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Production of Babbitt Metal Thin Film by Thermal Evaporation Method and Investigation of the Change of Thıs Thin Film With Heat Treatment Time

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Abstract
In this study, thin films of Babbitt alloy will be investigated. For this purpose, tin (Sn) based Babbitt alloy thin films on glass substrates were produced by thermal evaporation method and these thin films were heat treated at 120°C for different times. The crystal structure of non-heat treated and heat treated babbitt thin films were determined by x-ray measurements. It was observed that the thin films were formed as agglomerations on the crystal structure of tin and crystallization increased as the heat treatment time increased. The grain boundaries on the coating surface can be clearly seen from the SEM images and a decrease in grain size was observed. In addition, it was determined that the oxide layer was deposited on the surface depending on the treatment time applied to the thin films obtained. Finally, it was observed from the AFM images that the roughness value.

1. Introduction

Babbitt metal, invented by Isaac Babbitt in 1839, is a soft alloy of tin (Sn), lead (Pb), copper (Cu), and antimony (Sb). Also known as white metal. tin-based Babbitt alloys, which are among the Babbit alloy types, are highly preferred Babbitt alloy types due to their superior corrosion resistance, easy bonding and less dissociation tendency, although they are high cost alloys [1-3]. These metals are the most common classical bearing materials today, especially in engines, compressors, fans, pumps, large turbines, aviation engines and many more rotating machinery [4].

Mechanical wear loss in materials consists of friction caused by the moving contact of the material with another material [5].

Babbitt alloys are used as a primer on surfaces, especially in engine bearings, to minimize the negative effects of this wear [6].

In a study, a new alloy obtained by adding Babbitt alloy to a new alloy, small (0.07 m/s) and high (4.5 m/s) lubrication was applied to the wear test and it was determined that the wear rate decreased and there was a significant decrease in the coefficient of friction [7]. For this reason, compared to other alloys used in bearings, tin-based (Sn-based) Babbitt alloys are widely used in the main components of bearings due to their unique corrosion resistance. Tin-based Babbitt alloys generally contain about 3–8% by weight Cu and 5–8% by weight Sb. Therefore, the microstructures of these alloys also show different properties due to these differences in their compositions [8].

In recent years, gaps in surface engineering research have been identified and this has prompted scientists to conduct further research [9]. With the coatings on the surfaces of the material, it is aimed both to protect the existing properties of the material and to further develop the existing properties [10].

For this reason, depending on the developing technology and this demand (increase in the usage area), especially in the last fifty years, the interest in thin film has increased significantly. The materials produced by the thin film method today have many

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advantages in terms of both cost, functionality (performance) and aesthetics [11]. In addition, with the recent thin film studies, many new research areas have emerged depending on the thickness, geometry and structure of the produced film. It has led to diversity in usage areas by providing convenience in the integration of materials produced as a result of coating the materials with thin films with various devices. The wear on the surface of the material varies depending on the surface hardness, roughness, grain size, ambient temperature and lubrication regime of the material [12,13]. For this reason, it is of great importance to understand the mechanical properties of the thin film coating on the material surface [14]. Thin films obtained by coating are extremely hard and thermally extremely stable [15]. Babbitt alloys, which are produced with thin film technology, have many uses in cutting tools, drill bits, beds, many electronic devices, decorative coatings, car parts and many more due to their superior resistance to corrosion and ergonomic convenience in technological systems today [11]. The thermal evaporation method, which is one of the thin film production methods, has a wide range of uses and high efficiency. This method has superior properties such as precise control of the thickness of the produced film and obtaining a smooth surface (smooth), flexibility to adjust interfaces, and solvent-free [16,17]. It is known from SEM images in many studies that the surface is homogeneous and the grain size is very small in thin films produced by this method [18]. Therefore, this method is a useful method for improving the friction and wear behavior of a material. Amanov et al. determined that a thin and properly formed saturated nanostructure significantly increased the wear resistance [12]. Paulo Roberto Campos Alcover Junior et al. determined that the coefficient of friction of the coatings produced by the thermal evaporation method is lower than the coatings produced by the traditional methods and their hardness is at an equivalent level [19]. The element that affects the hardness of the material in Babbitt alloys is antimony. As the ratio of the antimony element in the alloy increases, the hardness ratio of the alloy increases and therefore the compressive strength of the alloy also increases [20]. However, this also negatively affects the fragility of the material. The aim of this study is to produce a thin film on the glass surface with Babbitt metal ($Sn_{58}Sb_{35}Cu_7$) by thermal evaporation method. Then, measurements such as crystal structures, optical properties and surface roughness of these thin films will be obtained and evaluations will be made according to these measurement results.

