Influence of heat treatment on interfacial microstructure of cast Babbitt/carbon steel bimetallic materials

Mohamed Ramadan¹,²*, Naglaa Fathy³

¹ Central Metallurgical Research and Development Institute (CMRDI), P.O. Box 87, Helwan 11421, Egypt
² College of Engineering, University of Ha’il, P.O. Box 2440 Ha’il, Saudi Arabia
³ College of Science, University of Ha’il, P.O. Box 2440 Ha’il, Saudi Arabia

*Corresponding author: mrnais3@yahoo.com

Abstract. Bimetallic material has been extensively employed as an advanced functional material in different industrial applications for its unique physical and mechanical properties. Bi-metallic material can be fabricated by bonding of similar and dissimilar materials. Variety of physical and chemical properties, such as wettability, reactivity, phase transformation, as well as thermal properties must be compatible to bond each other. The results showed that bonding interface area of heat treated Babbitt/steel bimetal using tinning mixture of flux+ Sn was improved by 9%. Otherwise, bonding interface area of heat treated Babbitt/steel bimetal using tinning mixture of flux + Sn + glycerol and, flux +Sn + petroleum jelly was improved by 93% and 70% respectively. For all used tinning conditions, the interface thickness layer increase with heat treatment process of Babbitt/steel bimetal.

1. Introduction

Sn- based Babbitt alloys mainly contain variety weights of Sb and Cu elements. They have low wear, high corrosion resist, good run-in properties and good behaviour in the absence of sufficient lubrication. For their good corrosion resistant in addition to previous mentioned properties, Sn- base Babbitt alloys are commonly used in the components of the steam turbines, engine, and compressor bearings. Sn- based Babbitt alloys are easily cast and retain reasonable mechanical properties at elevated temperatures. Sn- based Babbitt alloys are used as a lining metal bearing surface. The Sn-based Babbitt metal can be bonded to the metal bearing shell using chemically or mechanically routes. Commonly, there are three standard fabrication techniques for applying the Sn-based Babbitt to a substrate shell: static casting, centrifugal casting and arc spraying [1-5].

Among all other bi-metal bearings fabrication techniques, liquid-solid static casting technology considered the most economical one that allows the production of bearing layer elements directly. For the developing liquid-solid, bi-metal casting techniques much more attention on improving the interface bond of the bearing metal and substrate shell should be considered for the higher bond strength, durability and performance of the bi-metal bearings [6-10]. For the most liquid – solid bi-metal casting fabrication techniques, low carbon steel, stainless steel and/ or Cu alloys were used as solid substrate shells [2, 6-10].

Powder tin with flux mixture was considered as one of direct tinning process that is successfully used for Babbitt-steel bimetallic materials fabrication. Direct tinning process is a promising tinning process for solid steel substrate used for flat and horizontal bearings applications [11]. Recently, Glycerol and petroleum jelly were added to tin/flux mixture in order to facilitate the mixture for curvature surface solid steel shells application (ex. Journal Bearings) [11]. The addition of glycerol or petroleum jelly to tinning mixture significantly increases the voids and forming unbonded interface layer areas. The aim of current work is to improve the interfacial bonding of Babbitt/steel bimetal composite that fabricated using tinning mixtures contain glycerol or petroleum jelly.
2. Experimental Work

Babbit/carbon steel bimetal specimens were fabricated by using liquid-solid bimetal casting technique. Tinning process of Cu alloy solid substrate involves metallic tin/flux mixture deposition on the surface of Cu alloy solid substrate was explained elsewhere [12-13] The tinning mixtures using tin powder, flux, glycerol or petroleum jelly were reported in detail in previous work [11]. The chemical compositions of Babbit alloy and carbon steel substrate used for bimetal are given in Table 1. Specimens of approximate 40x20x18 mm³ were cut from three as-cast Babbit/carbon bimetal for heat treatment and microstructure investigation as well as hardness measurements. Specimens were heated to 210 °C for 120 min in an electrical heating furnace with heating rate of 10 °C/min. The samples were air cooled into room temperature.

| Materials       | Sb (wt.%) | Cu (wt.%) | Pb (wt.%) | C (wt.%) | Si (wt.%) | Mn (wt.%) | Cr (wt.%) | Sn (wt.%) | Fe (wt.%) |
|-----------------|-----------|-----------|-----------|----------|-----------|-----------|-----------|-----------|-----------|
| Babbit Alloy    | 6.5–7.5   | 2.5–3.5   | 0.35      | -        | -         | -         | -         | Bal       |           |
| Carbon Steel    | -         | 0.21      | -         | 0.18     | 0.32      | 0.45      | 0.14      | Bal       |           |

The Babbit/steel bimetal specimens were cut for microstructure investigation, ground, polished and etched with a 4% nital. Optical microscope and scanning electron microscope (SEM) fitted with an energy-dispersive X-ray spectroscopy (EDS) were used to investigate the Babbit/steel bimetal specimens. The hardness of Babbit/steel bimetal specimens was measured by Vickers microhardness testing machine. The hardness average value of five measurements of each of bimetal specimen were taken.

