Study of texture and recrystallization in commercial pure copper wire with and without heat treatment

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Abstract: Wire drawing is a necessary operation for the production of small diameter electrical wires. During this process, the shaping of the material is performed by a plastic deformation mechanism. The change in the shape of the metal causes the plastic deformation of each grain of the crystalline metal. In this work, we have studied a commercial copper wire. In this study, optical microscopy, electron microscopy transmission, Vickers hardness and X-ray diffraction were used. It is found that cold drawn wires are characterized by texture formation and dislocation cell rearrangement. Isothermal treatments were applied on the deformed yarns, which makes it possible to observe a recrystallization reaction which restores the mechanical properties and the initial structure.

1. Introduction

Wire drawing is a necessary operation for the production of small diameter electrical wires (He et al. 2003). During this process, the shaping of the material is performed by a plastic deformation mechanism. The modification of the shape of the metal leads to the plastic deformation of each grain of the crystalline metal. After the deformation, the displacements following the sliding planes extend the grains in a direction relative to the forces applied. This change of structure gives rise to a texture formation which causes the appearance of a crystalline anisotropy, of variable degree depending on the thermomechanical treatment imposed on the material. This anisotropy, especially after strong deformations, leads to a strong heterogeneity of mechanical and physical properties (Lakhtine 1986).

Materials that generally undergo cold drawing at room temperature producing a marked crystallographic texture, for which the orientation distribution is mainly a function of the degree of deformation and the composition of the alloy. It follows a repair step for a part of elimination of all the facts during the deformation. And on the other hand to regenerate a microstructure of granular morphology and a new preferential orientation.

This study aims to understand the evolution of textures during deformation by drawing. Similarly, the study of microstructural evolution during different heat treatments (Boumerzoug and Baci 2001, Boumerzoug et al. 2002).

2. Experimental procedures

The material used in this study is a commercial copper wire generally used as electric wire (table 1). This material is submitted to successive reduction by cold drawing process from ε = 14, 24 to 92 %. Different techniques have been used for this investigation: Optical microscopy (OM) and transmission election microscopy (TEM) observations of the wire were made along a longitudinal view and transversal section after etching with HNO3 for 1s. The thin foils for TEM observation were prepared from the longitudinal and transversal sections of the drawn wire. TEM was carried out with a electron microscope operating at 200 kV. In order to evaluate the mechanical properties of the wire, hardness Vickers measurements were applied. We notice that the rate of wire drawing is %, with S and So the final and initial section respectively.

X-ray diffraction was performed using the RIGAKU rear monochromator diffractometer and copper anticathode (λ = 0.154 nm). The samples were cut longitudinally and then polished using a colloidal silica abrasive on a vibrating polisher, so as to minimize the damaged area of the surface. The X-ray is therefore representative of grains having their planes parallel to the plane (DL, DT).

Table 1. Chemical composition of the studied material.

Elements of impurity	(Fe)	(Pb)	(Zn)	(S)	(Sn)	(Ni)	(As)	(Sb)	(Bi)
Rate(%)	0.005	0.005	0.004	0.004	0.002	0.002	0.002	0.002	0.001

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3. Results and discussion

3.1. Behaviour of copper wire after cold drawing

In this section, the objective of our study is to know the effect of cold wire drawing on structure and hardness of copper wire. The structure of drawn-wire after a series of section reduction is characterized by a regular orientation of the grains « texture ». Optical microscopic observations have shown after wire drawing (Fig. 1), that the grains align themselves along wire axis (texture) and a phenomenon of grain refinement is observed in the transversal section of the wire (Fig. 1c2). The phenomenon of hardening of the material occurred after cold drawing, because the hardness Vickers of wire increases with increasing the rate of wire drawing (Fig. 1). It is known that in polycrystalline metals, the individual crystals have different orientations, and the resolved shear stress for slip varies from grain to grain. The grain boundaries, being regions of considerable atomic misfit, act as barriers to dislocation motion, which lead to hardening of our material.

In our work, a TEM micrograph shows difference in structure between initial (Fig.2 a) and cold drawn wire (Fig2 b and c) along longitudinal section. A major feature of the deformed microstructures is the occurrence of micro bands (MB) within the grains (2b and c) in contrast to the initial wire (2a). On the other hand, the structure of initial wire is characterized by the presence of dislocation cells. The cells increase by increasing plastic deformation by wire drawing (Baci et al. 2008, Baci 2011).

