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INFLUENCE OF THERMOMECHANICAL TREATMENT ON THE ANNEAL HARDENING MECHANISM OF A CAST COPPER-SILVER ALLOY

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ABSTRACT
This paper reports results of investigation carried out on a cast copper-silver alloy containing 4at%Ag. The alloy and pure copper for the sake of comparison, were subjected to cold rolling with a final reduction of 20, 40 or 60%.
The cold rolled copper and copper-silver alloy samples were isochronally and isothermally annealed up to the recrystallization temperature. The hardness, strength and electrical conductivity were measured and DTA analyses performed.
Anneal hardening effect was observed in the alloy in the temperature range 160-300^{0}C, followed by an increase in the hardness and electrical conductivity. The amount of strengthening increases with increasing degree of prior cold work. The DTA analysis shows the exothermic character of this effect.
Keywords: Cast copper alloy, thermomechanical treatment, anneal hardening

1. INTRODUCTION
The strength properties of cold-worked substitional solid solutions are increased upon annealing up to the recrystallization temperature in several Cu based alloys systems. This strengthening effect is termed *anneal hardening* and is mainly applied to copper alloys when producing spring materials for electro-mechanical devices. Three general trends can be noted which characterize the phenomenon in all alloys systems. The amount of strengthening, which acompaines ageing, increase with increasing degree of prior cold work, the strengthening increase with increasing substituional element concentration, the strengthening due to ageing is decreasing function of the plastic strain at which the stength is measured [1, 2].
The mechanism responsible for this hardening effect is investigated in several copper based alloys after cold rolling and annealing at 150 to 300^{0}C. The effect has been investigated mainly in cast copper base alloys and some observations have been interpreted as indicating that atomic ordering is primarily responsible for the hardening effect [3]. On the other hand, in a recent detailed investigation of anneal hardening in Cu-Al alloys [1], it was concluded that solute segregation to dislocations gives rise to the predominant hardening mechanism. However, the mechanism responsible for this hardening effect is incompletely understood [2].

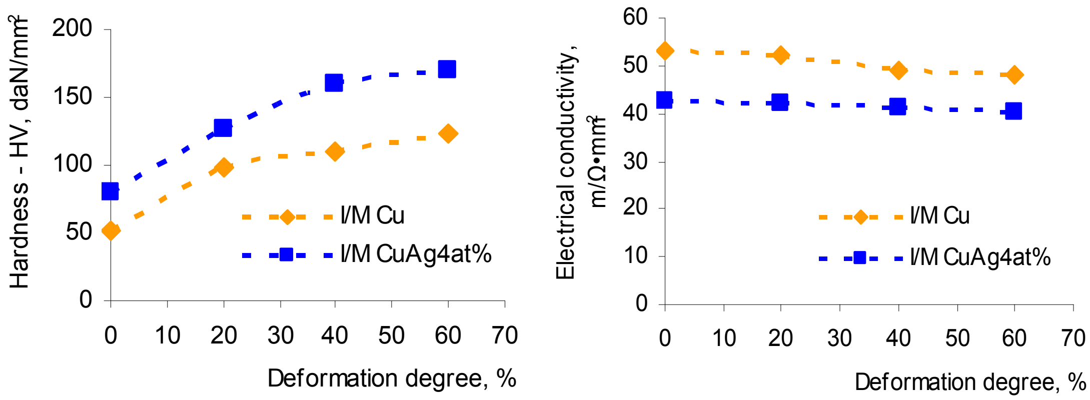
2. EXPERIMENTAL PROCEDURE
Investigated cast copper alloy containing 4at. % Ag of a solute, produced in laboratory for casting. For comparison, parallel specimens made from cast pure copper. Copper and copper alloy weighing aproximetly 2,6 kg, were melted in a furnace and cast in molds (sand-clay) with dimensions 65x25x180mm. The cast alloy was homogenized at 800 ^{0}C for 24 hours in a graphit and made samples with dimension 65x25x7 mm on the erozimat aparature. After that the cold rolling was carried out on the samples and obtained prefinaly dimensions 2,5; 3,3 and 5 mm. A heat treatment of 800 ^{0}C for 1 h followed by an ice-water quench was given. After that the copper and copper alloy

were subjected to cold rolling on the same dimensions of 2 mm, with different a final reduction of 20, 40 and 60 %.
The cold rolled copper and copper alloy samples were isochronally and isothermally annealed up to recrystallization temperature, during which the values of hardness, strength and electrical conductivity were measured and DTA-analysis was performed.

3. RESULTS AND DISCUSSION

3.1. Cold rolled cast samples

The hardness (Fig.1a) and microhardness (Fig. 5) of the samples during cold rolling increase with deformation degree due to deformation strengthening. Some higher hardness values were obtained for alloy, than for copper. Maximum values for hardness for copper is 125 HV but for alloy is 170 HV (deformation degree 60 %) i.e. maximum of work hardening was attained for the CuAg4at.% alloy.



