Bull. Mater. Sci., Vol. 25, No. 1, February 2002, pp. 59–62. © Indian Academy of Sciences.

Effect of thermomechanical treatment on mechanical properties and electrical conductivity of a CuCrZr alloy

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MS received 13 November 2000; revised 13 November 2001

Abstract. The CuCrZr alloy undergoes processes of precipitation during ageing. Besides precipitation hardening the strength is affected by cold deformation which is performed before and after ageing.

The cold deformation (D_1) before ageing accelerates the process of strength hardening, since it induces higher rate of precipitation from the saturated a-solid solution. Cold deformation (D_2) after ageing primarily affects the alloy strength.

In this paper the results of the effect of thermomechanical treatment on mechanical properties and electrical conductivity of a CuCrZr alloy are presented. The aim of the paper was to evaluate the most suitable combination of thermomechanical treatment and alloy properties.

Keywords. Copper–chromium–zirconium alloy; degree of cold deformation; thermal precipitation during ageing.

1. Introduction

Brasses find application in electro technique because of their high electrical and thermal conductivity. But, they find increasing use in car industry, mechanical building, electronics etc. Also, alloys of this system have application for making electrodes for autogene and electro-arc welding.

The electrodes made of ternary CuCrZr alloy have double life, they yield twice the number of welding spot compared to conventional electrodes made of binary CuCr alloy or CuZr alloy (Nikolaev *et al* 1978). CuCrZr alloys belong to the group of alloys that have high electrical conductivity and moderately high toughness. Consequently they are suitable for high loading parts such as springs, which conduct electricity, contact wheel, etc.

CuCrZr alloy after solutionizing has homogenous a-structure. Chromium precipitates from saturated matrix into either pure chromium and/or intermediate compound Cr_2Zr by the process of precipitation during ageing (Kuznecov *et al* 1979).

The particles of secondary phases, which are precipitated from saturated a-solid solution, participate in the mechanism of hardening. Also, particle shape, size and volume fraction influence the mechanism and degree of hardening (Novikov *et al* 1978). To slow down the alloy softening, it is necessary to decrease the size of particles of precipitate as much as possible and increase its volume fraction (Nikolaev *et al* 1978).

The process of thermomechanical treatment is often used for increasing the strength of CuCrZr alloy. This procedure includes water quenching, cold deformation before ageing (D_1) and precipitation during ageing. The cold deformation after ageing (D_2) is rarely employed. Of course, to reach the best combination of toughness and electrical conductivity it is necessary to make optimal choice of parameters of thermomechanical treatment.

The degree of cold deformation influences the mechanism of hardening, particle size, shape and volume fraction. Time and temperature of solution annealing and time and temperature of precipitation during ageing are the other parameters that are of importance (Novikov *et al* 1978).

According to some authors (Novikov *et al* 1978), the particles of precipitation in the shape of stick change into ball shape following fragmenting due to the use of D_1. Meanwhile, spherodization of particles of precipitation originated during D_1, could be undesirable specially if it is used in the temperature above recrystallization temperature. In other words, increasing of volume fraction of particles of precipitation is desirable while spherodization is not.

Consequently, the degree of cold deformation has a significant part to play in the process of hardening of the alloy and its characterization. Therefore, in this paper, the effect of different parameters of thermomechanical treatment (D_1, D_2, temperature and ageing time) on mechanical properties and electrical conductivity of CuCrZr alloy during precipitation are examined (Durašević *et al* 1998).

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2. Experimental

The CuCrZr alloy used in this work, had the following chemical composition: 0·6 wt% Cr, 0·09 wt% Zr, the rest being copper plus other trace elements. CuCrZr alloy employed conformed to Yugoslav standard JUS C.D12·006.

Alloy was made in middle-frequency induction vacuum furnace into cylindrical ingots 50 mm in dia. The cast ingots were plastically deformed by forging at 850°C to a size of 20 mm dia. After that, they were cold rolled on calibration rollers and drawn up to 4 mm dia. size. Then, they were drawn on trolley up to the diameter which depended on cold deformation before (D_1) and after (D_2) ageing.

The solution annealing was done at 950°C for 1 h in nitrogen protected atmosphere. The quenching was done in water to yield *a*-solid solution.

