ICMIEE20-047

# Experimental Analysis on the Physical Manners of Thermally Affected Bell Metal

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**ABSTRACT**
The effect of thermal annealing on copper based alloy bell metal has been conducted. The metal is prepared through conventional melting and casting process. Bell metal samples are isochronally annealed for 60 minutes at different temperatures up to 500ºC and isothermally annealed at various temperatures up to 350ºC for different period of time ranging from 15 to 240 minutes. Hardness values as well as sound intensity of differently heat treated alloy samples have been measured to study its after-effect. It is found that the bell metal shows continuous softening up to 300ºC due to stress relieving, recovery and recrystallization behavior of the experimental alloy. After that its hardness is seemed to be augmented because of the grain growth. The variation of sound intensity with temperature almost followed the similar pattern of hardness curve as a very hard, homogenous and extremely durable combination produces inferior sound. The sound intensity is seemed to be attenuating for a short period but hereafter it starts to increase to a maximum dB value due to the grain growth with the formation of new set of defect free grains. The optical response study is done using UV-VIS-NIR reflectance spectroscopy and it reveals that the spectral reflectance of the alloy increases initially due to chemical changes such as formation of copper oxides and decreases with temperature due to intermetallic formation, precipitation coarsening and recrystallization of the alloy. As cast state there are islands of α phase and needle-like matrix of β phase along the grain boundaries are observed into the microstructure. The study also reveals that the alloy attained almost fully recrystallized state after annealing at 300ºC for 60 minutes.

Keywords: Bell metal, annealing, sound level, reflectance, microstructure.

## 1. Introduction

Bell metal is a copper-based alloy which has a higher percentage of tin than regular bronzes. The copper and tin composition of this alloy can be in a ratio of 4:1 approximately [1]. This fundamental incorporation attributes to the long-lasting durability with resilient rigidity and higher resistance against rusting which makes it tougher than either of the constituents of copper and tin. Copper alloys with high tin contents have many industrial applications such as fabricating gears, pump impellers, propellers, bushings, bearings, piston rings, valve components, steam fittings and so on where the metal is subjected to heavy load, high friction and sliding as well as excessive temperature [2-4]. Abundant amount of heat generates during friction and collision and so high temperature behavior holds a significant deal of importance for this alloy. It is also more often used in making different forge tools, weapons, cannons, war industry components etc. along with in different religious mores and rituals [2]. There are some industries, which make vessels and other utensils utilizing this special alloy. It is also used in different decorative purposes and making statues, ornaments etc. So optical characteristics also holds a substantial importance to investigate the changes associated with its thermo physical properties. However, bell metal is also renowned for its excellent resonance when struck. The higher weight percentage of tin constituents offers the alloy to be more rigid and tough which is responsible for the enhanced resonance [5]. This is why this alloy is used in making musical instruments and bells.

A material can be thermally affected through various means for instance rapid friction, sliding, forging, grinding, machining, welding etc. Moreover, high impact collision with other objects, rapid heating or cooling, disastrous accidents, arson, firebombing can also be responsible for thermal influence. Different materials respond differently when they are subjected to high temperature according to their strength and high temperature sustainability. For example, thermal conductivity of iron attenuates significantly with increasing temperature whereas aluminum has less high temperature effect on its thermal conductivity. Annealing is a process, which implies quenching the supersaturated metastable solid solution from higher temperature, then again reheating to an intermediate temperature to permit the excess solute to form a secondary phase with precipitating out. This hard second phase particles offers obstruction in motion of dislocations as well as it makes difficult to shear so that large shear stress needed to move dislocation toward precipitate.

The objective of the present study is to investigate on the above-mentioned issues related to the effect of temperature in physical properties of bell metal, which is hardly found in any literatures. Therefore, in this paper the physical manners of thermally affected bell

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metal associated with material's hardness and optical characteristics are revealed through their evolution of thermal history. Acoustic experiment is also carried out to see whether its sound property improves by annealing or not. Microstructural analysis of the experimental alloy can unfold the thermal influence with a logical interpretation and helps to establish manufacturing techniques.

## 2. Experimental Procedure

The bell metal samples were fabricated via continuous casting and melting process. Commercially pure Copper and Tin were taken for the alloy preparation. Melting process was carried out using a clay-graphite crucible inside a natural gas fired pit furnace under suitable flux cover. For alloy production, copper and tin were fused in the clay-graphite crucible where the terminal temperature of the melt was tried to be maintained at 1300±15°C. A steel mold with the size of 20× 150 × 150 in millimeter was preheated at 200°C. Water-clay mixture was used inside the steel mold as a coating layer thereafter the molten cast was poured into that preheated steel mold. To determine the chemical composition, the alloy sample was investigated through Optical Emission Spectroscopy method. The chemical compositions of the experimental bell metal alloy are given in Table 1.

