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MEASUREMENT OF THE VARIATION OF MECHANICAL PROPERTIES WITH AGING TEMPERATURES FOR SAND CAST Cu-5Ni-5Sn ALLOY

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Abstract

The purpose of the investigation is to study the mechanical properties of copper-nickel-tin spinodal alloy and its effect with respect to aging temperatures using sand casting process without cold work. An alloy of Cu-5Ni-5Sn was melted in a crucible furnace under argon atmosphere and cast into sand moulds. Homogenized and solution treated specimens were aged at 300 °C, 350 °C, and 400 °C for different period of time. Specimens were tested for its mechanical properties such as micro-hardness, yield stress, tensile stress and percent elongation. It was found that the peak hardness increases with aging temperatures up to 400 °C. Yield and tensile stresses are proportional to hardness of the alloy. Percent elongation decreases with increase in hardness and stresses. Incremental yield stress increases with increase in aging temperature of the alloy. Also, the yield stress of the alloy is found to increase two times than that of traditional cast bronze alloys.

Keywords: Cu-Ni-Sn alloy, Modulated structure, Ordered structure, Hardness, Heat treatment, Sand casting.

1. Introduction

It is well known that the change in microstructure of the alloy has significant effect on its properties. The modulated microstructure structure produced by the spinodal decomposition and subsequent formation of ordered structures such as DO_{22} and LI_2 during aging treatment improves the strength of the spinodally decomposable copper-nickel-tin *(*Cu-Ni-Sn*)* alloys [1]. This alloy can be used as an alternative material for Cu-Be alloys having high strength by precipitation hardening [2, 3]. Various parameters such as alloy compositions, condition of the

Nomenclatures

DO_{22}	Ordered Structure
$L1_2$	Ordered Structure
$\gamma(DO_3)$	Inter Granular Precipitates
γ	Discontinuous Precipitates

alloy (wrought or cast), aging temperature and aging time are responsible for the strengthening effect in *(*Cu-Ni-Sn*)* alloys. Aging temperature is one of the critical parameter to obtain the maximum strength of the alloy in Cu-Ni-Sn system. It has been reported that there exists a critical temperature of aging *(*$T_R \sim 457$ °C*)* above which a discontinuous mode of decomposition takes place which reduces the strength of the alloy and aging below this temperature, the supersaturated solid solution decomposes spinodally forming a modulated structure [2].

Further, it is possible to obtain various combination of microstructures during the aging process by varying aging temperatures such as: (i) grain boundary + inter granular γ (DO_3) precipitates (ii) discontinuous γ precipitates (iii) spinodal (modulated structure) + ordered (DO_{22}) structure + discontinuous γ precipitates and (iv) spinodal + DO_{22} ordering + ($L1_2$ *and* DO_{22} ordering) [5]. Zhao et al. have reported that at higher temperatures that are above 500 °C, the microstructures of (i) and (ii) are seen and below which the microstructure of (iii) and (iv) are existed for the alloy composition of *Cu*-15*Ni*-8*Sn* [4].

Several studies were conducted to assess the mechanical properties of the alloy as follows. First the phenomenon of forming modulated microstructure known as 'spinodal decomposition' has been observed in Cu-Ni-Sn alloys [4-6]. A number of studies have shown that a substantial increase in yield stress in Cu-Ni-Sn spinodal alloys of various compositions [5, 7-9]. The investigation of the incremental increase in the yield stress between as-quenched and spinodally decomposed Cu-10Ni-6Sn alloys is essentially independent of temperature of the specimen during tensile testing [1]. It has been observed that the yield stress increases after an incubation period for Cu-9Ni-2Sn alloy whereas no incubation period was observed for Cu-9Ni-5Sn alloy, indicating the effect of *Sn* on the process of spinodal decomposition [2]. Also it is noted that the mechanical strength of rapidly solidified Cu-Ni-Sn alloys aged for spinodal hardening is superior to that of cast/homogenized alloys [10]. A decrease in the Ni content to 2 *wt.%* would change the mode of phase transformation from spinodal decomposition to precipitation hardening in Cu-Ni-Sn alloys [11]. Studies have also been conducted to investigate the effect of solutionizing and aging temperatures on the microstructure of these alloys [12-13].

