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INFLUENCE OF THERMOMECHANICAL TREATMENT ON THE PROPERTIES OF SINTERED Cu-4at%Au ALLOY

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ABSTRACT
Copper and copper alloy Cu-4at%Au were prepared by a powder metallurgical method. Sintered copper and copper alloy were subjected to the same thermomechanical treatment (include cold rolling with deformation degree of 60 %).The copper and copper alloy in the cold-rolled state was isochronally annealed up to the recrystallization temperature during which the hardness, micro hardness and electrical conductivity were measured. This investigation shows that the values of hardness, microhardness and electrical conductivity of cold deformed Cu-4at%Au alloy increase after annealing in the temperature range of 60- 320 ^{0}C, due to anneal hardening effect.
Keywords: sintered copper-gold alloy, anneal hardening effect, thermomechanical treatment

1. INTRODUCTION
Copper has excellent conductivity, but has poor resistance to softening and low strength at moderate temperatures. This presents a considerable problem to engineers and designers of electrical equipment. The last few years have seen a major effort devoted to the exploration of copper based alloys in the search for improvements in properties such as strength, conductivity, and stress retention at high temperatures [1-4]. Copper is conventionally hardened by solution and/or precipitation hardening and dispersion hardening. One of the mechanisms employed to improve the mechanical properties of single-phase copper alloys is anneal hardening whereby, considerable strengthening is attained when alloys in cold rolled state are annealed at 150-300 ^{0}C. This effect was investigated mainly on cast copper base alloys [5, 6].
Our preliminary investigations on I/M and P/M copper alloys shows anneal hardening effect in the temperature range of 150-300 ^{0}C, when hardness and strength increase with increasing substitutional solute concentration [7-9]. The amount of strengthening increases with increasing degree of prior cold work. DTA-analysis showed the exothermic heat effect in the temperature range, where the anneal hardening effect is observed [10]. No work has been done on the anneal hardening effect in sintered copper alloys except our research [11-19].
This paper presents part of our research relating to the anneal hardening effect in sintered Cu-4at%Au alloy. The aim of this study is to assess the influence of alloying with Au on the intensity of anneal hardening effect (strengthening) of sintered alloy after thermomechanical treatment.

2. EXPERIMENTAL
Specimens with dimension 12 mm wide, 30 mm long and 6 mm thick, were pressed employing a pressure of 350 MPa in a hydraulic press. The pressed compacts were sintered isothermally at 850 ^{0}C for 1 h, in a tube furnace under an atmosphere of hydrogen. After sintering, hardness, microhardness and electrical conductivity were measured on the specimens and then the prefinally cold rolling was carried out with different deformation degrees. After that the samples were solution annealed on 500

^{0}C during 45 minutes and quenched in ice water. The finally cold rolling with deformation degree of 60 % was performed. The cold rolled specimens were isochronally annealed at 30 minutes intervals in the temperature range 60-320^{0}C and the Vickers hardness, microhardness and electrical conductivity were measured.

3. RESULTS AND DISCUSSION

3.1. The influence of finally rolling on properties

Figure 1 shows the variation of hardness of copper and its alloy on degree of deformation during cold rolling. The hardness of the sintered samples increases with deformation degree due to strain hardening. Higher hardness values were obtained for alloys than for pure copper. Maximum value of hardness was about 133 HV for 60 % deformation *i.e.* maximum of work hardening was attained in the Cu-Au alloy.

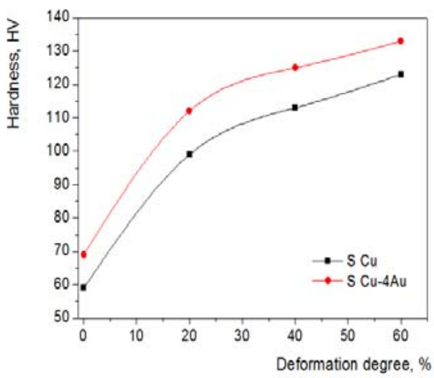

Figure 1. The change of hardness of cold rolled samples on deformation degree

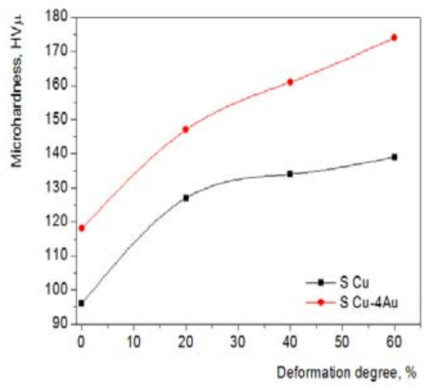

Figure 2. The change of electrical conductivity of cold rolled samples on deformation degree

Fig 2. shows the change of microhardness on deformation degree. Maximum value of micro hardness was about 170 HV for 60 % deformation *i.e.* maximum of work hardening was attained in the Cu-Au alloy than in pure copper.

