EFFECT OF STRAIN RATE ON MICROSTRUCTURE OF A LOW CARBON STEEL WIRE

H. BOUHALAIS , Z.LAROUK

Laboratoire de Microstructures et Défauts dans les Matériaux.
Département de Physique Université Mentouri Constantine- Algérie

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Résumé

L'importance commerciale des aciers au carbone faiblement alliés est du à leurs propriétés de déformation plastique. Ces propriétés de déformation permettent à ces aciers d'être fabriquer sous forme de fils. Cette étude concerne un acier destiné au tréfilage, produit par Trifisoud- Setif –Algerie sous forme de barres et contient (%poids) 0.05%C ,0.3%Mn, 0.1%S et 0.12%Cr. L'analyse par microscopie optique et microscopie électronique à balayage (SEM) est utilisée pour identifier la microstructure du matériau dans les conditions de réception avant et après la déformation. Il a été mis en évidence que les propriétés mécaniques dépendent du taux de tréfilage (τ_W). Les températures de recristallisation et la taille du grain sont déterminées et variaient avec τ_W.

Mots clés: Acier à bas carbone, déformation, tréfilage, microstructure, recristallisation.

Abstract

The commercial importance of low alloy carbon steels is due to their plastic deformation properties. These properties allow them to be formed into useful shapes such as wires. The present steel is produced by Trifisoud- Setif –Algeria and used for wiring. It is a low carbon steel wire containing mainly (weight %) 0.05%C, 0.3%Mn, 0.1%S and 0.12%Cr and is supplied as rods. The optical microscopic and SEM analyses are used to identify the microstructure of the material in as received and deformed conditions. It is found that tensile properties depend on the wiredrawing area reduction (τ_w). The annealing temperatures and the grain size are determined; they also vary with τ_w .

Keywords: Low carbon steel, deformation, wiredrawing, microstructure, recrystallization.

ملخص

ترجع الأهمية التجارية للفواليذ ،التي تحتوي على عناصر سبيكية ضعيفة، إلى قابليتها للتشوه الدائم. تسمح لها هذه الخاصية بتصنيع أسلاك فولاذية. تهتم هذه الدراسة بفولاذ موجه لصناعة الأسلاك من إنتاج شركة **Trifisoud** –سطيف– الجزائر. يحتوي هذا الفولاذ على (نسبة وزنية) **0.05%C, 0.1%S, 0.3%Mn** و **0.12%Cr** . أُستعمل التحليل بواسطة المجهر الضوئي و المجهر الإلكتروني الماسح (SEM) للتعرف على البنية المجهرية للفولاذ قبل و بعد التشويه. بيّنت النتائج أن خواص التشويه تتعلق بنسبة التشوه (τ_W). تمّ تحديد درجات الحرارة لإعادة البلورة و حجم الحبيبات و لقد وّجد أن درجات الحرارة تتغير كذلك مع τ_W. الكلمات

الكلمات المفتاحية : فولاذ سبائكي ضعيف، تشويه، صناعة الأسلاك، بنية مجهرية، إعادة البلورة.

Introduction

The wiredrawing process deals with tension tests in which a rod is stretched. The wire length is increased while its cross section area is reduced. It is a convenient way to shape materials with an increase in hardening. It is well known that plastic deformation involves in wiredrawing increases the density of dislocation. These dislocations, in turn, increase the yield strength of the material [1-2].

The presence of inclusions is very harmful for the wiredrawing process [3]. Gagné and Thibault [4] studied the effect of inclusion size, number, shape, distribution, and composition in hot rolling cast steel billets. Their results suggested that there is relationship between inclusion deformability and composition. They concluded that the number and size of inclusions must be at minimum level and need to be as deformable as possible in steel designed for wiredrawing.

Plastic strain given to the metal before annealing has a profound effect on the recrystallized grain size. Generally, higher strain produces smaller grain size. This effect is well explained by the process of recrystallization which depends on the rate of grain nucleation and growth [5].

1. Experimental procedure

The material is received in long rods with different diameters of 6, 4, 3.18 and 2.45 mm and produced by Trifisoud, Setif, Algerie". The chemical composition (weight %) is shown in table (1).