In summary, the above studies were conducted to assess the mechanical properties of few alloy compositions by varying aging temperatures and time, mostly in wrought condition (cold worked) of the Cu-Ni-Sn alloy systems. But no studies were reported in cast condition using thermal treatments such as homogenization, solution and aging. As a general rule the specimen prepared in cold worked condition will have much higher strength than that of cast condition (without cold working) because of the refinement of grain size (microstructure) by re-crystallization during the rolling process, whereas in cast condition, the grain size/microstructure remains same. Utilization of these spinodal bronzes in cast form also requires a data base of mechanical properties and their relationship to aging temperatures of the alloy, since in most of the engineering applications cast form of the material is preferable.

Therefore, the present study is carried out by using sand cast samples of Cu-5Ni-5Sn alloy by varying aging temperatures between 300 °C and 400 °C at fixed alloy composition to assess the effect of aging temperature on mechanical properties such as hardness, yield stress, tensile stress and % elongation of the spinodal decomposition alloy in order to find out the optimum aging temperature at which the maximum strength is obtained.

2. Experimental Procedure

The required alloy elements were procured in the commercial market in pure form as shown in Fig. 1. The wooden pattern with built in riser and sand moulds were prepared to make rods of size Ø 16 mm × 150 mm length. The alloying elements were melted in an electric arc furnace with an inert atmosphere. Argon was supplied into the furnace during the melting process. The molten metal of the alloy (Cu-5Ni-5Sn) was poured in to the sand moulds. After the solidification process, moulds are broken and cast rods were taken out from the mould. Then the final cast rods were inspected and tested for its size and composition (Fig. 2).

The cast rods were homogenized and solution heat treated at 820 °C. Further, the solution heat treated rods were aged for 2 to 5 hours at 300 °C, 350 °C and 400 °C. Inert atmosphere was used during the entire heat treatment processes in order to avoid oxidation of the alloy. The microscopic examinations were conducted using Carl-Zeiss metallurgical microscope (Make: Carl-Zeiss; Model: Axiovert 25CA).

The micro-hardness tester (Make: Mitutoyo; Model: HM-210A) is used to find out the Vicker's hardness of the alloy at various heat treated conditions of the specimens as shown in Fig. 3. Number of reading was taken on each specimen and average values were calculated.

Tensile properties were measured using (Make: Tinus Olsen; Model: H25K-S UTM) computerized universal testing machine (Fig. 4). ASTM standard (E 8M - 04) is followed to prepare specimens for the above tests. The dimensions of the tensile test specimens are shown in Fig. 5.

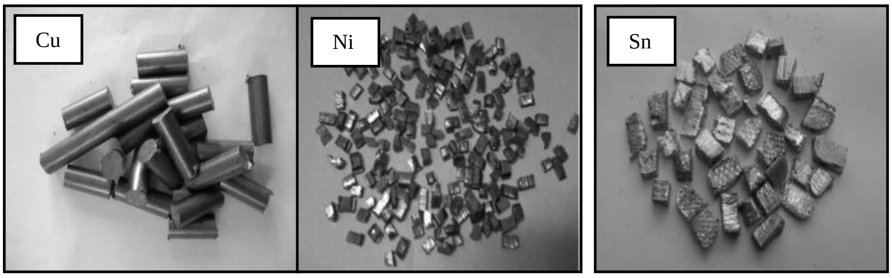

Fig. 1. Alloy elements of copper, nickel and tin.

Fig. 2. Cast rods of Cu-5Ni-5Sn alloy.

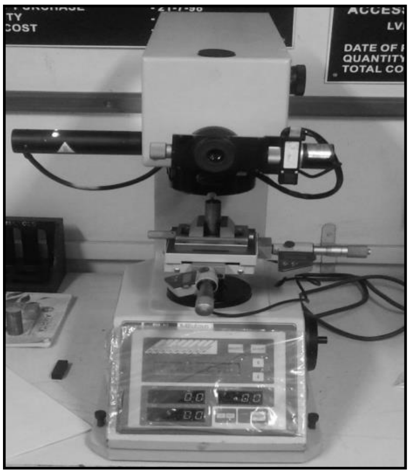

Fig. 3. Mitutoyo make micro-hardness tester.

