The effect of Sn content on the properties of surface refined Cu-Sn bronze alloys

Cherian Paula*, R. Sellamuthu

*Department of Mechanical Engineering, Amrita School of Engineering, Amrita Vishwa Vidyapeetham, Ettimadai, Coimbatore, TN- 641112

Abstract

An investigation was carried out to assess the effect of the Sn content on the microstructure, hardness and wear properties of surface refined Cu-Sn bronze alloys. The surface refining was carried out using the Gas Tungsten Arc (GTA) as heat source. Alloys of various compositions, (4, 6, 8, 10, 12 wt% Sn) were melted in a melting furnace under an argon atmosphere and cast into sand moulds in the form of rods. Microstructural evaluation of the as-cast, refined and homogenized specimens were conducted using an optical microscope. The Vicker’s Hardness Tester was used to measure the hardness of the modified layer and the wear testing was conducted using DUCOM Pin-On-Disc wear testing machine as per ASTM G99 standard under dry sliding condition in air. The microstructure of the modified layer showed a refined grain structure as compared to the coarse dendritic structure observed in the as cast sample. The homogenized specimen showed that there was no formation of any non-equilibrium phase due to rapid cooling. It was found that the hardness of the modified layer increases when the Sn content was increased from 4-12%. The wear rate decreases linearly with the Sn content. The Coefficient of Friction was found to remain constant irrespective of the hardness. The results of this study using GTA as heat source are comparable to those of previous works in which laser and e-beam heat sources were used.

Keywords: Tin bronze; surface refining; microstructure; hardness; wear rate; GTA

* Corresponding author. Tel.: +919489920114
E-mail address: cherianpaulk@gmail.com

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1. Introduction

The tribological properties of nonferrous and ferrous alloys can be enhanced with the application of an emerging method called Surface Refining Process (SRP). The SRP can be considered as an alternative to the conventional coating methods like PVD, CVD, electroplating etc. In this process, an appropriate moving heat source is employed to melt the surface of the substrate material to form a molten pool so that a modified layer forms on the surface upon solidification. The modified layer so formed is integral to the substrate material. In the case of traditional coating methods, the coating material may delaminate under various service conditions. Such a drawback can be resolved by the application of SRP, where the modified layer being the integral part will be found effective. Therefore, it is expected that the components treated by the SRP can carry a higher load than those coated by the traditional methods. By the application of the SRP, it is possible to enhance various properties such as surface hardness, wear resistance, corrosion resistance, thermal conductivity etc.

Many additional benefits are envisaged by the researchers. They are as follows. Formation of fine grain structure during solidification results due to the rapid cooling in the SRP [1]. Further, for the new alloy formation on solidification, alloying elements can be added to the molten pool [2]. It was also reported that due to the rapid cooling and/or alloy addition, new intermetallic compounds may also form in this process [3, 4]. Various refractive ceramic particulates like TiC, B₄C etc can also be added to the molten pool to form a metal matrix composite. The modified layer so formed exhibits high hardness [5,6]. Vanderberg and Draper [7] conducted a research on the laser melting of copper alloys. They have showed that laser surface melting of conventionally cast aluminium bronze resulted in the formation of several metastable phases. Shi et al [8,9] investigated the electron beam surface melting of aluminum bronze. They have reported that the hardness, corrosion resistance and wear resistance increased after the e-beam surface treatment. Benkisser et al [10] have studied the effect of laser surface melting on manganese aluminum bronzes and have reported an increase in the hardness after treatment. The effects of laser surface treatment on aluminum bronze has been studied by Anchev [11]. It was observed that pulsed treatment increased the hardness. The laser processing of various materials have been reported by Majumdar and Manna [12,13].

In view of the above studies, a systematic investigation is carried out in the present study on the surface refining of tin bronze using Gas Tungsten Arc (GTA) as heat source. The effect of Sn content on microstructure, hardness, wear rate and coefficient of friction of surface refined Cu-Sn alloys have been investigated. No previous work has been reported on the effect of Sn content and that of surface refining on the structure and properties of tin bronze.

2. Experimental Procedure

The tin bronze alloys with varying Sn content (4, 6, 8, 10 and 12 % wt) were prepared by sand casting process. The chemical composition of the castings was analyzed using arc spectrometry. The alloy compositions were found to be within a range of ± 0.2 % wt from the nominal composition. The cast specimens were machined into rods of dimension 150x30x30 mm. Surface refining was done on the machined specimen using GTA heat source to melt the substrate surface so as to form a modified layer on solidification. Argon was used as the shielding gas. The GTA process parameters used are current – 200 A, arc length – 1.5 mm, electrode diameter – 2.4 mm, speed – 1 mm/s, electrode angle – 180 degrees and argon flow rate – 12 ltr/min. The surface refined specimens were homogenized and solution heat treated at 820°C for 10 hours under argon atmosphere and cooled to room temperature.

