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Crystal Plasticity Analysis of Mechanical-Property Variations in Fine-Grain Heat Affected Zone of X100 Steel Gas Metal Arc Welding Joints

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Extended Abstract

Abstract

The welding process of high-strength pipeline steels induces high thermal gradients, causing microstructural and mechanical-property heterogeneity across joint regions. This study developed a physically-based crystal plasticity fast Fourier transform (CPFFT) model to quantify the effects of microstructural variations in the fine-grained heat-affected zone (FGHAZ) on tensile and fatigue properties relative to the parent material (PM). These microstructural evolutions include crystallographic orientations, grain dimensions, and the distribution of martensitic and bainitic phases. For this purpose, electron back-scatter diffraction maps of TMCP-ed X100 PM and Gleeble-simulated FGHAZ were inserted as the microstructure input to a quasi-3D full-field nonlocal crystal plasticity model in DAMASK. The CP model was calibrated based on the experimental tensile and fatigue properties of the PM and subsequently validated by comparing the corresponding FGHAZ data. Fatigue response was captured using a fatigue indicator parameter (FIP) based on the locally stored energy densities and stress concentration at grain boundaries, phase interphases, and slip bands. CPFFT results showed that the enhancement of tensile properties at the FGHAZ stemmed mainly from phase transformation, followed by crystallographic texture and grain-size variations. On the other hand, crystallographic texture made the most significant contribution to fatigue-property heterogeneity in the welding joint, followed by phase transformation and grain-size strengthening. This work establishes a process–structure–property simulation framework, necessary to evaluate the performance of welding joints in high-strength steels.

Keywords:

Dislocation-based nonlocal crystal plasticity fast Fourier transform Microstructure Mechanical properties Thermo-mechanical control process rolling Welding X100 steel