2. Material and Method

The thermal evaporation method is a system formed by melting and evaporating an alloy (or polymer) left in a crucible made of tungsten with the help of electric current under a high vacuum, and adhering these evaporated particles to the coating substrate at a certain distance from the crucible. The two most outstanding features of the thermal evaporation coating method compared to other methods are that a very homogeneous surface coating is obtained in this method and the coating thickness can be interfered with. In order to benefit from these two superior features, factors such as the amount of material placed in the crucible, the distance between the crucible and the coating substrate, the value of the current applied to the crucible for melting the material in the crucible and the application time of this current are very important. Coating processes were carried out in a Leybold brand Univex 300 thermal evaporator. Here, the glass substrate in the form of a sheet of 1 mm in size and 25 mm x 75 mm in size was cleaned first with alcohol and then with the ultrasonic cleaning method. This cleaned glass substrate was placed at a distance of approximately 18 cm from the tungsten crucible and the coating process was carried out in a vacuum environment of 6.4×10^{-5} mbar for 8 minutes. The coating process was carried out by applying a current of 335 A. Finally, the production process was completed by applying heat treatments for one hour, two hours, four hours and six hours at 120 °C, respectively. In order to determine the crystal structure analysis of Babbitt coatings produced by thermal evaporation on glass substrate, XRD analysis measurements were taken at room temperature using Rigaku Miniflex 600 brand X-ray device. AFM images were taken used to determine the surface morphology (roughness) of these coatings. Then, LEO Evo 40 brand SEM-EDX and Mapping measurements were made to determine the surface images and elemental distribution of the existing coating, as well as its qualitative and quantitative properties. The schematic of the experimental procedures is shown in Figure 1. Table 1 shows coding detail of samples and Figure 2 shows image of samples.

Figure 1. Detailed View of the Device of the Thermal Evaporation System

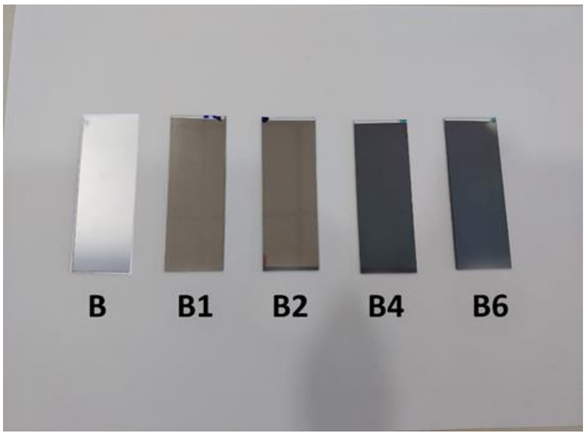

Figure 2. The image of the glass samples that have been coatedand heat treated

Table 1. Coding detail of existing samples

B	B1	B2	B4	B6
Glass specimen coated with Babbitt metal ($Sn_{58}Sb_{35}Cu_7$)	Glass specimen coated with Babbitt metal and heat treated for 1 hour	Glass coated with Babbitt metal Glass specimen heat treated for 2 hours	Glass coated with Babbitt metal Glass specimen heat treated for 4 hours	Glass sample coated with Babbitt metal and heat treated for 6 hours

4. Conclusion and Suggestions

Figures 3-7 show SEM-EDX and mapping images of exist coating. If we pay attention to the mapping image in Figure 3-a, the elements in the alloy are homogeneously distributed in the coating. In the SEM image in Figure 3-b, the grain and grain boundaries formed on the coating surface are clearly visible. Depending on the heat treatment applied to these coatings, oxide began to accumulate on the surface in the form of bubbles due to the tin and antimony elements in the alloy, and the oxide layer on the surface gradually increased in proportion to the duration of the applied heat treatment.

In a study, Kök et al. also determined that the oxide layer on the surface increased when they applied heat treatments at different values to the NiMnGa alloy [21]. This oxide layer accumulated on the surface caused a decrease in the amount of roughness on the surface, and this result is in harmony with the AFM results. In a thin film study conducted by Tasgın et al., they determined that the amount of roughness on the surface decreased significantly with the coating on the glass substrate, using AFM images [22].

