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Original Research Article

Experimental study of Portevin–Le Châtelier bands on tensile and plane strain tensile tests

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ABSTRACT

The aim of this article is to show that it is possible to create an experimental database to better model Portevin–Le Châtelier (PLC) phenomenon with two kinds of solicitation. Indeed, two kinds of specimen are tested: conventional tensile specimens and specimens designed for plane strain tensile test. In order to better understand this phenomenon and above all to put away any geometry effect, two materials are tested: one without PLC bands (AU4G) that is used as reference and AlMg3 which is well known for its PLC bands. The image correlation tool is used to analyse the creation and the spread of PLC bands. Characteristic parameters of the bands are then measured: width, angle, transported strain, strain rate, and velocity.

The originality of this paper is first to show that PLC bands are present during plane strain tensile test and then to characterize the bands thanks to image correlation. These experimental databases could be very useful for those who develop models on PLC phenomenon.

1. Introduction

In 1923, instabilities in plastic deformation are put into evidence on some light aluminium alloys. These instabilities result in more or less periodic oscillations on the stress versus strain curve. This heterogeneous deformation is at the origin of stress concentration leading to localized deformation in bands. This phenomenon is known as Portevin–Le Châtelier (PLC) effect.

Different authors have studied this phenomenon. For example, Darowicki et al. [1] have presented it as a series of transient signals on a stress–strain curve (serration). The authors have studied the potentialities of a discrete wavelet transformation applied to time-dependent filtering of serration types on the basis of stress–strain curves for aluminium alloys. Klose et al. [2] have introduced the development of PLC strain bands and their propagation by laser scanning extensometry during room temperature deformation of a polycrystalline Al–3 wt.Mg alloy. Maj et al. [3] have studied the influence of a geometrical notch on the PLC effect in an Al3Mg alloy.

Jobba et al. [4] have analysed the flow stress and work hardening behaviour in series of AlMg solid solutions between 4 K and 298 K. Sarmah et al. [5] have investigated the

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Table 1 – Mass composition of the 2 studied aluminiums.

	%Si	%Fe	%Cu	%Mn	%Mg	%Cr	%Ni	%Zn	%Ti	%Ag
AU4G	0.705	0.442	4.508	0.598	0.671	0.040	0.0046	0.222	0.051	0.00073
AlMg3	0.225	0.503	0.060	0.451	2.780	0.039	0.0039	0.067	0.016	<0.0005

Grey shade shows the magnésium percentage difference of the 2 aluminium.

correlation between the band propagation property and the nature and amplitude of serrations. Coër et al. [6] have studied the jerky flow in an AlMg alloy studied during simple shear tests at room temperature and various strain rates. Their paper features that both Piobert–Lüders and Portevin–Le Châtelier phenomena can be observed for a simple shear stress state. Kovács et al. [7] have examined PLC plastic instabilities in constant loading rate tensile tests. The authors have observed irregular instability steps in an intermediate stress rate region on the stress–strain curves.

Ozgowicz et al. [8] have studied the application of the acoustic emission (AE) method for the determination of mechanical properties of continuously cast industrial tin bronze CuSn6P, which reveals tendencies to unstable plastic flow connected particularly with the PLC effect. Mazière et al. [9] have investigated the critical condition for the occurrence of serrations during PLC effect on the AlMg aluminium alloy AA5754.

These bands were visible with eye and sometimes audible by human ear. This phenomenon also appears in other alloys, depending on the material composition and the conditions of the solicitation (strain rate and temperature). The magnesium-containing aluminium alloys are subject to a greater number of studies and researches as they are subject to this phenomenon.

The tensile test is classically used to highlight this phenomenon. It has been studied by numerous researchers such as Klose et al. [2,10], Onodera et al. [11], Kovács et al. [12], Jaroslav [13], Casarotto et al. [14] and Schneider et al. [15].

Modelling this phenomenon of strain localization is of interest and some models have been developed (Graff et al. [16,17], Wang et al. [18], Hu et al. [19] and Wang et al. [20]) and it is always interesting to confront these models to relevant experimental data. The confrontation is generally done during a tensile test and it could be interesting to do it for other kind of strain paths. This paper is divided into two main parts. In the first one, materials and the experimental setup are presented. In the second part, 2 solicitations are studied: tensile test and plane strain tensile test. In order to put away the geometry effect from PLC phenomenon, two different aluminiums are tested: AU4G and AlMg3. In this part, digital image correlation is exploited and so many characteristics of the bands are given such as propagation, width, angle, transported strain, and strain rate.

2. Materials and experimental setup

2.1. *Studied materials*

Two kinds of materials have been studied in this study: AU4G aluminium (2017 A) and aluminium containing magnesium (5754) which will be noted AlMg3. Their mass composition are given in Table 1.

2.2. *Samples*

Two kinds of sample are used to characterize the PLC effect. The dimensions of the samples are shown in Fig. 1: (a) for tensile test and (b) for plane strain tensile test.

The thickness is 1.5 mm for AU4G and 0.8 mm for AlMg3.

The rectangular shape for tensile test is classically used seeing above all when digital image correlation (DIC) is used to determine strains. The shape of the sample for plane strain tensile test with two holes has already been validated [21,22].

2.3. *Tensile experimental device*

All specimens defined in Fig. 1 are solicited using a tensile testing machine (INSTRON 5569 with a 50 kN load cell) coupled with a camera (CMOS EoSens CL 1280 × 1024 pixels). It is then possible to use image correlation tool to determine displacement and strain on the whole surface of the sample. The only condition is to put a speckle pattern of black and white paintings on the sample and to regularly take pictures during the test.

3. Influence of the solicitation on PLC bands

3.1. *Tensile test*

The first work is to found again what has already been observed during tensile test [23,24]. The first specimens (Fig. 1a) are solicited at room temperature with a speed of 5 mm/min and images are regularly taken (frequency: 1 im/s). The curves load versus time are given for the two aluminiums in Fig. 2.

The load serrations typical of PLC phenomenon are visible only on AlMg3: the tensile curve in Fig. 2b shows serrations

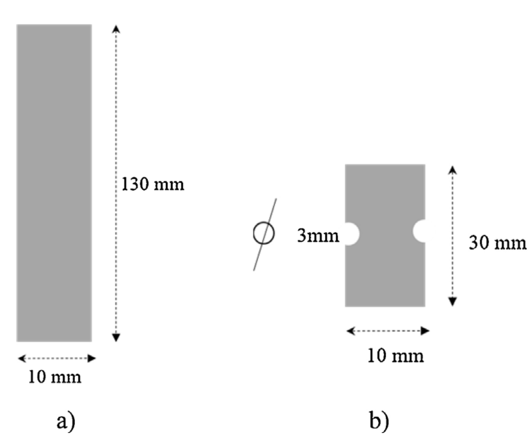

Fig. 1 – Dimensions of the 2 samples for (a) tensile test and (b) plane strain tensile test.