3. 2 Anneal hardening effect in sintered cold rolled alloy

Fig. 3 shows the dependence of hardness on the annealing temperature for sintered and 60 % finally cold-rolled copper and Cu-Au alloy. Fig. 3 shows that in the temperature range of of 60-350 ^{0}C, the hardness values increase for the alloy. After annealing above 260 ^{0}C for cold deformed Cu samples hardness drops significantly as a result of recovery and recrystallization. However, peak hardness was reached after annealing Cu-Au alloy at the same temperature of about 260 ^{0}C. It can be seen that the recrystallisation temperature for Cu-Au alloy is above 350 ^{0}C, i.e. alloying element Au causes an increase in recrystallisation temperature in comparison with pure copper. Also it was noticed that anneal hardening effect appeared in the alloy as a result of solute gold segregation to dislocations, analogous to the formation of Cottrel atmospheres in interstitial solid solutions, which results in strengthening and hardness increases. The maximum increase is about 31 HV at 260 ^{0}C for Cu-Au alloy. These data demonstrate clearly that the investigated alloy system exhibits the anneal hardening effect [5-8, 14-19].

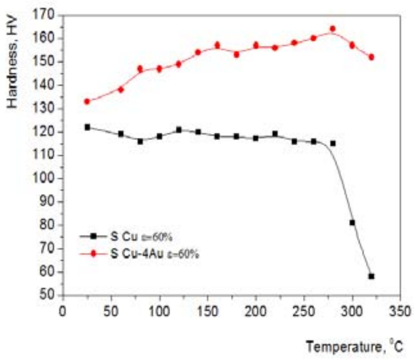

Figure 3. Hardness of cold rolled samples dependence on annealing temperature

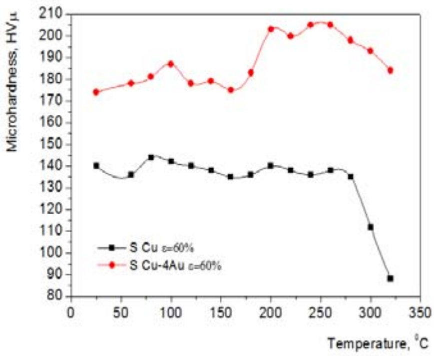

Figure 4. Microhardness of cold rolled samples dependence on annealing temperature

This effect was earlier investigated mainly in cast copper-base alloys containing Al, Ni, Au, Ga, Pa, Rh and Zn alloys [5,6]. The Fig. 4 shows the change of microhardness on annealing temperature. Also it can be seen that microhardeness increase due to anneal hardening effect in alloy, but for pure copper the values of microhardness drops significantly as a result of recovery and recrystallisation.

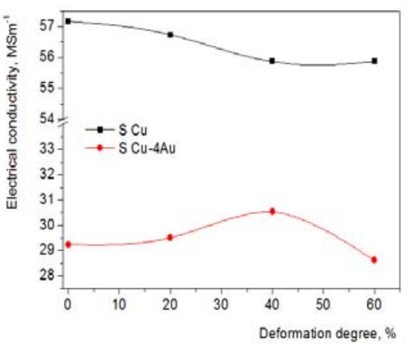

Figure 5. Dependence of electrical conductivity of cold rolled samples on deformation degree

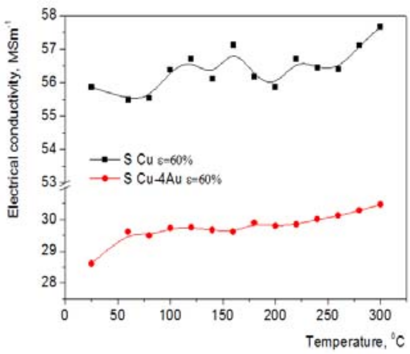

Figure 6. Electrical conductivity after thermomechanical treatment as function of annealing temperature (ε=60%)

Fig. 5 shows the dependence of electrical conductivity on deformation degree after cold rolling. It can be seen that electrical conductivity of pure copper is higher than for Cu-Au alloy. The electrical conductivity slowly increases during cold rolling because the porosity decreases. Fig. 6 shows the influence of the annealing temperature on the electrical conductivity. During annealing, the electrical conductivity of the deformed Cu-Au alloy slowly increased due to anneal hardening effect. It is because the solute element gold precipitates out from the supersaturated matrix. It can be seen that electrical conductivity both of copper and alloy increase with annealing temperature.

4. CONCLUSIONS

Based on experiments of the influence of thermomechanical treatment on the hardening mechanisms in Cu –Au alloy and comparisson with pure copper, the following conclusion are given:

1. The alloying element – gold was found was found to have a pronounced effect on the increase of the recrystallization temperature of the cold rolled sintered copper.
2. The anneal hardening effect has been observed in the cold rolled sintered copper-gold alloy, in the annealing temperature range of 60 –350 ^{0}C. The maximum hardness increase caused by anneal hardening effect was obtained with 60 % deformation degree, and it was about 31 HV on the temperture of 260 ^{0}C.
3. After annealing in temperature range of 60-350 ^{0}C, where anneal hardening effect was attained the, the electrical conductivity increase.

5. ACKNOWLEDGMENT

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