STUDY OF INDUSTRIAL ALUMINUM WIRE AFTER COLD WIRE DRAWING AND HEAT TREATMENTS

L. Baci, Z. Boumerzoug, C. Esnouf, M. Bouchear

The effect of plastic deformation by wire drawing on structure and properties of an industrial electric aluminum wire has been studied. Some heat treatments were applied on the drawn wires. For this investigation, different techniques were used: optical microscopy, transmission electron microscopy, hardness measurements and differential scanning calorimetry. We have observed texture structure along axis wire after the wire drawing process. This cold plastic deformation causes a phenomenon of material consolidation. However, the heat treatments applied on drawn wires lead to recrystallization phenomenon. We have found that in low temperature, the recrystallization reaction is observed only for reduction by wire drawing greater than 30 %.

KEYWORDS: wire drawing, plastic deformation, texture, recrystallization

INTRODUCTION

The operation which allows reducing wire diameter is called wiredrawing. The wiredrawing principle uses the metal plasticity to reduce the wire diameter. Wire drawing is one of the most frequently applied techniques in the wire manufacturing industry [1]. This process is one of the oldest metal forming processes. The regular orientation of the grains caused by external stresses during the drawing process is referred to as deformed texture. Formation of texture favors the anisotropy of mechanical and physical properties [2]. Likewise, the wire drawing process leads to consolidation of metal. However, the state of hard-drawn metals is unstable from a thermo-dynamic point of view. Heating of this type of material brings about processes of regeneration and recrystallization that restores all the properties featured by the metal before deformation. Recrystallization of deformed metallic materials is accomplished by the formation of new dislocation-free grains at specific sites in the as-deformed microstructure, their so-called “nucleation'', and their subsequent growth by consumption of the deformed surrounding matrix. The driving force for these processes is provided by the excess dislocation density that has been built up in the microstructure during the proceeding deformation [3]. The purpose of the present study is to clarify the effect of cold drawing on aluminum wire and the effect of isothermal treatment on drawn-wires. The temperatures chosen for this study were 350 and 450°C.

L. Baci
Departement of Mechanic, University of Biskra , BP, 145 , Algeri
baci_lamine@yahoo.fr
Z. Boumerzoug
Departement of Metallurgy, University of Biskra , BP, 145 , Algeria
zboumerzoug@yahoo.fr
C. Esnouf
INSA de Lyon , Villeurbanne , Cedex , French
M. Bouchear
University of Constantine , Ain El Bey Street , Constantine, Algeria

EXPERIMENTAL PROCEDURES

The materiel used in this study is an industrial aluminum electric wire of composition 0.01Cu, 0.08Si, 0.05Zn, 0.01Cr, 0.01Mn and 0.02 others elements. This material is submitted to successive reduction by cold drawing process from $\varepsilon = 17$ 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 10 ml HF + 17 ml HCL + 48 ml HNO_3 + 170ml H2O for 5 minutes. The thin foils for TEM observation were prepared from the longitudinal and transversal sections of the drawn wire. The specimens were examined in conventional TEM Jeol operating at 200 KV. Some slices were cut parallel to the longitudinal section and the transverse section so perpendicular to the drawing axis. The foils were mechanically thinned and then electrop-

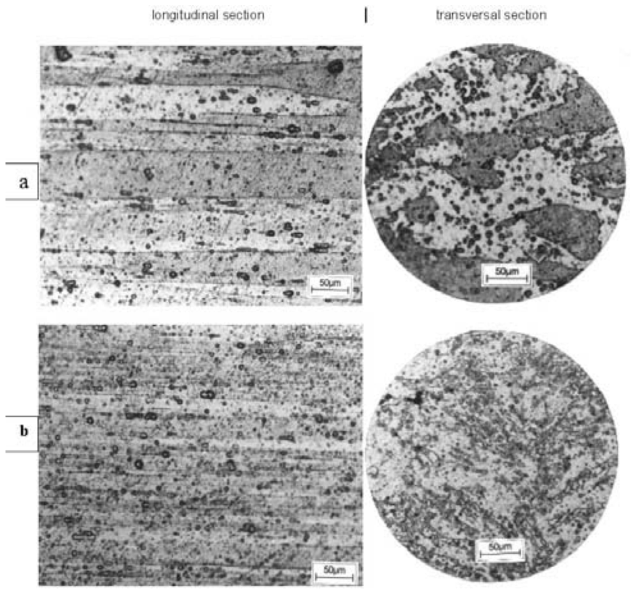

Fig. 1
Microstructures of aluminum wire after reduction by cold wire drawing: (a) ε = 17 %, (b) ε = 92 %.
Microstrutture di fili di alluminio dopo riduzione mediante trafilatura a freddo: (a) ε = 17 %, (b) ε = 92 %.

