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Abstract :

The dynamic strain aging phenomenon which occurs in some materials under certain temperature and strain rate conditions can cause a localization of the plastic strain in the form of bands (bands of Portevin Le Chatelier) which is detrimental on the material ductility (fracture toughness). At a microscopic strain, this phenomenon is explained by the interaction of mobile dislocations with the interstitial solute atoms. The dislocation gliding is not continuous, but discontinuous. Dislocations are temporarily stopped on the obstacles (forest, precipitates…) during a waiting time t_w. During this waiting time, the diffusion of the solute atoms creates an additional anchoring of dislocations. So, the phenomenon is active in a domain of strain rate and temperature. In C-Mn steels, the diffusive species are carbon and nitrogen and the DSA phenomenon occurs for common strain rate in a temperature range of 150-300°C which complicates the observation.

The increment of plastic strain associated with each band causes an increment in temperature which can be measured by infrared pyrometry. This experimental technique was used in this paper on a C-Mn steel heated around 200°C by an induction furnace to visualize the strain localization patterns. Some characteristics of these bands are measured and thus the evolution of these characteristics according to the strain rate is presented.

Keywords : C-Mn steels, Dynamic Strain Aging, Portevin le Chatelier Bands, infrared pyrometry

1. Introduction

Carbon Manganese steels are common steels very used in construction due to their ductility properties, low cost and ability to mechanical forming. Nevertheless, the metallurgy of these steels is rather complex, du to the interaction of solute atoms with dislocations during deformation which leads to metallurgical instabilities: Lüders strain, Static Strain Aging (SSA) and Dynamic Strain Aging (DSA).If these metallurgical instabilities induce an increase in hardness, unfortunately they produce a decrease of ductility detrimental to components safety [1-5]

In the Dynamic Strain Aging (DSA) phenomenon, the aging is sufficiently rapid to occur during straining. In this case, the localization of the strain is characterized in a tensile test by the formation and the propagation of plastic strain bands called Portevin-Le Chatelier bands (PLC bands). During a tensile test at imposed strain rate, DSA phenomenon is associated with serrations on the stress strain curve [5,6]. Each stress drop on the tensile curve corresponds to the formation of a band.

Three types of bands are identified : type A band corresponds to a continuous propagation of a front band along the specimen, type B band corresponds to the discontinuous but regular propagation of the bands and type C band corresponds to the chaotic formation (discontinuous and not correlated). At a microscopic strain, this phenomenon is explained by the interaction of mobile dislocations with the interstitial solute atoms. The dislocation gliding is not continuous, but discontinuous [7-10]. Dislocations are temporarily stopped on the obstacles (forest, precipitates…) during a waiting time t_w. During this waiting time, the diffusion of the solute atoms creates an additional anchoring of dislocations. So, the phenomenon is active in a domain of strain rate (which impose the dislocations speed) and temperature (which impose the diffusion of solute atoms). In C-Mn steels, the DSA phenomenon occurs for common strain rate in a temperature range of 150-300°C which complicates the observation [3-4].

In C-Mn steels, it is well established that the atoms which interact with dislocations are carbon and nitrogen. According to its greater solubility limit, nitrogen seems exert a more pronounced influence on aging than carbon does [1,2].

The PLC bands observation is extensively studied on aluminium alloys for which the DSA is operating at room temperature. The employed techniques are optical extensometry techniques [11], speckle interferometry techniques [12-13], digital image correlation [14-15], thermography by infrared camera [16-18]. The advantage of this later technique allows to estimate the increment of plastic strain carried out by the bands, which is an important parameter useful for the stress strain curve identification, necessary .

For the modelling of DSA phenomenon, recently, a review of the literature models has been drawn by [19]and for C-Mn steels by [20].

So, in this study, the infrared thermography has been used around 200°C, which is the operating temperature of the DSA phenomenon in C-Mn steels. The heating of the specimens has been achieved by an induction furnace (with an adapted coil inductor), which allows the temperature recording during the tensile tests.

After a presentation of the studied material, the used experimental techniques are described, and the obtained results (bands characteristics) are presented and discussed.

2. Materials

The studied material is a C-Mn Steel which is received as a 40 mm thick plate. The chemical composition (weight percent) is reported in Table 1. The plate is submitted to a prior normalization thermal treatment consisting of austenitising at 900°C followed by furnace cooling (until 300°C) and air cooling, thus leading to a microstructure composed of banded ferrite and pearlite

C	N	Mn	Al
0,190	0,011	1,07	0,0085

This material contains a very low aluminium content (0.0085%). This amount is too small to allow full precipitation of nitrogen atoms by aluminium nitride (AlN) formation during cooling from the austenitic region. Consequently, for this heat treatment, an amount of free nitrogen is still present in the lattice, making this alloy sensitive to Dynamic Strain Aging.

