*Journal of Mining and Metallurgy, 39 (3‡4) B (2003) 489-498*

# INFLUENCE OF TIME OF ANNEALING ON ANNEAL HARDENING EFFECT OF A CAST CuZn ALLOY

**S. Nestorović, Lj. Ivanić and D. Marković**

Technical Faculty Bor, University of Belgrade, Serbia and Monte Negro

*(Received 20 September 2003; accepted 15 October 2003)*

## Abstract

*Investigated cast copper alloy containing 8at%Zn of a solute. For comparison, parallel specimens made from cast pure copper. Copper and copper alloy were subjected to cold rolling with different a final reduction of 30,50 and 70%.*

*The cold rolled copper and copper alloy samples were isochronally and isothermally annealed up to recrystallization temperature. After that the values of hardness, strength and electrical conductivity were measured and X-ray analysis was performed.*

*These investigations show that anneal hardening effect at alloys was attained under recrystallization temperature in the temperature range of 180-300$^0$C, followed with an increase in hardness. The amount of strengthening increase with increasing degree of prior cold work. Also the X-ray analysis show the change of lattice parameter during annealing when anneal hardening effect was attained.*

*Keywords:* annealing, CuZn alloy, hardness, strength, electrical conductivity

## 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 strength, conductivity, and stress retention at high temperature [1].

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 [1-3].

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 acompanies 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 stength is measured.

The mechanism responsible for this hardening effect is investigated in several copper based alloys after cold rolling and annealing below recrystallization temperature [1,2].

Also, this strengthening effect is attained at several sintered copper based alloys after cold rolling and annealing to recrystallization temperature [3,4,5].

## 2. Experimental

Investigated cast copper alloys containing 8%Zn of a solute, produced in laboratory for casting. For comparison, parallel specimens made from cast pure copper.

Copper and copper alloy weighing aproximetly 2 kg, were melted in a furnace and cast in copper molds with dimensions 80x80x30 mm. The cast alloys were homogenized at $850^0$C for 24 hours in a graphit and made samples with dimension 80x30x7mm on the erozimat aparature. After that the cold rolling was carried out on the samples with intermediate anneals at $500^0$C for 1 h, a heat treatment of $500^0$C for 2 h followed by an ice-water quench was given. After that the copper and copper alloy were subjected to cold rolling with different a final reduction of 30, 50 and 70%.

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 X-ray analysis was performed.

## 3. Results and discussion

### *3.1. Cold rolled cast samples*

Hardness of sintered copper and Cu-Zn alloy during cold rolling increase with deformation degree due to deformation strengthening (Fig.1). Some higher hardness values were obtained for alloy, than for copper. Maximum values for hardness for copper is 126 HV but for alloy is 155 HV (deformation degree 70 %) i.e. maximum of work hardening was attained for the CuZn alloy.