olished by a jet polishing using an electrolyte solution (80 % ethylic alcohol and 20 % perchloric acid) at 15 °C. In order to evaluate the mechanical properties of the wire, hardness Vickers measurements were applied. For studding the development of recrystallization, a differential scanning calorimetry (DSC) is used. We notice that the rate of wire drawing is $\varepsilon = [(S_0 - S)/S_0] \times 100$, with S and So the final and initial section respectively. Initial diameter is 9.50 mm.

RESULTS AND DISCUSSION

Behaviour of aluminum wire after cold drawing

In this section, our objective is to know the effect of cold wire drawing on structure and hardness of aluminium wire. Optical microscopic observations have shown after wire drawing (Fig.1), that the grains align themselves along wire axis and a phenomenon of grain refinement is observed in the transversal section of the wire (Fig.1b). We notice that after low reduction (ε = 17 %) by wire drawing (Fig.1a), the grains elongate along the axis wire. However, at high reduction (eg. ε = 92 %) ,we can observe that these grains are strongly oriented in the direction of this axis (texture) (Fig.1b).
In our work, a TEM micrograph shows a difference in structure between initial wire (Fig.2 a) and cold drawn wire (Fig b) along longitudinal section. A major feature of the deformed microstructures is the occurrence of micro bands (MB) within the grains (3b) in contrast to the initial wire (3a). The structure of initial wire is characterized by the presence of dislocation cells. We notice, that it has been observed a dislocation structure in polycrystalline aluminium subject to cyclic deformation [4].

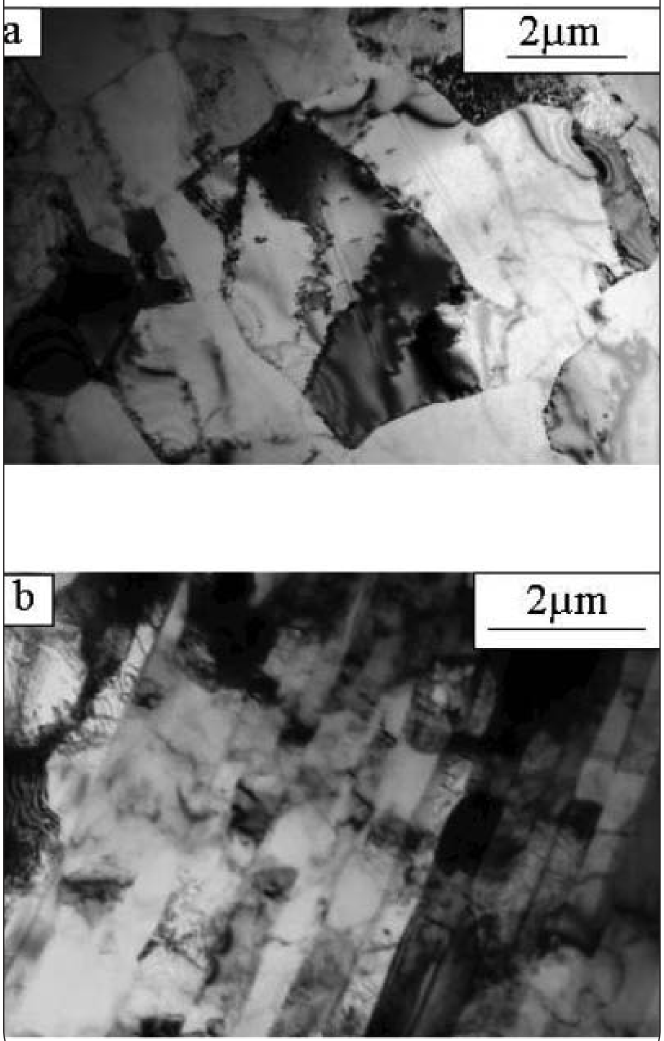

Fig. 2
TEM observations of : (a) aluminum wire, (b) after cold drawn wire (ε= 92 %).
Osservazioni al TEM: (a) filo di alluminio, (b) filo dopo trafilatura a freddo (ε= 92 %).