3. Results and Discussions

Microstructures of tin-based Babbit alloy and carbon steel substrate used for bimetallic composite fabrication are shown in Figure 1. SEM microstructures (Figure 2a) and EDS analysis (Figure 2b&c) of Cu₆Sn₅ and SnSb hard phases of tin-based Babbit alloy. Needles and asterisks shape of Cu₆Sn₅ phase are observed. It was reported [14–16] that the matrix of solid solution contains Cu₆Sn₅ and SnSb hard embedded phases produce a Babbit matrix has fatigue resistant properties.

![Figure 1](image1.png)

Figure 1. Microstructure of (a) Babbit alloy and (b) carbon steel substrate.
Figure 3 a, c & e shows the interfacial microstructures of Babbitt/steel bimetal for as-cast using tinning mixture of flux+ Sn, flux + Sn + glycerol and, flux + Sn + petroleum jelly respectively. Figure 3 b, d & f shows of interfacial microstructures of Babbitt/steel bimetal for heat treated bimetal of (a), (c) and (e) respectively. It is reported [11] that morphology of the interfacial layer of Babbitt/steel bimetal are a significantly affected by addition of bath glycerol and petroleum jelly to the mixture of tinning mixture. Using flux + tin mixture produces a discontinuous interfacial layer (Figure 3 a), otherwise the addition of glycerol or petroleum jelly to the tinning mixture produce a continuous interfacial layers (Figure c&e).

Although, the addition of petroleum jelly and glycerol to the tinning mixture stabilized the interfacial tin layer, much more interfacial unbonded area were produced especially with glycerol addition (see Fig. 3 c& e). Otherwise, the heat treated as-cast bimetal show significant improvements for interfacial bonding areas and their structure morphology (Figure 3 b, d&f). The influence of heat treatment especially heating time on the microstructure of tin-based alloy have been studied [17]. The precipitates morphology is changed by increasing the heating time, whereas the SbSn phase with cuboids shape is turned to sphere shape. In current research work the changes in interface structure and the bonding area could be due to surface energy considerations. At the higher heating temperatures of 210 °C, which is near to solidus temperature of Babbitt (220-230 °C) alloy, the effect of surface energy on Babbitt matrix is highly considered. Therefore, low melting point matrix area that could contains some impurities and in addition to the metal flow at relatively high temperature fill the voids on the interface resulted in increasing the interfacial bonding area.

Figure 4 shows the bonded interface area of as-cast and heat treated Babbitt/steel bimetal using tinning mixture of flux+ Sn, flux + Sn + glycerol and, flux +Sn + petroleum jelly. Bonding interface area of heat treated Babbitt/steel bimetal using tinning mixture of flux+ Sn is improved by 9%. Otherwise, bonding interface area of heat treated Babbitt/steel bimetal using tinning mixture of flux + Sn + glycerol and, flux +Sn + petroleum jelly is improved by 93% and 70% respectively.
Figure 3. Interfacial microstructures of Babbitt/steel bimetal for (a),(c) and (e) as-cast bimetal using tinning mixture of, flux+Sn, flux+Sn+glycerol and flux+Sn+petroleum jelly respectively and (b),(d) and (f) heat treated bimetal of (a),(c) and (e) respectively.

Figure 4. Bonded interface area of as-cast and heat treated Babbitt/steel bimetal using tinning mixture of, flux+Sn, flux+Sn+glycerol and flux+Sn+petroleum jelly respectively.
Figure 5 shows the interface layer thickness of as-cast and heat treated Babbitt/steel bimetal using tinning mixture of flux + Sn, flux + Sn + glycerol and flux + Sn + petroleum jelly. For all tinning conditions, the interface thickness layer increase with heat treatment process of Babbitt/steel bimetal. The increasing of interface layer thickness is mostly due to the higher diffusion rate of elements and the formation of FeSn intermetallics.

The heat treatment process applied in present study has improved the diffusion bond of Babbitt/steel bimetal using tinning mixture of flux + Sn, flux + Sn + glycerol and, flux + Sn + petroleum jelly. Whereas, higher diffusion at relatively higher near solidus temperature promotes the aimed acceptable bonding area between Babbitt bearing alloy and carbon steel shell. Therefore, based on the above analysis, the heat treatment for bimetal liquid–solid compound cast could be an effective tool for improve interfacial structure and bonding areas of sound and defected Babbitt/steel bimetal materials.

