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THE STRENGTHENING BY ANNEAL HARDENING EFFECT IN A CAST CuAl10 and CuZN10 ALLOYS

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ABSTRACT
This paper reports results of investigation carried out on cast copper-aluminium and copper-zinc alloys with 10 at% of alloying elements. The copper alloys were subjected to cold-rolling with deformation degrees of 20, 40 and 60%, and annealed below the recrystallization temperature. The values of hardness and electrical conductivity were measured 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) and electrical conductivity of both alloys.
Keywords: cast 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. The last few years have seen a major effort devoted to the exploration of copper-based alloys in the search for improvements of properties such as strength, conductivity, and stress retention at high temperature [1]. One of the processes which has the influence on the increase of mechanical characteristics is *anneal hardening*, consisting of annealing of the supersaturated solid solution up to the recrystallization temperature of several Cu based alloys. 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 [2,3].
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 [3].
The mechanism responsible for this hardening effect is investigated in several casts copper based alloys after cold rolling and annealing below recrystallization temperature [3,4]. Also, this strengthening effect is attained at several sintered copper based alloys after cold rolling and annealing up to recrystallization temperature [5-12].

2. EXPERIMENTAL
Copper-based alloys containing 10at %Al and 10at %Zn (CuAl10 and CuZn10 alloys) were melted in a laboratory electro resistance furnace and cast into a copper mold with dimensions 100x100x30mm. The cast alloys were homogenized at 850^{0}C for 24 hours in a graphit. Samples with dimensions 100x30x7mm were cut from the homogenized material and than cold rolled prefinally to the thickness

of 5, 3.3 and 2.5mm. After that the samples were subjected to a anneal (at 700^0C for 1h) and then samples were subjected to a finally reduction of 20, 40 and 60% by cold rolling, and the final thickness of all samples was the same, i.e. 2mm. For comparison, parallel specimens made from cast pure copper.

In the next stage samples were annealed in the temperature range between 150 and 500^0C (in steps of 20^0C up to 300^0C, and 50^0C after 300^0C) holding time at annealing temperature was 30min. Vickers hardness (applying load of 5kp) and electrical conductivity ("Sigmatest") were measured following each annealing. Five measurements were performed for each annealing temperature.

3.REZULTS AND DISCUSION

3.1. Cold rolled samples.

The hardness of samples increases with the degree of prior cold deformation due to the deformation strengthening (Fig. 1). Higher hardness values were obtained for alloys, than for copper. According to maximum values of hardness after 60 % deformation are 126, 160 and 206 HV, of copper, CuZn10 and CuAl10 alloy, respectively.

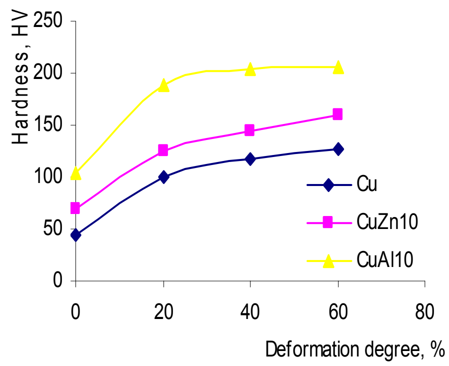

Figure 1. Dependence of hardness of cold rolled cast samples on deformation degree

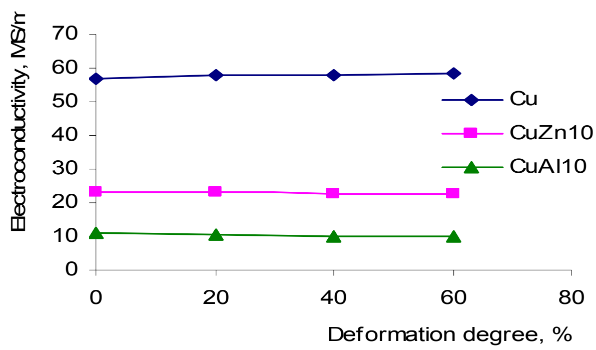

Figure 2. Dependence of electroconductivity of cold rolled cast samples on deformation degree

Fig. 2 shows the change of electrical conductivity after cold rolling. It can be seen that electrical conductivity of copper is higher than for CuAl10 and CuZn10 alloys, because the alloying elements decreases electrical conductivity. Fig. 2 also shows that electrical conductivity of alloys slowly decreases with the degree of prior deformation.