D_2 was done drawing on trolley with following degrees of deformation: 10%, 20%, 30%, 40% and 50%.

The ageing was done in nitrogen protected atmosphere at following temperature and time periods: 1·400°C, 6 h; 2·450°C, 6 h; 3·450°C, 3 h and 4·500°C, 3 h.

D_2 was done by drawing on trolley with following degrees of deformation: 0%, 10%, 30%, 40% and 50% up to the final diameter of 2 mm.

Samples of all mentioned variants were taken from alloy for mechanical and electrical conductivity examination.

Mechanical properties were evaluated on wire samples of 2 mm diameter and 300 mm length (using "Carl Frank" universal machine, Germany test set up).

Toughness, R_m and elongation degree, A_{200} were two parameters which were investigated in this work.

Electrical resistance was measured on samples of wire 2 mm in dia. and 1000 mm length. The values of electrical conductivity were calculated from the obtained values of electrical resistance.

3. Results and discussion

The mechanical properties and electrical conductivity results are given in figures 1–3.

These results can be investigated to correlate mechanical properties (R_m and A_{200}) and electrical conductivity. Thus it is seen that D_1 accelerates precipitation, which is an important factor in alloy hardening.

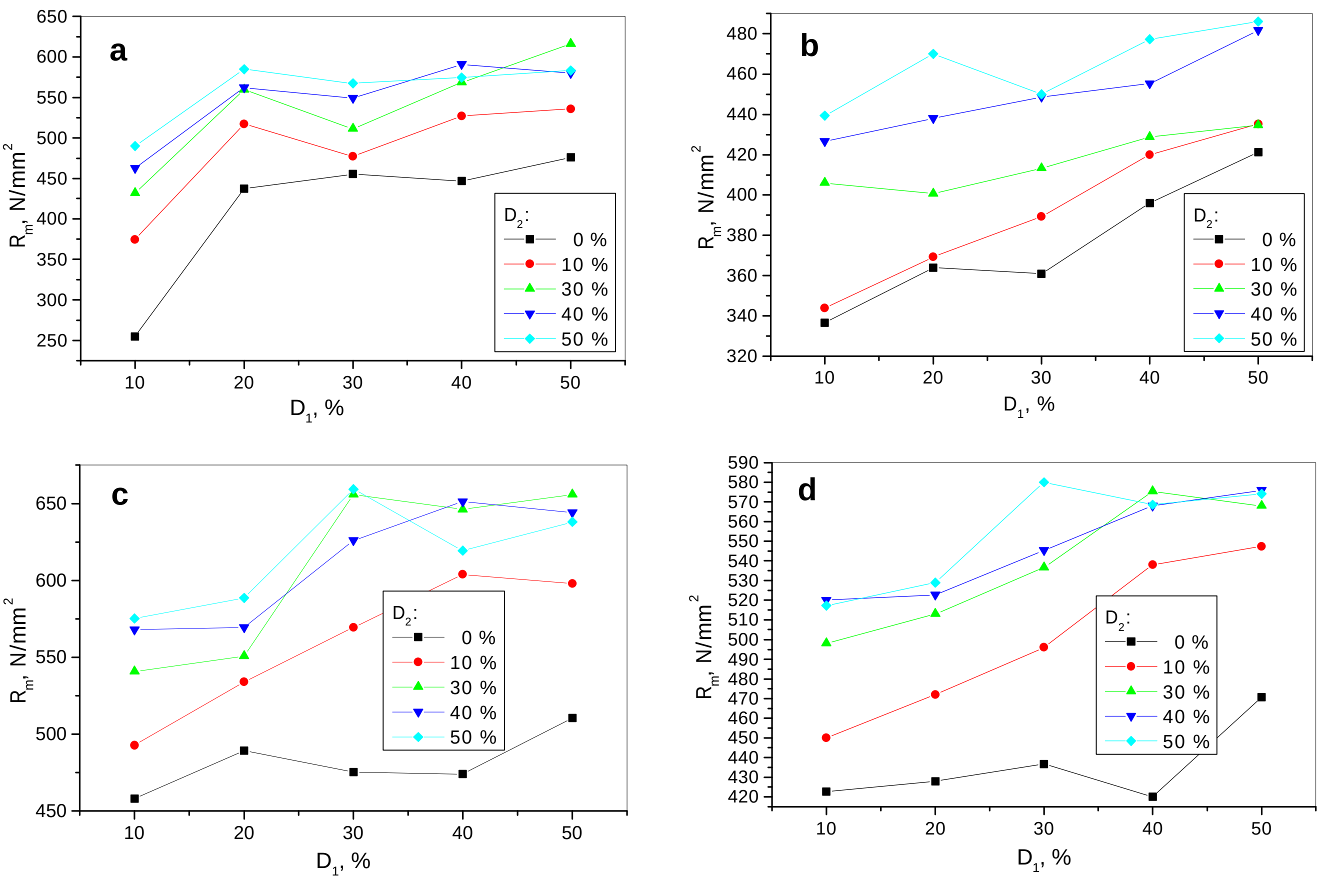

Figure 1. Influence of D_1 and D_2 and ageing parameters on R_m. **a**. 400°C for 6 h, **b**. 450°C for 6 h, **c**. 450°C for 3 h and **d**. 500°C for 3 h.

With increasing D_1, R_m generally increases, while A_{200} decreases, to a small extent and, at the same time, electrical conductivity slightly changes in both directions (figures 1–3).

