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Effect of MgO, \( \text{Al}_2\text{O}_3 \) and \( \text{FeCr}_2\text{O}_4 \) on microstructure and wear resistance of Babbitt metal (Sn–Sb–Cu)

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Abstract

In this study, the Sn–Sb–Cu alloy known as Babbitt metal and used as the coating material for the screw die surface of the journal bearings of the hydroelectric plants was reinforced with magnesium oxide (MgO), aluminium oxide (\( \text{Al}_2\text{O}_3 \)) and ferrochromium (\( \text{FeCr}_2\text{O}_4 \)) in order to ensure more efficient use of this alloy, formation were examined. The Babbitt prevent contact of the surface of the coating alloy with each other by acting as a separating oil layer having a 150 bar pressure. It is desired that the coating surface both resists against the high pressure applied and some part of the coating surface is asked to prevent from separating the surface of screw die as a result of high speed rotational motion and thus, damaging the shaft. Then, it was aimed to determine the wear resistance of the material as coating and the effects of the added %10 MgO, %10 \( \text{Al}_2\text{O}_3 \) and %10 \( \text{FeCr}_2\text{O}_4 \) on wear of material. As a result of the assessments carried out, it was suggested that the wear resistance of the coating would increase when the compound of \( \text{Al}_2\text{O}_3 \) was added into Babbitt metal. Purpose of the article used as coating material of babbitt metal, being investigated how to exert strong posture affected, under high pressure.

1. Introduction

The microstructure of tin-based white metals consists of a soft solid solution matrix and two intermetallic compounds (\( \text{Cu}_3\text{Sn}, \text{SbSn} \)) that are harder than the matrix. This special microstructure qualifies these alloys as a bearing material [1]. So-called white metals, i.e., alloys of the Sn–Sb–Cu system, are widely used as the material for sliding bearings that operate in oil (for example, bearings used in various industries, as well as in shipbuilding and car industry). They are also applied in hydroelectric power plants to support hydraulic turbines and electric generators. Tin-based Babbitt alloys commonly contain \( \text{Cu} \) and \( \text{Sb} \). The microstructures of these alloys vary due to differences in their compositions [2]. The mechanical wear loss that occurs in the objects results from the friction due to the moving contact with another material [3].

Miczic et al [4] discussed the comparison of parameters related with two production technologies (cast cladding and weld cladding) of soft slide layer on a high strength based metal (steel). Experimental data for these two technologies, such as macro and microstructure, hardness, porosity, bonding between white metal and steel base and appearance of segregations are analysed. In their study Pul et al [5] placed MgO powders with the particle size of 149 \( \mu \text{m} \) inside a steel tube so as to form the reinforcement- volume rate of 5, 10, and 15%. The infiltration tests were carried out with the alloy of Al containing 5% Mg at different temperatures, 550 mmHg vacuum for 5 min and the infiltration distances, the amount of pores, microstructures and fracture behaviours of the composites were examined. Seker et al [6] performed machining tests on Al matrix and MgO reinforced MMC materials produced at the reinforcement- volume rates of 5%,10% and 15% by stir casting method via Cementite Carbide (CC) and Coated Cementite Carbide (CCC) cutting tools in order to make some comments on the machinability of MMC materials. Senberber et al [7] the characterization of the synthesized products by examining the production of magnesium borate using MgO and boric acid reagents as a raw material and the factors affecting the production. Camtakan et al [8] investigated the removability of uranium from aqueous
solutions by using MgO as a nanocrystal material which is easily accessible, effective and cost-effective. In this respect, adsorption was used as a removal method. Nanocrystal MgO adsorbent was synthesized using a hydrothermal method. The synthesized adsorbent was characterized using SEM, XRD, and BET analyses. Altunu et al. [9] stated that 5–10–15 and 20% Al2O3 particle was used as reinforcement. Al2O3 powder was coated by Y2O3 and then it was added into aluminium. The aim of this study was the improvement of wettability by using Y2O3 coated Al2O3 particle reinforced aluminium matrix composites produced by using the squeeze casting method so that mechanical properties will be enhanced. Produced composite’s density, hardness and wear behaviour are examined and SEM microstructure was analysed. Gökmen et al. [10] produced pure aluminium and pre-alloyed Alumix 231 (Al–2.5% Cu–0.5% Mg–14%) Si based composite foams reinforced with Al2O3 particulate by using the powder metallurgy route. The effects of Al2O3 particles on the liner expansion, density and the size of porosity were determined. Erdoğan et al. [11] tried to define the abrasive characteristics of ferrochromium slag, which is an industrial waste produced as a residual product during ferrochromium production. Micro-abrasion method was used as abrasion test method. The specimens were also subjected to micro-abrasion tests using SiC and Al2O3 powders in order to evaluate the abrasive characteristics of the powder. Ay et al. [12] investigated the effect of chromium carbide (Cr7C3) on abrasive wear behaviour of Fe-C-Mo-FeCr composite in their study. The composite, which was produced by a powder metallurgy route, was containing 3 wt% Mo, 1.5 wt% C, and 4.8, 12 wt% FeCr with different particle sizes. In the experiments, the wear resistance of the samples was determined using different loads by a pin-on-disc wear tester. Yılmaz et al. [13] investigated the electric-arc furnace slag (Ferrochromium slag) utilization as filler material in hot mix asphalt. Slag was examined if it could be used in bituminous pavements instead of limestone filler. This property was conditioned by the amount and morphological size of the hard phases presented in the alloy, especially SnSb (β) and CuSn (γ). When hard phases were well refined, the wear resistance of the alloy was enhanced. There are data in the literature indicating that both fatigue strength [14] and wear resistance [14, 15] depend considerably on the material structural state. Melting point of the intermetallic compound Cu6Sn5 is higher than that of SnSb compound [16, 17]. Therefore a small amount of copper was added to melt in this study to facilitate formation of yet another metallic compound Cu4Sn5. Hence, it was reported to increase the elastic modulus of the Sn–Pb–Sb melt–spun bearing alloy with the addition of 5 wt% Cu. The low ductility of babbitt alloy is caused by brittleness of the phase, which has different sliding planes available for plastic deformation because of the hexagonal lattice [18]. The fast advance in the sector has increased the number of studies about development of bearing alloys as well as automotive and shipbuilding industries. Babbitt alloys have been widely used in bearing components due to their great anti-friction, excellent ductility, high thermal conductivity, and good compatibility [19, 20]. Compared to other bearing alloys, Tin-based (Sn-based) Babbitt alloys are broadly used in the key components of the bearing, especially in steam turbines, high-speed engines, and compressors, due to its unique excellent corrosion resistance [21, 22]. Moreover, Sn-based Babbitt alloys can maintain soft even after repeated loading cycles owing to their low melting points [23].