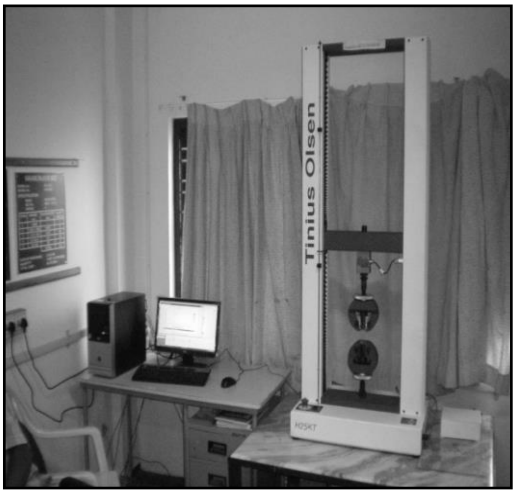

Fig. 4. Tinus Olsen make universal testing machine.

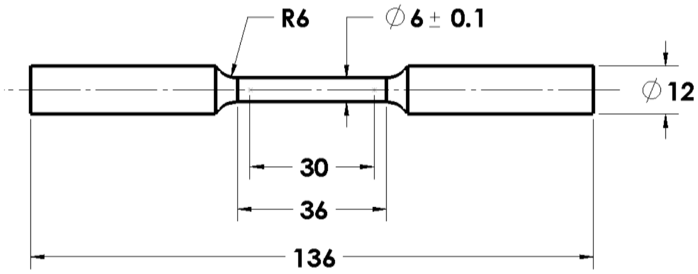

Fig. 5. Dimensions of the tensile test specimen.

3. Results and Discussion

Figure 6 shows the as-cast microstructure of Cu-5Ni-5Sn alloy with dendrite structure which is due to rapid solidification of the alloy during casting process. Figure 7 shows the micro-structure of 4 hour aged specimen at 400 °C. Here, the original as-cast microstructure was modified due to homogenization, solution treatment and aging process. Spinodal decomposition and ordering reactions takes place during the aging process [16]. Since, the modulated and the ordered structures are very fine which cannot be resolved by the optical microscopy [14]. The maximum hardness is obtained at this stage. Figure 8 shows the microstructure of 5 hour aged specimen, wherein precipitates are visible along the grain boundaries. It has been reported that the grain boundary precipitates are equilibrium α and γ *(DO_3)* phases [5]. Further aging will increase the amount of precipitate formation and reduce the hardness of the alloy [3, 14].

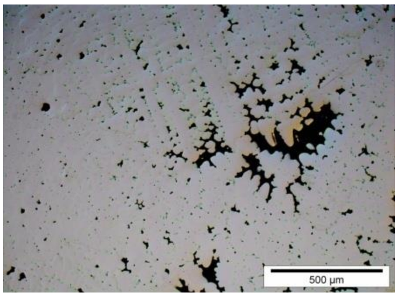

Fig. 6. As-cast microstructure of Cu-5Ni-5Sn alloy.

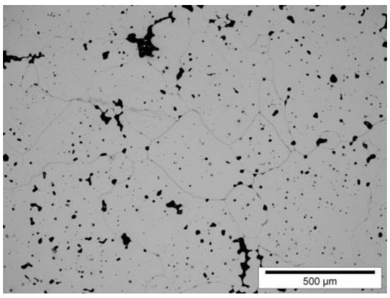

Fig. 7. The microstructure of 4 hours aged at 400 °C of Cu-5Ni-5Sn alloy.

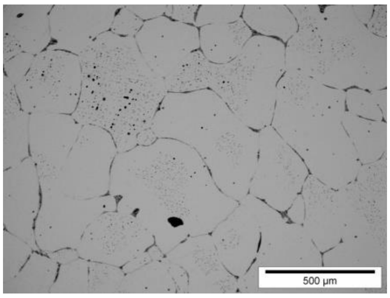

Fig. 8. The microstructure of 5 hours aged at 400 °C of Cu-5Ni-5Sn alloy.

