Investigation Wear Behaviour of Tin Bronze Alloy Prepared by Different Casting Techniques

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Abstract. The cement industry is one of the essential industries in Iraq that has taken a wide range of attention in many applied fields, but this industry faces some technical and engineering problems. One of these problems may cause consumption sliding bearing used in the kiln rotary of the Kufa cement plant. In this study, the effect of Antimony as an alloying element on the wear resistance behavior of tin bronze alloys produced by die and sand mold casting technique was investigated. The alloying element (Sb) was added with a percentage of 3, 5, and 8 wt. %. Wear tests were carried out using pin-on-disc. In the wear test, the applied load and rotating speed were selected to be 10, 20, 30 N, and 250 rpm, respectively. The prepared alloys have been characterized using the SEM and XRD techniques. It was concluded that the loss of CuSn12 alloy produced by the die mold casting technique was lower due to its higher hardness and wear resistance increased in general with increasing the applied load. The tin bronze + 8 wt% Sb has more wear resistance than tin bronze +5 wt% Sb, tin bronze +3 wt% Sb, and tin bronze alloys.

Keywords. Wear, Die, Sand, Friction, Tribology, Bronze, Worn surface.

1. Introduction
Tribology is the study of friction, wear, and lubrication of moving reactive surfaces relative to each other [1]. Copper-based alloys have a higher density than that for steels. Although the yield strength of some alloys is high, their specific strength is typically less than that of aluminum or magnesium alloys [2,3]. To obtain good results from a product, the technical specifications of casting processes are the most crucial factor. Investment, permanent mold, chemical sand, centrifugal, and mold can be used. For bronze made of tin, silicon, aluminum, and manganese, in addition to brass, permanent die casting is best suited [4]. For yellow brasses, die casting is well suited; however, expanding increasing the amounts of permanent mold alloys are also being die-cast. The limitations of both methods are the size of the casting, due to the reduction of mold life with large castings [5]. Copper and tin-based bronze are used as bearings materials which have high wear resistance [6]. The wear and friction properties of these materials can be enhanced by adding tin [7]. Bronze-tin (90% copper, 10% tin) is the most suitable material for bearings under corrosive conditions since they will be subjected to high temperatures and high loads[8]. The objectives of this paper are to find out the appropriate solution for the problem of sliding bearings that are used in the kiln rotary of the Kufa cement plant through improving the wear resistance of bearings that are made from the tin bronze (CuSn12) to reduce the time and cost of maintenance.
2. Experimental part

2.1. Materials used in this work
The chemical composition (wt%) of the tin bronze alloys obtained from the Kufa Cement plant without and with 3, 5, and 8wt% antimony as a determination by optical emission spectroscopy is presented in Table 1. This inspection has been in the state company for steel industries-Ministry of Industry and Minerals by using a computerized approach.

| Elements | Cu  | Zn  | Sn  | Si  | Mn  | Al  | Ni  | Pb  | Fe  | Sb  |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| M        | 85.35 | 1.02 | 12.50 | 0.003 | 0.0082 | 0.17 | 0.9 | 0.06 | -   |
| A1       | 86.15 | 1.20 | 12.31 | 0.0025 | 0.008 | 0.14 | 0.31 | 0.04 | 0.03 |
| A2       | 85.48 | 1.108 | 11.88 | 0.0025 | 0.0081 | 0.054 | 0.16 | 0.75 | 0.04 | 0.052 |
| A3       | 86.31 | 1.07 | 11.76 | 0.0027 | 0.008 | 0.044 | 0.15 | 0.34 | 0.03 | 0.086 |

2.2. Preparation of specimen and tests
Preparation of the samples of standard tin bronze alloys and Cu-Sn alloys with the addition of 3, 5, and 8 wt.% Antimony was done by using sand and die casting techniques. Melting standard tin bronze alloys and Cu-Sn alloys with the addition of 3, 5, and 8 wt. %pure Sb at 1000°C. Metals were placed in a graphite crucible in an electric resistance furnace. The molten metal was moved homogeneously by sticking for a long time, then poured into the mold cavity with sand and die casting. After solidification of the metal, the casting is removed from the mold. The turning machine cut all the castings into pieces with a thickness between (4-6) mm.

