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THE STRENGTHENING BY ANNEAL HARDENING EFFECT IN SINTERED COPPER-SILVER ALLOYS

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ABSTRACT
This paper reports results of investigation carried out on sintered copper and copper-silver alloys with 4, 8, 12 at% Ag.
The copper and copper alloys were subjected to cold-rolling with deformation degrees of 25, 50 and 75%, and annealed isochronally up to recrystallization temperature. Changes in hardness and electrical conductivity were followed in order to investigate the anneal hardening effect.
These investigation show that anneal hardening effect occurs in a temperature range of 180-350^0 C, followed with an increase in hardness (strengthening) of alloys.
Keywords: sintered copper alloys, cold rolling, anneal hardening effect

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. Copper has been hardened conventionally 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 150-350^{0}C [1,2,3,4.5]. 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 alloy systems. The amount of strengthening, which accompanies aging, increase with increasing degree of prior cold work, the strengthening increase with increasing substituional element concentration, the strengthening due to aging is decreasing function of the plastic strain at which the strength is measured. The mechanism responsible for this hardening effect is investigated in several casts copper based alloys after cold rolling and annealing below recrystallization temperature [4, 5].
Also, this strengthening effect is attained at several sintered copper based alloys after cold rolling and annealing up to recrystallization temperature [5 - 11].

2. EXPERIMENTAL PROCEDURE

Sintered copper base alloys were prepared using electrolytic copper powder and silver powder, with different at% Ag. Alloy 1: Cu – 4 at %Ag, alloy 2: Cu - 8 at %Ag and alloy 3: Cu-12 at % Ag. For comparison the specimens was made from pure electrolytic copper powder.
The specimens, with dimension 12mm wide, 30mm long and 6,5mm thick, were pressed with the pressure of 300 MPa on a hydraulically press. The pressed compacts were sintered isothermally at 790^0 C in a horizontal tube furnace under an atmosphere of high purity dry hydrogen for 1h. After

sintering the hardness and electrical conductivity were measured on the specimens, and than the cold rolling was carried out with different deformation degrees (25, 50, 75 %). The cold-rolled specimens were isochronally annealed at 30 min intervals in the temperature range 150-500^0 C and the Vickers hardness and electrical conductivity were measured.

3. RESULTS AND DISCUSSION

3.1. Cold rolled-sintered samples

The hardness of the sintered samples during cold rolling increased with deformation degree due to deformation strengthening (Fig.1). Some higher hardness values were obtained for alloys, than for copper, i.e. maximum of work hardening was attained for the alloys (maximum values of hardness was about 172 HV-deformation degree 75%).

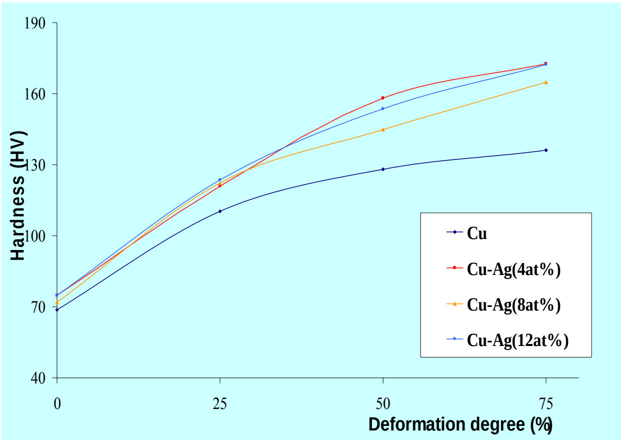

Figure 1. Dependence of hardness of cold rolled sintered samples on deformation degree

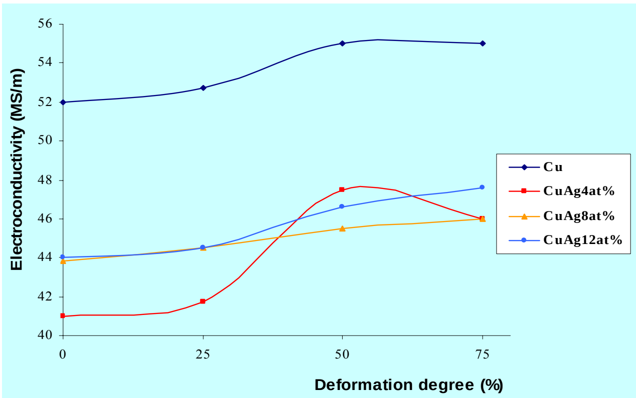

Figure 2. Dependence of electronductivity of cold rolled sintered samples on deformation degree

3.2. Annealed cold rolled sintered samples

Figure 3. shows the dependence of hardness on annealing temperature for the sintered and after that cold-rolled with 50% total deformation degree copper and alloys samples. The recrystallization temperature for the copper sample for 50% deformation degree is above 280^{0}C, but for alloys is above 350^0 C, i.e. the alloying element Ag cause an increase in recrystallization temperature in comparison with pure copper. Figure 3. shows that in the temperature range of 180 - 350^0 C the hardness values increase for the applied deformation degree of 50 %. The hardness value increase for 22HV, at 260^{0}C for the alloy CuAg4at%; for the alloy CuAg8at% the hardness value increase about 36HV at 260^0 C. For the alloy CuAg12at% the hardness value increase about 24HV at 240 ^{0} C. It can be seen the maximum increases value is for alloy CuAg8at%.