Figure 9 shows the variation in the hardness of the alloy at different aging temperatures as a function of aging time. The behaviour observed is same for all the aging temperatures. The hardness increases with aging time up to a maximum value and then decreases. The variation in the hardness is attributed to the change in microstructure of the specimen during the aging process. The modulated structure due to spinodal decomposition and the formation of ordered structures during aging process *(DO_{22}* and *$L1_2$)* increases the hardness to a maximum value and the subsequent formation of grain boundary precipitates reduces the hardness during prolonged aging [2, 14]. The trend observed in this study is in agreement with that of Zhang et al. and Deyong et al. [10, 14]. Therefore, it can be concluded that the hardness of the alloy is dependent on the aging time. It is also to be noted from the figure that the peak hardness obtained at 4 hours for all aging temperatures. This shows that the increase in aging temperature does not affect the peak aging time for this alloy compositions.

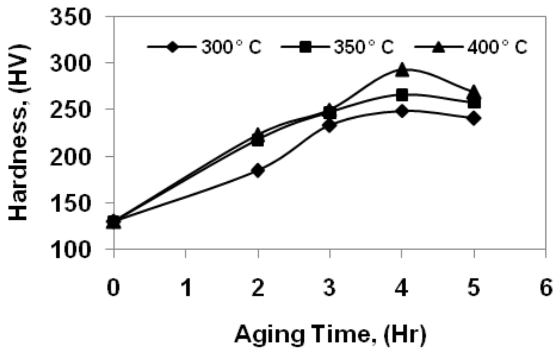

Fig. 9. Variation of hardness of Cu-5Ni-5Sn alloy with aging temperatures and time.

Further, Goudeau et al. have reported that the strength of the alloy is mainly due to ordering reactions [15]. But it is clearly explained by Zhao and Notis that the combination of modulated structure, DO_{22} and $L1_2$ ordering produces maximum hardness/strength in the alloy [4], which is purely depends on: (i) alloy composition (ii) aging temperature and (iii) aging time. Therefore it is required to find out the optimum temperature and time for each alloy compositions.

Figure 10 indicates the relation between peak hardness and aging temperatures. The maximum hardness obtained for this alloy composition is at 400 °C, which may have produced maximum modulated and ordered structures. Since, we have not aged the specimen beyond 400 °C; we cannot conclude that this may be the maximum aging temperature to produce peak hardness. Hence, further study is required to conclude the optimum aging temperature. As stated earlier, a study may be conducted up to 457 °C (critical temperature) aging temperature. It is also to be noted that if the aging temperature and time used are above or below the optimum value, then the ordering reactions will be partially responsible for the hardening of the alloy [4]. Therefore, spinodal decomposition produces strength to the alloy at the beginning of the aging process; latter ordering processes are highly responsible for the same, which depends on aging temperature and time.

Figure11 shows the variation of hardness with % elongation as a function of aging time for all the aging temperatures. It is observed from the figure that the % elongation varies inversely to the hardness of the alloy.

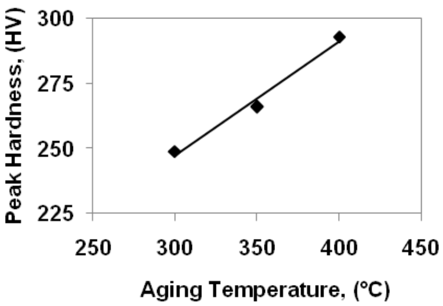

Fig. 10. The variation of peak hardness of Cu-5Ni-5Sn alloy with aging temperature.

