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INFLUENCE OF DEFORMATION DEGREE AT COLD-ROLLING ON THE ANNEAL HARDENING EFFECT IN SINTERED COPPER-BASED ALLOYS

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Abstract

Samples of copper-based alloys, Cu-4at%Zn, Cu-8at%Zn and Cu-5at%Ni-2at%Sn and pure copper have been prepared by a powder metallurgical method. The samples were subjected to cold rolling to 30, 50 and 70% in reduction, followed by annealing up to the recrystallization temperatures. Anneal hardening effect has been observed with the alloys in an annealing temperature range of 180-400^{0}C, the hardness being increased with the amount of reduction at the prior cold - rolling.

Keywords: copper-base alloys, cold rolling, powder metallurgy

1.Introduction

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

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strength, conductivity, and maintenance of strength at high temperature [1]. Copper has excellent conductivity, but has poor resistance to softening at moderate temperatures. This presents a considerable problem to engineers and designers of electrical equipment. Copper alloys are widely used as spring contact materials because of their conductivity, corrosion resistance, formability, nonmagnetic behavior and large yield strength to elastic modules ratio. Copper has been hardened conventionally by solution and/or precipitation hardening and dispersion hardening [1-3]. One of the mechanisms employed to improve the mechanical properties of single-phase copper alloys is anneal hardening, whereby considerable strengthening is attained when copper alloys in cold-rolled state are annealed at 150 – 300^{0}C. However, the mechanism responsible for this hardening effect is incompletely understood (2-4). The effect has been investigated mainly in cast copper-base alloys and some results have been interpreted as indicating that atomic ordering is primarily responsible for the hardening effect [2]. On the other hand in a recent detailed investigation of anneal hardening in Cu-Al alloys [3], it was concluded that solute segregation to dislocations gives rise to the predominant hardening mechanism. The hardening has been ascribed to different mechanisms such as hardening by Cottrell and Suzuki locking, solute clusters, ordered clusters and precipitation hardening. The phenomena have been investigated in numerous papers, particularly on the model systems Cu-Zn and Cu-Al, but detailed studies of the underlying processes are still lacking.

Previous studies on anneal hardening showed that the amount of strengthening increases with increasing degree of prior cold work and with increasing substitutional element concentration[3-11].

This paper presents part of our research relating to the anneal hardening effect on a number of copper based alloys. The aim of this study is to assess the influence of alloying with zinc, nickel and thin on intensity of anneal hardening effect. The purpose of these experiments is to find out optimal conditions, that is, the deformation degree and quantity of alloying elements which lead to the effect of anneal hardening in investigated alloys.

2. Experimental

Sintered copper based alloys were prepared using an electrolitycal copper powder and powders of nickel, zinc and tin with different composition: Cu-4at%Zn, Cu-8at%Zn and Cu-5at%Ni-2at%Sn. For comparison pure copper specimens were made from electrolitycal copper powder. The specimens, with dimension 12 mm wide, 30mm long and 6,5mm thick, were pressed with the pressure of 300 MPa on a hydraulically press at room temperature. The pressed compacts were sintered isothermally at 850^{0}C for 1h in a horizontal tube furnace under an atmosphere of high purity dry hydrogen. After sintering the hardness and electrical conductivity were measured on the specimens, and then cold-rolling was carried out with different deformation degrees (30, 50 and 70%). Our preliminary investigations on various sintered copper alloys have been shown that the porosity is in the range of 6-10%, while it, after cold rolling with deformation degrees in the range of 20-70%, belongs to the values between 3 and 0%. The cold-rolled specimens were isochronally annealed at 30 min intervals in the temperature range of 150 -500^{0}C and the Brinell hardness and electrical conductivity were measured. Electrical conductivity was measured using the equipment LEIFÄHIGKEIT, produced by Institute Dr FÖRSTER, Reutlingen, Deutchland (with two etalons for two different ranges). Electrical conductivity was measured on three different sites and, then, the average values were calculated with a precision of 0,1%.

3. Results and Discussion

3.1. Cold rolled sintered samples

The hardness of the sintered samples after cold rolling increased with deformation degree due to deformation strengthening. Some higher hardness values were obtained for alloys, than for pure copper. Maximum hardness was about 165 HB for deformation degree of 70% i.e. maximum of work hardening was attained for the alloy CuNi5Sn2 (Fig.1).