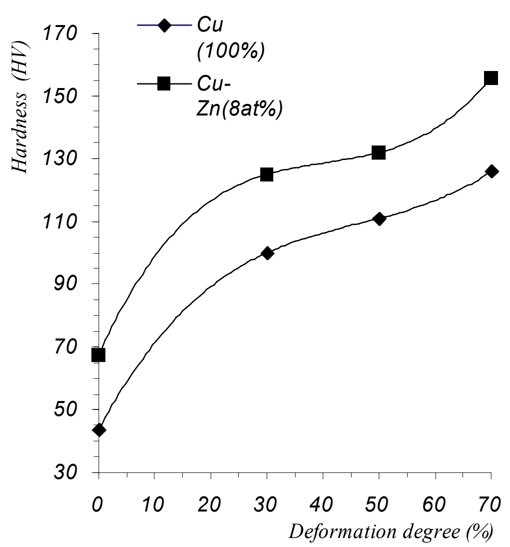


*Figure 1. Dependence of hardness of cold rolled samples on deformation degree*

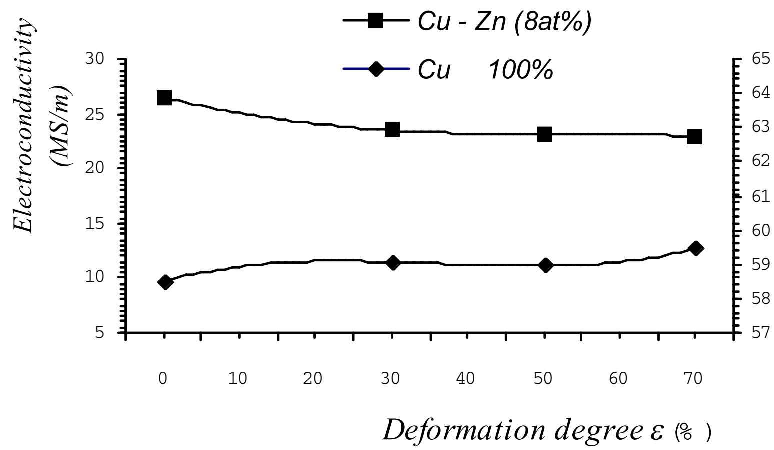


*Figure 2. Dependence of electrical conductivity on deformation degree*

Figure 2. 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 CuZn. Also Fig. 2. shows that electrical conductivity for alloy 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 3 and 4. show the dependence of hardness on annealing temperature for the cast and after that cold-rolled copper and copper alloy samples with deformation degrees 30,50,70%. Figure 3. shows that the recrystallization temperature for the copper for all applied deformation degree is above 200$^0$C, because the hardness decrease On the Fig. 4. can be seen that for the alloy recrystalization temperature is above 350$^0$C, also for all applied deformation degrees, i.e. the alloying element Zn cause an increase recrystallization temperature in comparison with pure copper.

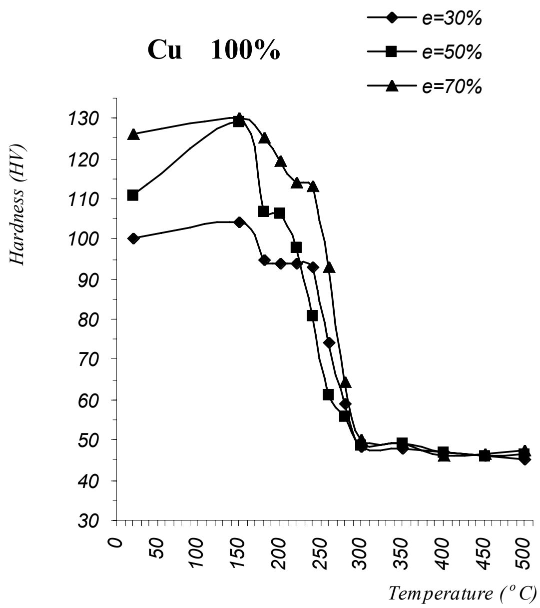


*Figure 3. The change in hardness of cold rolled copper with annealing temperature*

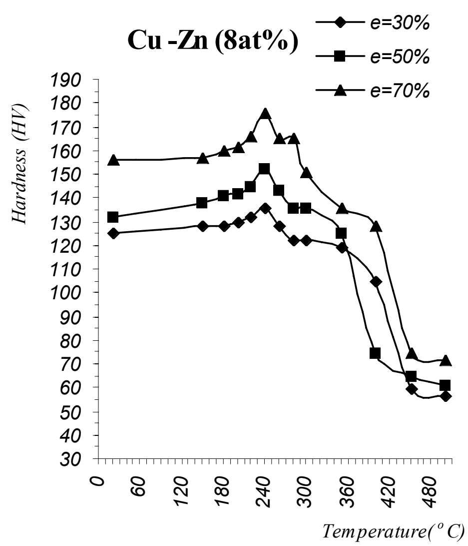


*Figure 4. The change of hardness of CuZn alloy with annealing temperature*

Figure 4 shows that in the temperature range of 180-300$^0$C, for the alloy CuZn, the hardness values increase for all the applied deformation degrees (30, 50, 70%). On the temperature of 240$^0$ C, the hardness values increase for 11HV for deformation degree of 30%, for 20HV for deformation degree of 50% and for 30HV for deformation degree of 70%. The hardness values increase remarkably for 70% deformation degrees for the alloy CuZn. 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.[10].

This effect has been investigated mainly in the cast copper-base alloys containing Al, Ni, Au, Ga, Pd, Rh and Zn [2]. The results would tend to support the hypothesis that solute segregation to dislocation, analogous to the formation of Cottrel atmospheres in intersticial solid solutions, is primarily responsible for anneal hardening phenomenon [1,2].

During annealing the samples after cold rolling, the values of electrical conductivity of copper slowly increase with annealing temperature due to recovery and recrystallization. Electrical conductivity of alloy increase above 180$^0$C temperature, due to anneal hardening effect Bader at al.[1] obtained the similar results by electrical resistivity measurements.