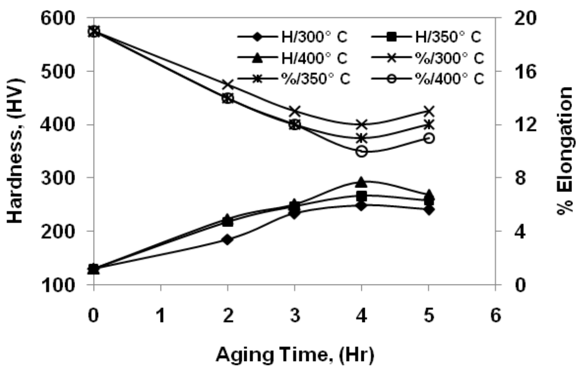

Fig. 11. Variation of hardness and % elongation of Cu-5Ni-5Sn alloy with aging time.

Figure 12 shows the relationship between yield stress and hardness values obtained for various aging temperatures as a function of aging time. It is seen from the figure that the yield stress proportionally increases with hardness of the alloy. So, we may conclude that the yield stress is proportional to hardness of the alloy.

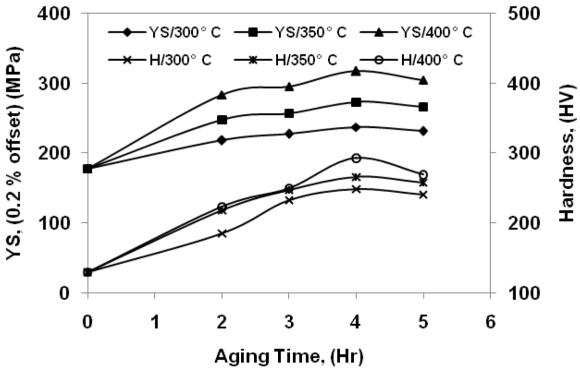

Fig. 12. Variation of yield stress and hardness of Cu-5Ni-5Sn alloy with aging temperature and time.

Figure 13 shows the relationship between yield stress (0.2% offset), tensile stress and % elongation of the alloy with aging time. It can be seen that in all the aging temperatures the yield and tensile stresses of the alloy increases with aging time up to 4 hours and then started to decrease. The maximum value of yield stress obtained when the alloy is aged at 400 °C for all the aging time. This shows that within the test paramerters selected, the aging temperature of 400 °C is an optimum temperature for producing peak strength due to maximum spinodal decomposition and ordering range in this alloy composition. The result is in consistent with Schwartz and Plews for the alloy composition of *Cu*-9 *wt.% Ni*-6 *wt.% Sn* alloy (Refer to Figures 3-5) [5]. The increase in strength with aging time may be due to work-hardening effect during tensile testing. Schwartz and Plews have reported that the magnitude of this work-hardening effect increases slowly with time at a fixed aging temperature and also increases slowly with aging temperature [5].

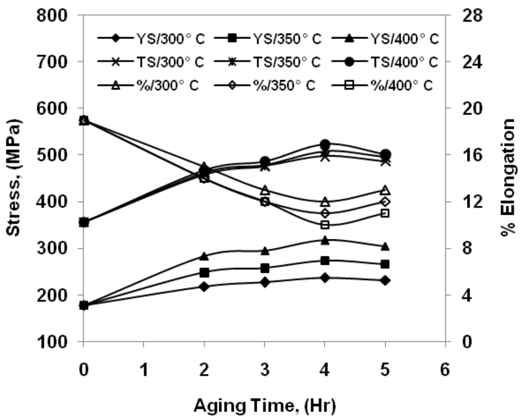

Fig. 13. Variation of stresses (YS & TS) and % elongation with aging time.

Figure 14 shows the incremental yield stress with aging temperature and time of the alloy. The increase in the yield stress which accompanies spinodal decomposition is one of the most important properties of the spinodal alloys. It has been observed from the experimental results that the aging temperature has significant effect on incremental yield stress (ΔYS = YS (aged) – YS (as-quenched)) as compared to aging time. Figure 15 shows the data extracted from the plot (Fig. 3) of Kato and Schwartz for 300K (27 °C) [1]. The trend observed in this study is also in agreement with that of Kato and Schwartz [1]. Hence, it may be concluded that the increase in aging temperature increases, incremental yield stress of the alloy. It is also to be noted from Figs. 14 and 15 that the magnitude of the incremental yield stress is significantly high in the case of Kato and Schwartz as compared to this study and which may be due to variation in alloy composition (Kato and Schwartz : Cu-10Ni-6Sn; This study: Cu-5Ni-5Sn and cold work. In this study only cast alloy was used without cold work.