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). Fig. 2 suggests that the first effect exceeds the second one in the present case.

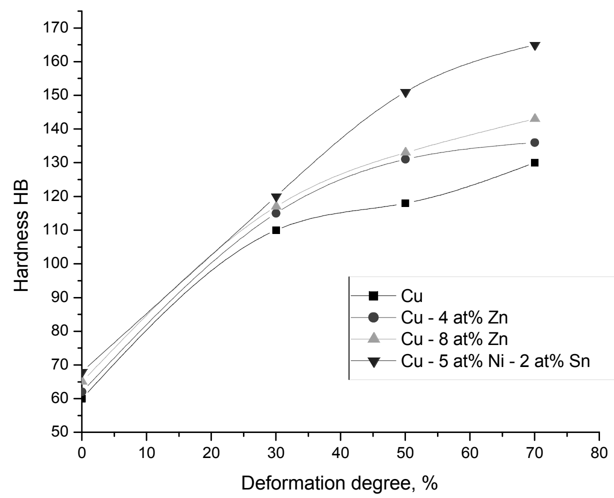

Fig. 1. Dependence of hardness of cold -rolled sintered samples on deformation degree

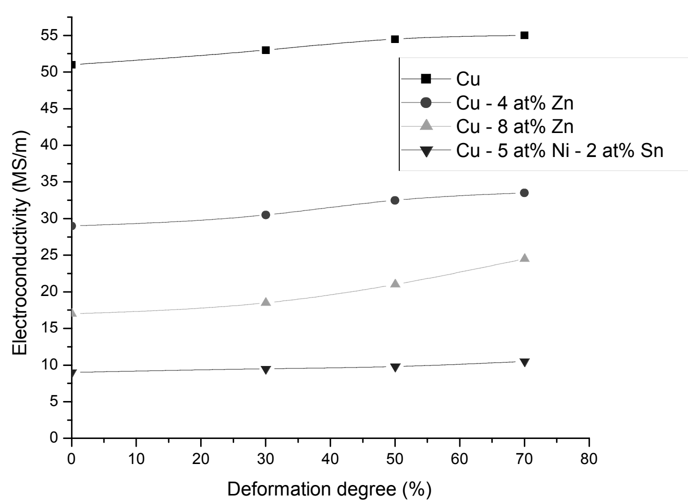

Fig. 2. Dependence of electrical conductivity of cold rolled sintered samples on deformation degree

It can be seen that the electrical conductivity for sintered copper is higher than that for sintered alloys and therefore the contents of the alloying elements must be less, because alloying elements decrease electrical conductivity.

Fig. 3 shows the microstructure of CuNi5Sn2 alloy after cold rolling with 70% deformation degree. Optical microphotograph of a microstructure shows deformed crystalline grains. This is confirmed by visible shear bands after cold rolling. It can be seen that the grain boundaries are parallel with rolling direction.

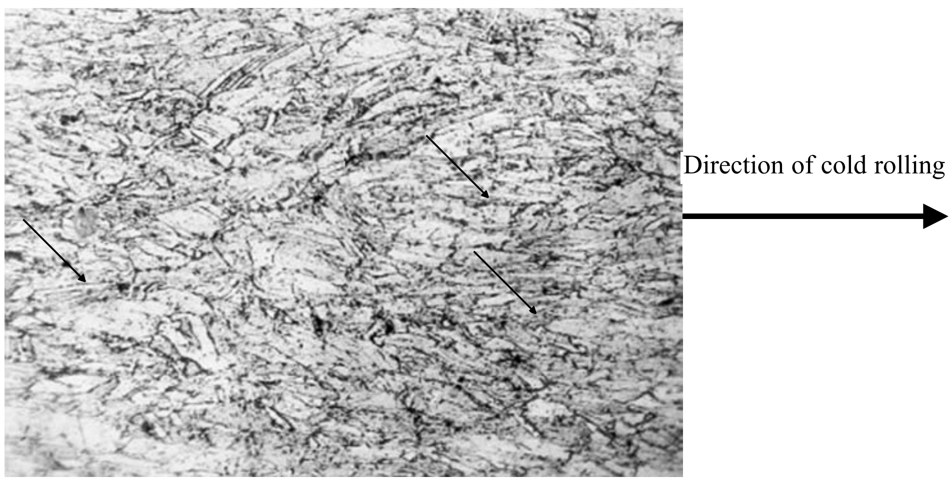

Fig. 3. Optical microphotograph of a microstructure of CuNi5Sn2 alloy 70% deformed x 600

