard intermetallic compounds of Cu6Sn5 in acicular or polygonal form and Sn-Sb in polygonal or cuboid form. The existence of these hard intermetallic compounds raises the hardness of the alloy and reduces its coefficient of friction, as the rise in precipitate formation promotes a drop in the material's coefficient of friction, allowing the bearing's operating temperature to be reduced [12].

4. Wear results

Leaded tin bronze alloy's tribological behaviour was investigated while taking into account process variables including load, sliding velocity, and sliding distance. Table 2 includes a list of the process parameter applied in this procedure and their corresponding levels. The cast sample specimen was manufactured and machined to a square shape of 10 mm. prior to performing the friction and wear test, the samples are washed with acetone and dried. To examine the outcomes of each experiment, three sets of trials were run at ambient temperature.

EN31 hardened steel plate with strength of 60 HRC was used to investigate the dry sliding behavior of lead tin bronze according to ASTM G99. The ratio of applied load and sliding speed to a given wear rate during service life. The sliding wear behavior at a large sliding distance of 3000 meters for the 100 N loads is shown in Table 3.

Table 2. Friction Wear Experiment results

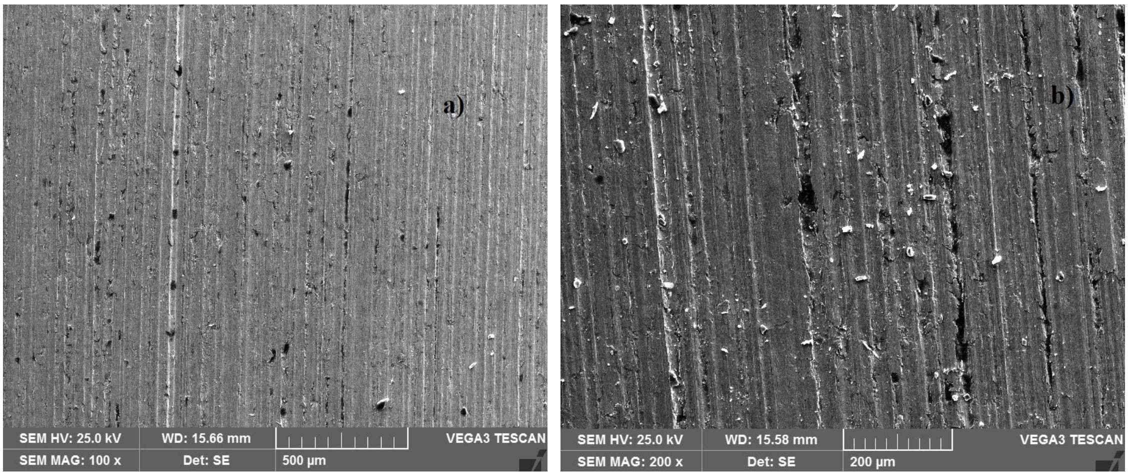
Sl no	Coefficient of friction	Specific wear rate $mm^3/N\text{-}m$	Sliding velocity m/s
1	0.69	7.8×10^{-6}	1
2	0.72	1.1×10^{-5}	3
3	0.68	7.6×10^{-6}	5

The exact wear rate that develops for a load of 100 N and 1m/s is displayed in Table 2. In Fig. 5d, shallow grooves that are seen in the parallel direction of sliding. The SEM micrographs of the worn-out surface of leaded tin bronze are seen in Figure 5.The copper also developed tiny fissures, which is another factor.

Since the lead particles are removed from the wear track and spread onto the contact surface, which causes adhesive wear on the worn surface as illustrated in Fig. 5e, the lead interfacial area has not enhanced the specific wear rate. The transition from an adhesive to an abrasive mode of wear mechanism causes a high specific wear rate when the sliding velocity is increased from 1 m/s to 3 m/s. It denotes a close contact between the two surfaces that has been plastically distorted, resulting in deeper grooves and scoring with pits as seen in Fig. 5f. The particular wear rate is significantly increased by the abrasive wear mechanism. The specific wear rate lowers as the sliding velocity is increased to 5 m/s because the lead alloy particles spread across the contacting surface and create stable lubricating coating. Table 2 shows the impact of sliding velocity and applied load on the coefficient of friction. As the sliding speed reaches 3 m/s, the COF rises. This is a result of the stable lead lubricating film failing.