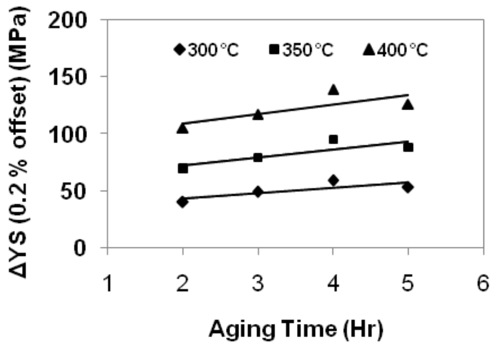

Fig. 14. Variation of incremental yield stress with aging temperature and time.

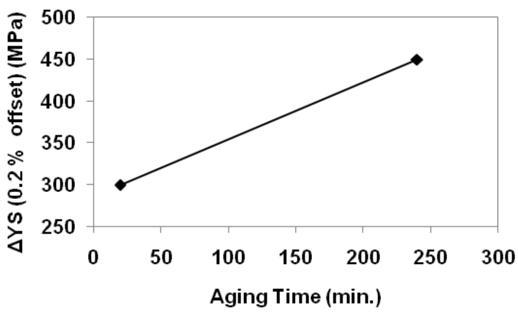

Fig. 15. Variation of yield stress with aging time, at 300 K tensile test temperature (Data of Kato and Schwartz [1]).

It is known that most of the bronze alloys are not heat treatable except copper-berilium alloys and are used either in as such cast or cold worked condition to enhance their mechanical properties. The heat treatable copper-berillium alloys provide high strength due to cold work and precipitation hardening effect and are suffers from high cost and health hazards. To alternate this Cu-Be alloys, the heat treatable spinodal bronze alloys are found suitable to replace Cu-Be and provide strength equivalent to Cu-Be alloys with less cost and hazards free. All the previous studies on spinodal bronze alloys mainly focused on wrought condition and some are using powder metallurgy technique. The component produced using powder metallury technique is very costly and also it has component design limitations. The alloy in wrought condition is also not used in all the cases.

To overcome these situations it is necessary to develop and use alloys in cast condition. Hence, to know the strength of the spinodal bronze alloys in cast condition, this study is conducted and compared with that of cold worked spinodal bronze alloys [1-2, 5] as well as some of the traditional non-heat treatable cast bronze alloys as shown in the Table 1 [17]. It is found that the yield stress of the cast spinodal alloy (this study) approximately 2 times higher than that of traditional cast bronze alloys and the cold worked spinodal bronze alloys is more than two times than that of cast spinodal bronze alloy. Hence, we may conclude from the result that the application requires high strength to weight ratio in cast condition in place of traditional cast bronze, we may use cast spinodal alloys with suitable aging temperature and time.

Table 1. Comparison of yield stress of cast spinodal bronze alloy with cold worked spinodal bronze alloys and some traditional cast bronze alloys.

Alloy	Yield Stress (MPa)
Conventional non-heat treatable, cast-bronze alloys	138 - 152
Spinodal, cast-bronze alloy (This study)	317
Spinodal, cold worked bronze alloys	580 - 700

4. Conclusions

The important findings in the present study can be summarized as follows.

- Hardness increases with aging time to a maximum value and then decreases. The increase in hardness is due to the formation of modulated and ordered structures. The decrease in hardness is due to the formation of grain boundary precipitates.
- Peak hardness increases with increase in aging temperatures.
- Percent elongation decreases with increase in hardness, yield and tensile stresses of the alloy.
- Yield stress is function of hardness of the alloy.
- The aging temperature has significant contribution to produce ordered structures such as DO_{22} and $L1_{2,}$ which in turn produce maximum strength to the alloy.
- Incremental yield stress depends on aging temperature.
- Yield stress of the cast spinodal alloy (This study) is approximately two times higher than that of traditional bronze alloys and the cold worked spinodal bronze alloys are more than two times that of cast spinodal bronze alloy.

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