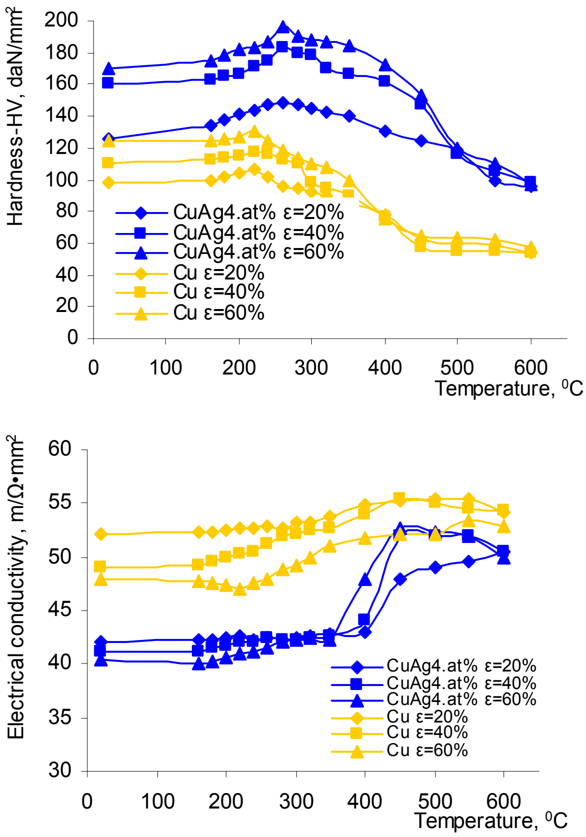
a) b)

Figure 1. Dependence of hardness (a) and electrical conductivity (b) of cold rolled samples on deformation degree

Figure 1b shows the changes of electrical conductivity during cold rolling i.e. the dependence of electrical conductivity on deformation degree. It can be seen, that the electrical conductivity for pure copper is higher than for alloy CuAg4at.%. Also fig. 1b. shows that electrical conductivity for both samples slowly decreases with the deformation degree. However, it is known that the increase in cold working results in a decrease in electrical conductivity.

3.2. Annealed cold rolled cast samples

Figure 2a shows the dependence of hardness on annealing temperature for the cast and after that cold-rolled copper and copper alloy samples with deformation degrees 20, 40, 60 %. It can be seen that the recrystallization temperature for the copper for all applied deformation degrees is above 220^0C, but for the alloy is above 400^0C, also for all applied deformation degrees, i.e. the alloying element Ag cause an increase in recrystallization temperature in comparison with pure copper.
Figures 2a. shows that in the temperature range of $160\text{-}400^0$C, for the alloy, the hardness values increase for all the applied deformation degrees (20, 40, 60%). On the temperature of 260 ^{0}C the hardness values increase for 22HV for deformation degree of 20%, for 23HV for deformation degree of 40% and for 27HV for deformation degree of 60%. The hardness values increase remarkably for 60% deformation degrees for the alloy CuAg4at.%. It can be explained by the fact that the amount of strentghening effect i.e. *anneal hardening effect* increase with increasing degree of prior cold work [4-10]
This effect has been investigated mainly in the cast copper-base alloys containing Al, Ni, Au, Ga, Pd, Rh and Zn. The results would tend to support the hypothesis that solute segregation to dislocation, analogous to the formation of Cottrell atmospheres in intersticial solid solutions, is primarily responsible for anneal hardening phenomenon [2].



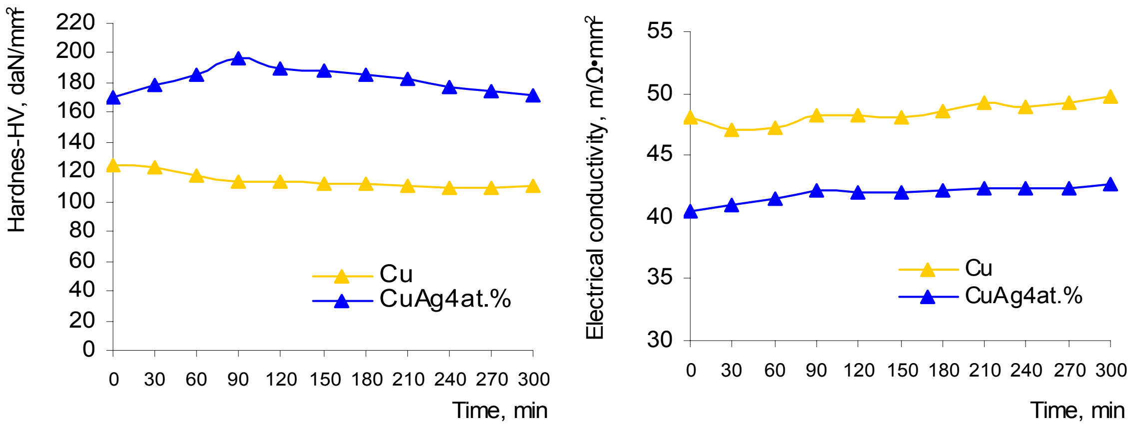
a) *b)*

Figure 2. The change of hardness (a) and electrical conductivity (b) of cold-rolled samples of copper and copper alloy with annealing temperature

During annealing the samples after cold rolling, the values of electrical conductivity of copper slowly increase with annealing temperature due to recovery and recrystallization, figure 2b. Electrical conductivity of alloy increase above 220^{0}C temperature, due to anneal hardening effect Bader at al. 1976, obtained the similar results by electrical resistivity measurements [1].