3. Experimental procedures

4. Results

Fig :Stress-strain curve

A rajouter sur la courbe contrainte -déformation

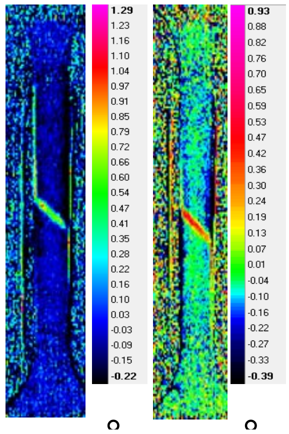


Figure ? represents the position of the initiated bands along the specimen axis. On the graphics of figure ?, this position is normalized by the length of the sample which varies during the test. In order to eliminate the edge effects, only the bands sufficiently far away from the edges (i.e. formed between 10% and 90% of the specimen length) are represented. On figure ? we can notice that the formation of the bands is done in a well-ordered way. We can observe a discontinuous propagation of these bands along the length of the specimen. We can conclude that the observed bands are of type B

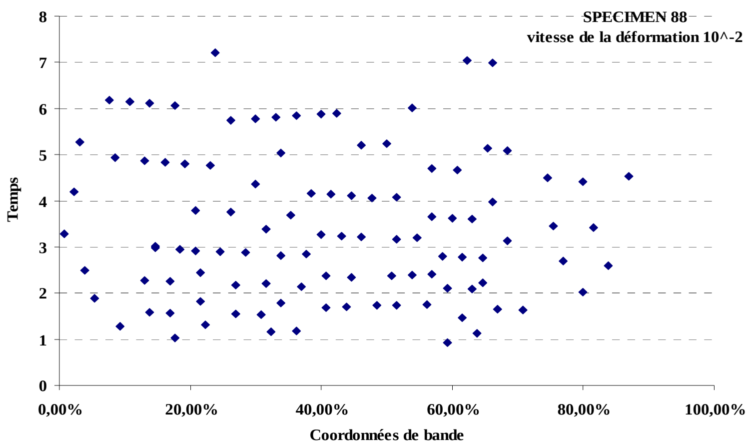
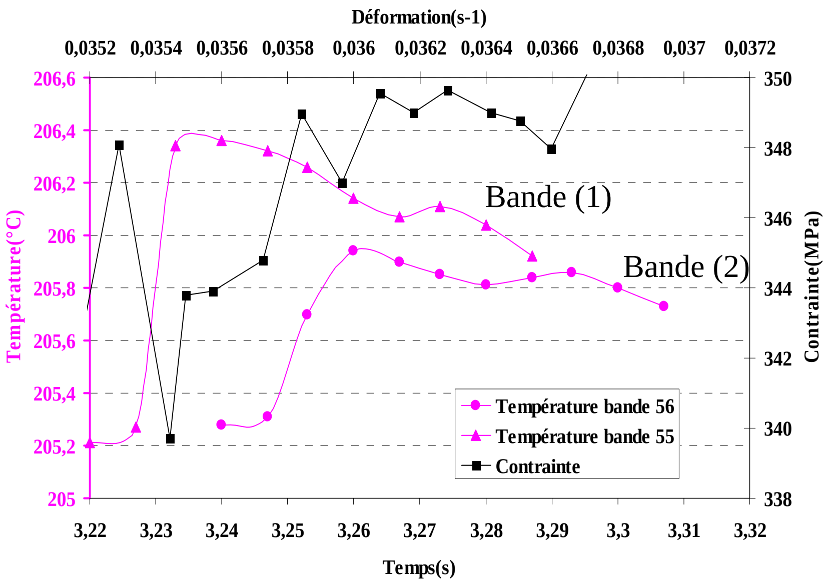
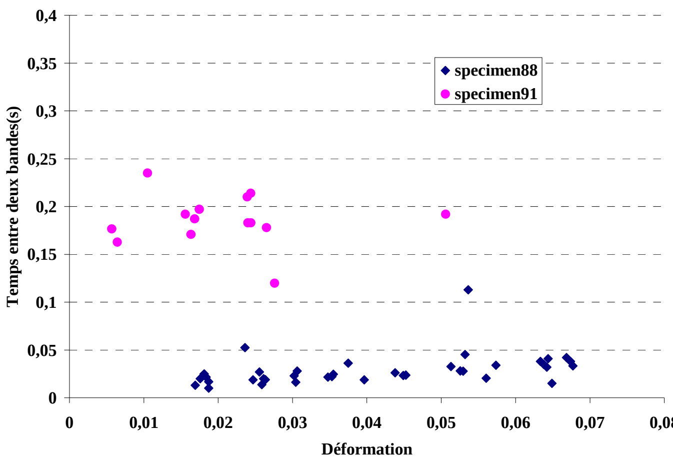


Figure ? shows the temporal evolution of the temperature in the centre of two consecutive bands (pink curve) and the evolution of the stress (for the same deformation). We can notice an increase in the temperature which corresponds to the plastic strain during each band formation. In the case of this test, for a nominal strain of ? , the temperature increment during the formation of the first band (t = ? s) is ?. This curve allows to define the time of band formation and the time between two consecutive bands noted respectively t_f and t_{mb}. The time of band formation is defined as the time corresponding to the temperature increase from 5% to 95% of the total temperature increment in the band (see figure). In the case of the test for a nominal strain of ?, the time of band formation can be estimated at ? for the first band and ?ms for the second. Figure ? also allows to define the time between two consecutive band formations. We suppose that the moment of band formation is the time when the increase in temperature in the band reaches 50% of the total temperature increment. In the case of figure ?, time between two band formations is about ?ms for a nominal strain of ?%.