2.3. X-Ray diffraction (XRD)
The XRD test was conducted in order to find out the identification of the phases of each specimen. This test was done at the University of Tehran in Iran. The XRD generator with copper designed to 40 kV and 30 mA, the scanning speed of 2 degrees per minute, was used. The scanning rate was 0-120.

\[ D_p = \frac{K\lambda}{\beta \cos \theta} \]  

Where: 
- \( D_p \) : crystallinmedium diameter(Å) 
- \( K \) : Constant Secherer is equal to 0.94 
- \( \lambda \) : X-ray wavelength (1.5406 Å) 
- \( \beta \) : line extending half the ultimate intensity(radians) 
- \( \theta \) : Bragg angle(d deg ree)

2.4. Wear test
Dry sliding wear behaviour was studied using a pin on the disc concept in the Department of Metallurgical Laboratories / College of Materials Engineering / University of Babylon, using 250 rpm and a constant sliding distance 6 cm with 10, 20, and 30N load. The specimen is weighed before the test using 0.0001 precision electrical balance. After a different period of time (5, 10, and 15 minutes), the wear instrument is shown in Fig.1 was used. The wear rate was calculated using the following formula [9]:

\[ WR = \frac{\Delta W}{1000 \rho L S} \]  

Where: 
- \( WR \) = Wear rate(mm³.Nm); \( VL \) = Volume loss = \( \Delta W/\rho \times 1000 \)(mm³); \( \Delta W \) = the mass loss of the material; \( \Delta W = W_o - W_i \); \( W_o \) = Initial mass of sample(gm); \( W_i \) = Final mass of sample(gm); \( L = \)
Normal load \( (N) \); \( S = \text{Sliding distance} = 2\pi N t \text{(m)} \); \( r = \text{Wear track radius(m)} \); \( N = \text{Revolutions per minute(r.p.m)} \) and \( T = \text{time(min)} \).

3. Results and discussion

3.1. Results of X-ray diffraction

The X-ray diffraction analysis has been used for tin bronze alloy without and with 3, 5, 8 wt.% Sb. The X-ray peaks for the elements depend on the intensity and theta degree so that the element’s data in (intensity-2θ) listed in X-ray data charts. The results of X-Ray diffraction have been shown in the followings:

- Fig (1) represents the X-ray diffraction patterns for tin bronze alloy, which shows the peaks of copper oxide and tin oxide intermediate compound SnO2. Copper oxide appears in \( 2\theta = (43^\circ.095) \) while tin oxide in \( 2\theta = (63^\circ.140) \). Also, the peaks depend upon the lattice parameter for each element formed after polishing the surface. The copper phase is \( \alpha - \text{Cu} \), which involves an FCC structure, and the tin is \( \beta - \text{Sn} \), which adopts a BCT structure. The crystal structure of SnO2 is tetragonal, [10].

- Fig (2) represents the XRD patterns of Cu-12Sn alloy (tin bronze alloy) with an addition of 3% Sb which appears the peaks for intermetallic compound Cu6Sn5, copper oxide, and tin oxide. In the sample that is containing Cu, the reflexes of the \( \alpha - \text{Cu} \) phase, which involves an FCC structure, and the tin is \( \beta - \text{Sn} \), which approves a BCT structure. Intermetallic typical phase Cu6Sn5 a new appearing phase with monoclinic [11].

- Fig (3) represents the XRD patterns for the tin bronze alloy with an addition of 5% Sb, which shows the peaks for intermetallic compound Cu6Sn5 phase, which monoclinic and intermetallic compound Cu11Sb3 at \( 2\theta -(43.626\circ, 51.314\circ, 62.963\circ) \). The tin and antimony elements, which have a low melting temperature, are incompletely soluble in the \( \alpha - \text{Cu} \) form new intermetallic [12]. The intermetallic compound \( \text{(Cu}_{6}\text{Sn}_{5}) \) occurs at a diffraction angle between those of pure copper and pure tin.

![Figure 1. X-ray diffractions of Cu-12Sn alloy.](image1)

![Figure 2. X-Ray diffraction of Cu-12Sn-3Sb alloy.](image2)

![Figure 3. X-Ray diffraction of Cu-12Sn-5Sb alloy.](image3)
Fig (4) shows the XRD patterns for the tin bronze alloy with an addition of 8% Sb, which shows the peaks for the intermetallic compound of Cu11Sb3 as well as Cu6Sn5. The copper phase is α-Cu, which involves an FCC structure, and the solder is β-Sn, which approves a BVT structure. The crystal structure of ζ-Cu6Sn5 monoclinic and ε-Cu11Sb3 is HCP.