For the alloy aged at 400°C for 6 h an abrupt increase of R_m (figure 1a), electrical conductivity (figure 3a) increasing with D_1 till 20%, while for A_{200} an initial rapid decrease (figure 2a), can be noticed. With further increase of the deformation degree, R_m, A_{200} and electrical conductivity slightly changed.

Alloys, aged at 450°C for 6 h, 450°C for 3 h and 500°C for 3 h show (figures 1b, c, d) increasing R_m and slightly decreasing A_{200} (figures 2b, c, d) with increasing D_1. At the same time, electrical conductivity changes slightly in both directions (figures 3b, c, d).

Also, noticeable is the fact that R_m shows the highest value at ageing at 450°C for 3 h, while fairly satisfactory results can be seen for ageing at 400°C for 6 h, 500°C for 3 h and 450°C for 6 h (figure 1). A_{200} does not show essential differences, except for samples treated by following regime: $D_1 = 10\%$, 400°C for 6 h, $D_2 = 0\%$ (figure 2). The highest value of electrical conductivity has samples which are aged at 500°C for 3 h, while satisfactory results are obtained on ageing at 450°C for 3 h (figure 3).

Evidently, with increasing D_2, R_m increases (figure 1) because of hardening of the alloy.

The highest value of A_{200} is displayed by sample with $D_2 = 0\%$, while with further increase of D_2, A_{200} slightly changes (figure 2). The changing of D_2 does not show essential influence on values of electrical conductivity (figure 3).

Based on the above presented data the combinations of thermomechanical treatment, which yielded optimal characteristics, are the following: (a) quenching → 50% D_1 → 450°C for 3 h → 40% D_2, (b) quenching → 50% D_1 → 450°C for 3 h → 50% D_2.

The first combination of thermomechanical treatment gave the highest values of toughness ($R_m = 644$ N/mm^2), and electrical conductivity (IACS = 83·81%), and elongation ($A_{200} = 1\%$) is approximately equal to those samples treated by other regimes.