C	Mn	Si	S	P	Ni	Cr	Cu
0.05	0.3	0.1	0.025	0.02	0.12	0.12	0.12

Table 1

The material is formed using a wiredrawing machine BREITENBACH type Standard 1R/4VZ. The access speed is 3.79 m/s and the out one is 9 m/s, the process is carried out at room temperature using a soap of silicate as a lubricant and tungsten carbide dies.

The reduction of area by wiredrawing (τ_w) is calculated as follow:

$$\tau_w = \left[1 - \left[\frac{d_2}{d_1} \right]^2 \right] \times 100 \qquad (1)$$

Where d_2 is the final wire diameter and d_1 is the initial one. Optical Metallography examination, using a ZEISS microscope equipped with AXIO-VISION software used for image analysis, is carried out on samples after grinding, polishing and etching in a solution of 2% concentrated nitric acid in ethanol. The polished samples are also used for hardness measurements, which were made using a Vickers hardness testing, LEITZ type, at 2Kg load. The measurements are taken from five different indentations. Prior ferrite grain size measurements are carried out on five different images using the three circle technique [6]. Scanning Electron Microscope (SEM) TESCAN type, equipped with energy dispersive X ray (EDAX), is used.

Tensile machine type of ZWICK, of 100 KN as a maximum weight, is used with a deformation rate of 2 mm/min piloted by PC. Specimens for tensile testing are machined from rods and each one have 150mm of length, tensile tests are carried out at room temperature up to fracture.

An annealing of wiredrawing specimens is carried out at different temperatures for different holding times. The total recrystallization temperatures are determined for different τ_w; samples are then quenched in water (table 2).

τ_w (%)	55.5	72	83
T_{rec}(°C)	520	500	480
t_{rec}(min)	300	420	1020

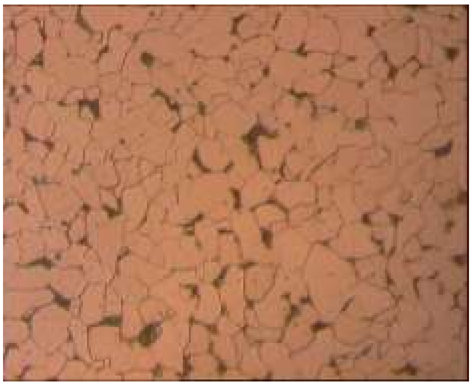
Table 2

2. Results and discussion

The optical microscopic analyses, in as received conditions, show that the material before deformation has a homogenous structure of equiaxed ferrite and pearlite with 11μm of grain size. However, as a result of deformation these grains are elongated in the direction of

Wiredrawing process (Figs.1a, b and c).

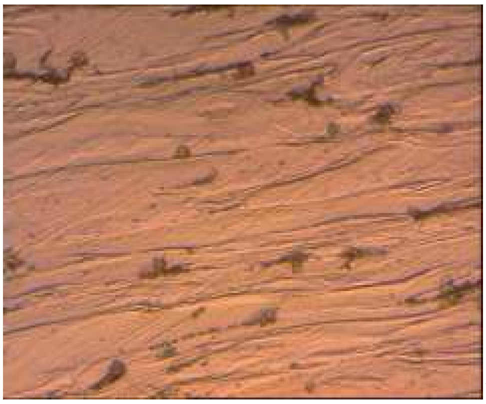
20µm



a

10µm

b



10µm

c

Figure 1 : Optical micrographs of the material in as received conditions: a) ϕ =6mm, b) ϕ =3.18mm, c) ϕ = 2.45mm.

The strength and hardness of the material in as-received conditions are taken as the base strength of the wire. The tensile tests for all specimens, in as received conditions or deformed prior to testing, show essentially similar character. The failure is ductile with a pronounced necking for all wires (Fig.2).

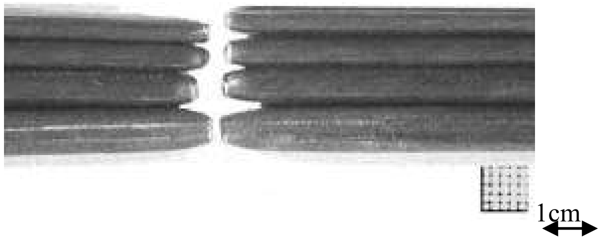


Figure 2 : Optical micrograph showing the ductile failure of the material.