![Figure 4. X-ray diffractions of Cu-12Sn-8% Sb alloy.](image)

3.2. Results of wear test

3.2.1. Result of test time. The plots of specific wear rate vs time at different normal forces have been determined. Figs (5 to 12) show specific wear rate vs. time of tin bronze alloys in a sand mold and die casting at different applied load and Sb content. From the observation of the figures, when the test time increases, the rate of wear increases gradually, and also it decreases with increasing antimony content for all the tested specimens. This is because more time of friction tends to detach more material from the specimen. This increase in specific wear rate has been assign to the increase in plastic deformation on the surface of the material and grains pulled out. Moreover, time is one of the other factor effects on wear rate. In contrast, when the time increased from 5 minutes to 10 minutes, the friction between the surfaces increases, then the temperature increases, softening also occurs, and the particles tend to remove from the surface, which leads to an increase in material removal rate. The increase in wear rate could be minimal and almost constant with increasing time; this sliding is attributed to the tin element in the alloy reinforcement due to its solubility in the solubility (α) of the solution is rigid tin in copper reaches. With increasing time, the slip rate increases to wear and tear to reach stability state. In addition to the specific wear rate of sand mold casting alloys higher than the specific wear rate of die casting alloys[13].

![Figure 5. A graph of illustration of specific wear rate vs time for tin bronze sand mold casting at different applied load.](image)

![Figure 6. A graph of illustration of specific wear rate vs time of tin bronze-3 wt% Sb sand mold casting at different applied load.](image)
3.2.2. Results of antimony addition. To study the influence of Sb addition on the specific wear rate of CuSn₁₂ alloy, the specific wear rate with Sb content under 30N load at 15 minutes time for two type of castings plotted in the Fig (13). This figure displays the specific wear rate decrease as the Sb content increases in both cases. The addition of Sb to the base alloy (CuSn₁₂) meaningfully increases the hardness and hence, the wear resistance compared to the base alloy. Generally, the wear of the copper alloys increases with the increase in hardness, so that the increases in hardness increases the wear resistance of the alloys. Wear has been decreased with the increase of Antimony to 8 %Sb, at a rotational speed of 250 rpm and time equal to 15 minutes. The resultants have been presented in all figures, which refer to the wear rate of the alloys increases with time and decreases with increasing elements for alloys. These results are in agreement with reference [14].
3.2.3. Results of the applied load. The influence of the applied load on the specific wear rate for all specimens plotted in Figs (14 to 16) increases the amount of applied load. From the figures, it can be noticed the increasing the ‘specific wear rate,” adding Sb content, is much more in comparison to when the Sb content is added in a certain proportion [14]. It can be seen that the “specific wear rate” of all tested samples under 30N load is higher than that of 20N and 10N. Also, 20N is higher than that for 10N. The reason for this variation is obvious. The increasing of the “specific wear rate” after increasing the load can be due to the increase of the friction force on the surface of the alloy increasing the removed material. The increase of load leads to a higher wear rate, where the wear transform from medium wear to transition wear and then to severe wear and this is due to the plastic formation of the tops of the surface protrusions of the sample, which leads to an increase in the density of dislocations and thus the occurrence of emotional hardening when the load increases to 30 N. Small cracks in the surface of the sample and then meet these cracks with each other or with the lines of wear because of the removal of thin layers of metal that are easily removed towards the slide to form debris wear. These results in agreement with references [13,14].

Figure 13. A graph of illustration of wear rate vs Sb content of the specimens at rotational speed 250 r.p.m and time 15 min. at different applied load.

Figure 14. A schematic of illustration of applied loads vs. specific wear rate of different alloys at rotation speed 250 r.p.m, sliding time:5 min radial distance: 3 cm.

Figure 15. A schematic of illustration of applied loads vs. specific wear rate of different alloys at rotation speed 250 r.p.m, sliding time:10 min radial distance: 3 cm.

Figure 16. A schematic of illustration of applied loads vs. specific wear rate of different alloys at rotation speed 250 r.p.m, sliding time:15 min radial distance: 3 cm.
4. Conclusions
The conclusions that can be drawn from this work are summarized as follows:
1. X-ray diffraction patterns of tin bronze alloy show the peaks for copper, tin, and intermetallic compound Cu3Sn.
2. X-ray diffraction patterns of tin bronze -3%Sb show peaks for copper, tin, small amount of Antimony, and intermetallic compound Cu3Sn, Cu12Sb3.
3. Increasing of Sb content up to 8% shows the peaks for the copper, tin, small amount of Antimony and shows the intermetallic compound of Cu3Sb as well as Cu10Sn3.
4. The wear resistance of the Copper-tin-Antimony alloys increases with the increase in alloying elements, and weight loss increases as the normal load increases.
5. The Cu-Sn12- 8% Sb alloy shows the highest wear resistance in comparison with other alloys.
6. The wear behavior of Cu-Sn12-Sb alloys changes from mild wear (oxidative wear) at low loads to metallic wear at high loads.

5. References
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