3.2. Annealed cold rolled sintered samples

Figure 4 shows the dependence of hardness on annealing temperature for the cold-rolled sintered samples of copper and alloys with 70% deformation degree. It can be seen that the recovery and recrystallization temperature for pure copper sample are above 180^{0}C, but above 350^{0}C, 400^{0}C and 500^{0}C for alloys CuZn4 and for CuZn8 and CuNi5Sn2 respectively i.e. the alloying elements (Ni, Zn and Sn) cause an increase in the recovery and recrystallization temperatures in comparison with pure copper.

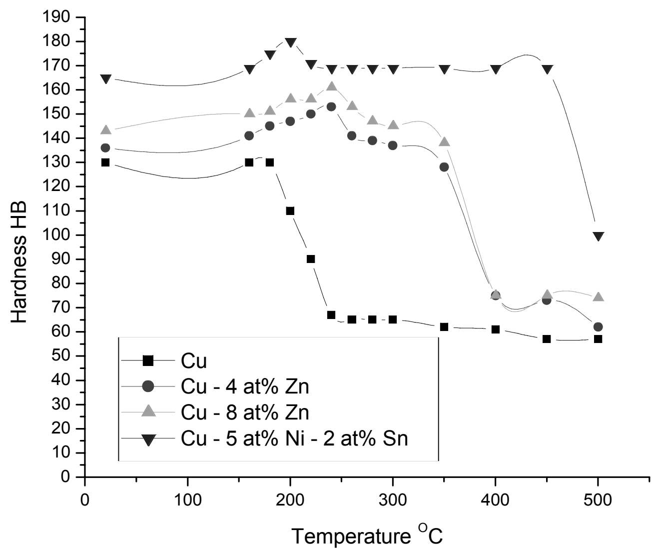

Fig. 4. The change in hardness of cold-rolled (70%) sintered samples with annealing temperature

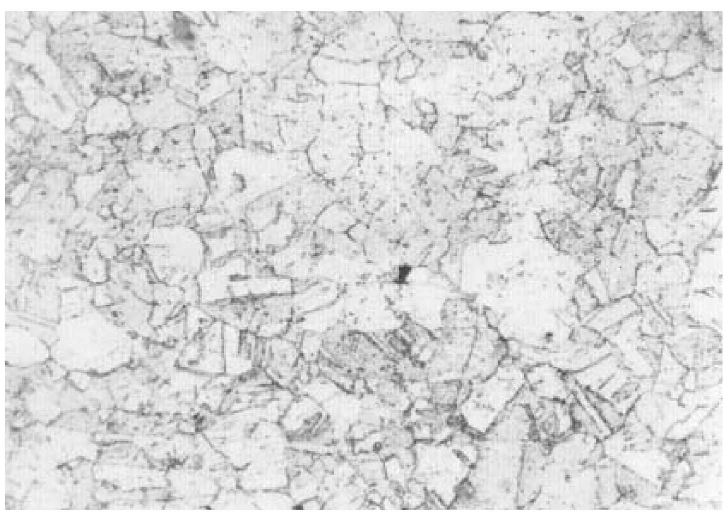

Fig. 5. Optical microphotograph of a microstructure of annealed CuNi5Sn2 alloy, x 600

Recrystallization of the cold worked alloy (Fig.5), after annealing at 500^0C for one hour.