3.2. Annealed cold rolled cast samples

Figure 3. shows the dependence of hardness on annealing temperature for the cast and after that cold-rolled (with deformation degrees 20, 40, 60%) CuAl10 and For CuZn10 samples the hardness increases with increase of the degree of prior deformation. This increase is about 21 HV (in comparison with the initial cold-rolled condition) for 60% deformation, and the anneal hardening effect is more pronounced than for 40% deformation (the hardness increase is about 16 HV) and for the deformation of 20% (the hardness increase is about 11 HV). For CuAl10 samples hardness also increases with the previous cold work, with higher values than in the case of CuZn10 samples. The anneal hardening effect of 30 HV(60%) is somewhat higher than for the deformation of 40% (the hardness increase is about 25 HV and for the deformation of 20% (the hardness increase is about 14 HV).comparison with the initial cold-rolled condition) for 60% deformation, and the anneal hardening effect is more pronounced than for 40% deformation (the hardness increase is about 16 HV) and for the deformation of 20% (the hardness increase is about 11 HV). For CuAl10 samples hardness also increases with the previous cold work, with higher values than in the case of CuZn10 samples. The anneal hardening effect of 30 HV(60%) is somewhat higher than for the deformation of 40% (the hardness increase is about 25 HV and for the deformation of 20% (the hardness increase is about 14 HV).

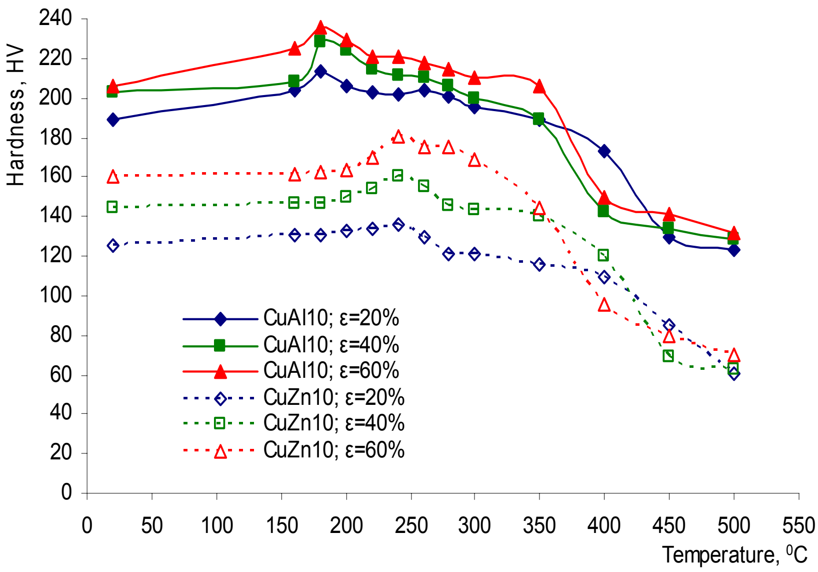

Figure 3. Hardness of annealed samples of CuAl10 and CuZn10 alloy with annealing temperature