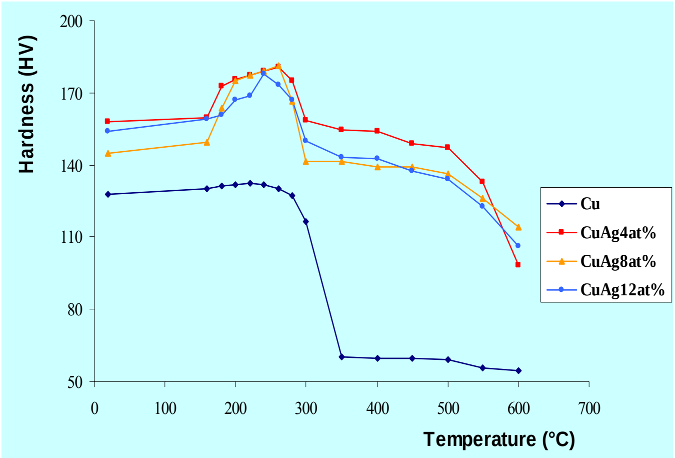

Figure 3. Variation of hardness of cold-rolled (50%) sintered copper and alloys with annealing temperature

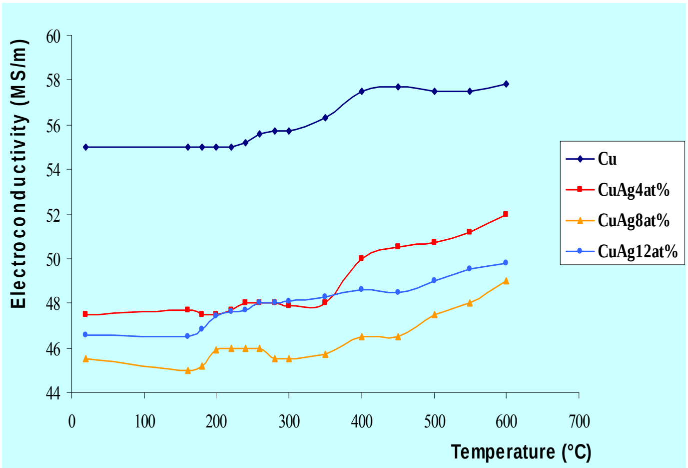

Figure 4. Variation of electroconductivity of cold-rolled (50%) sintered copper and alloys with annealing temperature

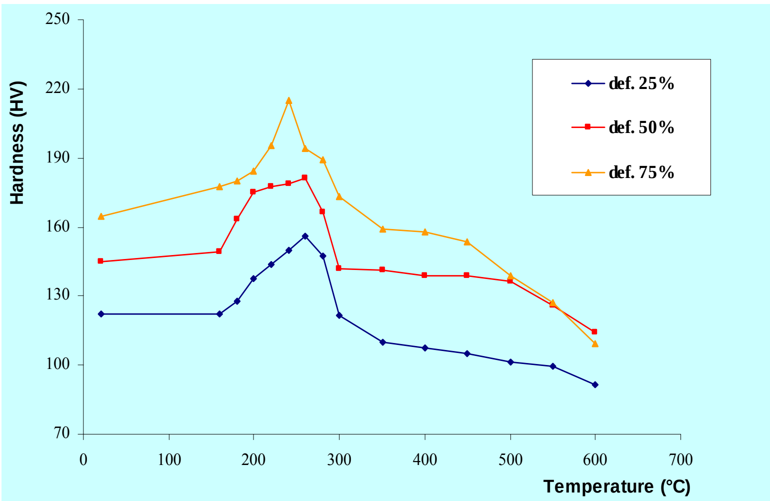

Figure 5. Variation of hardness of cold rolled (25,50, 75%) sintered copper alloy CuAg8at% with annealing temperature

Figure 2 shows the dependence of electrical conductivity on deformation degree after cold rolling. It can be seen that the electrical conductivity slowly increases with deformation degree, what is a results of two effects. Decrease in the porosity during cold rolling results in increase in electrical conductivity (effect 1). However, it is known that the increase in cold-working results in decrease in electrical conductivity (effect 2). The first effect is bigger than the second, and electrical conductivity increases as a results [7].

During annealing the values of electrical conductivity of copper slowly increase with annealing temperature (Fig.4) due to recovery and recrystallization. Electrical conductivity of alloys increases above 200 ^{0}C temperature, due to anneal hardening effect, and due to recrystallization. Bader at all [3] obtained the similar results by electrical resistivity measurements.

Figure 2. and 4. show that the electrical conductivity for sintered copper is higher than for sintered alloys, because the alloying elements decreases electrical conductivity

Figure 5. shows that in temperature range of 180-350^{0}C, for the alloy CuAg8at% the hardness values increases at all deformations (25,50 and 75%); by about (34, 36, and 50 HV). The hardness values increase remarkably for 75% deformation in the alloy. This can be explained by the fact that the amount of strengthening effect i.e. anneal hardening effect increases with increasing degree of prior cold work [6, 8, 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 interstitial solid solutions, is primarily responsible for the anneal hardening phenomenon [3, 4]

The anneal hardening effect is well known for Cu-based solid solutions alloys. This is due to the fact that these alloys are widely used as spring contact materials where strength in elastic/plastic limit is of primary significance and has, therefore been investigated extensively.

4. CONCLUSIONS

1) The alloying element silver was found to have a pronounced effect on the increase of recrystallization temperature of the cold rolled sintered copper alloys.
2) The anneal hardening effect was attained under recrystallization temperature in the temperature range of 180-350^{0} C followed with an increase in hardness.
3) The amount of strengthening increases with increasing degree of prior cold work.
4) The maximum values of hardness was attained at CuAg8at% alloy, deformation 75%.
5) Anneal hardening may be considered as a genuine hardening mechanism in analogy to other basic hardening mechanisms such as work, grain size, solid solution and dispersion hardening.
6) The results can be applied to derive the composition and processing variables, which determine the practical use such as the strengthening effect of sintered copper alloys.

5. REFERENCES

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