Figure 6. shows the change of hardness after cold rolling with 70% deformation degree with the time of annealing on the 240$^0$C temperature, were the maximum of anneal hardening effect was attained. It can be seen that hardness increases for 30,60,120,150 min, due to anneal hardening effect and after that decreases slowly with annealing time. After 5 hours the hardness values is some higher than for cold rolled state. It can be explained by the fact that anneal hardening effect has influence on recrystallization temperature. After 120 min of annealing the maximum hardness values increase due to anneal hardening effect for 30 HV. After 300min of annealing the the recrystallization is not occurs, because the values of hardness is some higher than for cold rolled state.

Figure 7. shows the change of electrical conductivity during annealing time of 300min. annealed on temperature of 240$^0$ C, for alloy CuZn. It can be seen that electrical conductivity increases for the first 30min due to anneal hardening effect and after that, also slowly increases.

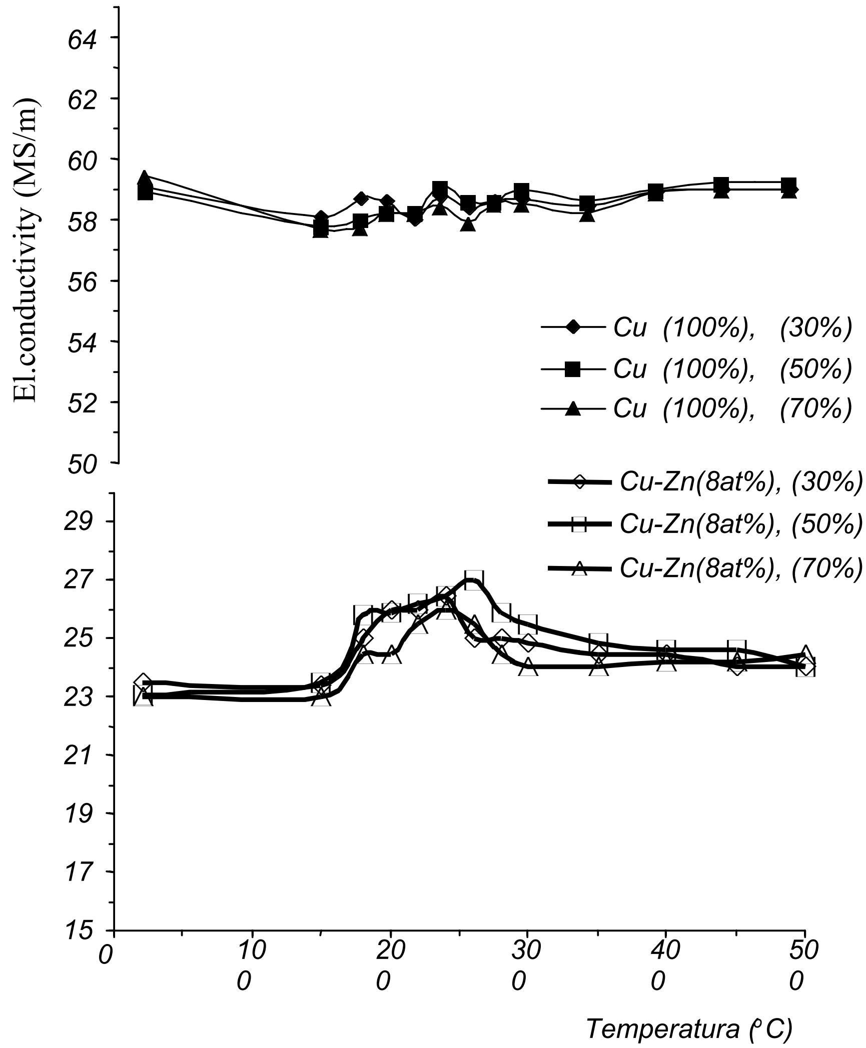


*Figure 5. The change of electrical conductivity of cold-rolled samples of copper and copper alloy with annealing temperature*

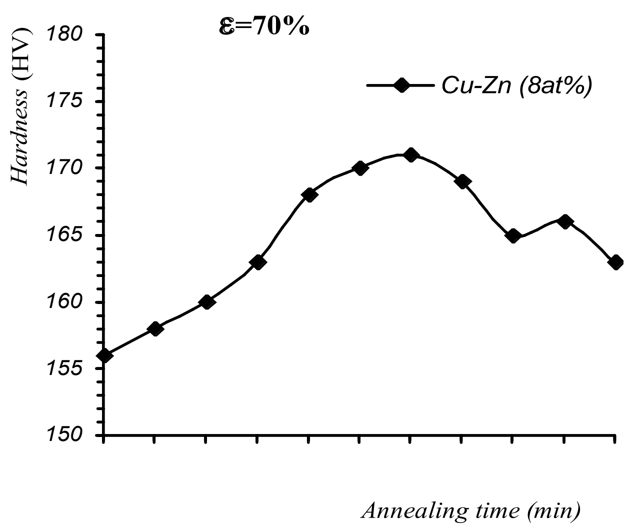


*Figure 6. The change of hardness of cold-rolled (70%) samples of CuZn alloy with annealing time on the 2400C temperature*