To remove the oxide layer from the surface, the samples were fabricated through machining process and then different samples of 15 x 15 x 4 $mm^3$ size were prepared. After that, they were annealed at different temperatures for different time ranges. They were sanded mechanically with emery papers of 300, 600, 800 and 1200 grits. A Micro Vickers Hardness Tester machine was used to measure the hardness of the annealed samples. Several indentations from different locations of the sample surfaces were taken where the knoop indenter was allowed to apply 1Kg load with the time duration of 10 seconds.

A metal plate was obtained with the size of 90 x 60 x 10 $mm^3$ from the cast through machining process. It was also annealed at different temperatures for one hour. An experimental set up of wooden platform was used to measure the sound intensity level of the bell metal plate while the plate was struck with a striker. The differently annealed metal plate was hanged through a pair of chain and a bearing ball of stainless steel was used to apply the force on the metal plate to create sound. The system was ensured to apply identical force each time. An industrially usable digital sound level meter of model "Digital Sound Level Meter AS804" was used to measure the sound intensity level. To get accurate result a Digital Sound Calibrator was used to calibrate the digital sound level meter. The reflectance test was carried out with the UV-VIS-NIR Spectrometer. The annealed samples were machined to smooth powder form to perform this test.

The optical metallography of the samples was characterized through a conventional optical microscope named OPTIKA. To create a scratch free polished surface, a wet polishing machine with velvet-clothed wheel was used with additional assistance of alumina powder where Acetone was also employed as a cleaning agent. Ammonium Hydroxide with 3% Hydrogen peroxide were taken in the ratio of 1:1 as the metallographic etchant. The alloy samples were then cleansed and allowed to be dried to study carefully in optical microscope at various magnifications. For characterizing the individual phases in microstructures a Scanning Electron Microscope was used. The annealed samples of 300°C were analyzed through the SEM using the identical etchant solution used in characterizing the microstructure.

**Table 1** Chemical Composition of the experimental alloy (wt%).

| Sn | Ni | Al |
|---|---|---|
| 24.935 | 0.019 | 0.005 |

| Si | Cr | Mn | Cu |
|---|---|---|---|
| 0.001 | 0.004 | 0.001 | Bal |

## 3. Results and Discussions

### 3.1.1 Isochronal Annealing

The result of isochronal annealing of the cast alloy at various temperatures for 60 minutes is displayed in Fig. 1. From the figure, it is evident that the experimental alloy has shown continuous softening at increasing annealing temperatures. The minimum hardness was observed at 300ºC. After 300ºC, the hardness value increased slightly and further dropped up to 500ºC. It is known that copper-tin alloys with high tin contents show high value of hardness, and the value of hardness increases with increment in tin percentage in the alloy [6]. Since bell metal is a copper alloy with high tin content, it shows a high hardness at room temperature. A similar case is also seen in the hardness curve as well. The experimental alloy shows highest hardness value at room temperature. However, that value starts to decrease gradually with increase in isochronal annealing temperature. Significant alleviation of hardness occurred at 300ºC, which could be due to the effect of recrystallization of the alloy at this temperature [7]. Copper alloys with tin content are known to recrystallize with increase in annealing temperature, and the alloy reaches minimum hardness with complete recrystallization [8]. After 300ºC, it is seen that the hardness of the alloy slightly elevated. The main cause behind this could be the anneal hardening of the alloy at this temperature [9]. Further increase in annealing temperature decreased the overall hardness of the alloy, and the least hardness value was found at 500ºC due to over-annealing conditions.