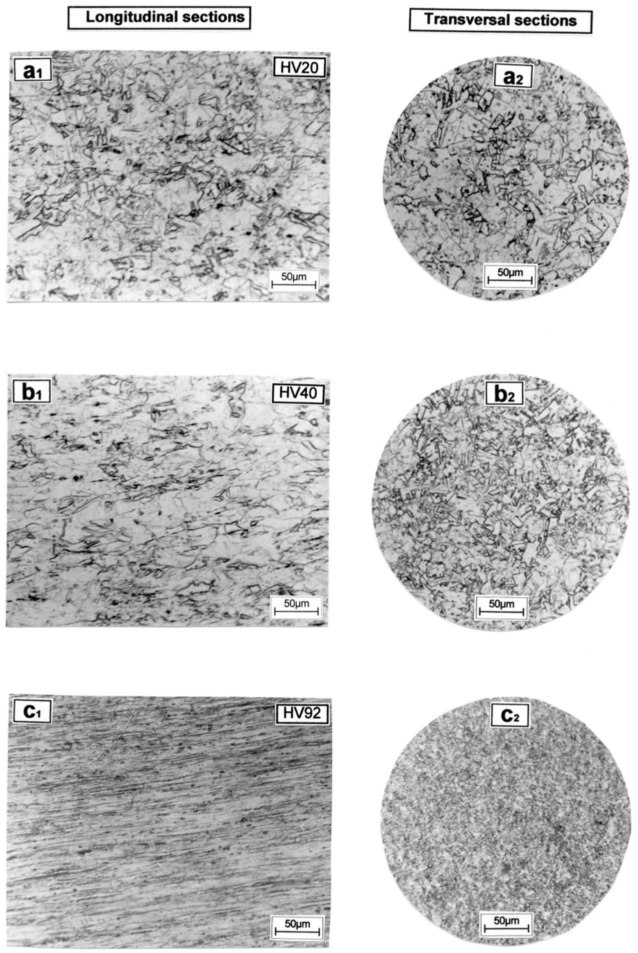

Fig. 1. Microstructures of copper wire: (a) before and after reduction by cold wire drawing: (b) ε = 36,4%, (c) ε =85,62 %.

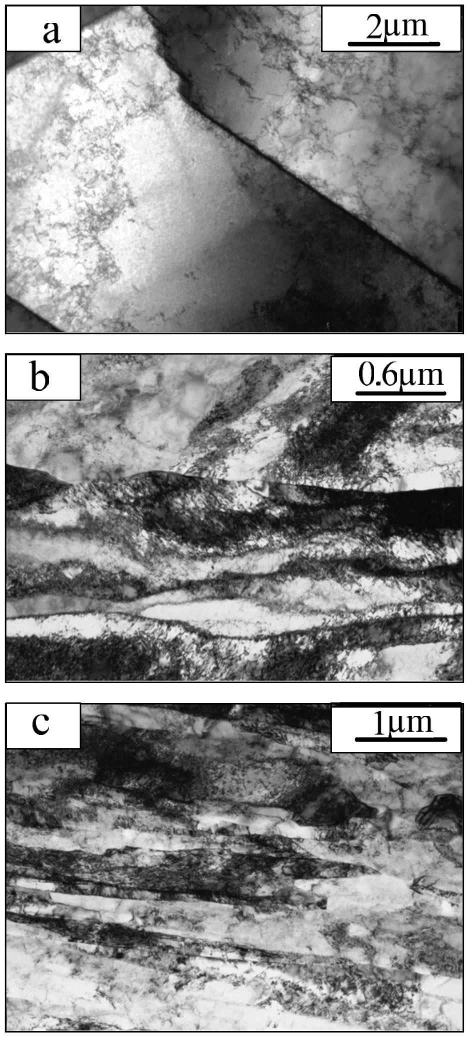

Fig. 2. Observation by MET of (a) copper wire and drawn wire after reduction (b) ε = 36,4%, (c) ε =85,62 %.

The evolutions of the amplitudes of the peaks of the acquisition of X-ray on a longitudinal section (DL, DT) show that the copper generates peak intensity ratios {220} and that this preferentially forms a texture of the {111} type. This finding is reflected in Figure 3, where the changes in intensities according to the rate of reduction. The intensity of the peaks {220} passes through a maximum that can be located at 40-50% of deformation, on can conclude that the texturing type {111} of this material and is less pronounced. It is also probably accompanied by components of varied texture.

3.2. Effect of heat treatment on drawn electric wire

In this part of our study, we have applied an isothermal temperatures (350°C) on our cold drawn wires. However, the state of hard-drawn wire is unstable from a thermodynamic point of view. 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 (Stuwe 1961, Leber 1960, Grewen 1970, François 1991).

