Influence of Thermomechanical Treatment on the Anneal Hardening Mechanism of a Sintered Cu-4at.%Ag Alloy

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Abstract. This paper reports results of investigation carried out on a Cu-4at. %Ag alloy prepared by powder metallurgy (P/M) technique. The alloy Cu-4at.%Ag and pure copper (for the sake of comparison) were subjected to the same thermomechanical treatment, which included cold rolling to reductions of 20, 40 and 60%, isochronal annealing up to the recrystallization temperature and isothermal annealing. Anneal hardening effect observed in Cu-4at.%Ag in the temperature range of 180-400°C was accompanied with increase of hardness. Hardness was also increased by the degree of previous cold rolling.

Introduction

Despite the good ductility and relatively low material cost of copper alloys, their application as structural materials is rather limited due to their low specific strength. Several methods, such as solid solution hardening, precipitation hardening and dispersion hardening, have been used to strengthen copper alloys [1]. One of the mechanisms employed to improve the mechanical properties of single-phase copper alloys is anneal hardening.

In solid solutions of deformed Cu annealed below recrystallization temperature a hardening effect called anneal hardening is produced through the interaction of solute atoms with lattice defects. This effect may cause a considerable increase of flow stress, when solute locking to dislocations plays the most important role, although solute segregation to stacking faults may not be disregarded [2,3].

However, the mechanism responsible for this hardening effect is not completely understood. The annealing hardening effect is well known for cast copper-based solid solution alloys. This is due to the fact that these alloys are widely used as spring contact materials and have, therefore, been investigated intensively [4].

In the literature no work has been done on anneal hardening effect on the P/M copper alloys. The present study gives results of investigation of anneal hardening effect on P/M copper-silver alloys.

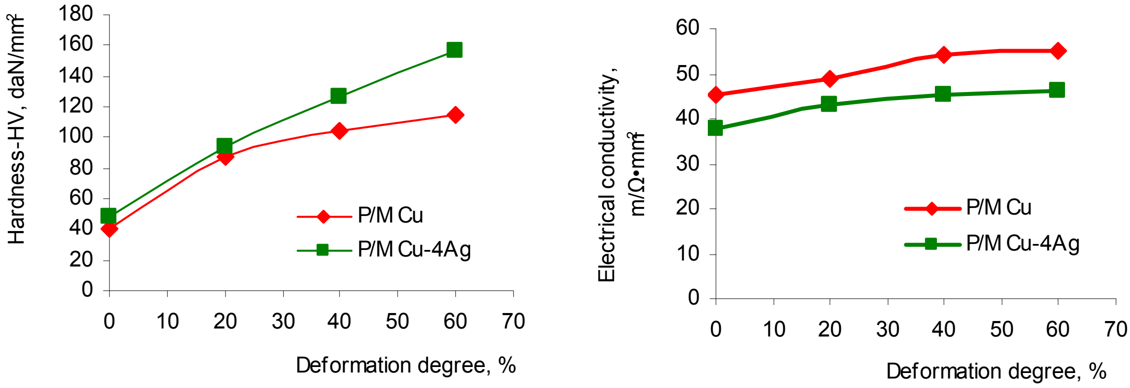
Experimental procedure

Copper and copper-based alloys were prepared applying powder metallurgy (P/M) technique using electrolytic copper powder and silver powder, with 4at.% Ag (Cu-4Ag in the further text).

The specimens, with dimensions 12 x 30 x 6.5 mm were pressed with the pressure of 350 MPa in a hydraulic press. The pressed compacts were isothermally sintered at 790°C for 1h in a horizontal tube furnace under the atmosphere of high purity dry hydrogen. After sintering the hardness, microhardness and electrical conductivity were measured on the specimens, and than the cold rolling was carried out with different deformation degrees (20, 40 and 60 %). The cold rolled copper and Cu-4Ag alloy samples were isochronally (at 30 minutes intervals in the temperature range 180-600°C) and isothermally (at 260°C in the time range 0-300 min) annealed. The values of Vickers hardness (applying load of 50N) and electrical conductivity ("Sigmatest") were measured after each test.

Results and discussion

Cold rolled-sintered samples. The hardness and microhardness of the sintered samples during cold rolling increased with deformation degree due to deformation strengthening (Fig.1a and Fig. 2). Somewhat higher hardness values were obtained for alloy Cu-4Ag, than for pure copper, i.e. maximum values of hardness was about 156 HV for deformation degree of 60%.



a) b)

Fig. 1. Dependence of hardness (a) and electrical conductivity (b) of cold-rolled P/M Cu and Cu-4Ag samples on deformation degree

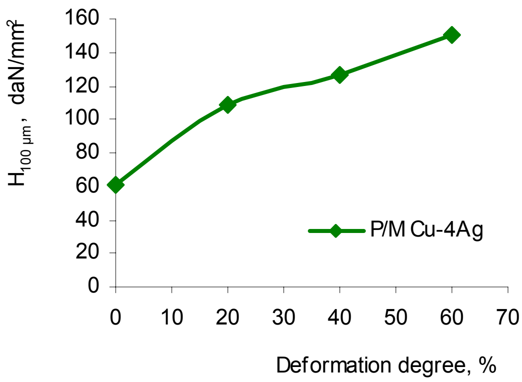


Fig. 2. Dependence of microhardness of cold rolled P/M Cu-4Ag sample on deformation degree.