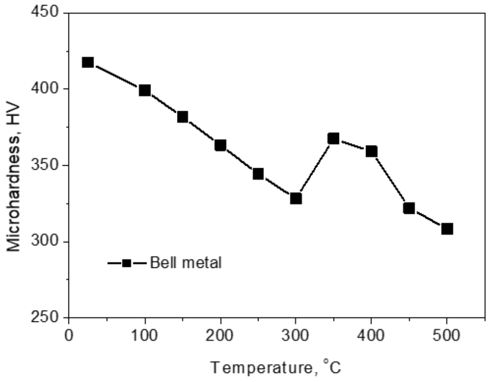



**Fig.1** Isochronal annealing curve of the bell metal alloy annealed for 1 hour

3.1.2 Isothermal Annealing

The variation in hardness of the experimental bell metal alloy when it was isothermally annealed at 250ºC, 300ºC and 350ºC respectively for different time periods are shown in Fig. 2. The annealing time ranges up to 4 hours. In case of annealing temperatures 250ºC and 300ºC, the hardness drops down steadily with increasing annealing time. But after 60 minutes the hardness at 250ºC reaches a constant value and maintains that value up to 240 minutes. The hardness at 300ºC follows a similar trend. It is clear from the experimental results that increase in annealing time alleviated the hardness of the alloy [10]. At 350ºC, the experimental alloy reaches maximum hardness within 30 minutes of isothermal annealing. The probable cause of this could be the effect of anneal hardening of the alloy at early stages of isothermal annealing at that temperature. After 60 minutes, the hardness value drops continuously up to 240 minutes. One of the major causes behind decrease in hardness is the recrystallization and grain growth of the alloy during the annealing process. It is known that recrystallization is a temperature dependent as well as time dependent phenomena [11]. It is probable that the continuous softening of the alloy with increasing annealing time occurred due to recrystallization of the alloy. After 240 minutes of annealing, the experimental alloy shows least hardness value at 350ºC.

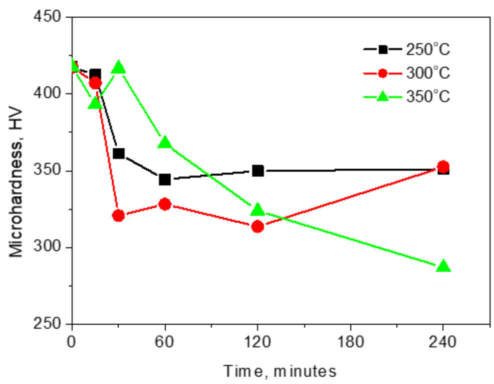



**Fig. 2** Isothermal annealing curve of the alloy

3.2 Sound Intensity Characteristics

Bell metal has unique resonance due to the combination of low internal damping and low internal sound velocity. Figure 3 reveals that, while striking the bell metal plate with the striker, maintaining identical force for each case, the as cast experimental alloy created sound intensity of 105 dB. After annealing at the temperature of 100ºC its sound intensity slightly attenuated and following that it showed the least sound power of 102.5 dB at 200ºC. However after that, with the increase of annealing temperature it showed enhanced sound property creating 105 dB while annealed at 300ºC, thereupon it reached its maximum intensity level of 107 dB at 400ºC. It can be said that it happened due to the initiating of grain growth followed by stress relieving, recovery and recrystallization. This new grain growth again tends to show their initial damping ability and resonance when struck. At annealing temperature of 500ºC, a sudden slight drop in sound intensity level is seen creating 103 dB at that temperature. It occurred because the alloy got farther recrystallized state at that elevated temperature. A whole new set of defect free grains are created through this further recrystallization [12]. The strained grains are replaced by new strain-free grains with low dislocation density. It can be said that the sound level did not decay significantly with annealing rather bell metal has ability to withstand with good acoustic characteristics even at elevated annealing temperatures. The quality of sound is improved due to the annealing effect [13]. The sound intensity curve of the alloy followed almost similar trend of hardness curve. It can be reasonably assumed that the variations in the hardness associated with the bell metal alloy as a result of annealing at different elevated temperatures, which also can be considered as an important factor influencing the acoustic performance [14]. Other terms influencing its sound property are the materials' internal damping, elasticity, density, free volume, intermolecular attraction etc. which have a temperature dependence phenomenon and they change with the variation of temperature [15]. This is why it is reasonable to find minimum hardness and least sound intensity at different temperatures.