Figure 3a. shows the change of hardness after cold rolling with 60 % deformation degree with the time of annealing on the 260 ^{0}C temperature, were the maximum of anneal hardening effect attained. It can be seen that hardness for alloy increases for 30, 60, 90 min, due to anneal hardening effect and after that decreases slowly with annealing time, however, for pure copper the hardness slowly decrease due to recovery and recrystallization. After 5 hours the hardness values of alloy sample is some higher than for cold rolled state, because the recrystallization is not occurs. It can be explained by the fact that anneal hardening effect has influence on recrystallization temperature. After 90 min of annealing the maximum hardnes values increase due to anneal hardening effect for 26 HV.

Figure 3b. shows the change of electrical conductivity during annealing time of 300 min annealed on temerature of 260 ^{0}C, for copper and alloy CuAg4at.%. It can be seen that electrical conductivity increases for the first 90 min due to anneal hardening effect and after that, also slowly increases.



a) *b)*

Figure 3. The change of hardness (a) electrical conductivity (b) of cold-rolled sample of copper and aopper alloy CuAg4at.% with the time of annealing on the 260 ^{0}C temperature

Finally, some property changes other than hardening response during annealing may be considered in support of solute segregation to dislocations. In the previous investigation of anneal hardening of a CuAl alloy [1], it was shown that the major decrease in electrical resistivity during annealing cannot be accounted for by short range ordering. It was conclused that segregation to dislocations is the only consistent interpretation for the major portion of the change in resistivity

Figure 4. shows the courve of DTA analysis, it can be seen that in temperature range of 240- 400 ^{0}C, was found exothermic heat effect, i.e. anneal hardening effect

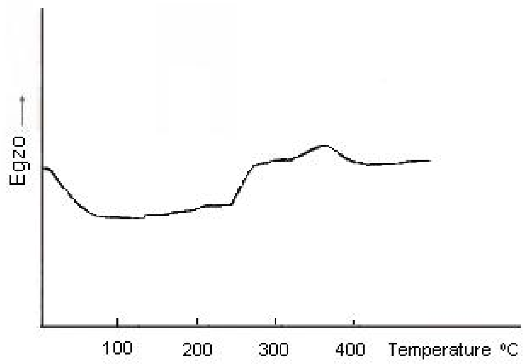


Figure 4. DTA for cold rolled samples of CuAg4at.% alloy deformed with 60% degree

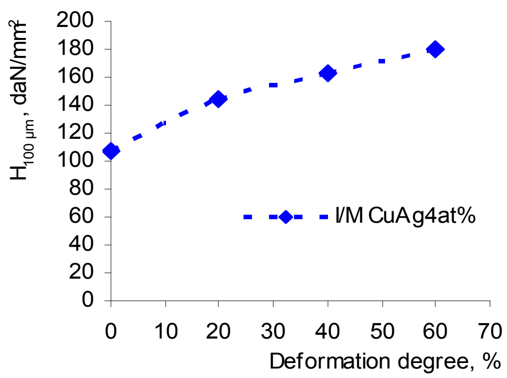


Figure 5. Dependence of microhardness of cold rolled samples on deformation degree

The anneal hardening effect is well known for Cu base solid solutions alloys. This is due to the fact that these alloys are widely used as spring contact materials where strength in the elastic / plastic limit is of primary significance and has, therefore, been investigated intensively. Anneal hardening has also been found in the Al-Cr system where a size misfit of about 5 pct exists, similar to the magnitude of the misfit in the Cu-Rh system [2].

4. CONCLUSIONS

1. The alloying element silver were found to have a pronounced effect on the increase the recrystallization temperature of the cold rolled copper alloy CuAg4at.%.
2. The anneal hardening effect was attained at alloy CuAg4at.%, under recrystallization temperature in the temperature range of 160-400^{0}C followed with an increase in hardness and electrical conductivity.
3. The amount of strengthening increases with increasing the degree of prior cold work, the maximum values of hardness increases for 27HV at 260^{0}C (60% deformation degree).

4. The anneal hardening effect dependence of time of annealing occours on 260^0C to 300 min.
5. The maximum value of the exotermic heat effect is found about 260^0C temperature (DTA analysis).

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