In addition, if we pay attention to the SEM images in Figure 3-a - 7-a, respectively, as the duration of the applied heat treatment increases, the copper element in the alloy accumulates in the coating (on the surface) through agglomeration, and this result is also supported by the EDX results.

It was determined that agglomerations occurred on the surface coated with 97Se-3CeO_2 thin film due to the heat treatment applied on (100) and (101) planes [22]. The reason for this agglomeration is that the melting point between the copper element (Cu) and the tin and antimony elements (Sn and Sb) in the Babbitt alloy is known.

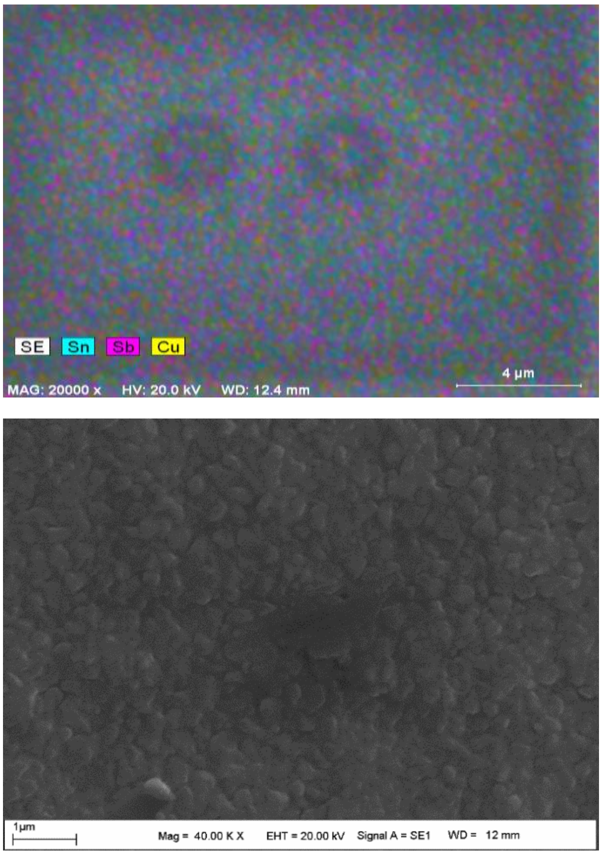

Figure 3. a) mapping image of sample B, **b)** SEM image of sample B

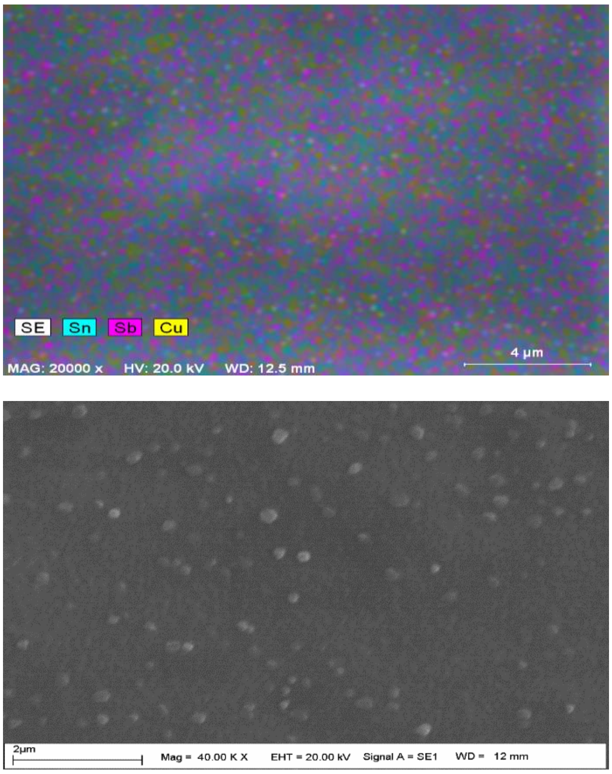

Figure 4. a) mapping image of sample B1, **b)** SEM image of sample B1

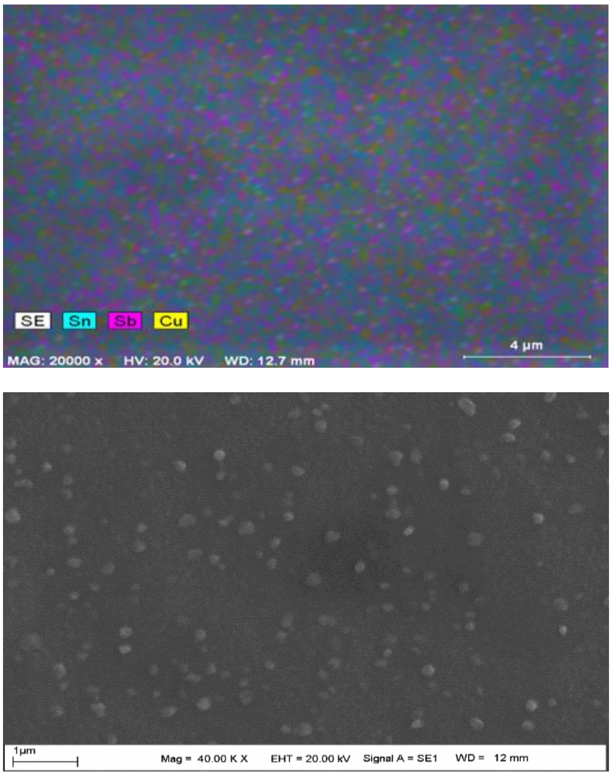