4. Conclusions

A significant improvement of interfacial bonding area of interfacial microstructure of heat treated cast Babbitt /carbon steel bimetallic materials prepared with flux+ Sn, flux+Sn+glycerol and , flux+Sn+petroleum jelly was achieved. Bonding interface area of heat treated Babbitt/steel bimetal using tinning mixture of flux+ Sn is improved by 9%. Otherwise, bonding interface area of heat treated Babbitt/steel bimetal using tinning mixture of flux + Sn + glycerol and, flux +Sn + petroleum jelly is improved by 93% and 70% respectively. For all used tinning conditions, the interface thickness layer increase with heat treatment process of Babbitt/steel bimetal.

Acknowledgment

The authors gratefully acknowledge technical Staff of Foundry Technology Lab of Central Metallurgical R&D Institute for their support of their research program.
References

[1] Diouf P and Jones A 2010 Metallurgical and Materials Transactions A Investigation of Bond Strength in Centrifugal Lining of Babbitt on Cast Iron 41A 603-609.

[2] Fathy N and Ramadan M 2018 AIP Conference Proceedings Influence of volume ratio of liquid to solid and low pouring temperature on interface structure of cast Babbitt-steel bimetal composite, 1966 020028; doi: 10.1063/1.5038707.

[3] Valeeva A K, Valeev I S and Fazlyakhmetov R F 2014 J Frict. Wear. Effect of Structure of B83 Babbit on Its Wear 35 311–315.

[4] Sadykov F A, Barykin N P Valeev I Sh, and Danilenko V N 2003 J. Mater.Eng. Perform. Influence of the Structural State on Mechanical Behavior of Tin Babbit 12 (1) 29–36.

[5] Ji X and Chen Y 2016 J. Mater. Eng. Perform. Tribological Behavior of Babbit Alloy Rubbing Against Si3N4 and Steel Under Dry Friction Condition 25 (3) 750-755.

[6] Ramadan M, Fathy N, Abdel Halim K S and Alghamdi A S 2019 International Journal of Advanced and Applied Sciences New trends and advances in bi-metal casting technologies 6 (2) 75-80.

[7] Gawronski J, Szajnar J, Wróbel P 2004 Journal of Materials Processing Technology Study on theoretical bases of receiving composite alloy layers on surface of cast steel castings 157-158 679-682.

[8] M. Ramadan, B. Ayadi, W. Rajhi and A.S. Alghamdi 2020 Key Engineering Materials Influence of Tinning Material on Interfacial Microstructures and Mechanical Properties of Al12Sn4Si1Cu/Carbon Steel Bimetallic Castings for Bearing Applications 835 108-114.

[9] Cholewa M, Wróbel T and Tenerowicz S 2010 Journal of Achievements in Materials and Manufacturing Engineering Bimetallic layer castings, 43:1 385-391.

[10] Ramadan M 2015 Advanced Materials Research Interface characterization of bimetallic casting with a 304 stainless steel surface layer and a gray cast iron base 1120-1121 993-998.

[11] Fathy N 2018 Engineering, Technology & Applied Science Research Interface Microstructure Investigation of Babbit -Carbon steel Composite Using Flux With Glycerol and Petroleum Jelly Additives 8 (3) 3028-3031.

[12] Ramadan M, Alghamdi A S, Subhani T and Abdel Halim K S 2020 Materials Fabrication and Characterization of Sn-Based Babbitt Alloy Nanocomposite Reinforced with Al2O3 Nanoparticles/Carbon Steel Bimetallic Material 13 2759; doi:10.3390/ma13122759.

[13] Ramadan M, Alghamdi A S, Hafez K M, Subhani T and Abdel Halim K S 2020 Materials Development and Optimization of Tin/Flux Mixture for Direct Tinning and Interfacial Bonding in Aluminum/Steel Bimetallic Compound Casting 13 5642.

[14] Koutsýk J and Veselá J 2004 J. Mater. Process. Technol. Evaluation of white metal adhesion (conventional casting and thermal wire arc spraying) by ultrasonic non-destructive method 157–158 724–728.

[15] Barykin N, Sadykov F and Aslanian I 2000 J. Mater. Eng. Perform. Wear and failure of Babbitt bushes in steam turbine sliding bearings. 9 10–115.

[16] Sadykov FA, Barykin NP, Valeev IS and Danilenko VN 2003 J. Mater. Eng. Perform. Influence of the structural state on mechanical behaviour of tin Babbit 12 29–36.

[17] Moazami Goudarzi M, Jenabali Jahromi S A and Nazarboland A 2009 Materials and Design Investigation of characteristics of tin-based white metals as a bearing material, 30 2283–2288.