The results are presented in table (3). It can be seen that the tensile properties vary with initial wire diameter prior to testing. The relatively low rupture ductility (ε_r) for the material indicates that there is significant effect of reduction of area prior to testing, due to wiring process. Table 3 also shows the increase of yield str (R_e) and the strength tensile (R_m) as a function of the area reduction (τ_w).

ϕ (mm)	τ_w (%)	Hv (Kgf/mm²)	R_e (N/mm²)	R_m (N/mm²)	ε_r (%)
06	-	122	176.8	370.7	28
04	55.5	222	537.2	613.1	18
3.18	72	229.6	696.7	709.0	22
2.45	83	250.5	713.1	742.0	22

Table 3

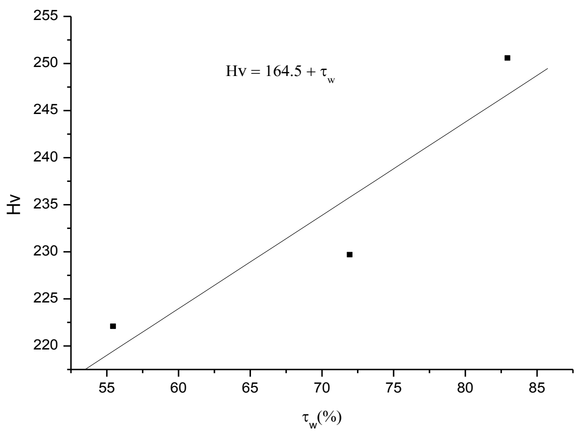
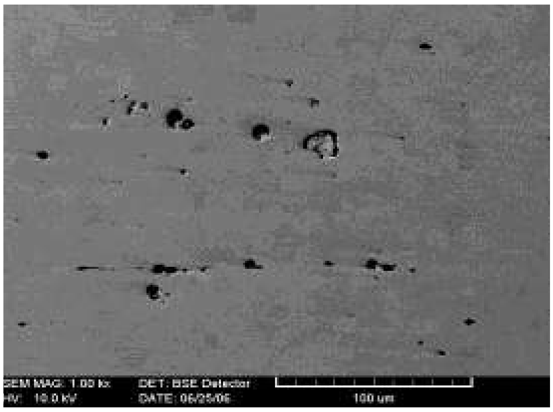


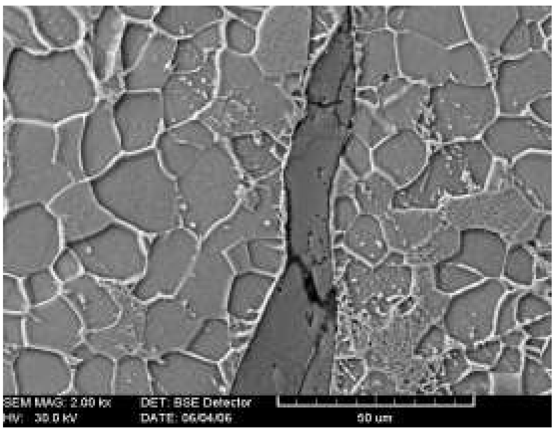
Figure 3 : Hardness as a function of τ_w in as received conditions

This variation is a direct consequence of the increase of dislocation density generated after the wiredrawing process. However, similar results are observed with the increase of hardness (Hv) versus τ_w (Fig.3.). This figure shows a linear relationship between Hv and τ_w. Generally, the hardness of the material increases with strain hardening due to plastic deformation and additional elements (substitutional and/or interstitial)[7]. These elements and grain boundaries play an important part in interacting with dislocations and inhibiting their movement.

SEM examination of the polished cross section in as – received conditions reveals the presence of inclusions which are flat/elongated and distributed at random directions (Fig.4 a and b.).



(a)



(b)

Figure 4: SEM Micrographs (a and b) of polished samples showing the presence of inclusions.

This figure (Fig.4b.) also shows that the cohesion of the inclusions to the matrix is not entire. The weak link between inclusions and the matrix acts as preferable sites for nucleation and growth of micro cracks. Theses inclusions are also found in fractured surface (Fig.5).

