Deformation Behaviour and Damage Formation in DP1000 at Different Scales using Digital Image Correlation

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Abstract. In this paper, deformation behaviour and damage initiation is studied in Dual Phase steels (DP1000) using Digital Image Correlation (DIC) at the scale of the microstructure. Tensile tests are carried out until failure inside a Scanning Electron Microscope (SEM). Images recorded at regular intervals throughout the test are subsequently processed using Digital image Correlation (DIC) for full-field strain measurements. Low and high magnification images are used at every step in order to analyse deformation and damage at different scales with both statistically-meaningful results and accurate strain measurements around damage sites.

Introduction

Dual Phase steels have gained a lot of attention primarily in the automotive industry due to their ideal combination of excellent formability and high strength to weight ratio. These attributes enable car manufacturers to reduce the weight of vehicles while ensuring passengers' safety during impact. In order to fully maximise the potential of DP steels towards the development of future steels with improved properties, further research is focused on understanding the deformation and failure mechanisms operating in DP steels at the microstructural scale. Although various studies based on full-field strain measurements carried out at the scale of DP steels' microstructures have been published in recent years (e.g. [1],[2]), results are often reported over small areas of microstructures and/or with limited spatial resolution. This work has been focused on developing a new experimental procedure to produce statistically-meaningful results over representative areas of microstructures with high spatial resolution.

Experimental Methods

Material. The material investigated for this study is DP1000 steel supplied as 1.5 mm-thick sheets. A tensile specimen is first polished and then etched in a 2% nital solution to reveal the microstructure shown in Fig. 1(a). The white phase in the image corresponds to martensite while the dark phase is ferrite.

Experimental Procedure. The sample is tested using a 5kN tensile micro-test module stage working inside the SEM chamber. The test is interrupted at regular intervals, until failure, to record images at both low and high magnifications (300x and 800x). Images are subsequently analysed using the LaVision [3] DIC software to produce strain distribution maps using the natural features of the microstructure.

Results

Tensile strain distributions over a large area of the microstructure is shown in Fig 1(a) for an applied strain slightly lower than that corresponding to the UTS. The tensile axis is horizontal in the images. This result shows the heterogeneity of the deformation at the scale of the microstructure with intense strain bands orientated at 45^{o} with respect to the loading direction, and local values as high as 48% for 30% applied strain. Plastic deformation first starts in the ductile ferrite phase and then extends to the martensite phase which experiences large deformation in the two-phase steel with local values as high as 48%.The particular map of Fig 1(a) has been selected as it corresponds to the early formation of damage in the martensite phase as shown, for instance, in Fig 1(c) in the region highlighted with a white rectangle in Fig. 1(a). Fig. 1(b) shows the same area of the microstructure before deformation. Damage starts at the interface between ferrite and martensite and then propagates through the martensite island. Fig. 1(e) shows the high spatial resolution strain map obtained using the higher magnification images for the same applied strain of 30%. The local strain value at the damage initiation site is 25.5% while the lower magnification image returns a value of 30% is returned for the lower magnification image (Fig. 1(a)) using an adapted interrogation window size to produce a successful correlation. Fig. 1(d) shows the strain map before the onset of damage. A local strain value of 11.55% is measured and can be reliably used for the analysis of damage nucleation in the martensite phase of DP1000 steels.

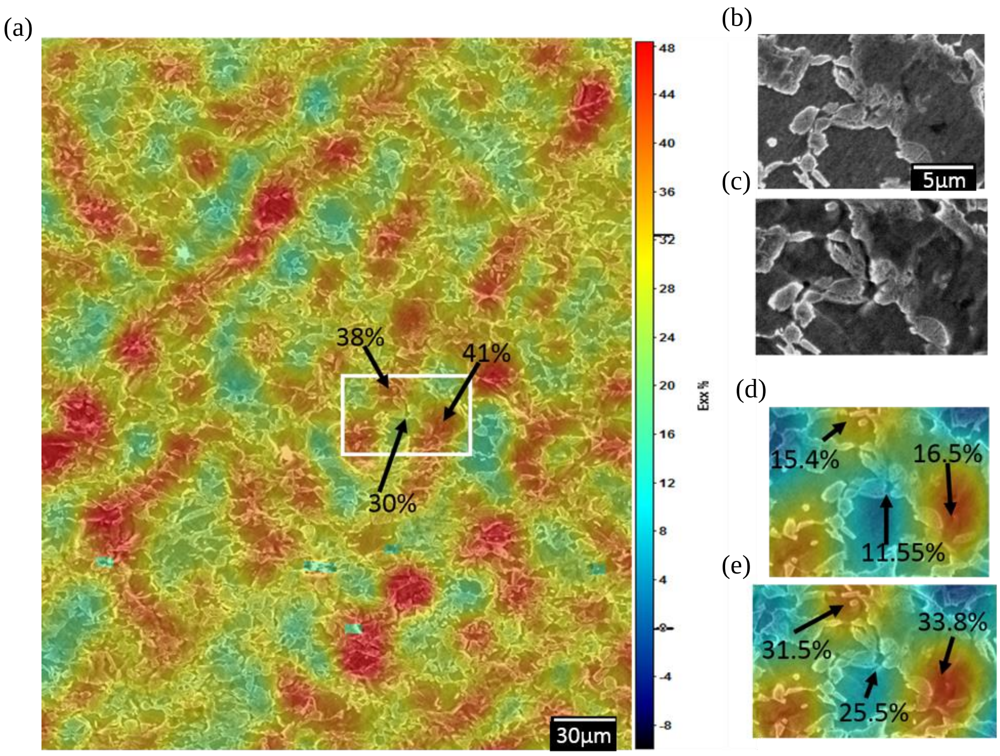

Figure 1: (a)Tensile strain distribution map over a large area of the DP1000 microstructure for an applied strain of 30%. The brighter phase is martensite and the darker phase is ferrite, (b) undeformed microstructure in the region highlighted by the white rectangle in (a), (c) same area of the microstructure after the appearance of damage in the martensite phase, (d) high spatial resolution tensile strain map before the onset of damage and (e) high spatial resolution strain map for 30% applied strain as damage appear. The tensile axis is horizontal in all images.

Conclusion

An experimental procedure has been developed to analyse deformation and damage in DP steels over representative areas of microstructures using DIC at different scales using micromechanical testing inside a SEM. Statistically-meaningful results of strain distributions leading to damage initiation in the martensite phase with high spatial resolution strain measurements at damage location sites can be obtained to inform multi-scale deformation and damage models. A local strain value of 11.55% was measured before the onset of damage in the particular martensitic area highlighted in this paper.

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