EVOLUTION OF TEXTURE AND MECHANICAL AND ELECTRICAL PROPERTIES IN THE COPPER WIRES: DRAWN AND ANNEALED

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Abstract
This study is one following previous work realize on the copper wires. In this work we examine the evolution of the microstructure, the texture and the mechanical and electrical properties on of the DUCAB (98.33% Cu) copper wires.

On the drawn wires, the microstructural analysis showed a microstructure with grains deformed and lengthened parallel to the axis of wiredrawing. After annealing, the microstructure became normal with a new distribution of the grain size, the grain size increased slightly for small and medium deformations and has almost doubled for large deformations (> 80%).

Measures of texture carried out by EBSD, revealed the presence of two competitive fibers <111> and <100> to the deformations less than 45% in the drawn wires. Beyond this deformation it is the fibre <111> which becomes majority. On the other hand, in the recristallized wires it is only the fibre <111> which was majority even for the weak deformations.

With regard to the mechanical and electrical proprieties, we can say that wiredrawing deteriorates these two proprieties. Indeed, we found the decrease in elongation (%) A of the drawn wire according to the deformation increases. There was also an increase in the strength at break (Rm) and electrical resistivity (ρ). After recrystallization annealing at 260 °C for 30 minutes, these proprieties were stabilized at values very close to those of the wire machine (the initial state) for all studied deformations.

Keywords: wiredrawing, recrystallization, microstructure, texture, fiber <111>

1. INTRODUCTION
In spite of the appearance of new alloys, some with good electric conductivities, others with high mechanical, physical and chemical performance; however copper remains the only metal which joined together these properties at the same time. For these reasons copper remain the one of the most popular metallic materials used for electric wire applications [1].

The drawing is the process by which electrical cables are manufactured. The drawing is to reduce the size of a wire by passing through one or more dies, under the effect of a tensile force (stretching). The structural changes brought about by the cold plastic deformation affect the properties of metals. In this work some of these changes like: microstructure, texture, some mechanical properties and electrical resistivity are investigated.

The texture of Cu grains exhibit a major <1 1 1> and a minor <1 0 0> fiber texture in the as-drawn wire condition [2]. This texture is intensified with an increasing number of passes and the ratio of these two components varies greatly with stacking fault energy [3]. the drawing causes a lengthening of grains along the axis of wiredrawing. Like any deformation, wiredrawing causes also a hardening of the structure [1, 2]. The electrical proprieties of copper are still little approached in literature.
2. STUDIED MATERIAL AND EXPERIMENTAL PROCEDURE
The studied material is a commercial DUCAB copper wire-drawn to different rates of reduction. In this study, we defined a deformation level which is calculated by the following relation:

$$\varepsilon = \frac{S_i - S_f}{S_i} \times 100$$

Where: $S_i$ designates the section of the initial state and $S_f$ designates the final sections of the wire.

Tab. 1 Chemical composition (ppm) of the used copper

<table>
<thead>
<tr>
<th>Impurities</th>
<th>O₂</th>
<th>S</th>
<th>Fe</th>
<th>Ni</th>
<th>Zn</th>
<th>C</th>
<th>Sb</th>
<th>Bi</th>
<th>As</th>
<th>Te</th>
<th>Mn</th>
<th>Co</th>
<th>Ag</th>
<th>Pb</th>
<th>Cd</th>
<th>Zr</th>
<th>Si</th>
<th>Se</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppm</td>
<td>220</td>
<td>3.6</td>
<td>0.8</td>
<td>2.1</td>
<td>0.1</td>
<td>0.9</td>
<td>0.4</td>
<td>0.1</td>
<td>0.4</td>
<td>0.1</td>
<td>0.3</td>
<td>0.02</td>
<td>0.4</td>
<td>0.2</td>
<td>0.01</td>
<td>0.1</td>
<td>0.02</td>
<td>0.2</td>
</tr>
</tbody>
</table>

The methods of characterization used within the framework of this study are: electron back scattering diffraction (EBSD), optical and electronic microscopy, microhardness, the tensile test and the measurement of electrical resistivity.

3. RESULTS AND DISCUSSION

3.1 Texture
We should mention that the as received wire (initial state) present an isotropic structure, therefore has no texture in its microstructure

- **Drawn state**
  The EBSD analysis carried out for pole figures (figure 1: a and b) shows the appearance of a texture parallel to the axis of drawing, consisting of two fibers $<111>$ and $<100>$. This made up texture was observed in most works studying deformed copper [4-7]. In some works [6,8,9] the alone $<111>$ fiber was observed. For all deformations examined, it was found that the intensity of the $<111>$ fiber increases strongly than the $<100>$ fiber (Fig. 1: b). This reflects that the majority fiber is the fiber $<111>$ for the cold-drawn copper.
  On ODF (Fig. 3 a and b) the opposite happens, the intensity of the $<111>$ and $<100>$fibers at deformation level $\varepsilon = 90\%$ has decreased compared to that of $\varepsilon = 67\%$. In contrast, the surface of ideal positions has increased. In their work To stack and al. and Jakani and al. found that for strongest deformation ($e>90\%$) it is rather the fiber $<100>$ which is more stable than the fibre $<111>$.
  In conclusion we note that the wire-drawn texture in copper can be described as a combination of two fibers $(111)$ and $(100)$ where $<111>$ is the majority fiber.