Figure 5. a) mapping image of B2 sample, **b)** SEM image of B2 sample

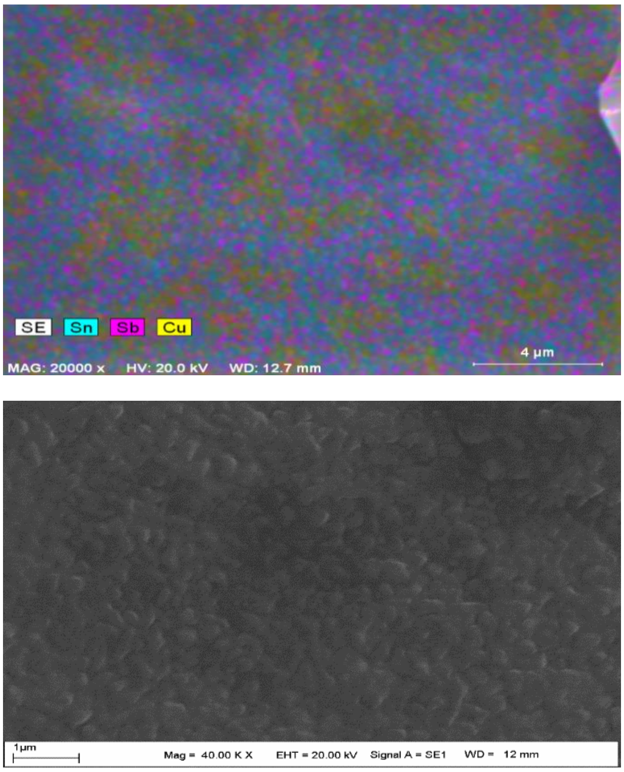

Figure 6. a) Mapping image of B4 sample, **b)** SEM image of B4 sample

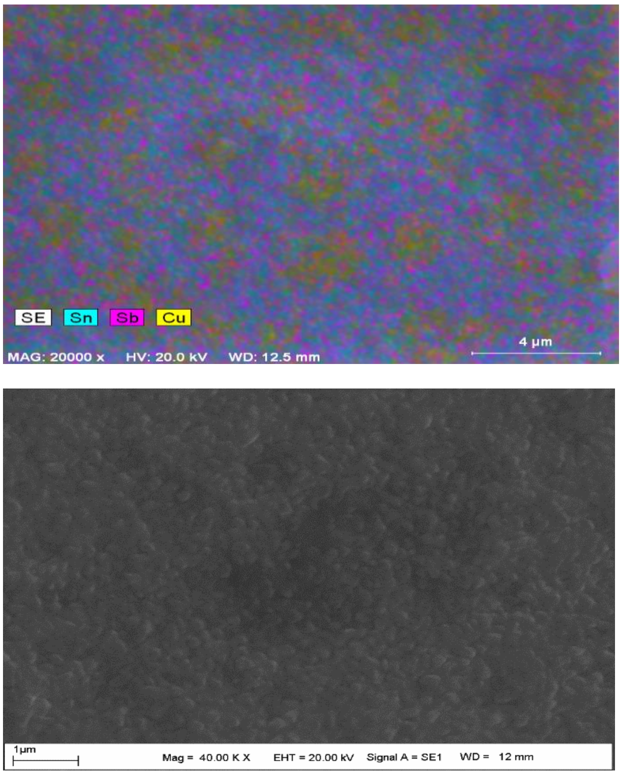

Figure 7. a) mapping image of sample B6, **b)** SEM image of sample

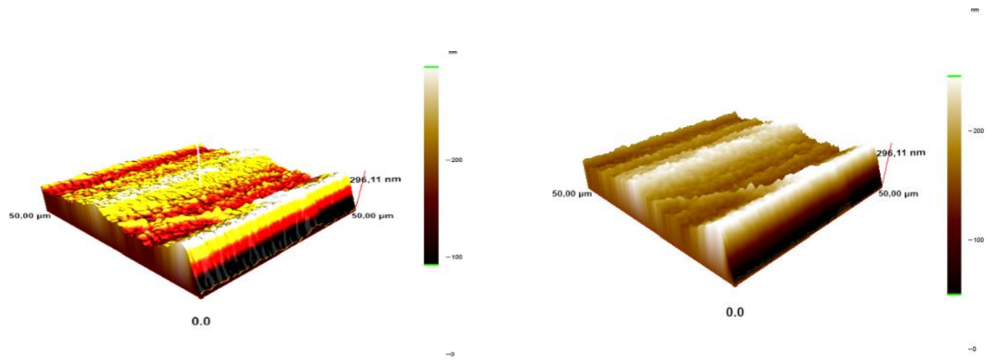

Figure 8. AFM (Surface Spectroscopy) image of sample B

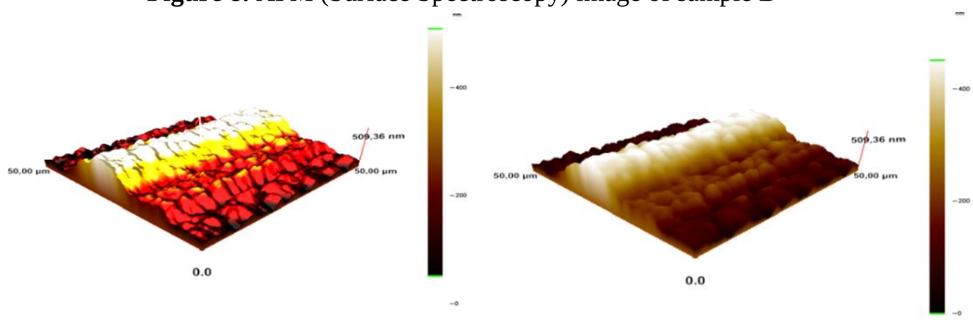

Figure 9. AFM (Surface Spectroscopy) image of B1 Sample

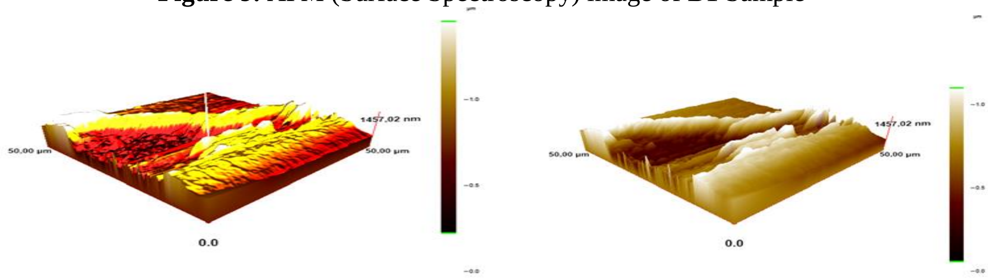

Figure 10. AFM (Surface Spectroscopy) image of B2 sample

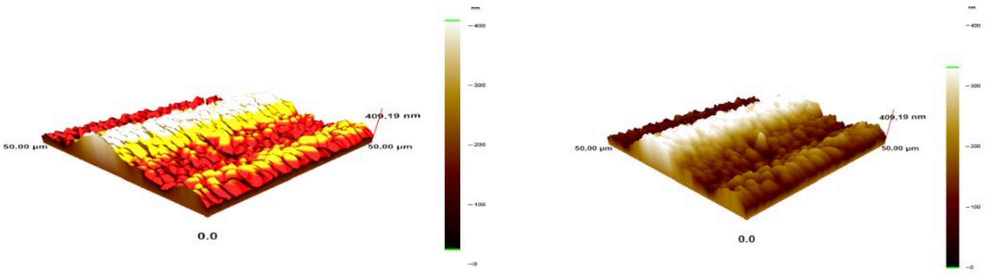

Figure 11. AFM (Surface Spectroscopy) image of B4 sample

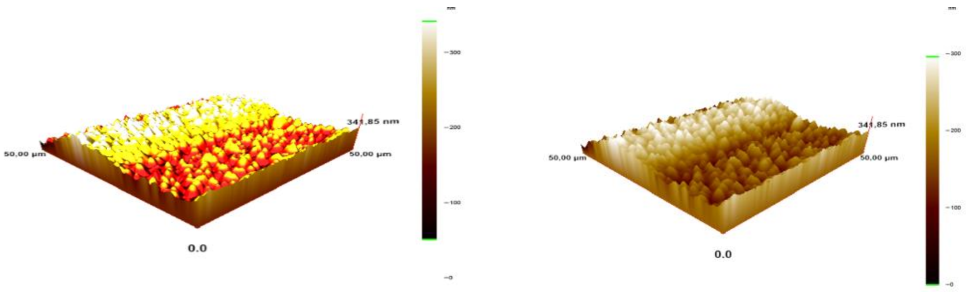

Figure 12. AFM (Surface Spectroscopy) image of B6 sample

Table 2. AFM surface roughness values of existing samples

	B	B1	B2	B4	B6
Average roughness value (Ra) (nm)	29.14	106.37	170	73.2	48.25