Effect of heat treatment on drawn electric wire

In this part of our study, we have applied two isothermal temperatures (350 and 450°C) on our cold drawn wires. We have observed that these heat treatments have an effect on the structure of drawn wire reduced above a critical plastic deformation _c. In this study, the hardness measurements were the first technique that allow us to determine ε_c. The comparison between the hardness curves of different drawn wires, i.e., before (Fig. 3-curve a) and after (Fig.3 -curves b,c and d) heat treatment shows that for a rate of reduction of 30 %, the first curve(curve a) crosses the other curves in critical zone. The aluminum drawn wires become softer from this crossing point (ε_c = 30 %). It has been reported, that at elevated temperatures of deformed aluminum, annihilation of dislocations by cross slip and climb becomes

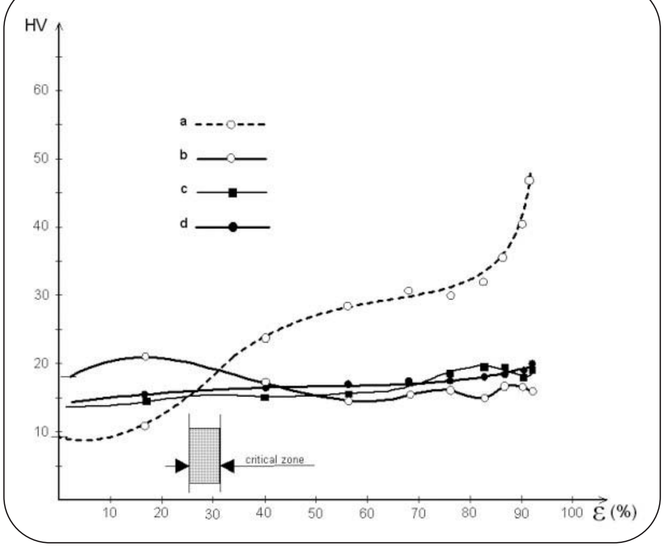

Fig. 3

Vickers hardness curves of aluminum wire after cold wire drawing (curve a) and followed by isothermal heat treatment for 1 h at 350 °C (b-d).

Curve di durezza Vickers di filo di alluminio dopo trafilatura a freddo (curva a) e seguita da trattamento termico isotermico per 1 h a 350 °C (b-d).

easier, therefore, dislocations have a greater opportunity to be annihilated within sub-grains [5].

On the other hand, this critical zone is confirmed by optical microscopy, during two isothermal treatments (350 and 450°C) applied on drawn wires (Figs.4). For a rate of reduction below the critical reduction (30 %), the structure remains unchanged during isothermal treatment at 350°C (Fig. 4a), but only a phenomenon of grain boundary migration is observed at 450°C (Fig.4b). However, for higher reductions (ε > 30 %) a phenomenon of primary recrystallization is developed at two isothermal temperatures (Fig. 4c and d).

The results obtained by optical observations or hardness measurements are confirmed by DSC during the heating of different wires. The curves obtained by D.S.C (Fig. 5) reveal exothermic peaks when heating in the temperature range (250 ¨C 450¡ãC), exactly at 310¡ãC, corresponding to a recrytallization process at this temperature for drawn wires reduced above 30 % (Fig. 5 curves: c-h). The intensity of exeothermic peak increases with increasing a reduction by cold wiredrawing wich corresponding to a quantity of energy stored by plastic deformation. For reductions below 30 %, we can not observe an exothermic peak when heating (Fig. 5 curves a and b). We conclude that 30 % of reduction corresponds to a critical plastic deformation for the occurrence of a recrystallization process in aluminium wire.

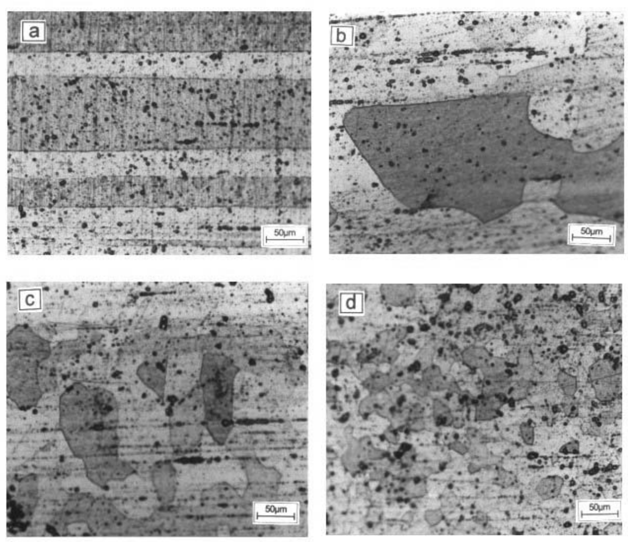

Fig. 4

OM microstructures along longitudinal sections of annealed aluminum cold drawn aluminum wires: (a) reduced ε = 17 % + annealed 1 h at 350 °C, (b) ε = 17 % + annealed 1 h at 450°C, (c) reduced ε = 56 % + annealed 1 h at 350 °C and (d) ε = 56 % + annealed 1 h at 450°C.