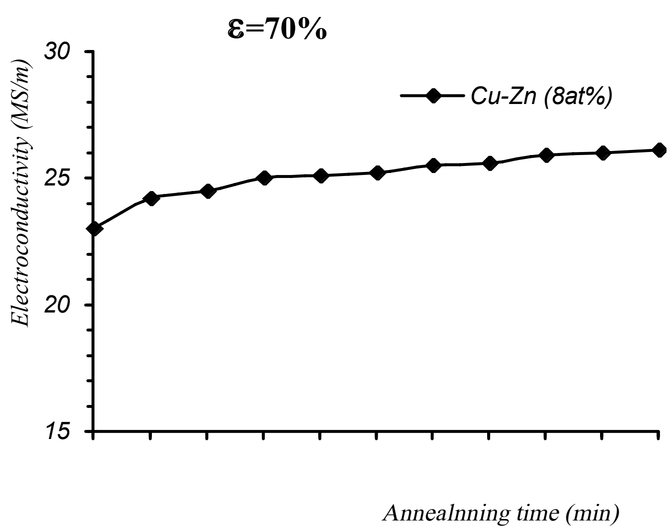


*Figure 7. The change of electrical conductivity of CuZn cold-rolled (70% ) samples with annealing time on the 240 0C temperature*

X-ray analysis shows that lattice parameter changes of cold worked CuZn alloy during annealing, have also led to the conclusion that solute clustering at dislocations should be one of the major causes of the observed changes.

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 AlCr system where a size misfit of about 5 pct exists, similar to the magnitude of the misfit in the CuRh system.

## 4. Conclusions

1. The alloying element zinc were found to have a pronounced effect on the increase the recrystallization temperature of the cold rolled copper alloy CuZn.
2. The anneal hardening effect was attained at alloy CuZn, under recrystallization temperature in the temperature range of 180-300$^0$C followed with an increase in hardness and electrical conductivity.
3. The amount of strengthening increases with increasing the degree of prior cold work.
4. The anneal hardening effect was attained in the time range of 120-240 min.
5. Anneal hardening may be considered as a genuine hardening mechanisms in analogy to the 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 copper alloys.

## References

1. D.G. Morris, *Powder Metalurgy*, (42)1(1999) 20.
2. N.C.Kothari: *Modern Developments in Powder Metallurgy*, Toronto, 16 (1984) 361.

3. S. S. Salkova,T.V. Pisarenko, V.G. Segel, N.N. Pavlov and A.R. Shestyuk: *Russ. Powder Metall.*9(1991) 88.
4. R. Z. Vlasyuk, V. D. Kurochkin, A. A. Mamonova and O. A. Shevchenko: *Russ. Powder Metall.*, 4(1989)43.
5. M.Bader. G.T.Eldis and H. Warlimont: *Metall. Trans.,* 7A (1976) 249.
6. J.M. Vitek and H.Warlimont: *Metall. Trans.*, 10A (1979) 1889.
7. S. Nestorovic, D. Markovic and B. Stanojevic: *Journal of Metallurgy*, Belgrade, (3)4(1997)297.
8 S. Nestorovic and D. Markovic, *Mater. Trans., JIM,* (40)3(1999) 222-225
9. S. Nestorovic and D. Markovic, Advanced Science and Tehnology of Sintering, Eds. B. D. Stojanovic, V.V. Skorkho and M. V. Nikolic, Plenum Publishing Corporation, New York, (1999)617-622.
10. S. Nestorovic and D. Tancic, Europen Congress and Exhibition on Powder Metallurgy, Nice, France, Proceedings, 2(2001)158-164.
11. S.Nestorovic and D.Tancic International Conference Deformation and Fracture in Structural PM materials DF PM 2002, Slovakia, Stara Lesna, Conf. Proceedings, 2(2002)144-147.
12. S.Nestorovic,B.Milicevic and D.Markovic,*Science of Sintering*, 34(2002)167.