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### 2. Material and method

In this study, Babbitt metal of based Sn–Sb–Cu used as coating with addition of MgO, Al2O3 and FeCr2O4. The chemical composition of Babbitt metal was carried out using the instrument as shown in table 1.

The addition mounts or percentages of MgO, Al2O3 and FeCr2O4 to the base alloy (Sn–Sb–Cu) are shown in table 2(a). Table 2(b) gives the properties of the added powders. Figure 1 shows the flow chart of the present study. Figure 2 shows the surface coated of Babbitt metal on the screw die surface which is a surface part of the journal bearings.

### 3. Experimental results

#### 3.1. Examination of SEM-EDS analysis results

In this study, how 10% MgO addition can affect the Babbitt metal, the Babbitt metal of the present study, used as coating material was investigated. Since MgO, a difficult material for the casting industry, reacts with oxygen
Table 2. (a) Categorization of samples used in this study according to addition of MgO, Al₂O₃ and FeCr₂O₄.

| 1 N | Sn–Sb–Cu Alloy + 10% MgO |
| 2 N | Sn–Sb–Cu Alloy + 10% Al₂O₃ |
| 3 N | Sn–Sb–Cu Alloy + 10% FeCr₂O₄ |
| 4 N | Sn–Sb–Cu Alloy Babbitt metal |

(b) Properties of added powders.

| Additional powders | Purity | Density g cm⁻³ | Particle size μm | Particle shape | Crystal structure | Company |
|--------------------|--------|----------------|------------------|----------------|-------------------|---------|
| MgO                | 96%    | 3.58           | 74               | Tuber          | Hexagonal        | ZAG Chemistry |
| Al₂O₃              | 99%    | 3.96           | 40               | Algular        | Kubik            | ZAG Chemistry |
| FeCr₂O₄            | 88%    | 4.83           | 50               | Algular        | Izometrik        | ZAG Chemistry |

Figure 1. Flow chart of the study.

Figure 2. Coated screw die surface of the journal bearing.
when MgO turns into melting state, and burns like gunpowder, the casting process should be carried out under vacuum (in oxygen-free environment). It was thought that tin (Sn) constituting the base metal would melt at 232 °C, MgO added in powder form via inoculation (in micron), would take the role of grain making in the structure, and take part in the structure without reacting with oxygen. When the regional EDS analysis from the surface material given in figure 5 and the point analysis given in table 3 were examined as a result of study, it has been seen that MgO burnt by reacting with oxygen somehow and small amount of MgO was present in the alloy. Small amount of MgO in the alloy has slightly affected the general structure of the material and decreased the microhardness values.

