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STUDY OF TYPE A TO TYPE B PORTEVIN LE CHATELIER BAND TRANSITION BY INFRARED THERMOGRAPHY

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1. INTRODUCTION

In the dynamic strain aging phenomenon, under certain temperature and strain rate conditions, the plastic strain becomes heterogeneous, and bands of plastic strain of few millimetres of width are created and are propagated along the tested sample. It is the dynamic interaction of mobile dislocations with the solute atoms in insertion or substitution which is at the origin of the phenomenon [1,2]. These bands are known under the name of bands of Portevin Le Chatelier (PLC). For a test at imposed strain rate, they are associated on the tensile curve with repeated serrations resulting from a succession of stress drops.

These serrations on the tensile curve can be classified in 3 types depending on the spatiotemporal appearance of these bands. The type C corresponds to a chaotic creation of the bands (discontinuous and not correlated). Each drop of stress on the tensile curve corresponds to the formation of one band. The type B corresponds to the discontinuous but regular creation of the bands (each new band is created just above of the preceding band and so on). Type A, on a macroscopic scale is the continuous propagation of a band occurring on one edge of the specimen and being propagated until the other edge. A type of serration on the tensile curve which is more or less easily identifiable is associated with each type of band (A, B or C). When the strain rate increases (the waiting time of dislocations decreases) or the temperature decreases (mobility of the diffusing species decreases) the localization of the bands evolves from the type C to the type B and then to the type A.

In order to study the spatiotemporal evolution of PLC bands, we used in this paper the infrared thermography technique [3,4]. Indeed the plastic deformation is accompanied by a dissipation of mechanical work into heat what causes an increase in the temperature. In a first part we will describe the material and the experimental device. In a second part, we will present the results obtained for the bands of the type A and type B. Then we will detail the evolution of the bands parameters according to strain and we will more particularly discuss on the type A – type B transition.

2. EXPERIMENTAL DEVICE

The material used this study is an aluminium-copper alloy (4% copper) heat treated at 500°C during 30 minutes and then water quenched. Immediately after quench, the copper concentration content in substitutional solid solution is high and this alloy is sensitive to DSA in a temperature range around 20°C.

Immediately after quench, tensile tests were carried out on a screw driven machine at the ambient temperature with a strain rate of 1.19×10^{-2} s^{-1}. Prismatic specimens of 12mm width, 3mm thickness and 60mm length were machined.

The measurement of the temperature field on the specimen surface is carried out with a pyrometry technique. We thus use an infra-red camera. The characteristics of the camera and the experimental methodology are given in [4]. In the performed test, the refresh frequency of the camera is 320Hz what corresponds to a period of 3.125 ms.

3. RESULTS AND DISCUSSION

During the test, a transition from type A bands towards type B bands appears when the nominal strain increases. The value of the nominal strain when the transition occurs is difficult to evaluate, because in a strain range around this transition we show at the same time bands of type A and bands of type B. Also it is easier to define the strain range of the transition. We can estimate this transition strain range between 5% and 6%.

In order to explain this transition from type A to type B, we are more particularly interested in the comparison between time of band formation and time between two band formations. The methodology of the determination of this two characteristics is shown in Fig. 1 (for the type B band).

Fig. 2 shows the evolution of the time between two band formations (t_{mb}) according to the nominal strain when this quantity is measurable (type B band). It is noted that time between two band formations increases with the nominal strain. On Fig. 2, we can show that the evolution of the time between two band formations follows a linear law with the nominal strain in a log-log diagram. Thus, we can write a relation between t_{mb} and the nominal strain ε:

$$t_{mb} = D\varepsilon^{E} \qquad \text{with } D = 0.15 \text{ and } E = 0.6068 \qquad (1)$$

The standard deviation between the experimental results and the regression is of 0.07s. The increase of the time between two band formations with the nominal strain was already noted by Jiang et al. [5] in an Al4%Cu alloy. More recently Ait-Amokhtar et al. [6] also showed in experiments that this time between two bands (called reloading time) increases when the nominal strain increases. This effect can be explained by the fact that the waiting time of mobile dislocations and thus the time between two band formations increase with the strain. Indeed, we can express the waiting time t_w according to elementary plastic deformation noted Ω and the strain rate $t_w = \Omega / \dot{\varepsilon}$. It can be consider that the elementary plastic deformation increase linearly with the strain. An increase in the nominal strain thus results in an increase in the waiting time and thus an increase in the time between two band formations.

