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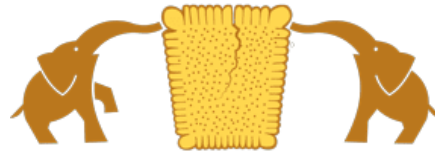
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Pixel-wise full-field strain measurements for analysis of strain heterogeneities with regards to the material microstructure

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Abstract — A new optical-based pixel-wise full-field strain measurement method is proposed. This method allows for high spatial resolution quantification of strain heterogeneities. It is based on the production of a fine speckle pattern, the use of a large sensor camera with high magnification lens and a pixel-wise optical flow algorithm. The measured strain localizations are analyzed with regards to the microstructure of a ferritic-pearlitic steel.

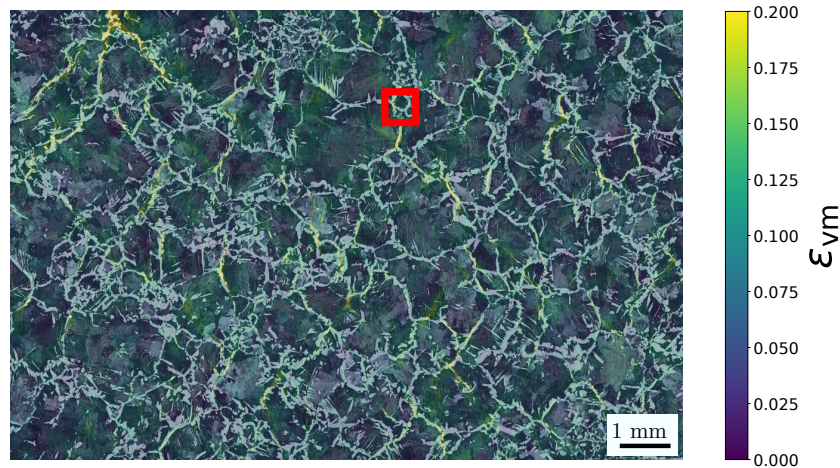
Keywords — Pixel-wise DIC, DISflow, Strain localizations, Microstructure

Introduction Differences in grain size and orientation in polycrystals lead to strain heterogeneities at the microstructure scale when subjected to external load. Measuring and analyzing these heterogeneities is key for better understanding of the mechanical behavior and deformation mechanisms of the material. Digital Image Correlation (DIC) is a well-known and widely utilized technique for full-field displacement measurements. Yet it remains challenging at the microscopic scale where high spatial resolution is required and errors induced from optical sources cannot be neglected. In consequence electron microscopy is often used in high magnification DIC works [1]. However, the absence of free surfaces is troublesome for future dialogue with numerical simulations. In this paper an optical-based pixel-wise full-field strain measurement method on the microstructural scale is presented.

Methods The method is illustrated on a ferritic-pearlitic steel used in railway gears. The characteristic size of the microstructure ranges from 30 to 200 μm . Therefore measuring relevant strain fields at this microstructural scale calls for high spatial resolution. This challenge is addressed by a small dogbone tensile specimen with a cross-section of 10 mm^2 and a gauge length of 16 mm. Then a special protocol is established for production of a very fine speckle pattern and a 47.5 MPix sensor camera with a 4X magnification lens attached is used (1 pix = 1.2 μm). Last but not least, a pixel-wise optical flow algorithm is used. The solution is first initialized by fast inverse search for correspondences with sub-windows matching. It is then refined iteratively following the variational model proposed by Brox et. al. [2]. The optical flow term and the smoothness term are merged into one single energy value to be minimized. In consequence sharp discontinuities are allowed as opposed to smoothing the fields after computation. Like conventional DIC algorithms, a downscaling pyramidal strategy is employed to initialize the displacement fields on a lower resolution. The fast inverse search and the variational refinement model are implemented in the Dense Inverse Search (DIS) optical flow algorithm of OpenCV [3].

Results The microstructure was characterized prior to the application of the speckle pattern by Optical Microscopy and Scanning Electron Microscopy (SEM). It is repositioned in the DIC referential thanks to four small Vickers indents in the corners. Displacement fields are measured with pixel-wise DIC during uniaxial tensile testing with elastic unloadings. The test is carried out with a 10 kN Kammrath & Weiss

tensile module. It is stopped before 10 % macroscopic strain. Strain heterogeneities measured after the last unloading are compared to SEM images of the deformed specimen as illustrated in Fig 1. The softer pro-eutectoid ferrite seems to deform more than the harder pearlite. Strain localizations are also observed on the ferrite pearlite interfaces. The microstructure is then segmented by constituent and by ferrite grain. Strain evolution during the test is analyzed with regards to the different segmentations. Pro-eutectoid ferrite is confirmed to undergo more plastic strain than pearlite but no specific mechanical behavior is highlighted on the ferrite pearlite interfaces. In addition no conclusion can be drawn between ferrite grain size and strain value. A thinner tensile specimen should reduce the uncertainty caused by the uncharacterized microstructure in the thickness. Crystallographic orientation mapping is also required for in-depth understanding of crystalline plasticity.



(a) Strain field (ϵ_{vm}) superposed on optical micrography for a homogeneous strain in the tensile direction equal to 0.0922. A Region of Interest (ROI) is red boxed.



(b) SEM image of ROI before tensile testing (c) SEM image of ROI after tensile testing (d) Zoomed strain field (ϵ_{vm}) on ROI

Figure 1: Analysis of strain heterogeneities during uniaxial tensile testing with regards to the microstructure

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