When SEM images of the same point of the sample no. 1 given in figure 4 at different magnifications (130×, 320×, 650×, 2000×) were examined, it was observed that Sn, Sb, Cu, Mg got regularly dispersed in the tin which formed main material and plain cube-like parts seeming as embedded in the material were the compounds of SnSb that started precipitating at 265 °C; the cubic alloy of SnSb rose to the surface of melt when specific weight of these precipitates was lower than that of their environment. When SEM images in figure 4 were examined, this cubic structure was clearly seen; in examinations carried out from the regional EDS analysis and figure 5, Sn and Sb were present in the cubic parts and the surface of the same parts contained copper and this was supported by the point analysis in table 7. The microhardness values of these areas were higher than that of other areas that is caused by the formation of SnSb compound and the increase in the hardness and wear resistance.

The second alloy was prepared by adding 10% 10 Al2O3 into the Babbitt metal. Al2O3 was present in the areas with hard plain structures rather than the areas with high rate of tin, and copper and also it was present in the areas with high rate of copper and antimony and formed hard structures caused by the compound forming in these areas even if it is a ductile material. This is a compound which is hard to be present in the material since it has lower rate of density than tin (Sn) and copper (Cu). Al2O3 in the liquid alloy is highly bonded to oxygen. Aluminum in contact with the air in the environment, reacts with oxygen, causing the structure to become much better. The microhardness values in table 7 clearly indicated how affective Al2O3 added into the alloy was.

It was observed in SEM images taken to investigate the effects of 10% Al2O3, added into the Babbitt metal in the sample no.2, in the structure (figure 6) that SnSb which was different from the MgO added sample no.1 and appeared like a cube by forming a compound was not cubic, but long flats and blocks.

In the copper-tin compounds, the copper will form a compound with tin to prevent the movement of the cubic structures in the structure containing SnSb due to the differences in the density without being spread to the entire material and assume a network role which prevents the cubic structure of SnSb from emerging. In this alloy, Al2O3 took different roles with both tin and copper, and thus hardened the structure.

Table 3. EDS Point Analysis of the Sample N. 1.

| Position | % Sn   | % Sb  | % Cu  | % Mg |
|----------|--------|-------|-------|------|
| 1        | 71.56  | 26.18 | 2.13  | 0.13 |
| 2        | 92.16  | 5.73  | 1.88  | 0.23 |

Figure 3. Wear apparatus (CSM Tribometer).
When the regional and point analyses given in figure 7 and table 4 were examined, it was seen that the cubic structures were composed of Sn and Sb, as well as small amount of the copper, added Al and O.

When the microhardness values of the sample no.3 in table 7 were examined, it was observed that white metal alloy hardened and formed a harder structure than other three samples.

It will be very difficult for 10% FeCr$_2$O$_4$ compound added into the Babbitt metal to melt in this alloy and move with the alloy as integrated to the alloy in terms of melting degree. To eliminate this situation, the compound of FeCr$_2$O$_4$ was ground in crushers and prepared in micron scale. FeCr$_2$O$_4$, was added into the melt Sn–Sb–Cu alloy by the inoculation method.

When EDS analyses were examined in figure 9 and table 5, it was observed in different zoomed SEM images of the same point in figure 8 that the compound of FeCr$_2$O$_4$ could not be penetrated in the tin; however, even this amount had positive effects on the material and made the structure regular.

The sample no. 4 which was present in four different samples and took a role as the material of main alloy of this study contained the Sn–Sb–Cu alloy. This alloy used as the coating material is not affected by external factors (oxidation) since it is ductile, can absorb vibration and has higher rate of tin; thus, it is a material having all the properties we are looking for in several coatings.

The Sn–Sb–Cu alloy must be produced under proper conditions by the proper casting and coating methods, since this alloy has a property of rapid solidification. Otherwise, many different structures are formed. When
microhardness values of the sample were examined in Table 7, it was observed that the microhardness values were low.

When examining SEM images of the Babbitt metal which is the material of main alloy in Figure 10, it was observed that the structure was composed of fully precipitated SnSb and tin is a binder in the intermediate areas; when examining regional EDS analysis from Figure 11 and Table 6, it was seen that the amount of copper was maximum 7.84 in the point analysis even if the copper seemed more on the surface.