5. Scanning Electron Microscopy

The wear surfaces of the samples were examined by scanning and electron microscope. Shown below are the microstructures of the worn out surface of the metal alloy. The large wear tracks were observed on the surface. This is because a longer friction time tends to remove more material from the sample. This increase in specific wear rate is associated with an increase in plastic deformation at the surface of the material and extruded grains. In addition, time is one of the other factors affecting the rate of wear. Conversely, if the time increases from 5 to 10 minutes, the friction between the surfaces increases, then the temperature rises, softening also occurs, and the particles tend to leave the surface, which leads to an increase in the material removal rate. SEM microstructures of the wear surfaces were obtained as lead acts as an additional lubricant; delamination and signs of wear are observed on its surface.



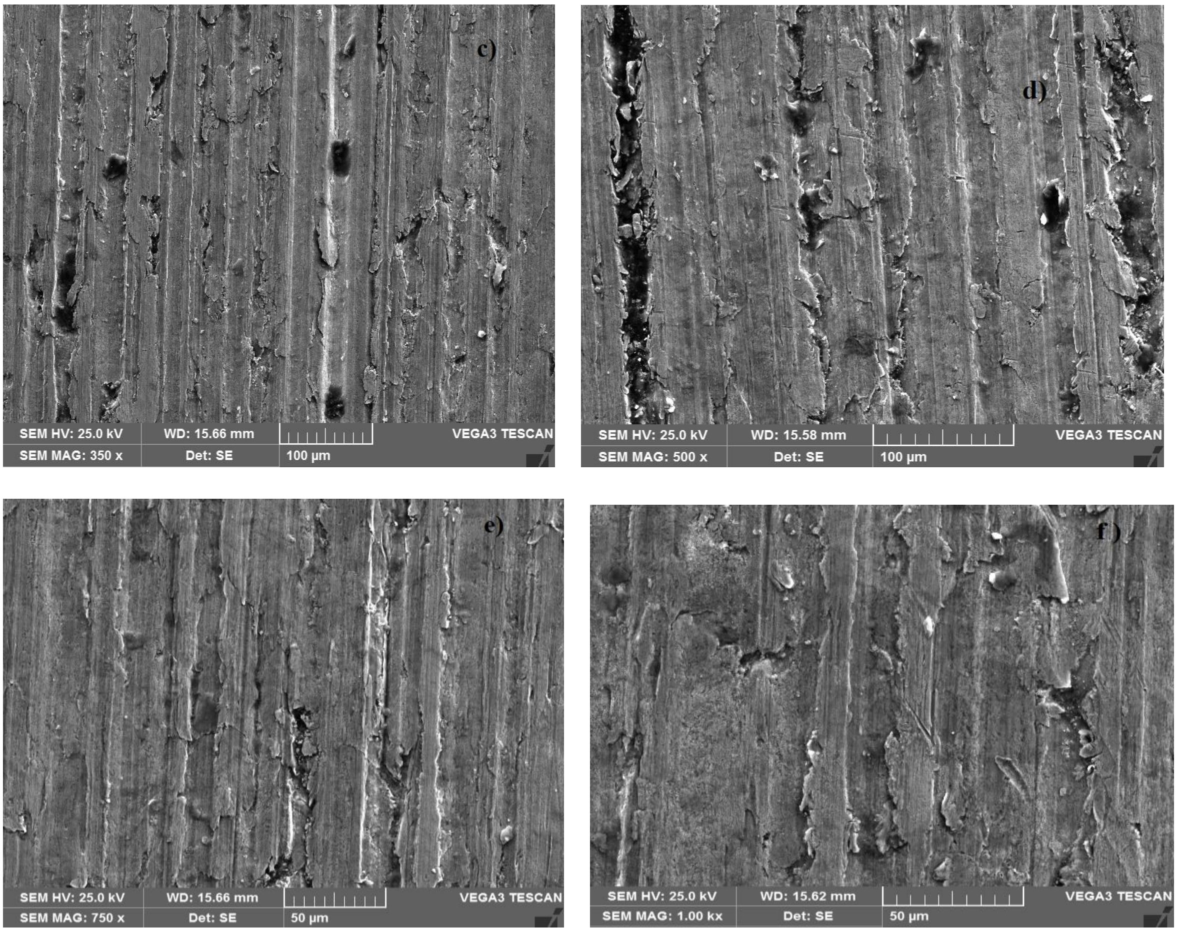


Figure 5. SEM micrographs of Wear scars test pieces of Casted copper, tin-lead alloy at load 100N and slide distance 3000m,Figure5(a)-5(b) at speed of 1 mm/s, Figure 5(c)-5(d) at speed of 3 mm/s, Figure 5(e)-5(f) at speed of 5 mm/s.

Ploughing, distortion, and spreading of material on the worn surface of the failing bearing are also seen by the SEM. Apart for the dark patches representing lead, the backscattered electron image (Fig.5a and 5b) confirms that the worn surface is chemically uniform. Darker spots of transferred materials are seen on the worn surface. These patches are stretched along the sliding direction to some extent. Figure 5c depicts a bare region two and a patchy area probably of transfer layer on the worn surface of a good sample.
On the samples, the grey areas were seen to be discontinuous. They appear more often on the surface as the sliding distance rises. The surface of the failed sample, on the other hand, is reasonably clean and shows no such deposits. This sample also showed signs of extreme plastic deformation and smearing.