Fig. 3 shows the evolution of the time of band formation (t_f) according to the nominal strain in the case of the bands of type B. The curve on Fig. 3 highlights a reduction in the time of band formation with the strain. In a log-log diagram (fig. 3), this evolution can be considered as linear. A linear regression enables us to obtain a power law evolution of the time of band formation according to the strain:

$$t_f = F\varepsilon^G \qquad \text{with } F = 0.0008\text{s and } \qquad G = -1.0925 \tag{2}$$

The values measured in this study are the same order as those measured by Louche et al [7] (the development time of the band is estimated at 10 ms in an alloy Al-4wt.%Mg) and by Tong et al [8] (the development time of the band is estimated between 3ms and 5ms in an alloy Al-2.5wt.%Mg). However no data is available in the literature concerning the evolution of this time of band formation according to the nominal strain.

On the Fig. 4, the time between two bands formations t_{mb} and the time of band formation t_f are plotted versus ε from equations (1) and (2). For one strain value, the two straight lines intersect. On the left hand of the intersection, the time of band formation t_f is greater than the time between two bands formations t_{mb}. In this case, it is impossible to distinguish two consecutive band formations and we are in a continuous propagation of the plastic strain front (type A band). From Fig. 4, the intersection is for $\varepsilon = 4.6\%$, that is to say of the same order that the experimental value (5 –6%) determined for the transition type A-type B for the test performed for this study.

3. CONCLUSIONS

In this paper, we studied the Portevin Chatelier bands of type A, B in a Aluminium Copper alloy using the temperature measurement technique by infra-red thermography. We are more particularly interested in the study of the time of band formation and the time between two band formations according to the nominal strain. In particular, we highlighted an increase in the time between two band formations and a reduction in the time of formation with an increase in the nominal strain. We noted that in the case of bands of type B which corresponds to a discontinuous propagation, the time of band formation is lower than the time between two band formations. We also showed that the type A – type B transition from a continuous propagation towards a discontinuous propagation corresponds to the equality between the time of band formation and the time between two band formations.

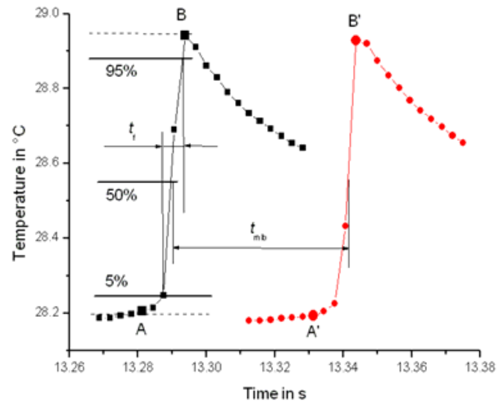

Fig.1 – Temperature evolution in the center of two consecutive bands

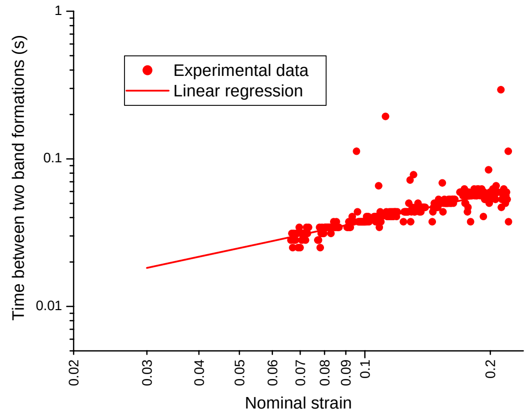

Fig. 2 - Evolution of the time between two band formations

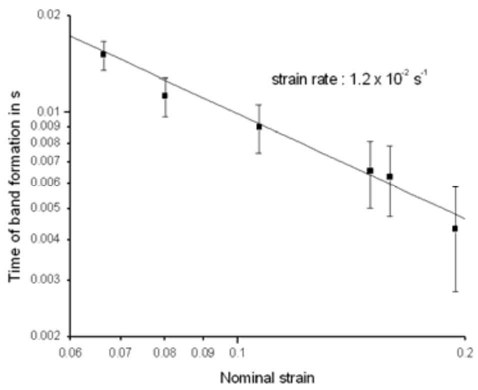

Fig.3 – Evolution of the time of band formation

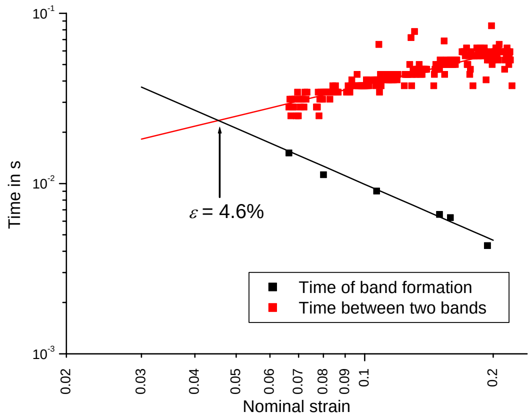

Fig. 4 – Comparison of time between two band formation and time of band formation

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