Microstrutture OM lungo sezioni longitudinali di fili di alluminio trafilati a freddo sottoposti a ricottura: (a) riduzione ε = 17 % + ricottura 1 h a 350 °C, (b) ε = 17 % + ricottura 1 h a 450°C, (c) riduzione ε = 56 % + ricottura 1 h a 350 °C e (d) ε = 56 % + ricottura 1 h a 450°C.

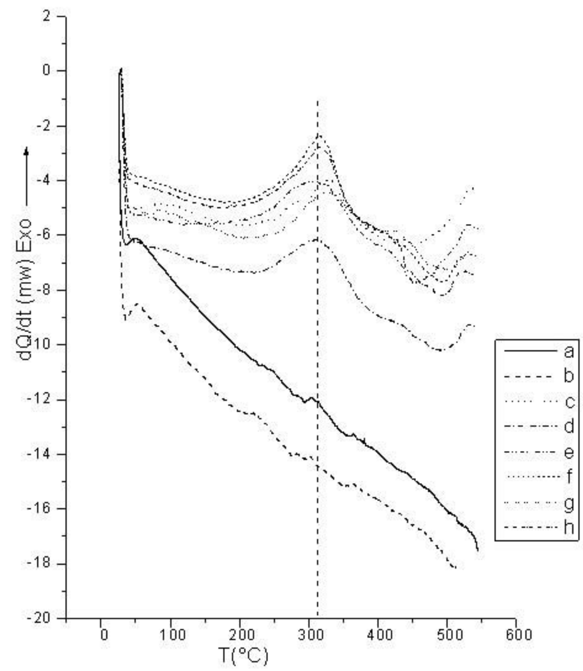

Fig. 5

DSC curve (a) aluminum wire and cold drawn wires (curves b- h : ε = 17 , 56, 67, 76, 82, 87 and 92 %). (heating rate: 5 °C / min).

Curve DSC (scansione calorimetrica differenziale) : (a) filo di alluminio and e fili trafilati a freddo (b- h : ε = 17, 56, 67, 76, 82, 87 e 92 %). (velocita' di riscaldo: 5 °C / min).

CONCLUSIONS

In conclusion, our investigation represents a contribution to the study of the effect of cold drawing on metallic wire. To obtain electric wires which different sections, cold wire drawing is only economic process. The aluminum electric wire is taken as the subject of our study. This material is submitted to successive reductions by cold wire drawing process. We have observed a consolidation phenomenon of drawn wires, characterized by texture structure. On the other hand, the phenomenon of recrystallization is observed during heat treatments, but , only the drawn wires reduced above a critical plastic deformation of $\varepsilon_c = 30\ \%$.

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ABSTRACT

STUDIO SU FILO DI ALLUMINIO INDUSTRIALE DOPO TRAFILATURA A FREDDO E TRATTAMENTO TERMICO

Parole chiave: alluminio e leghe; trafilatura a freddo, deformazione plastica, ricristallizzazione

Nella presente memoria e' stato studiato l'effetto della deformazione plastica mediante trafilatura a freddo sulla struttura e le proprietà di un filo elettrico di alluminio industriale.
I fili trafilati sono stati in seguito sottoposti a trattamenti termici. Per questa indagine, sono state utilizzate diverse tecniche di analisi: microscopia ottica, microscopia elettronica a trasmissione, misurazioni della durezza e di scansione calorimetrica differenziale (DSC). Si e'osservata una struttura a textura lungo l'asse del filo dopo il processo di trafilatura.
Questa deformazione plastica a freddo provoca un fenomeno di consolidamento del materiale. Tuttavia, i trattamenti termici effettuati su fili trafilati hanno provocato il fenomeno di ricristallizzazione. Si e' constatato che alle basse temperature la reazione di ricristallizzazione si verifica solo nel caso di una riduzione mediante trafilatura superiore a un valore critico di deformazione plastica pari a $\varepsilon_c = 30\%$.