Abstract

Tempered martensitic steels are used in many industrial applications such as automobile industry, powerplants and high pressure piping due to their high strength, toughness, creep and wear resistance. These steels have a lath-like hierarchical microstructure consisting of sub-units known as blocks and packets inside prior austenite grains. The mechanical properties are governed by the size, morphology and orientation of these microstructural entities. Such characteristics are particularly related to martensitic steels due to their hierarchical block and packet microstructure and they have specific orientation distributions and morphologies resulting from martensitic transformations. As a result of the very fine and complex microstructure, it is a demanding task to characterize the global mechanical behavior of these steels as a function of their microstructure. The primary objective of the present work is to understand and conduct a complete characterization of such complex microstructures on the subgrain level in order to investigate the mechanical properties of steels.

The present work includes the modeling and simulation of martensitic microstructures in which the relationship between mechanical properties on microstructure of tempered martensitic steels has been investigated. The mechanical properties of martensitic microstructures have been computationally homogenized by using crystal plasticity finite element method. Microstructure of these steels has been described with the help of a simplified representative volume element (RVE) and macroscopic response is evaluated through volume averaging. Yield surfaces have been generated for various RVEs with changing microstructures, which can be utilized to fit a yield function used in continuum scale modeling. As a result, yield surfaces for single crystal demonstrated a strong anisotropy in mechanical behavior. In contrast, a gradual increase in isotropy is observed for larger microstructure containing packets and prior austenite grains, which is inline with the nanoindentation experiments in martensite packets performed in the lath martensitic microstructure [Kaus, 2015]. Furthermore, size effects associated with martensitic microstructural features have also been investigated using the non-local crystal plasticity model with GND hardening contributions [Ma and Hartmaier, 2014a]. Simulation results could capture the observation "smaller is stronger" which has been
frequently found in experiments [Stoelken and Evans, 1998, Swadener et al., 2002, Suzuki et al., 2009] conducted on different materials.

In final part of the thesis, non-Schmid constitutive model for body centered cubic (bcc) material is utilized for martensite modeling. By taking the bcc structure of martensite into account, the non-Schmid contributions are included in crystal plasticity formulation. The constitutive model of [Köster et al., 2012] is modified and the approach of [Weinberger et al., 2012] and [Hale et al., 2015] has been adopted. The crystal plasticity parameters are determined by fitting the tensile stress strain curves of pure iron. Different non-Schmid formulations are used to obtain realistic deformation behavior close to experiments.