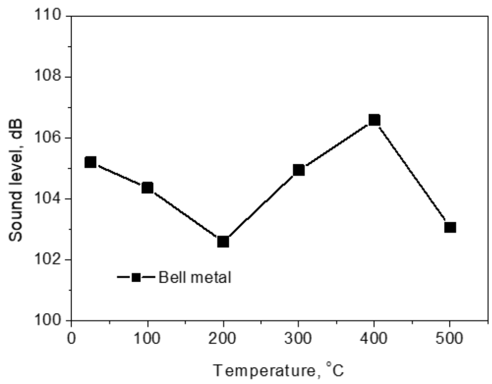



**Fig. 3** Sound intensity level of the bell metal alloy with annealing temperatures

3.3 Optical Properties

Spectral reflectance curve is a plot of reflectance of the cast alloy as a function of wavelength. The variation of reflectance of the bell metal alloy with wavelength at room temperature and various annealing temperatures are displayed in Fig. 4. The wavelength in this study ranges from UV to the Infrared region. At each annealing temperature the spectral reflectance curves followed that of an ideal copper-tin alloy, with the peak reflectance value at a given wavelength being different at different temperatures. From the graph it is seen that the reflectance of the alloy increased with the increase in wavelength, with the lowest value being at UV and the highest at Infrared region. These phenomena occurred at each annealing temperature. The reflective index became smaller with the increase in wavelength, which lead to increase in the value of reflectance of the alloy. From the spectral reflectance curve, it is seen that the reflectance value of the experimental alloy increased initially and then decreased with annealing temperature. The initial increase in reflectance can be ascribed to the generation of oxide films on the exterior of the alloy resulting in increased reflectance value [16]. As the annealing temperature augmented the absorptance value of the alloy increased as well, which subsequently lead to the decrease in the percent reflectance of the alloy [17]. Moreover, increase in annealing temperature is known to cause grain growth in bell metal alloy. Reflectance of an alloy is associated with its grain structure, as increase in grain size causes decrease in overall reflectance value [18]. From the Optical Micrograph of the alloy annealed at 300ºC for an hour (Fig. 5.b) it is seen that the alloy achieved recrystallization at that temperature and a new set of grains was formed. From the reflectance curve it is evident that the optical properties of this new set of grains is similar to that of the original, since reflectance is dependent on the intrinsic properties of the material surface [19]. Therefore, the variation in percent reflectance can be attributed to the overall grain structure of the alloy and it changes with the annealing temperature.

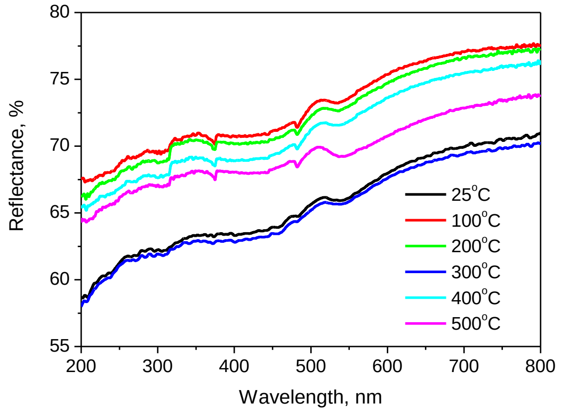
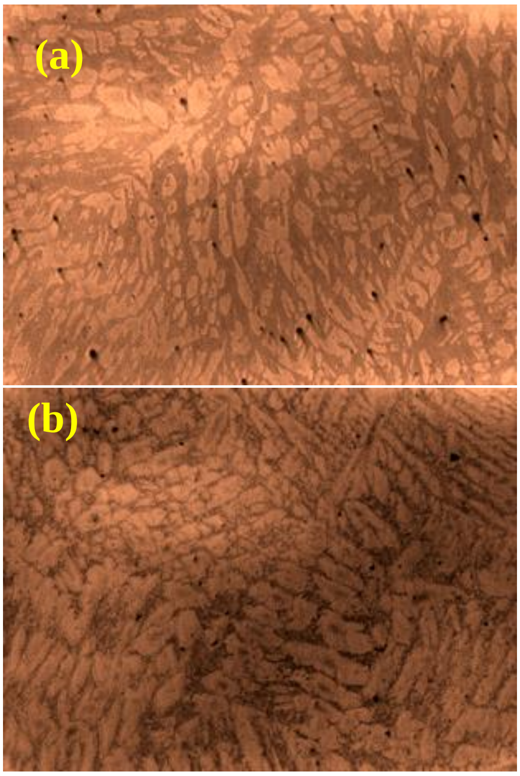



**Fig. 4** Percent reflectance of the bell metal alloy with incident wavelength for different temperatures

3.4 Optical Micrograph

The physical properties of an alloy are significantly influenced by its microstructure. The optical micrographs of the cast alloy at room temperature and after annealing at 300ºC and 500ºC for one hour are shown in the Fig. 5. From the micrographs, it is seen that there are visible changes in the microstructure of the experimental alloy at different annealing temperatures. In all temperatures, the cast alloy showed relatively coarse non-uniform grain structure. From the micrograph of the experimental alloy at room temperature, it is seen that there are islands of α phase and needle-like matrix of β phase along the grain boundaries (Fig. 5.a). This is the typical grain structure of copper alloys with high tin content [20]. The needle-like β phase is formed due to the peritectic reaction occurred during the solidification of the alloy. From the optical micrograph of the experimental alloy after being annealed at 300ºC (Fig. 5.b), it is seen that the grains are almost completely recrystallized. There is a further recrystallization of the microstructure of the alloy after annealing at 500ºC (Fig. 5.c). It is evident from the hardness curve due to Isochronal Annealing (Fig. 1) and microstructure of experimental alloy that the recrystallization of the grain structure is the reason behind the continuous decrease in hardness of the cast alloy [21]. Therefore, it can be stated that the hardness of the alloy is correlated with the microstructure and it decreased as the amount of recrystallized grain structure increased.



