BSSM Measurements Lecture 2021

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Martensite-ferrite nano-plasticity and slip transfer unraveled by two-sided high-resolution SEM-DIC and EBSD on isolated interfaces

In the automotive industry Dual Phase (DP) steels are frequently used to replace conventional steels, reducing (CO_2) emission without compromising safety. The superior mechanical properties of DP steels make them extremely suitable for parts of the chassis and bodywork of a car, however, during sheet forming operations the material sometimes fails unexpectedly at strains well below the theoretical limit. This unexpected failure can be traced back to a lack in understanding of the deformation mechanisms governing plasticity at the microscopic scale. Plasticity of the ferrite (F) and martensite (M) phase has been intensely investigated, however, little is known about the F/M interaction at the phase boundaries in the heterogeneous DP microstructure. Investigating the interaction between ferrite and martensite in a well-defined manner for isolated and microscopic features is not a trivial task. Indeed, several challenges are introduced, such as measuring deformation fields at high resolution, assigning plasticity to specific features of the heterogeneous microstructure and limiting the number of interactions during plasticity deformation. This work addresses these challenges to identify the deformation mechanisms governing plasticity at (and in the vicinity of) the F/M interface.

An experimental method is followed combining nanoscale uniaxial tensile testing of isolated F/M interfaces, high resolution in-situ Scanning Electron Microscope Digital Image Correlation (SEM-DIC) and a novel data alignment framework. Individual deformations are tracked with high accuracy, whilst the alignment framework provides microstructure correlated strain fields, allowing for assignment of plasticity mechanisms to specific phases/features of the microstructure. Several unique F/M interfaces were carefully selected and isolated into nano-tensile specimens for testing. The effectiveness of this experimental data alignment framework is validated by showcasing the alignment on one of these specimens. Ultimately, crystallographic orientations, various micrographs and SEM-DIC data were aligned to a reference SEM dataset with accuracies below 100nm, 50nm and 15nm, respectively.

Using this experimental method, the initiation, evolution and interaction of plasticity across the F/M interface has been investigated for nano-tensile specimens with a low and high angle F/M interface. First, two specimens with low angle F/M interfaces are analyzed, one with a smooth and one with a jagged F/M interface. Both specimen presented strain localization at lath boundaries in martensite, supporting previous observations of SBS. In the case of a smooth F/M interface, strain in ferrite is slightly more complex and appears to be a combination of multiple slip systems. For the specimen with a jagged interface the strain localizations continue in ferrite as discrete slip traces aligned with the lath boundaries. Thereafter, two specimens with high angle F/M interfaces are analyzed. These specimens both showed complex and chaotic plastic deformation of the ferrite phase, yet highly localized strain parallel to the lath boundary traces in the martensite phase. Based on these experiments, conclusions are that I) boundary sliding in martensite near an F/M interface is possible for favorably oriented martensite laths and II) complexity in ferrite plasticity is closely related to slip transmissibility across the F/M interface, however, activation of slip systems is governed by the Schmid factor and deformation compatibility at the F/M interface.