Computational modeling of strain localization and fracture using microstructural information

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COMPUTATIONAL MODELING OF STRAIN LOCALIZATION AND FRACTURE USING MICROSTRUCTURAL INFORMATION

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Abstract: Strain mapping at various length scales and its relationship to both microstructural features and mechanical behavior has been greatly advanced over the past years through the use of optical, non-contact full-field measurement techniques, capable of measuring 2D and 3D surface deformations. An integrated experimental and numerical approach for the characterization of small scale plasticity under monotonic and cyclic loading is presented in this work.

1. Introduction
In this work, state-of-the art experimental techniques were used to provide information about microstructure and deformation evolution for two fundamental mechanics problems: strain localization initiation on an anisotropic hexagonal closed packed material and crack growth on a Nickel superalloy specimen under low-cycle fatigue conditions. This information was used as input to computational models developed to simulate strain localization phenomena using microstructure-specific information related to crystallographic parameters such as twinning and texture [1] and progressive damage on a compact tension specimen respectively [2].

2. Results
Tensile specimens were prepared from a 25.4 mm thick plate of a commercial magnesium AZ31 alloy along the normal to rolling (ND) or transverse to rolling (TD) direction using Electrical Discharged Machining (EDM) and loaded to failure. Quantitative microstructure information was extracted through Electron Backscatter Diffraction (EBSD) measurements while the specimens’ deformation was monitored using a Digital Image Correlation (DIC) system. In the proposed computational model, strain localizations were instigated through a stiffness degradation scheme, in accordance with the softening that occurs in shear band regions due to the reorientation caused by twinning. In order to quantify strains inside the localized regions, DIC data were used to compute strain values for two separate fields of view (FOV) as shown in Fig. 1a. The average values for the full FOV and the one marked by the red rectangle are presented for the ND and TD tension experiments in Fig. 1b and 1c respectively. These results demonstrate that the average longitudinal strain in the shear band region of the ND specimen quickly rises up to a maximum value of 2.7 times that of the average strain of the sample, while the corresponding value for the TD specimen reaches a peak of 1.87. This finding is considered an indication of the twin contribution to the shear band strain.

On the other hand, compact tension samples from a Nicked superalloy with yield strength of 1213 MPa were machined and loaded under fatigue loading (R value equal to 0.05, frequency 10 Hz) over a period of ~25000 cycles. The profile of the calculated strain field ahead of the crack tip allowed the quantification of the plastic zone size and corresponding plastic accumulation values at different fatigue life stages. The calculated DIC parameters were then utilized

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in a confined crack tip plasticity model, calibrated using bulk stress-strain measurements datasets on round-bar specimens. The adopted material model used to simulate progressive damage was based on a rate-independent version of the nonlinear kinematic hardening model developed by Chaboche [3]. The results revealed a linear trend of the opening displacement around the crack tip as function of cycles. Representative comparative plots of the model prediction and DIC data are given in Fig. 2.

Figure 1. (a) specimen geometry and used field of view for DIC measurements. Ratio between average strain of DIC shear band field of view (FOV) and full FOV for ND (b) and TD (c) specimens.

Figure 2. (a) Comparison of model prediction (left) and DIC data (right) for the total strain field $\varepsilon_{yy}$ at 6000 cycles. (b) Deviation of the two approaches along the loading direction at 6000 cycles.

3. Conclusions
The integrated experimental and computational investigation on strain localization in Mg alloys presented herein contributes to the understanding of the role of such instabilities to the macroscopic mechanical behavior. Further, the confined crack tip plasticity model adopted was able to adequately capture the crack opening displacements in various stages of the specimen’s fatigue life providing a predictive tool for fatigue crack growth estimation.

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