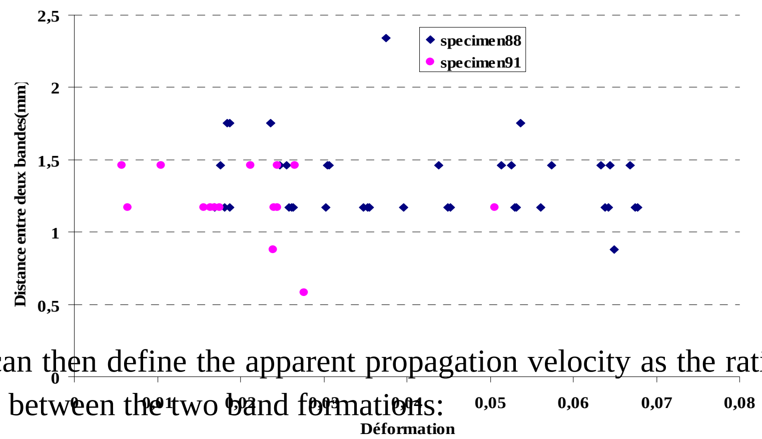
Figure

Figure ? shows the evolution of this time between two bands formation according to the nominal strain for two strain rates, when this quantity is measurable. It is noted that time between two band formations increases with the nominal strain and decreases when the strain rate increases.



The figure ? shows the fields of temperature increment on the specimen surface corresponding respectively to the two band formations presented on figure ?. These two cartographies of the temperature increment show that the increase in temperature and thus the plastic deformation are localised in a band across the width of the specimen. The slope angle between the band direction and the specimen traction axis is of ?± ?°. The figure ? (à faire) represents the profile of the temperature increment along the specimen axis (x axis) which corresponds to the first and the second bands represented on the figure ?. The temperature increment is taken for the first and the second bands respectively between the points A and B and the points A' and B'. These two profiles enable us to define the bandwidth along the traction axis noted *d* and the distance between two consecutive bands along the traction axis noted δ. In the case of the test and for a nominal plastic deformation of ? the bandwidth and the distance between two consecutive bands along the traction axis are respectively equal to ?± ? mm and ?± ? mm. The uncertainty on the bandwidth and on the band spacing is related to the pixel size of the camera. A calculation similar to that presented in **Erreur ! Source du renvoi introuvable.** shows in our case, that a refresh frequency of 320Hz enables us to strongly limit the error on the bandwidth due to the heat diffusion. It can be estimated at approximately 0.05mm what is lower than the size of a pixel (0.3mm).

Figure ? represents the evolution of the band spacing along the axis of the specimen according to the nominal strain for the various tests. This figure shows no variation in the band spacing when the plastic strain increases.

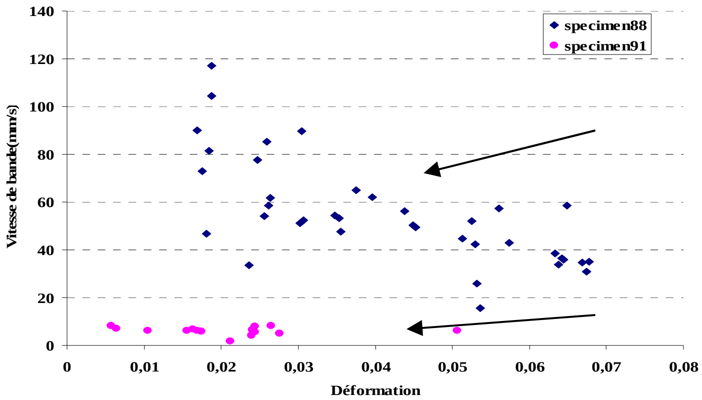


We can then define the apparent propagation velocity as the ratio between the band spacing and the time between the two band formations:

Figure. Distance entre deux bandes consécutive en

$$V_{app} = \delta / t_{mb} \qquad (1)$$

Considering the two consecutive bands presented on figure ? for a nominal strain of ?% and a strain rate of ?s^{-1} we measure d = ?mm and t_{mb} = ? ms. We thus obtains an apparent propagation velocity V_{app} of ? mm/s.



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