The specimens were cut, polished and macro-etched using the usual metallurgical technique. Microstructural examination was conducted for as cast, surface refined and homogenized specimens using Carl-Zeiss Inverted Metallurgical Microscope. The hardness on the surface of the modified layer was measured using the Vicker’s Hardness Tester. A load of 100 gmf was applied for duration of 15 s to measure the hardness. The microhardness was taken at different locations on the modified layer for each specimen and an average value was calculated. The wear testing was conducted using a DUCOM make Pin-On-Disc wear testing machine. A hardened steel (En 31) disc plate with a hardness of Rc 60 and surface roughness of Ra 0.15 μm was used as the counter-face material as per ASTM G99 standard under dry sliding condition in air. The wear testing conditions used were as follows: Load- 20 N, Speed- 424 rpm, Track diameter- 110 mm, Velocity- 2.5 m/s, Time- 600 s and Sliding...
distance- 1500 m. The following were determined using the data obtained from the data acquisition system in the tribometer. (i) height loss vs time (ii) coefficient of friction vs time (iii) frictional force vs time. The wear rate was calculated from the slope of the height loss vs time plot. The experimental setup is shown in figure 1.

![Experimental setup](image1)

**3. Results and Discussion**

**3.1 Microstructure**

A typical dendritic structure was observed in the as cast Cu-Sn alloys. Figure 2 shows the microscopic image of Cu-10Sn alloy in as cast condition. Figure 3 shows the surface refined Cu-10Sn alloy. A fine grained structure was observed after surface refining of the alloys as shown in the figure. Therefore it is inferred that the refinement of microstructure occurs upon surface refining.

![As-cast Cu-10Sn alloy, 200X](image2) ![Refined Cu-10Sn alloy, 200X](image3)
Figure 4 shows the microscopic image of the homogenized Cu-10Sn alloy specimen. It was observed that the dendritic structure was fully eliminated after homogenization. No secondary phase formation was detected after heat treatment on the alloy.

![Homogenized Cu-10Sn alloy, 200X](image)

**Fig. 4 Homogenized Cu-10Sn alloy, 200X**

### 3.2 Hardness

The variation in hardness with Sn content for various alloys is shown in figure 5. Hardness was found to increase with Sn content. The substrate hardness increased from 105HV to 154HV with increase in Sn content. Further surface hardness of the modified layer increased from 171HV to 301HV. The increase in the surface hardness is attributed to the increase in Sn content of the substrate as well as due to the fine grain structure formed on rapid solidification after surface refining process. The hardness value of this study is plotted along with the data of previous studies in figure 6. The hardness data reported in the previous studies range 300 – 400HV and the hardness value of this study are comparable to the data of previous studies, showing the consistency of the present work.

![Hardness variation with Sn content](image)

**Fig. 5 Hardness variation with Sn content**

![Hardness comparison data](image)

**Fig. 6 Hardness comparison data**
3.3 Wear rate

A typical height loss versus time plot for the modified alloy of this study is shown in figure 7. It can be observed that the height loss increases linearly with the sliding time. Figure 8 shows the variation in wear rate with Sn content for substrate as well as surface refined specimens. Wear rate was found to decrease with increase in Sn content.

Figure 9 and 10 show the variation of wear rate with hardness for substrate as well as for the refined specimens. It can be found that the wear rate decreased with increase in the hardness, an observation which is consistent with that of Archard's theory [14].

| Sn Content | Wear Rate (x 10^-4 mm^3/m) |
|-----------|-----------------------------|
| Cu-4Sn    | 24                          |
| Cu-6Sn    | 20                          |
| Cu-8Sn    | 18                          |
| Cu-10Sn   | 16                          |
| Cu-12Sn   | 14                          |

| Hardness (HV) | Wear Rate (x 10^-4 mm^3/m) |
|---------------|-----------------------------|
| 75            | 22                          |
| 100           | 20                          |
| 125           | 18                          |
| 150           | 16                          |
| 175           | 14                          |

Fig. 7 A typical wear plot  
Fig. 8 Wear rate variation with Sn content  
Fig. 9 Wear rate vs. Hardness (substrate)  
Fig. 10 Wear rate vs. Hardness (refined)
Figure 11 shows the wear rate comparison of substrate and surface refined specimen of this study along with the data of the other studies. It is noted from the plot that the wear rate data obtained from this study are comparable to the data of previous studies.

![Figure 11: Wear rate data comparison](image)

**3.4 Coefficient of friction**

A typical plot of Coefficient of Friction versus time is shown in Figure 12. The plot shows a transient period along with a steady-state regime which may be due to the effect of work hardening and/or accumulation of debris. Figure 13 shows the friction coefficient values of the present study along with the data of previous studies. The Coefficient of friction remains almost constant irrespective of the increase in hardness.

![Figure 12: Typical CoF plot](image)  ![Figure 13: Hardness vs.CoF comparison](image)
4. Conclusions

The following conclusions are drawn based on the results of this investigation: (i) the surface refining process improves the hardness and wear properties of the alloy; (ii) the hardness and wear rate are found dependent on the Sn content of the alloy; (iii) the wear rate decreases with hardness, an observation consistent with Archard’s theory and also the wear data obtained are comparable to that of previous studies, (iv) the Coefficient of Friction is found to be a constant and is independent of the hardness, an observation in agreement with that of previous studies; and finally, (v) GTA heat source is found to be a viable and economical heat source owing to its wider coverage when compared with laser/ e-beam heat sources.

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