

# Experimental investigation of early strain localizations on polycrystalline $\alpha$ -Fe in cyclic loading.

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**Abstract.** A novel experimental approach has been devised to investigate the phenomenon of strain localization in polycrystalline  $\alpha$ -Fe samples subjected to cyclic loading. During Low Cycle Fatigue (LCF) loading, local strain measurements were obtained along the width of the semi-circular notch in the specimen using an in-situ optical-based Digital Image Correlation (DIC) technique with a suitable resolution. The resultant strain fields were mapped onto the microstructure to identify the locations of plasticity and potential crack initiation sites.

**Keywords.** Experimental investigation, Early strain localizations, Polycrystalline, Cyclic loading, Material deformation, and Kinematic field measurements.

## Introduction

Polycrystalline metals are widely used in engineering applications due to their superior mechanical properties. However, the presence of multiple grains with different orientations and sizes within a polycrystalline material can result in non-uniform strain distributions, known as strain heterogeneities. These heterogeneities can lead to premature failure and limit the material's performance [1,2], making it crucial to understand the mechanical behavior and deformation mechanisms of polycrystals. In recent years, numerous studies have investigated the effects of strain heterogeneities on the mechanical response of polycrystalline metals. However, there is still a lack of understanding regarding the underlying mechanisms in cyclic loading and the relationship between microstructure and macroscopic behavior. This study aims in understanding polycrystalline metals and their response to external loads, with a particular focus on strain heterogeneities. It also discusses and presents the methods used for measuring and analyzing these heterogeneities and their impact on the material's durability and reliability during cyclic loading.

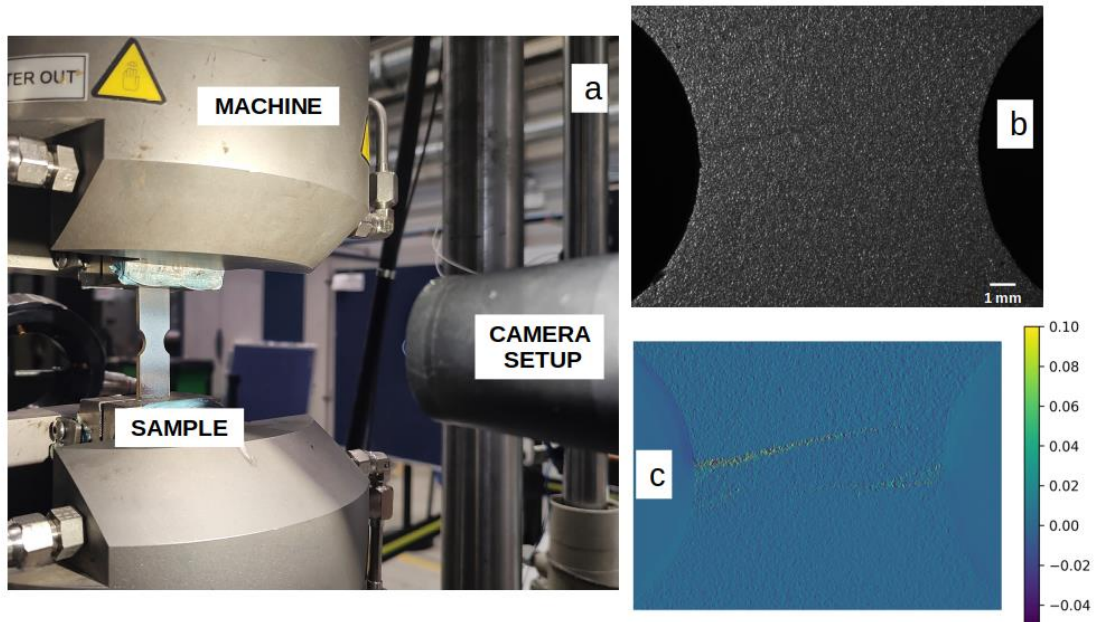
The application of the DIC technique for measuring full-field displacement has gained considerable popularity. However, the conventional large-scale testing machine setups present difficulties in capturing and processing quality images, which has constrained the utilization of DIC in this area. Here we introduce an experimental approach to explore the influence of microstructures on fatigue life by utilizing DIC to observe in-situ strain localizations and crack initiation during cyclic loading. This method offers a comprehensive understanding of the impact of microstructures on the mechanical behavior of materials and their response to cyclic loading. The insights gained from this study can aid in the design of high-performance polycrystalline materials for various engineering applications.

## Methodology

This study aimed to investigate the mechanical properties of ARMCO 99.9% pure iron (0.001C–0.004Si–0.05Mn–0.003P–0.003S–0.015Cr–0.009Cu–0.002Mo–0.014Ni–0.002Sn, in weight fraction) under LCF loading using DIC. To achieve this, a flat specimen with dimensions of 70mm length, 3mm thickness, and 10mm width at the narrowest point of a semi-circular notch was cut and mechanically polished to a  $\frac{1}{4}$   $\mu\text{m}$  diamond suspension. A region of interest (ROI) was marked to serve as a reference for data repositioning. The microstructure of the specimen was characterized using optical microscopy. To enable DIC, a speckle pattern was applied to the surface of interest to induce local grey-level variations.

An INSTRON 8501 servo-hydraulic machine, fitted with a 100kN load cell (*Fig. 1a*), was utilized to carry out the test. The specimens were subjected to cyclic loading with a positive stress ratio, and the maximum load values were set just below the yield stress. Under the influence of a stress concentration factor ( $k_t$ ) of approximately 1.7, the ROI experiences plastic deformation. This loading condition was sustained until the initial cracks were detected. The test was conducted at room temperature and with a frequency of 1 Hz. To synchronize the machine and camera, an external signal generator was utilized, which produced sine waves for the machine and square waves for the camera to trigger at the cycle peaks. A XIMEA MC124MG-SY-UB XiC camera equipped with a JENOPTIK JENmetar™ Telecentric 1x/12LD lens captured images (*Fig. 1b*).

Synchronization of all device drivers was accomplished using a T7-Pro LabJack mini-lab, and data acquisition was executed with an internally developed CRAPPY library [3] in the Python programming language. The captured images were processed using an internally developed pixel-wise DIC tool, GCPu\_OpticalFlow [4] to obtain kinematic fields (*Fig. 1c*). The strain fields of the last cycle were measured and compared to SEM (Scanning Electron Microscope) images of the deformed specimen.



**Figure 1. Illustration of (a) Mounted sample, (b) Speckle pattern, and (c) Strain field in loading axis.**

## Results

Primary observation revealed that initial plastic deformation occurs at the edge of the notch region due to stress concentration at the surface profile and follows a path through grains of large sizes. While a prior investigation on the same material under monotonic tension [5] indicated no significant correlation between plastic structure and grain size, a slight correlation was observed with grain orientation. This highlights the importance of crystallographic orientation mapping in obtaining a comprehensive understanding of crystalline plasticity. These findings have profound implications for optimizing and designing polycrystalline materials for various structural applications and provide valuable insights into their mechanical behavior under cyclic loading.

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