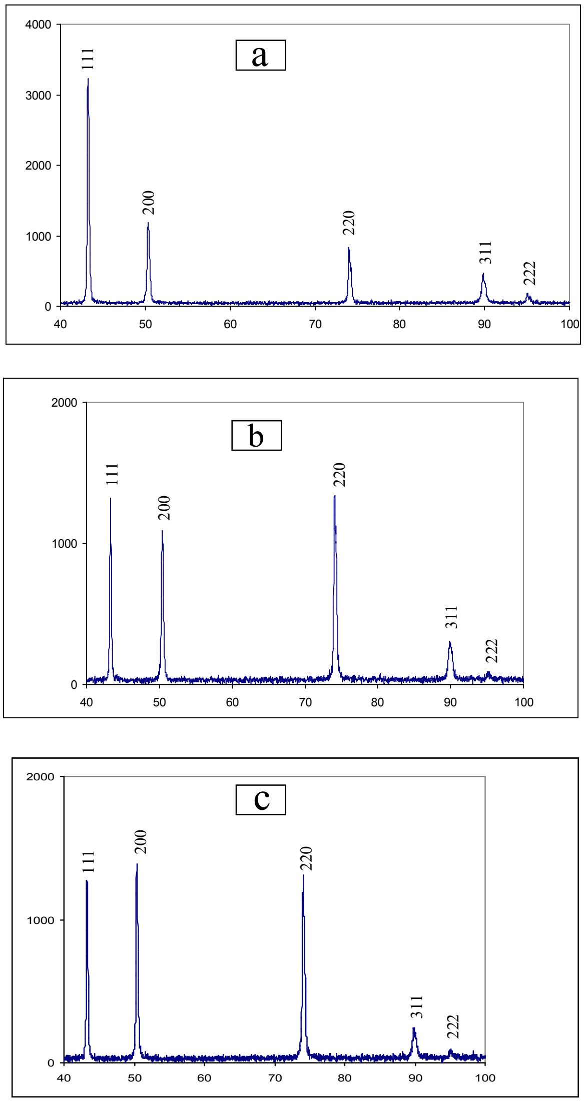

Fig. 3. XRD spectrum of copper wire (a) and after reduction by cold wire drawing: (b) ε = 36,4 % and (c) ε = 74,56 %.

We have observed that this heat treatment has an effect on the structure of drawn wire reduced above a critical plastic deformation εc. On the other hand, this critical zone is confirmed by optical microscopy, we notice, that isothermal treatment (350 °C) applied on drawn wires were performed by optical microscopy (Figs. 4). Observations of annealed drawn wires shows that: - For a rate of reduction below the critical reduction (36,4 %), at 350°C, the structure remains unchanged (Fig. 4a). However, for higher reductions (ε > 36,4 %) a phenomenon of primary recrystallization is developed at 350 °C (Fig. 4b and c). On the other hand, a phenomenon of softening of materials is observed (Figs. 4) by different hardness measurements obtained in our annealed drawn wires.

We conclude that 36,4 % of reduction corresponds to a critical plastic deformation for the occurrence of a recrystallization process. It has been reported, that at elevated temperatures of deformed aluminum, annihilation of dislocations by cross slip and climb becomes easier, dislocations, therefore, have a greater opportunity to be annihilated within sub-grains (Niewczas et al.

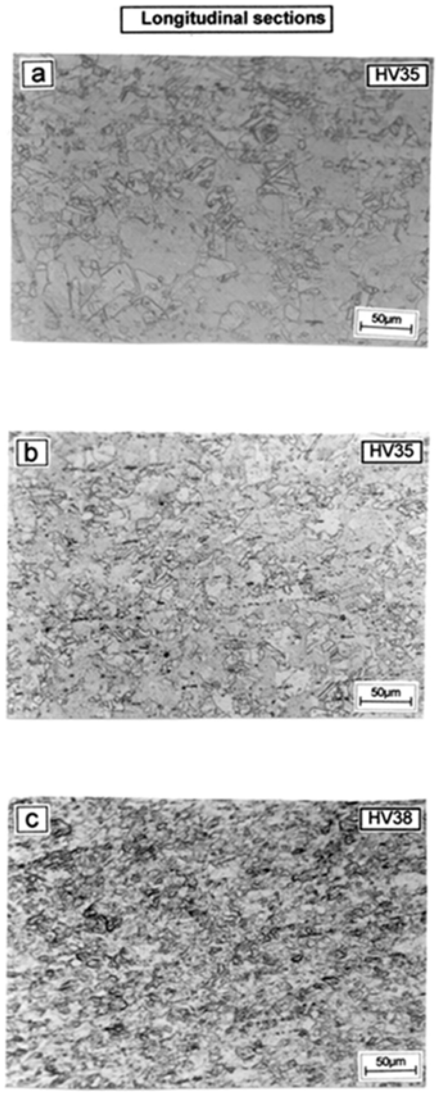

Fig. 4. OM microstructures along longitudinal and transverse section of copper wire reduced by cold wire rawing: ε =14,24 %, (b) ε = 36,4% and (c) ε = 85,62 % and annealed at 350 C for 20 minutes.

2004, Wang et al. 2004). It is obtained that recovery involves the annihilation of point defects and dislocations, the arrangement of dislocation into lower energy configuration and the formation and grain growth of subgrains (Montesin and Heizmann 1990, Humphrey and Hatherly 1996).

6. Conclusion

The results obtained show that the effect of the cold deformation by wire drawing results in a consolidation of the drawn copper. This consolidation results in the formation of a texture with grains very elongated along the axis of deformation, and a decrease in ductility. These effects are all the more marked as the degree of hardening is high. The micrographs of the states analyzed by TEM in drawn copper deformation ε = 36.4%, some areas of the sample show a dislocation cell structure. This type of microstructure invades the sample as the deformation increases. In the drawing direction, these cells are distributed within elongated subgrain. The subgrain walls are assimilated to dense walls of dislocation. The X-ray curves which generates by drawing much higher peak intensity ratios {220} and which therefore preferentially develops a texture of {111} type. This proves the existence of a deformation texture. The recrystallization phenomenon is observed during thermal treatments, but only for plastic deformation ε ≥ 36.4%.

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