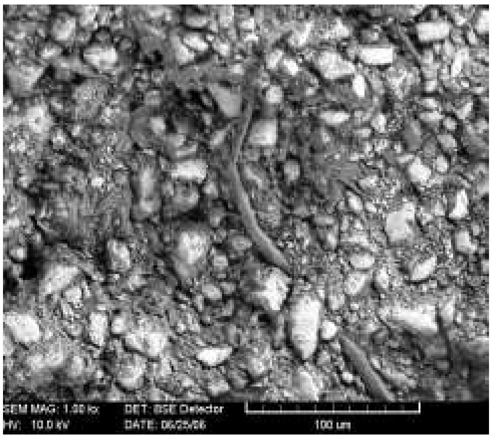


Figure 5 : SEM Micrograph of fractured surface showing the presence of inclusions.

The EDAX analysis shows that the inclusions are iron oxide (magnetite) [8]. The average diameter of these inclusions (D_i) is about 10 µm and the ratio D_i/D_w of the present steel is very low. The reduction per pass of this steel is expected to be quiet high since Tandon et al. [3] found that maximum reduction per pass is inversely proportional to the D_i/D_w.

During plastic deformation energy is stored in the material in the form of dislocations. The process of recrystallization allows it to be released [9].

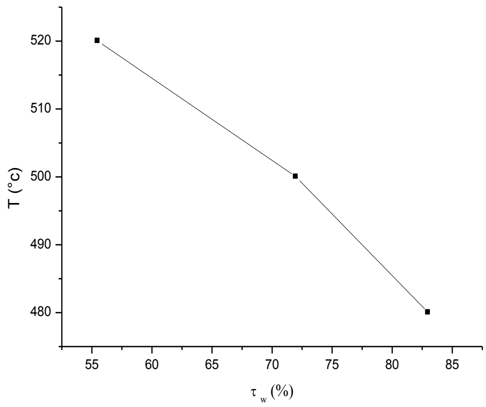


Figure 6 :Total recrystallisation temperature as a function of area reduction τ_w.

Wiredrawing process followed by recrystallization at different temperatures for different annealing times is needed in order to soft the deformed material. Hence, the total recrystallized wires show severe loss in bulk hardness (Table 4). It has been found that the increase of the cold working accelerated the softening of the CP-Ti isothermally annealed [10]. Figure 6 shows that the recrystallization temperature deceases with the increase of the area reduction. The process of wiredrawing raises the multiplication of sites necessary for new grains nucleation.

τ_w (%)	55.5	72	83
Hv_{rec}(Kgf/mm^2)	102	110	120
d_{rec}(μm)	8	7	5

Table 4

The heat treatments of recrystallization are chosen carefully and led to a drastic softening without producing coarse grains (less than 11μm) , i.e result in grain refinement of the structure (Table 4). Figure 7 shows the variation of the hardness of the recrystallized wires (Hv_{rec}) versus inverse root square of corresponding grain sizes (d_{rec}(mm)). It can bee noted that this plot is similar to Petch and Hall relationship [11]. A linear relationship is observed between Hv_{rec} and d_{rec}. This relationship permits to estimate the hardness of the material for a given recrystallized grain size. However, it necessary to note that the slope of this relationship for Ti alloy is much lower than (about 0.22) the slope of the present material [11].

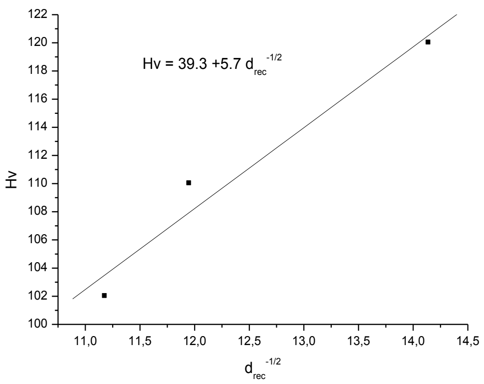


Figure 7: Hardness of recrystallized material versus $d_{rec}^{-1/2}$

CONCLUSION

It is appropriate to sum up the objectives of this study and its achievements

- It has been demonstrated that the initial microstructure is ferrite-pearlite with 11 μm ferrite grain size for the non deformed material. Moreover, the steel contains inclusions with small diameter (about 10μm).
- The wiredrawing process increases material strength.
- Annealing Process results in drastic softening of the material and producing a smaller grain size.
- A linear relationship between Hv_{rec} and d_{rec} is established and is the type of :
  $Hv_{rec} = 39.3 + 5.7\ d_{rec}^{-1/2}$

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