Accepted Manuscript

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PII: S0749-6419(17)30694-0

DOI: 10.1016/j.ijplas.2018.06.003

Reference: INTPLA 2358

To appear in: *International Journal of Plasticity*

Received Date: 4 December 2017

Revised Date: 7 June 2018

Accepted Date: 7 June 2018

Please cite this article as: Roth, C.C., Morgeneyer, T.F., Cheng, Y., Helfen, L., Mohr, D., Ductile damage mechanism under shear-dominated loading: In-situ tomography experiments on dual phase steel and localization analysis, *International Journal of Plasticity* (2018), doi: 10.1016/j.ijplas.2018.06.003.

Ductile Damage Mechanism Under Shear-dominated Loading: In-situ Tomography Experiments on Dual Phase Steel and Localization Analysis

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Abstract. The nucleation, evolution and coalescence of voids is the well-established mechanism leading to ductile fracture under tension-dominated loading conditions. From a theoretical point of view, the same mechanism also applies to shear-dominated loading conditions. Here, an attempt is made to provide for the first time tomographic evidence of damage nucleation and evolution under shear-dominated loading in a modern engineering material. Monotonic experiments are performed on a flat double gage section smiley-shear specimen on the laminography stage of a synchrotron X-ray line. Based on fifteen scans of the entire gage section ~~at a voxel resolution of~~ $\cancel{\sim 1\mu m^3}$, the mesostructural evolution inside a ferrite-bainite steel (FB600) is imaged in 3D up to the instant of specimen fracture. It is found that the as-received material includes a volume fraction of about 0.015% CaO particles. Upon mechanical loading at stress triaxialities evolving from 0 to 0.3, the ductile matrix detaches from these $\cancel{\sim 5\mu m}$ ~~diameter~~ second phase particles, creating a prolate void space whose principal axis is aligned with the principal direction of the applied macroscopic field of deformation. The void space continues to grow while developing micro-crack like features. A large deformation analysis is performed on a representative volume element of the particle-matrix mesostructure replicating the experimental observations of void growth in an approximate manner. Furthermore, the simulation results suggest that a porosity as low as 0.05% is already sufficient to cause the ductile failure under shear-dominated loading through the formation of a band of localized plastic deformation at the mesoscale. ~~The combined experimental-numerical results demonstrate that the well-known ductile damage mechanism of void nucleation, growth and coalescence is also responsible for ductile failure at low stress triaxialities~~.

Keywords: Ductile damage, simple shear, void evolution, stress state, in situ 3D synchrotron imaging