Multiscale Investigation of Deformation in Dual-Phase Steel under Non-Proportional Loading

This study investigates the micromechanical deformation behavior of the dual-phase steel DP800HHE under biaxial and non-proportional loading conditions by combining in-situ neutron diffraction experiments with multiscale numerical simulations. The objective is to evaluate the predictive capability of a crystal plasticity framework for complex loading paths and to improve the understanding of phase-specific deformation mechanisms.

Three representative loading paths were examined: (I) purely biaxial tensile loading, (II) plane strain tension followed by biaxial tension, and (III) biaxial tension followed by plane strain tension. These loading paths were selected to capture both proportional and non-proportional deformation behavior. The macroscopic stress response was determined using finite element simulations that reproduced the experimental specimen geometry and loading conditions. The resulting stress histories served as input for crystal plasticity simulations.

Based on the crystal plasticity simulations, phase-resolved lattice strains for ferrite and martensite were calculated and compared with the experimentally measured lattice strain evolution obtained from in-situ neutron diffraction. This comparison enabled a detailed validation of the simulation framework across different deformation paths and loading transitions.

The results demonstrate that the dislocation-density-based crystal plasticity model captures both the macroscopic stress response and the phase-specific lattice strain evolution with good accuracy for all investigated loading paths. In particular, the framework successfully reproduces the effects of load-path changes and the associated micromechanical response. These findings confirm the suitability of the proposed multiscale simulation approach for predicting deformation behavior in dual-phase steels under complex biaxial loading conditions and provide valuable insight into the underlying phase interactions during non-proportional deformation.