Phase Transformations in Supermartensitic Stainless Steels

This doctoral thesis presents research work that elucidates the major phase transformations in supermartensitic stainless steels and their impact on the mechanical properties. Supermartensitic stainless steels are martensitic steels with particularly low C and N content and are based on the Fe-Cr-Ni system. This class of steels is weldable, strong, tough and shows good resistance to wet-corrosion. Thus, it is of special interest for off-shore applications in the oil and gas industry. Supermartensitic stainless steels solidify as δ-ferrite, transform largely to austenite during cooling above A3 and transform almost entirely to martensite during cooling to room temperature. In this condition, the material is hard and brittle. The above listed properties are obtained by annealing the material in the inter-critical temperature region (in between A1 and A3), by which the material is softened as a result of tempering of martensite and partial reversion of austenite at grain boundaries. Just above A1 reverted austenite forms enriched in Ni in an attempt to fulfill thermodynamic equilibrium. Partitioning of Ni stabilizes reverted austenite against martensite transformation during cooling to room temperature. In the present work, the most relevant phase transformations were analyzed and are presented in the order of their occurrence during materials processing. A first study investigated the kinetics of the δ-ferrite-to-austenite transformation during solidification and cooling with the aim of predicting the amount of retained δ-ferrite at room temperature. Another study concerned the in-situ measurement of the evolution of lattice strains and stresses in austenite and martensite during martensite formation. Subsequently, tempering of martensite was studied by analyzing the redistribution of interstitial elements, C and N, relaxation of phase-specific stresses and recovery of the martensite substructure. The role of Ni-diffusion in austenite reversion from lath martensite was clarified by conducting kinetics analysis of austenitization during isochronal heating. Two distinct stages of transformation were observed experimentally and predicted by kinetics modeling and were found to be governed by redistribution of Ni. Microstructure characterization of inter-critically annealed samples revealed austenite formation as thin films on lath boundaries and other grain boundaries. Analysis of compositional measurements indicated that reverted austenite is mainly stabilized by a redistribution of Ni. The stable fraction of reverted austenite at room-temperature was not noticeably affected by immersion in boiling N2, but progressively reduced during holding at 194.5 K. Strain-induced martensite formation from reverted austenite during tensile testing of differently annealed conditions was studied in-situ with in-situ synchrotron X-ray diffraction. The experiments yielded data on stress-partitioning, evolution of the substructure, and anisotropy of lattice strains of austenite and martensite, which could be associated to the macroscopic stress. Finally, the presented research contains a study on the recently developed materials characterization method transmission Kikuchi diffraction in on-axis configuration.

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