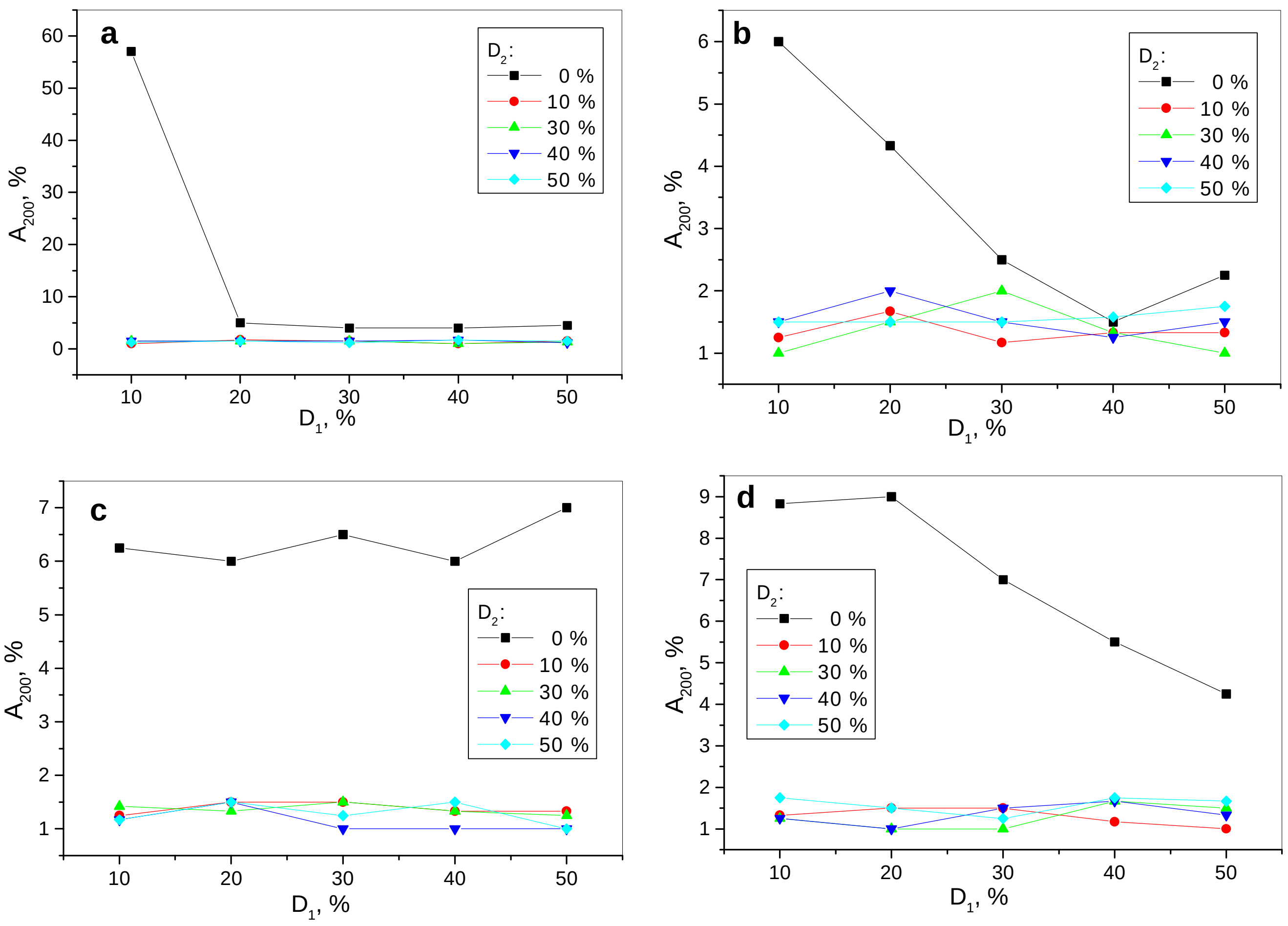

Figure 2. Influence of D_1 and D_2 and ageing parameters on A_{200}. **a**. 400°C for 6 h, **b**. 450°C for 6 h, **c**. 450°C for 3 h and **d**. 500°C for 3 h.