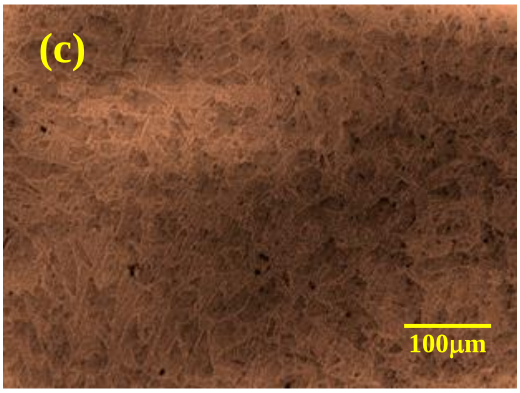



**Fig. 5** Optical micrograph of the experimental alloy at a) RT, b) 300°C and c) 500°C

3.5 SEM Micrograph

The SEM micrograph and the EDS spectrum of the sample analysis of the experimental alloy, after being annealed at 300ºC for 1 hour, are shown in Fig. 6. The grains of the alloy are visible in the SEM micrograph and they appear to be almost fully recrystallized. This observation directly corresponds to the drastic drop in hardness when the alloy was annealed at 300ºC for 1 hour. The weight percentages of elements observed by the EDX analysis of the SEM are 74.08% Cu and 25.92% Sn.

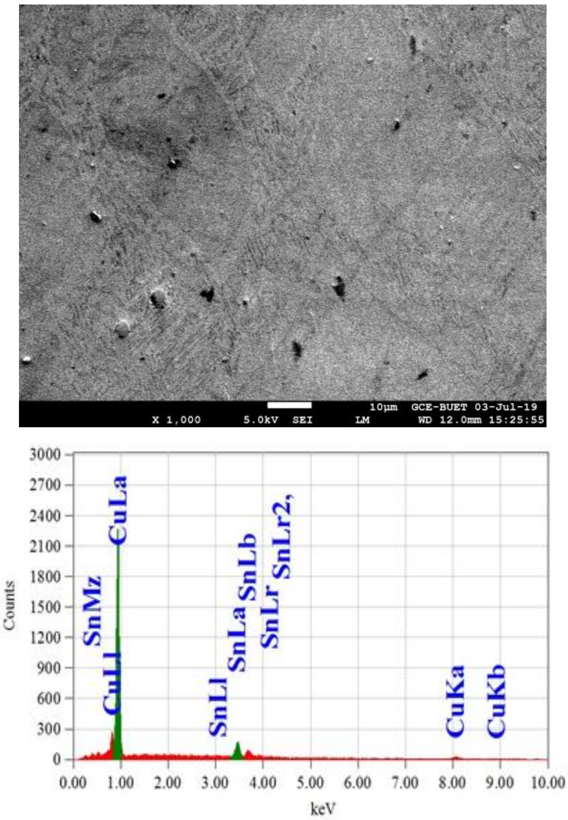



**Fig. 6** SEM micrograph of the experimental alloy annealed at 300ºC for one hour

## 4. Conclusions

Bell metal showed continuous softening when it is annealed for different time ranges. While annealing isochronally, after the recrystallization at 300°C it started increase in hardness for short amount of time due to the formation of new sets of grains but again showed softening at more elevated temperatures. The isothermal hardness curves of the experimental alloy also showed attenuation in hardness with time. The sound intensity with temperature curve reveals that the sound quality improves with annealing hence bell metal has ability to withstand its unique resonance although it is thermally affected at elevated temperatures. It can be said that the sound characteristic curve showed almost similar trend of hardness curve of the alloy at different temperatures. The optical reflectance behavior of the alloy were typical of bell metals containing high tin content which was increased at first due to oxide film formation and then the value was seen to be decreasing with increasing annealing temperature. The microstructural analysis provided insight to the correlation between grain structure and hardness of the alloy as the hardness dropped with increasing amount recrystallized grains.

## 5. Acknowledgement

This effort is aided and assisted by the Department of Mechanical Engineering of Bangladesh University of Engineering and Technology, Dhaka, Bangladesh. The authors wish to thank the Directorate of Advisory, Extension and Research Services and the Department of Glass and Ceramics Engineering of Bangladesh University of Engineering and Technology, Dhaka, Bangladesh for allowing the use of laboratory facilities.

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