Study of Lüders bands in a bainitic steel

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Abstract

In this paper, Lüders bands are studied using Digital Image Correlation (DIC). Monotonic tensile tests were performed on flat bainitic steel samples. Strain localization in form of bands and propagation was observed but, unlike Lüders phenomenon, the strain remains inhomogeneous during the whole test and this first strain localization will be the precursor of necking and fracture. This phenomenon will be further investigated by looking at the microstructure of the sample and by following the deformation of the microstructure at several moments during a tensile test.

Introduction

Several metallic alloys exhibit Lüders bands, which correspond to a material instability resulting into inhomogeneous deformation at the mesoscopic level. In the presence of Lüders bands, the stress/strain curve exhibits a peak of stress more or less pronounced, followed by a plateau where the strain increases at constant stress. Locally, at the beginning of the plateau, a strain localisation in a form of a slip band develops and propagates through the whole sample. At the end of the plateau, the strain should be homogeneous in the whole sample. Physically, this phenomenon is attributed to the interaction of the solute atoms with the mobile dislocations. During aging, the solute atoms diffused toward the dislocations, therefore, a higher stress level is required to unpin the dislocations and start plastic deformation. The dislocations are unpinned progressively in the sample which corresponds to the propagation of the strain band during the plateau. [1,2]

This effect can be observed through various methods like the brittle coating [3] or infrared camera [4], but one of the most common techniques is Digital Image Correlation (DIC). This is a contactless technique used to measure local deformation on the whole surface of a sample.

The aim of this work is to study Lüders bands and strain localization in a bainitic steel during tensile tests using DIC technique.

Material and method

Monotonic tensile tests were performed at room temperature on bainitic steel flat samples. Digital Image Correlation (VIC 3D software) was used to measure the local strain on the sample's surface. A sensitivity study to some of the DIC parameters was performed in order to determine the appropriate post-processing parameters (subset, step, and filter size) for our study. The subset corresponds to the size of the square that will be tracked to measure the displacement, the step corresponds to the distance between the centres of two subsets and the filter size to the number of points used to compute strain from displacement. The size of the virtual strain gauge can be computed using the following equation:

$$L_{vsg} = step\ x\ (filter\ size - 1) + subset \qquad (1)$$

The smaller the virtual strain gauge is, the more accurate the study of local phenomenon, for example necking, will be. The bigger the virtual strain gauge is, the lower the spatial resolution is, which can lead to an underestimation of strain to fracture in that case. However, a smaller resolution also tends to create a lot of noise, which directly affects the precision of the measure at low strain, for example the computation of the Young's modulus. The choice of appropriate parameters must be a compromise regarding the aim of the study.

Results

Fig. 1 shows the local strain on the sample's surface at several moments during the tensile test, highlighted by black dots on the stress/strain curve. We observe a localization of the strain at the beginning of the plastic deformation followed by a propagation of the strain along the specimen. Unlike classical observations of Lüders bands, the strain field at the end of the propagation is not completely homogeneous but presents a strain localization which will be the precursor of the necking area.

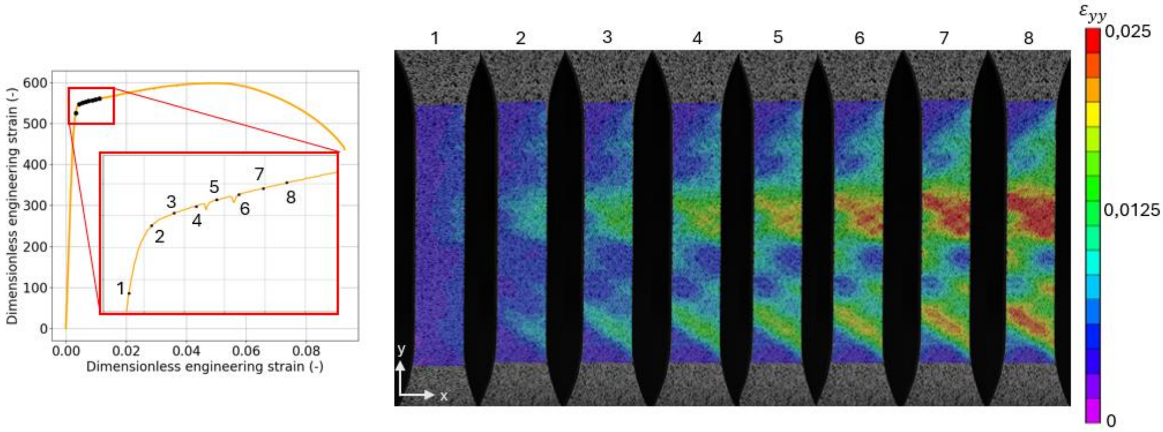

Figure 1 Strain field on a sample at several moments through the test, highlighted by the black dots on the engineering stress/strain curve on the left.

Fig.2 shows the strain rate on a line along the sample through the test. The index on the x-axis corresponds to the index of the image taken during the test. The right y-axis corresponds to the stress curve, plotted with white dashes, while the left y-axis represents the position on a line along the sample (represented by the red dash path on the tensile specimen). We can see on this figure that the plastic strain starts at two locations (at approximately index 70) and propagates afterwards through the whole specimen. The strain in one of the two localizations zones remains higher and happens to be the precursor of the necking area later on.

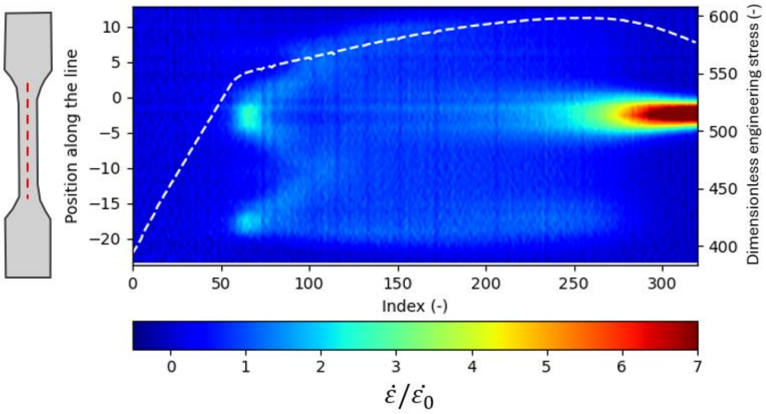

Figure 2 Strain rate on a line along the sample through the test. The right y-axis corresponds to the engineering stress curve, plotted with white dashes. The y-left axis corresponds to the position on a line along the sample (represented by the red dashes).

This phenomenon is not conventional and will be further investigated by observing the microstructure of the sample. A sample will be polished on one side, to be able to observe the microstructure. On the other side of the sample, a regular speckle pattern will be applied to compute macroscopic strain field using DIC. A tensile test will be performed by pulling on the sample until a certain amount of strain, then the sample will be unloaded, and an image of the microstructure will be taken on the whole length of the sample. The process will be done at several strain levels on the same sample. Eventually, DIC will be used to compute strain on the images of the microstructure.

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