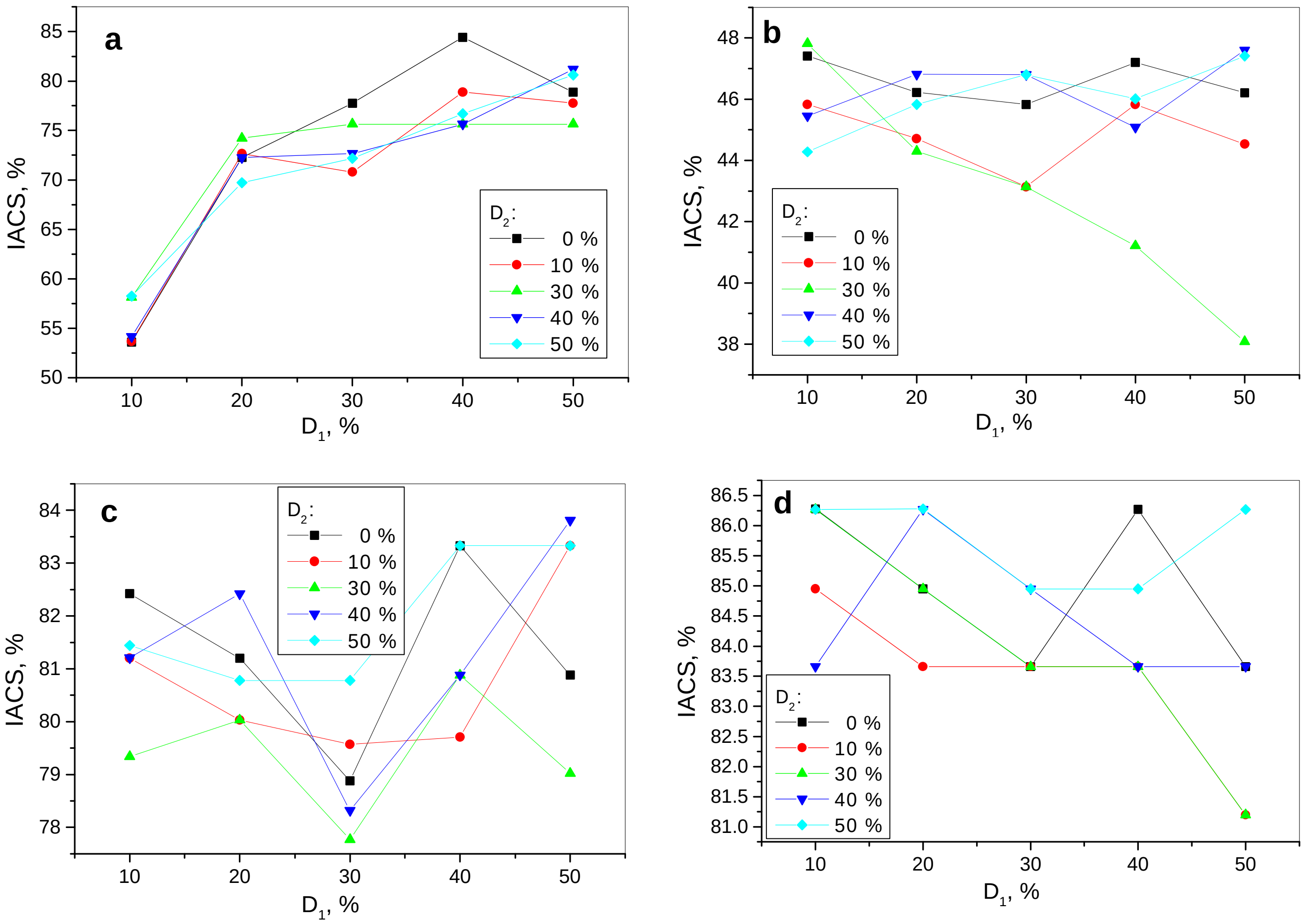

Figure 3. Influence of D_1 and D_2 and ageing parameters on electrical conductivity (IACS). **a**. 400°C for 6 h, **b**. 450°C for 6 h, **c**. 450°C for 3 h and **d**. 500°C for 3 h.

The second combination of thermomechanical treatment gave approximately the same values as the first combination (R_m = 638 N/mm^2, IACS = 83·33% and A_{200} = 1%).

4. Conclusions

Based on results obtained, the following conclusions can be drawn.

(I) With increasing degree of the cold deformation D_1, R_m shows an increase, A_{200} slightly decreases while electrical conductivity changes slightly.
(II) The highest value of R_m is at ageing at 450°C for 3 h. A_{200}, on the other hand, does not show essential differences. Samples aged at 500°C for 3 h have the highest electrical conductivity.
(III) R_m increases with increasing degree of cold deformation, without essential changes in A_{200} and electrical conductivity.
(IV) The combinations of thermomechanical treatment which gave optimal characteristics are the following: (a) quenching $\rightarrow$ 50% $D_1 \rightarrow$ 450°C for 3 h $\rightarrow$ 40% D_2, and (b) quenching $\rightarrow$ 50% $D_1 \rightarrow$ 450°C for 3 h $\rightarrow$ 50% D_2.

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