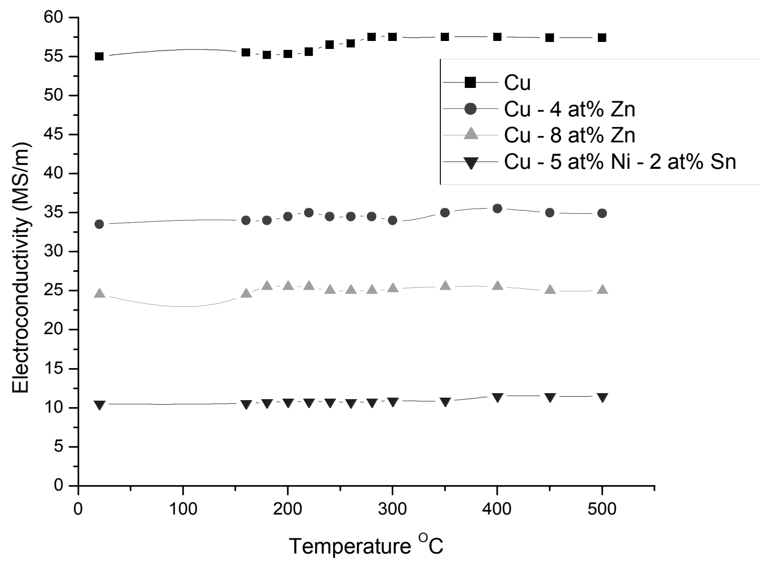

Fig. 6. The change of electrical conductivity of prior cold–rolled sintered samples of alloys with annealing temperature

During annealing the values of electroconductivity of copper and alloys slowly increase with annealing temperature (Fig. 6) due to recovery and recrystallization.

Figure 7 shows the change of hardness for applied deformation degrees of 30, 50 and 70% for alloy CuZn8. The hardness increased with increasing the deformation degree remarkably by about 25HB (in comparison with initial cold rolled state), for deformation degree of 70%, on temperature when annealed at 220^0C, i.e. anneal hardening effect is more expressive then for 50% (the hardness increase by about 13Hv) and than for deformation of 30% (the hardness increase by about 11Hv).

The anneal hardening behavior of copper alloys solid solutions with a constant 4at%, of solute content of Al, Au, Ga, Ni, Pd, Rh, and Zn was previously reported [4]. If we assume solute segregation to dislocations, analogous to the formation of Cottrell atmosphere, as the mechanism of anneal hardening effect, the flow stress should be increased by the binding of solute atoms to dislocations[4] . The contribution of anneal hardening to the flow stress was shown to decrease rapidly with increasing plastic strain[4]. The interactions of solute atoms with lattice defects such as dislocations, vacancies and stacking faults introduced during rolling, however, may also cause a considerable increase in flow stress. Solute interactions with vacancy clusters could possibly contribute to the strengthening too[3]. For detailed investigations of hardening effect it is necessary to apply electron microscopy.

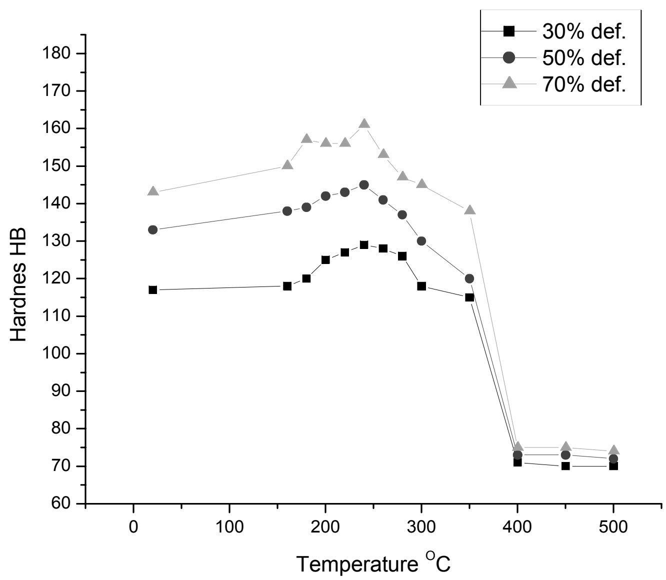

Fig.7. The change of hardness of prior cold-rolled sintered CuZn8 alloy with deformation degree and annealing temperature

4.Conclusions

1) The alloying elements nickel, zinc and tin were found to have a pronounced effect on the increase of recovery and recrystallization temperature of cold rolled sintered copper alloys.

2) Anneal hardening effect was attained in the temperature range of 180 – 400^0C.

3) The amount of strengthening increased with increasing degree of prior cold work.

4) The strengthening increase with increasing substitutional element concentration.

5) Anneal hardening effect is more expressive in ternary than binary systems.

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