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The maximum of hardness for CuAl10 set of samples is around 180^{0}C and for CuZn10 set of samples is around 240^{0}C. After the maximum is reached hardness decreases slowly and at about 350^{0}C an abrupt decrease of hardness occurs. This decrease of hardness near 350^{0}C corresponds to the start of recrystallization.
The recrystallization temperature for the pure copper is reported to be around 200^{0}C [4] because of then it is obvious that the anneal elements Zn and Al increases recrystallization temperature of alloys at about 350^{0}C.
Fig. 4 shows that the electrical conductivity for both sets of samples increase due to the anneal hardening effect. The slow increase above 350^{0}C is probably due to recovery and recrystallization. Bader et al. [2] obtained the similar results by electrical resistivity measurements.
Figure 5 shows the change of hardness with time during annealing at 180^{0}C for CuAl10 samples and at 240^{0}C for CuZn10 samples. For CuAl10 samples hardness increases due to anneal hardening effect up to 150min but for CuZn10 samples hardness increases up to 180min, then slowly decreases with annealing time. After 5h of annealing the values of hardness are higher compared to the cold-rolled condition for both set of samples which implies that the recrystallization does not occur. This may be explained by the fact that anneal hardening effect shifts the onset of recrystallization to higher temperatures.

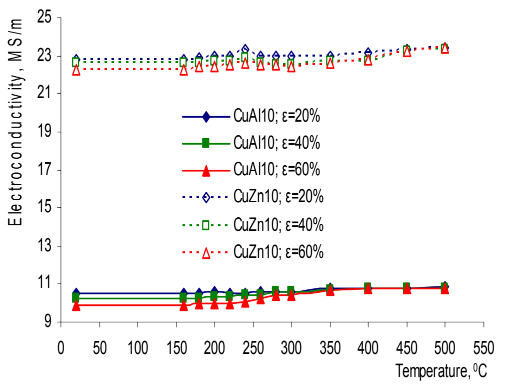

Figure 4. Electroconductivity of annealed samples of CuAl10 and CuZn10 alloys with annealing temperature

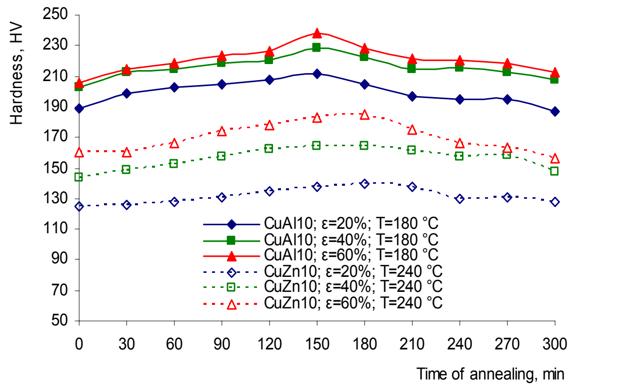

Figure 5. Hardness of samples after annealing (at 180^{0}C for CuAl10 and at 240^{0}C for CuZn10) as a function of time of annealing

After 150min of annealing the maximum of hardness of CuAl10 samples increases after prior deformation of 20, 40 and 60% for 23, 25 and 32 HV, respectively.
After 180min of annealing the maximum of hardness of CuZn10 samples increases after prior deformation of 20, 40, 60% for 15, 20 and 25 HV, respectively.
The change of electrical conductivity of samples after annealing (at 180^{0}C for CuAl10 and at 240^{0}C for CuZn10) as a function of time of annealing is the same as results on fig. 4. Generally, electrical conductivity increases during time of annealing. The X-ray analysis show the change of lattice parameter during annealing when anneal hardening effect was attained. The DSC analysis shows the exothermic character of this effect [9].

4. CONCLUSION

Aluminium and zinc as alloying elements were found to have a pronounced effect on the increase of the recrystallization temperature of the cold rolled cast copper alloys.
The anneal hardening effect was attained below recrystallization temperature in the temperature range between 160^{0}C and 350^{0}C and was followed by an increase in hardness and electrical conductivity.
The amount of strengthening increases with increasing the degrees of the prior cold work and the maximum of hardness was established for 60% of deformation.
Alloying by aluminium has more pronounced influence on strengthening than alloying with zink.
The results can be applied to derive the composition and processing variables which determine the practical use such as the strengthening effect of copper alloys.

5. REFERENCES

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