Coupled Experimental-Numerical Analysis of Strain Partitioning in Metallic Microstructures: The Importance of Considering the 3D Morphology

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Abstract A coupled experimental-numerical approach is used to investigate the strain partitioning in microstructures of high-strength steels. The comparison between calculated and measured strain fields reveals significant deviations in some regions of the microstructure; these deviations can be explained by the missing subsurface microstructure in the simulated microstructure. Therefore, the effects of the subsurface microstructure on strain partitioning in a 2D region of interest is systematically evaluated. The results clearly show that for both, experimental analyses and numerical investigations, the consideration of the full 3D morphology is of utmost importance.

Introduction
Understanding how the microstructure affects the local strain and stress distribution in metallic materials is of high relevance for the development of improved strong yet damage tolerant engineering alloys. Digital image correlation (DIC) techniques allow investigating the strain partitioning in metallic microstructures during deformation at high spatial resolution. Crystal plasticity modelling based on the measured microstructure can complement such investigations and provide stress fields in addition to the experimentally obtained strain fields.

Experimental Characterization and Numerical Simulations
We present DIC investigations on dual phase (DP) [1,2] and martensitic steel microstructures [3] together with results of corresponding crystal plasticity simulations. Scanning electron microscopy is employed to acquire the initial microstructure that lays the basis for the crystal plasticity model as well as the microstructure at subsequent deformation states required for DIC. More precisely, Electron Backscatter Diffraction (EBSD) is used to characterize the initial microstructure which is converted into a crystal plasticity model for simulations employing DAMASK, the Düsseldorf Advanced Material Simulation Kit [4]. The sample is then deformed and characterized in Secondary Electron (SE) imaging mode for micro-DIC analysis. This integrated experimental–numerical approach allows for a direct comparison of the results obtained by both methods and, hence, enables a critical assessment of their advantages and disadvantages. While in some regions a good correlation between calculated and measured strain fields is observed, significant deviations in other regions of the microstructures are revealed. Post-mortem investigations on the DP specimen show that the subsurface microstructure, which is absent in the simulations owing to the confinement to experimental 2D data, can explain these deviations. A similar conclusion can be drawn from the comparison of strain partitioning in the martensitic steel sample (see Fig. 1), where the specific formation mechanism of lath martensite allows to deduce the through–thickness microstructure from the surface characterization only.

![Fig. 1: A martensitic microstructure [3] in the undeformed configuration and the computed and measured strain fields at approx. 4% strain in loading direction.](image-url)
To confirm these findings based on the comparison between experimental and numerical results and quantify the deviations between a 3D and a corresponding 2D simulation, we calculate the deformation of a 3D microstructure acquired by 3D [5]. Since the destructive 3D-EBSD serial sectioning approach inhibits the DIC analysis, only numerical results can be obtained. To investigate the effect of the 2D assumption, individual 2D models are created and their results are compared to the full 3D simulation. We show that taking the full 3D microstructure into account drastically changes the stress and strain partitioning in comparison to a 2D simulation approach.

Fig 2: Equivalent stress mapped onto the deformed microstructure of a 3D DP steel. The black box indicates the undeformed configuration.

Conclusions
Our findings have consequences for both, simulation studies and experimental investigations: When performing simulations, it is imperative to use a 3D model unless micromechanical effects stemming from the microstructure beneath the surface can be excluded or quantified. When analyzing results of 2D DIC measurements, it is infeasible to understand the strain partitioning from the observed 2D microstructure alone as they are heavily influenced by the hidden subsurface microstructure.

References