Square root of mean roughness value (Rq) (nm)	39.04	126.72	230	87.64	58.80

AFM (Surface Spectroscopy) images and roughness results are given in Table 2 in Figure 8-12 respectively. In Figure 8, the surface image of the B coating without heat treatment is given and the average roughness value was determined as 29.14 nm. If the Ra values of the B1 and B2 coatings given in Figure 9-10 are considered here, an increase in the roughness value on the surface was observed due to the oxide layers that started to form on the surface with the heat treatment applied to the coating, and this value was determined as 170 nm. As the duration of the heat treatment applied to B4 and B6 coatings is increased, an increase is observed in the oxide layer accumulated on the surface, and this increase (deposition) caused the surface to be completely covered with an oxide layer and this caused the roughness value (Ra) of the surface to decrease gradually to 73.2 and 48.25 nm respectively. In Figure 13, x-ray diffractograms of bulk and thin-film Babbitt alloys and of Babbitt thin-film heat-treated at 120 ˚C at room temperature are given. Obtained x-ray measurements are indexed according to the literature [23-26].

According to the crystal structure investigations, SbSn, Sn and Cu_6Sn_5 compounds were found in the bulk Babbitt alloy, and after it was turned into a thin film, it was observed that crystallization took place in the form of agglomerations on the Sn element [22]. Similarly, in several thin film studies, it has been observed that thin films are formed as agglomerations on a certain crystal layer [27,28]. Peaks at 30˚ and 43˚ are also Cu6Sn5 compound phase. When the effects of the heat treatment time on the crystal structure of Babbitt thin film are examined, it is seen that the intensity of the x-ray curve increases and new peaks occur with the heat treatment time.