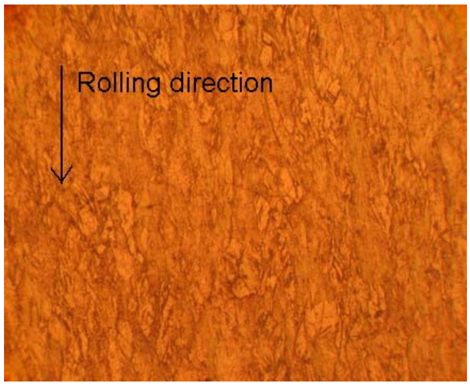


Fig.3. Microstructure of Cu-4Ag alloy 60% deformation degree (optical microphotograph x 200)

Fig. 1b shows the dependence of electrical conductivity on deformation degree. It can be seen, that the electrical conductivity of pure copper is somewhat higher than alloy Cu-4Ag. Also, Fig. 1b shows that electrical conductivity slowly increases with the deformation degree due to decrease of porosity and compaction of samples during cold-rolling.

Fig. 3 shows the deformed crystalline grains of Cu-4Ag alloy after cold rolling with 60% deformation degree. This is confirmed by visible shear bands after cold rolling. It can be seen that the grain boundaries are parallel with rolling direction.

Annealed cold-rolled sintered samples. Fig. 4 shows the dependence of hardness on annealing temperature for P/M and then cold-rolled copper and Cu-4Ag samples with deformation degrees 20, 40, 60 %. It can be seen that the recrystallization temperature of copper for all applied deformation degrees is around 220°C, but for the alloy is around 400°C, also for all applied deformation degrees. These results suggest that the addition of Ag causes an increase in recrystallization temperature in comparison with pure copper.

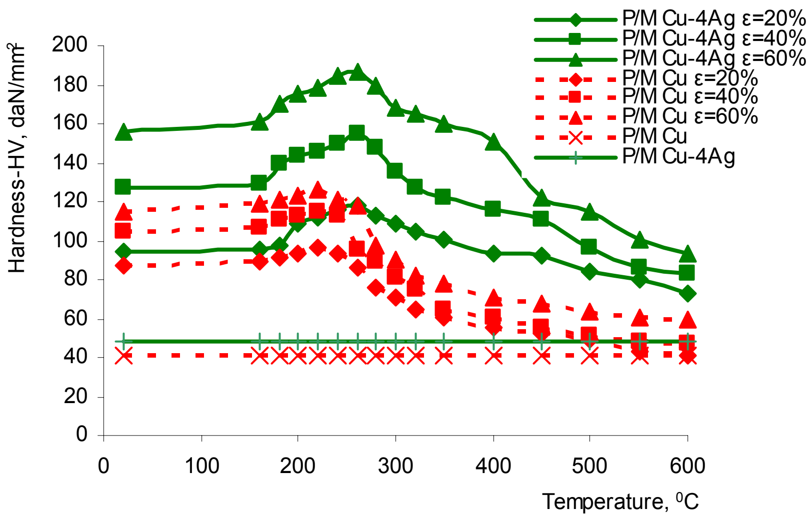


Fig. 4. The change of hardness of cold-rolled samples of Cu and Cu-4Ag with annealing temperature

Fig. 4 also shows that for Cu-4Ag in the temperature range of 180-400°C the hardness values increase for all the applied deformation degrees (20, 40, 60%). At 260 °C the hardness values increase for 24 HV for deformation degree of 20%, for 28 HV for deformation degree of 40% and for 31 HV for deformation degree of 60%. These results may be explained by the fact that the amount of strengthening effect, i.e. the *anneal hardening effect* increases with increasing degree of prior cold work [5-10].