![Fig. 1: IPF of $<111>$ and $<100>$ fiber for the drawn state, a) $\varepsilon=40\%$ ; b) $\varepsilon=90\%$](image1)

![Fig. 2: IPF of $<111>$ and $<100>$ fiber the for annealed state, a') $\varepsilon=40\%$, b') $\varepsilon=90\%$](image2)
Annealed state

In the case of the state reheated (fig. 2: a' and b') and (fig. 4: a' and b'), the composition of texture does not change, it is the same fibers <111> and <100> which forms the texture of the recrystallization. For the weak ones and average deformations it is the fiber <111> which appears majority than the fiber <100>. On the other hand, In contrast, for the same deformations, it is clear that the amount (intensity) of the fiber <100> increased compared the deformed state.

In our case, for all the deformations studied ≤ e 90%, it can be concluded that the recrystallization texture is the same as that of the drawn state, with changing ratios of quantities of fiber <111> and <100>, but it is always the fiber <111> witch is remaining majority.

3.2 Microstructure and Grains size evolution

The micrographies of figures (Fig. 5 and Fig. 6) were taken along the cross section of the wire. These micrographs clearly show that there is a grain refinement by increasing the deformation (Fig. 5: a and b). This refinement of grains is actually a contraction of elongated grains along the axis of drawing. The measurement shows the average grain size is from 8 to 12 microns for small deformations ε = 40%. The average grain size decreases according to the deformation increases, it becomes less than 5 microns for large deformations ε = 90%. In the case of annealing at 260 °C for 30 minutes, the grain size does not change much between low (ε = 40%) and high (ε = 90%) strains. For the same strain level, there is a grain refinement between the state drawn and annealed state for all deformations. But if we extend the holding time, this result can changes, as it can be seen in the strong deformation where the grain size less than 5 micrometers becomes up to 11 micrometers.

3.3 Mechanical properties

Regarding the mechanical properties of son drawn, we note that the drawing considerably reduces the elongation and greatly increases the mechanical strength at break as can be seen in Figures 7 and 8. This result is because the high concentration of vacancies and dislocations induced by deformation hardening product. These defaults block the movement and hardens the structure. Usually these defaults are quickly eliminated by heat treatment; indeed after 30 minutes of holding at 260 °C, these proprieties became very close to that of as received wire.
Fig. 5 Microstructure of drawn state:

- a) $\varepsilon=40\%$
- b) $\varepsilon=90\%$

Fig. 6 Microstructure of annealed state:

- a') $\varepsilon=40\%$
- b') $\varepsilon=90\%$

Fig. 7 Evolution of lengthening according to the deformation
3.4 Electrical properties

Figure 9 illustrates the evolution of the electrical resistivity in function of the deformation. In this figure we see that the deformation leads to an increase of the electrical resistivity, this can also be explained by the presence of defaults (vacancies and dislocations) in the hardened structure. After recrystallization the resistivity decreases but remains superior to that of as received wire. This result is due in large part to the grain refinement after drawing. Indeed, multiplying the number of joins grain constitutes barriers on the movement of electrons. On the other hand, if we assume that all other defaults (vacancies and dislocations) are eliminated after annealing, it is recognized that in reality the only change that persists at the annealed wire is its texture. For mechanical proprieties, we can accept that the texture of recrystallization has a contribution on the rate of return of these proprieties to the initial state. But for the electrical proprieties, can we assign a part of this result to the texture formed by the fibers <111> and <100>? At this stage of the research, it is very difficult to answer this question. It can be suggested to do other analyzes and other measures to be able to clarify this assumption.
4. CONCLUSION
The main conclusions that can be taken from this experimental study on copper wire drawing can be
summarized in these points:
- In our case, the texture of the deformed state and that of the annealed condition are identical and are
  composed of two fibers: the majority fiber <111> and the fiber minority <100>.
- Deformation stabilizes the fiber <111> and recrystallization stabilizes the fiber <100>.
- Recrystallization leads to a refinement of the grain depending on the applied strain rate.
- As expected, drawing deteriorates the mechanical and electrical properties of the material by hardening
  microstructure. The return to the stable state is affected by a heat treatment. As to the interpretation
  of the results of electrical resistivity after recrystallization, they are largely attributed to the refinement of
  grains which has increased the number of grain boundaries.

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