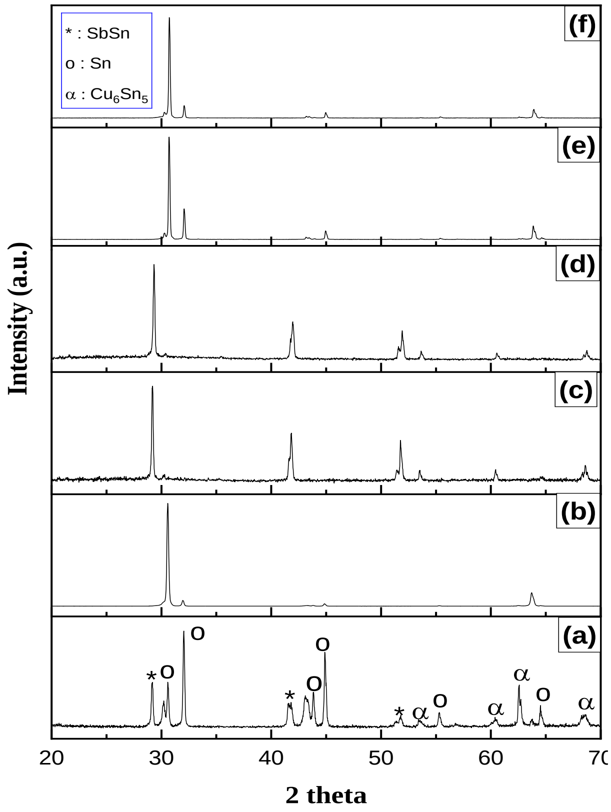

Figure 13. a) Babbitt alloy **b)** thin film Babbitt alloy without heat treatment **c)** Babbitt alloy film subjected to 1 hour heat treatment **d)** Babbitt alloy film subjected to 2 hours heat treatment **e)** Babbitt alloy film subjected to 4 hours heat treatment **f)** Babbitt alloy film subjected to 6 hours heat treatment

As a result of the study, it was determined from the mapping images that the Babbitt thin film coating applied to the glass surface were spread homogeneously on the glass surface. According to the data obtained from the surface spectroscopy (AFM) images, an increase in the oxide layer on the surface was observed in proportion to the heat treatment applied to the coating. This increase also caused a decrease in the roughness value on the surface. In addition, from the SEM images, it is seen that the grain sizes in the coating decrease in proportion to the applied heat treatment and therefore the roughness on the surface decreases. The lowest roughness value on the surface was obtained in the B1 sample, which was not heat treated, while the highest roughness was obtained in the B2 sample, which was heat treated for two hours.

According to the X-ray measurement results, all Babbitt thin films showed that the Sn element was deposited on the main crystal structure, and the intensity of the crystal structure peaks increased with the heat treatment time and indicating that the degree of crystallinity increased.

References

1. A. Zeren, E. Feyzullahoglu, M. Zeren, "A study on tribological behaviour of tin-based bearing material in dry sliding" *Materials & design*, vol.28, no.1, pp. 318-323, 2007.
2. M.Ö. Bora, O. Coban, T. Sinmazcelik, V. Günay, M. Zeren, "Instrumented indentation and scratch testing evaluation of tribological properties of tin-based bearing materials" *Materials & Design*, vol.31, no.6, pp. 2707-2715, 2010.
3. A. Zeren, "Embeddability behaviour of tin-based bearing material in dry sliding" *Materials & design*, vol.28, no.8, pp. 2344-2350, 2007.
4. X. Zhao, R. Lai, X. Hai, "A study on the microstructures and properties of selective laser melted babbitt metals" *Journal of Materials Engineering and Performance*, vol.28, no.9, pp. 5433-5440, 2019.
5. O. Karpuz, M.V. Akpinar, "İnce Agrega Türünün Kaplama Betonunun Aşınma Direncine Etkisi" *Yapı Teknolojileri Elektronik Dergisi*, vol.5, no.2, pp. 1-8 2009.
6. P. Diouf , A. Jones, "Investigation of bond strength in centrifugal lining of babbitt on cast iron" *Metallurgical and Materials Transactions* A, vol.41, no.3, pp. 603-609, 2010.
7. L. Korshunov, N. Noskova, A. Korznikov, N. Chernenko, N. Vil'Danova, "Effect of severe plastic deformation on the microstructure and tribological properties of a babbit B83" *The Physics of Metals and Metallography*, vol.108, pp. 519-526, 2009.
8. Y. Tasgın, Effect of MgO, "Al2O3 and FeCr2O4 on microstructure and wear resistance of Babbitt metal (Sn–Sb–Cu)" *Materials Research Express*, vol.6, no.4, pp. 046548, 2019.
9. B. Leszczyńska-Madej, M. Madej, J. Hrabia-Wiśnios, A. Węglowska, "Effects of the processing parameters of friction stir processing on the microstructure, hardness and tribological properties of SnSbCu bearing alloy" *Materials*, vol.13, no.24, pp. 5826, 2020.
10. A. Özkartal, D.T. Noori, "Effects of thermal annealing on the characterization of p-NiO/n-GaAs heterojunctions produced by thermal evaporation" *Journal of Materials Science: Materials in Electronics*, vol.32, no.10, pp. 13462-13471, 2021.
11. R. Messier, "Thin film deposition processes" *MRS Bulletin*, vol.13, no.11, pp. 18-21, 1988.
12. A. Amanov, B. Ahn, M.G. Lee, Y. Jeon, Y.-S. Pyun, "Friction and wear reduction of eccentric journal bearing made of sn-based babbitt for ore cone crusher" *Materials*, vol.9, no.11, pp. 950, 2016.
13. M.C. Türküz. "Fiziksel buhar biriktirme yöntemi ile yapılan zirkonyum nitrür ince film kaplamanın kaplama parametrelerinin incelenmesi ve optimizasyonu" *Fen Bilimleri Enstitüsü*, 2006.
14. W.D. Nix, "Mechanical properties of thin films" *Metallurgical transactions A*, vol.20, no.11, pp. 2217-2245, 1989.
15. M. Rao, M. Shekhawat, editors. "A brief survey on basic properties of thin films for device application" *International Journal of Modern Physics: Conference Series*, vol.22, 2013. World Scientific, pp.576-586, 2013.
16. S.-R. Bae, D. Heo, S. Kim, "Recent progress of perovskite devices fabricated using thermal evaporation method: Perspective and outlook" *Materials Today Advances*, vol.14, pp. 100232, 2022.
17. S. Wang, X. Li, J. Wu, W. Wen, Y. Qi, "Fabrication of efficient metal halide perovskite solar cells by vacuum thermal evaporation: A progress review" *Current opinion in Electrochemistry*, vol.11, pp. 130-140, 2018.
18. A.W. Batchelor, "Engineering tribology" *Butterworth-Heinemann*, 1993.
19. P.R.C.A. Junior, A.G.M. Pukasiewicz, "Evaluation of microstructure, mechanical and tribological properties of a Babbitt alloy deposited by arc and flame spray processes" *Tribology International*, vol.131, pp. 148-157, 2019.