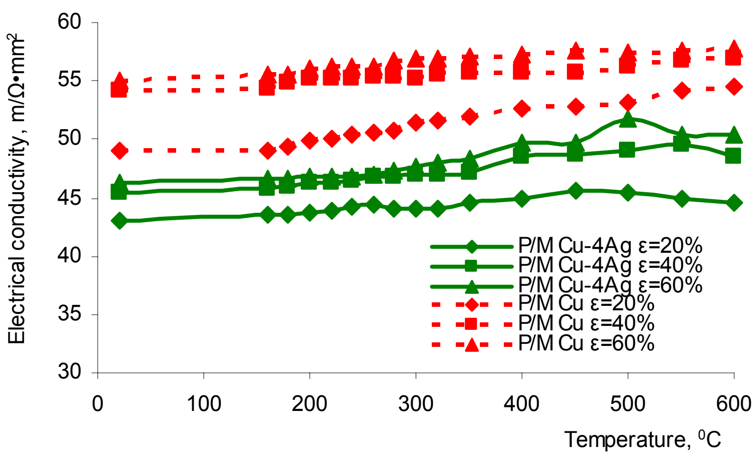


Fig. 5. The change of electrical conductivity of cold-rolled samples of Cu and Cu-4Ag with annealing temperature

This effect has been investigated mainly in the cast copper-based alloys containing Al, Ni, Au, Ga, Pd, Rh and Zn. The results from the literature [3, 4] support the hypothesis that solute segregation to dislocations, analogous to the formation of Cottrell atmospheres in intersticial solid solutions, is primarily responsible for the anneal hardening phenomenon.

During annealing of previously cold-rolled samples, the values of electrical conductivity of copper slowly increases with annealing temperature due to recovery and recrystallization (Fig. 5). Electrical conductivity of Cu-4Ag alloy increases above 220°C temperature, due to the anneal hardening effect. Bader et al. obtained the similar results by electrical resistivity measurements [3].

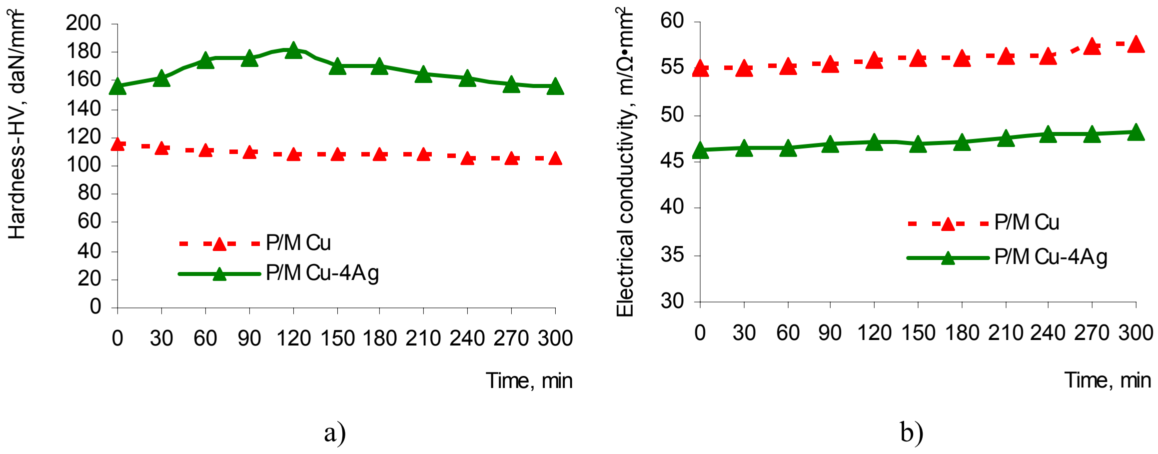


Fig.6 The change of hardness (a) and of electrical conductivity (b) of cold-rolled sample of copper and copper alloy Cu-4Ag with the time of annealing at the 260 °C temperature

Fig. 6a shows the change of hardness after cold rolling with 60 % deformation degree with the time of annealing at the 260°C where the maximum of anneal hardening effect was attained. It can be seen that hardness of Cu-4Ag alloy increases up to 120 min due to anneal hardening effect and then slowly decreases with annealing time. However, the hardness of pure copper slowly decreases from the beginning of annealing time due to the recovery and recrystallization. After 5 hours the hardness values of Cu-4Ag alloy are higher than that of cold-rolled condition because the recrystallization was not occured. This can be explained by the fact that the anneal hardening effect retards the recrystallization temperature. After 120 min of annealing the maximum hardness increases for 25 HV due to anneal hardening effect in comparison with initial cold-rolled state.

Fig. 6b shows the change of electrical conductivity during annealing time for 300 min at 260°C, for copper and alloy Cu-4Ag. It can be seen that electrical conductivity slowly increases during the whole time of annealing interval.

Summary

The anneal hardening effect was attained in alloy Cu-4at%Ag below recrystallization temperature in the temperature range of 160-400°C accompanied with an increase in hardness and electrical conductivity. The amount of strengthening increases with increasing of the degree of prior cold work. The maximum value of hardness increase (31 HV at 260°C) was established at 60 % deformation degree. It was found that the addition of 4at.% of Ag has a pronounced effect on the increase the recrystallization temperature of the cold-rolled copper. After isothermal annealing, the anneal hardening effect of alloy Cu-4at%Ag occurs at 260°C after 300 min.

Acknowledgement

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