Analysing the worn specimen's cross-sections in the sliding direction. Significant plastic flow was seen along the worn surface of the failed specimen along the sliding direction.The influence of lead and tin on the microstructure, mechanical properties and friction and wear parameters of the CuSnPb alloy was investigated. The results show that the effect of lead on the friction and wear properties depends on the evolution of the alloy microstructure as the addition of lead increases. Both the hard matrix and the soft second phase were formed by the addition of lead. The modified dendritic Cu structure and lead solution improved the Cu matrix, resulting in better load-carrying capacity. Not only did the tin produce small and uniformly distributed Pb particles, but it also weakened their strength, allowing a lead film to form during friction and wear tests. All these microstructural changes supported in maintaining a good lubricant coating[13].

The effects of lead and tin on the microstructure, mechanical characteristics, and friction and wear parameters of the CuSnPb alloy were studied. The figure shows large furrows and peeling pits on the worn surface of aluminium bronze materials, with the furrows related to the peeling pits. The particles extracted from the matrix damage the wear surface and cause furrows when stressed. This is due to the abrasive wear. Since the grinding pair is harder than copper tin.

Figure 5(a-f) exhibits visible adhesion traces on the tin friction surface. During the friction process of tin lead, adhesion forms when the local compressive stress at some contact points on the surface reaches the yield strength. Surface wear occurs when the friction pairs change relative to one other.Similar phenomenon were also obereved in the other literatures F. Akhlaghi,et al.,[16],C.S.Ramesh, et al.,[17],Mahdavi S.,Akhlaghi, F.[18] and Nagesh D,et al.,[19-20].

6.Conclusion

It is to conclude that, journal bearing manufactured from metal based material may be effectively used in industries due to better mechanical properties of leaded tin bronze materials. Initially, the lead particles disrupt the alloy's copper matrix, restricting the mobility of dislocations and, as a result, producing a tiny amount of confined deformation close to the sliding surface. Second, the interfacial barrier between lead and the surrounding copper matrix is weak, which encourages the formation of microcracks there. Increasing the lead content in continuous cast alloys also seems to reduce the alloy's rate of wear.

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