20. P. Diouf, A. Jones, "Investigation of bond strength in centrifugal lining of babbitt on cast iron" *Metallurgical and Materials Transactions A*, vol.41, pp. 603-609, 2010.
21. M. Kök, G. Pirge, Y. Aydoğdu, " Isothermal oxidation study on NiMnGa ferromagnetic shape memory alloy at 600–1000° C" *Applied surface science*, vol.268, pp. 136-140, 2013.
22. Y. Taşgin, M.S. Kanca, M. Kök, "Investigation of surface morphology, optical properties and the gamma radiation effect on selenium coated glass substrate containing rare earth oxide" *Optical Materials*, vol.140, pp. 113921, 2023.
23. D. Zhang, F. Zhao, Y. Li, P. Li, Q. Zeng, G. Dong, "Study on tribological properties of multi-layer surface texture on Babbitt alloys surface" *Applied Surface Science*, vol.390, pp. 540-549, 2016.
24. M. Kamal, A. El-Bediwi, A. Lashin, A. El-Zarka, "Copper effects in mechanical properties of rapidly solidified Sn–Pb–Sb Babbitt bearing alloys" *Materials Science and Engineering: A*, vol.530, pp. 327-332, 2011.
25. M. Beger, P. Jurči, P. Grgač, S. Mečiar, M. Kusý, J. Horník, "CrxNy coatings prepared by magnetron sputtering method" *Kovové Materiály-Metallic Materials*, vol.51, no.1, pp. 1-10, 2013.
26. Y. Ni, N. Sun, G. Zhu, S. Liu, J. Liu, G. Dong, "Effect of different Cu6Sn5 morphology on the tribological properties of Babbitt alloy" *Industrial Lubrication and Tribology*, vol.74, no.5, pp. 580-587, 2022.
27. C.R. Dhas, R. Venkatesh, R. Sivakumar, A.M.E. Raj, C. Sanjeeviraja, "Fast electrochromic response of porous-structured cobalt oxide (Co 3 O 4) thin films by novel nebulizer spray pyrolysis technique" *Ionics*, vol.22, pp. 1911-1926, 2016.
28. A. Erlacher, M. Ambrico, V. Capozzi, V. Augelli, H. Jaeger, B. Ullrich, "X-ray, absorption and photocurrent properties of thin-film GaAs on glass formed by pulsed-laser deposition" *Semiconductor science and technology*, vol.19, no.11, pp. 1322, 2004.