TEMPERATURE AND DEFORMATION EFFECTS ON THE RECRYSTALLIZATION MICROSTRUCTURE OF WIRE DRAWN COPPER

Salim MESSAOUDI a, Mosbah ZIDANI a, Thierry. BAUDIN b Chems Eddine DERFOUF a, Abdelmalek BOULAGROUN a and Marie Hélène MATHON c

a Department of Metallurgy, University of Biskra - B.P: 145 – Biskra – 07000 Algeria

b Laboratory of Physico-chemistry of Solid State - ICMMO, UMR CNRS 8182 - Building 410 University Paris-South, 91405 Orsay Cedex - France

c Léon Brillouin Laboratory, CEA(DSM-DRECAM) - CNRS, CEA Saclay, 91191 Gif sur Yvette, France

Abstract
The aim of this his work is the study of the effect of deformation and annealing on microstructure and mechanical properties of cold drawn copper wire. It was found that drawing leads, pass after pass, to an elongation of the grains parallel to the drawing axis. This microstructural change was followed by a change in mechanical properties; hardness, tensile and breaking strength increased with deformation level. In contrast, elastic elongation and elongation at break decreased with.

After isothermal annealing at 160 °C, there was a beginning of recrystallization of the deformed microstructure after 9 minute hold. It was found that the surface formed by recrystallized grains increased with the holding time and deformation level, to the detriment of the area occupied by deformed grains. As time is prolonged, recrystallization lead wire towards a ductile state similar to initial state of first wire.

The methods of characterization used in the present study are: optical microscopy, microhardness (load 500 g) and the tensile test.

1. INTRODUCTION
Copper is one of the most popular metallic materials used for electric wire applications [1, 2]. This choice is not influenced only the electrical properties of copper but also by its mechanical and chemical properties. Let us note well that the copper wires used in electric cabling are generally drawn cold [3].

The state of hard-drawn metals is obviously unstable from a thermo-dynamic point of view. The deformation induces dislocations, vacancies (and/or agglomerates) [4, 5, 6]. Heating of this type of material brings about a process of regeneration and recrystallization that restores all the properties featured by the metal before deformation.

In this work, we wanted to examine the evolution of the microstructure and mechanical properties of cold drawn copper wire depending on the level deformation, time and temperature of annealing.

2. STUDIED MATERIAL AND EXPERIMENTAL PROCEDURE
The material used in this study is a commercial copper wire (initial section S₀= 8.00 mm); its composition is given in Table 1.

Table 1 Chemical composition (ppm) of the used copper

| Impurities (ppm) in the copper ETP-1 (Cu min = 99.95% mass) |
|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| O₂ | Ag | As | Sb | Bi | Se | Te | Fe | Co | Ni | Zn | Cd | Sn | Pb | S |
| 201 | 9.6 | 0.4 | 0.4 | 0.1 | 0.2 | 0.1 | 0.8 | 0.02 | 0.7 | 0.1 | 0.01 | 0.05 | 0.2 | 3 |
The drawn samples are collected at factory ENICAB at each wire drawing passes, it returns to us to calculate the deformation level by the following relation:

\[ \varepsilon = \frac{S_i - S_f}{S_i} \times 100 \]

\( S_i \) and \( S_f \) designate respectively the initial and the final sections of the wire. For this work, a large number of drawn wires were chosen.

Then the samples prepared for the study that follows:

- **Metallographic analysis**: optical microscopy (OM) observations of the wire were made along a longitudinal plane and transverse after polishing and etching with (Acids Nitric concentrated 55%).
- **Microhardness**: microhardness Vickers measurements were performed before and after annealing at 500 g loading.
- **Tensile test**: the tensile tests were taken also for both wires with Zwick/Roell tensile testing machine.

3. RESULTS AND DISCUSSION

3.1 Initial state and drawn state

- **Microstructure**

The microstructure of the initial wire shows a little dispersion in grain size on both transversal and longitudinal section. This heterogeneity shares the wire in two areas: the area of the heart and the peripheral zone.