![Figure 6. SEM images of Al₂O₃ added into Babbitt metal (320×, 650×, 3000×).](image6)

![Figure 7. EDS analysis of Al₂O₃ added into Babbitt metal.](image7)

**Table 4.** EDS point analysis of the sample no. 2.

| Position | Sn   | Sb   | Cu   | Al  | O   |
|----------|------|------|------|-----|-----|
| 1        | 55.34| 37.71| 5.11 | 0.38| 1.46|
| 2        | 87.54| 6.84 | 4.17 | 0.18| 1.27|

**Table 5.** EDS point analysis of the sample no. 3.

| Position | Sn  | Sb  | Cu  | Cr  | Ni | O  | Fe  |
|----------|-----|-----|-----|-----|----|----|-----|
| 1        | 48.05| 41.19| 3.65| 1.42| 0.81| 2.76| 2.12|
| 2        | 86.78| 5.63 | 4.12| 0.78| 0.68| 0.93| 1.08|
3.2. Results of wear test

Wear tests were carried out using disc on ball test equipment in CSM Tribometer wear test device (figure 3) at room temperature. The samples were prepared at the size of Ø30 × 10 mm. Ceramic balls with a 6-mm diameter were used as counter element. The samples were cleaned with alcohol before the tests and the wear surface roughness of the samples was taken at 150 m, 300 m and 450 m in order to calculate the wear losses. It was used for the calculation of volume loss. The temperature and humidity of the test environment were 25 °C and approximately 35%, respectively. A load of 7 N was applied to the samples during the wear. The sliding speed and sliding distance were determined as 10 cm h⁻¹ and 150 m, respectively (figure 12). Also, the wear rate of the ceramic ball used as the counter element was determined in the first and last weight loss of the ball.

When volumetric wear losses of the wear samples were examined, it was seen that the volumetric mass loss of the sample no: 4., Babbitt metal (white metal) was minimum (0.0188 mm³), the reason for this was thought that the main material was a ductile material since 80% of the main material it was composed of Sn, the worn particles were bonded by Sn and thus, could not be separated from the base material (table 8).

When the hardness values were studied; the volumetric wear loss and the mass wear loss of the FeCr₂O₄ added sample no.3 which had the highest microhardness value among other samples were 0.025 19 mm³ and 0.008 (g) respectively and it was the mostly worn material; the reason was that FeCr₂O₄ added into the main alloy (white metal) hardened the structure and caused the particles worn from the Sn, main matrix, to rupture much easier and to be separated from the material.

When the sample 1 was examined; it was observed that volumetric wear loss was 0.033 23 mm³ and this value was higher than other three samples. When the mass wear was examined; the white metal with 0.003 (g) was worn at the same rate with the mass wear loss.
In the sample no. 2, it was seen that the volumetric wear loss and mass wear loss were 0.22196 mm$^3$ and 0.001 (g), respectively, and the material was not worn much in terms of the mass. The profilometer results indicating the wear depth were given in figure 13.

### Table 6. EDS point analysis of the sample no. 4.

| Position | Sn   | Sb   | Cu   | Ni  |
|----------|------|------|------|-----|
| 1        | 64.91| 27.92| 4.97 | 2.2 |
| 2        | 87.58| 3.87 | 7.84 | 0.71|

In the sample no. 2, it was seen that the volumetric wear loss and mass wear loss were 0.221 96 mm$^3$ and 0.001(g), respectively, and the material was not worn much in terms of the mass. The profilometer results indicating the wear depth were given in figure 13.

### 4. Results and discussion

In this study, it was tried to turn the coating material of Sn–Sb–Cu alloy known as the Babbitt metal (white metal) into more qualified material so as to be used in the journal bearings by forming alloy difference. The Babbitt metal is a ductile material with content of 80% Sn under normal conditions and is easy to be applied on the surface of hard steel material by electric arc spray method due to its vibration absorption property.
Since this metal is a bearing material that operates under high pressure, at high rpm value and has a melting degree of 232 °C, it was aimed to ensure much more effective use of this material by adding this alloy with different metals. Even if antimony (Sb) and copper (Cu) present in this alloy hardened the structure, it was seen

Figure 12. Macro and optical images of four samples.
that it was not sufficient. Therefore, the alloy was added with MgO, Al₂O₃ and ferrochromium (FeCr₂O₄) and to which extent and how it was effective were investigated.

1. It was determined by EDS analysis that 10% MgO added into the Babbitt metal was burnt as a result of reacting with external atmosphere even if it was included in the liquid metal as powder, and was not penetrated in its structure. The Babbitt was added with small rate of MgO, and it was considered that this addition had no significant effect on the wear resistance.

2. On the other hand, the addition of 10% Al₂O₃ to the alloy made the alloy free from undesired slag and pollutants by moving towards the surface of liquid metal due to the density difference of Al. The hard structures were formed in the areas of the Babbitt alloy with high rate of copper (Cu) and antimony (Sb).

3. When we added Babbitt metal with the compound of 10% FeCr₂O₄ that we frequently see in the steel alloys, it was observed that it was the alloy with the highest microhardness among other samples.

4. According to the evaluations made, it has been determined that the wear resistance of the coating will increase when it is was with the compound of Al₂O₃ in addition to the Babbitt metal.

5. When we examine the abrasion test results, MgO, Al₂O₃, FeCr₂O₄ have negative effects on volumetric wear loss. When we look at the mass wear loss, FeCr₂O₄ adversely affects, but Al₂O₃ has positive effects.

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