In the case of son drawn, there is a microstructure composed of grains elongated along the axis of drawing. This stretching increase with the deformation level and leads to a microstructure of elongated grains resembling fibers aligned against each other. On cross section, the grain surface is gradually narrowed as the drawing in advance. Towards the higher strains (91.66%), the grains appear to become points.
Microhardness measurements (Fig. 2) show an increase in the hardness of the wire with an increase in the percentage of drawing. This increase is mainly attributed to the hardening caused by the drawing. Related to the previous studies [3, 4, 6, 7-9] deformation causes the formation of dislocation and twins. It was found that deformed Cu contains a high density of dislocations and also small vacancy clusters formed by the agglomeration of deformation-induced vacancies. The presence of these defects constitute barriers which block the movements of the crystalline plans what appears by an increase in microhardness.

Fig. 2 Vickers micro-hardness curve of the copper wire after cold wire-drawing.
Tensile test

The results of the tensile tests reported in table 2, show an increase in the yield stress (Rp0,2) and breaking strength (Rm), and a reduction in elongation at the fracture of drawn wire, compared to the as received wire. The evolution of the elongation at break reflects the behavior of hardened wire. However, the interpretation of the evolution of the elastic limit (Rp0,2) and tensile strength (Rm) is not evident. According to Mohamed G. et al [10], the deformed material stores energy in the form of defaults. This energy is generally proportional to the deformation level applied. So, to further deform this material must apply forces (constraints) that are proportional to the energy stored in it. This clearly explains the increase in the yield stress (Rp0,2) and tensile strength (Rm) in function of increasing deformation level. Finally we can say that these results confirm the state of hardness previously observed.

Table 2 Results of tensile test before and after annealing

<table>
<thead>
<tr>
<th>Deformation level ε(%)</th>
<th>Drawn state</th>
<th>Annealed state</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Am(%)</td>
<td>Rp0,2(N/mm²)</td>
</tr>
<tr>
<td>0</td>
<td>42</td>
<td>140</td>
</tr>
<tr>
<td>28.59</td>
<td>6.1</td>
<td>300</td>
</tr>
<tr>
<td>47.97</td>
<td>2.9</td>
<td>355</td>
</tr>
<tr>
<td>61.40</td>
<td>1.9</td>
<td>384</td>
</tr>
<tr>
<td>71.64</td>
<td>1.8</td>
<td>402</td>
</tr>
<tr>
<td>84.59</td>
<td>1.8</td>
<td>426</td>
</tr>
<tr>
<td>91.66</td>
<td>1.5</td>
<td>443</td>
</tr>
</tbody>
</table>

3.2 Annealed state

Microstructure

According to the microstructures of the fig 3, we can deduce that the annealing at 160 °C allows to start the mechanism of recrystallization in drawn wire. By this observation we can say that the beginning of the recrystallization occurred in the around of the first 3 minutes of holding. This report is deduced from the change appeared on the microstructure of wire deformed with 71.64% and 91.66% and heated during 3 minutes. On the other hand for deformation level 47.97%, the change which occurred does not appear on these microstructures. The change in the microstructure of wire increases according to the time of holding and becomes very apparent after 75 minutes of annealing. According to these microstructures, we can clearly identify the surface occupied by the recrystallized grains and the surface occupied by the grains still in a deformed state. This indicates that the recrystallization still partial in wire witch is strongly drawn. But after 180 minutes of heating the recrystallization appears to be complete in all deformed wires. For the annealing prolonged beyond 300 minutes, we noticed a light increases in grains size compared to the grains of the as received wire.
Fig.3 (OM) Microstructure (500X) of copper wire after deformation and isothermal annealing at 160 °C during: 1 min; 3 min; 75 min and 180 min respectively.

- **Tensile test**
  
The results of the tensile tests of deformed wire and annealed wires, consigned in the preceding table, clearly show a return of the mechanical properties of the wire annealed towards a ductile state near to that of the first wire.

4. **CONCLUSION**

This study allowed us to deduce the following conclusions:

- Drawing causes development of a fibrous microstructure accompanied by a change in certain mechanical properties such as increased hardness, elastic limit and resistance to mechanical failure and the decrease in elongation at break.
- Annealing at 160 °C leads to recrystallization phenomenon just after the first few minutes of holding of deformed wire.
Recrystallization leads to a gradual return of mechanical properties to those of a state close to the initial state.

5. REFERENCES
3. TRAPIED, G., Mise en forme du cuivre et des alliages de cuivre, M660, 1981