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Effects of Mechanical Deformation on Dislocation Density, Phase Separation and Hydrogen Diffusion in 4130 Steel

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Interrupted uniaxial tensile tests have been performed on a AISI 4130 pressure vessel steel in air and high-purity hydrogen environments. Results from neutron diffraction measurements collected at Oak Ridge National Laboratory reveal a partitioning of ferrite and martensite phases as a function of applied strain. Dislocation densities of the two individual phases were extracted by analyzing the broadening of their Bragg peaks using a Williamson-Hall approach and reveal an order of magnitude increase when the material is strained beyond its ultimate tensile strength (UTS). In addition, a strain-induced phase transformation from predominantly martensitic steel to a ferritic steel was observed. Figure 1 displays the weight fractions for each of the two phases as a function of applied strain determined from multiphase fits to the diffraction data. Measurements are currently in progress on samples strained under various hydrogen pressures to determine its effects on the formation of dislocations and phase partitioning.

For quantifying hydrogen diffusion within these steel microstructures, quasielastic neutron scattering (QENS) measurements were performed on strained steels. Analysis of the QENS spectra collected from our sample strained to its UTS reveals a decrease in the activation energy for the diffusion of hydrogen compared to that in bulk bcc Fe, suggesting the presence of dislocations act as pathways for enhancing hydrogen diffusivity. Lastly, scanning Kelvin probe force microscopy (SKPFM) was used to characterize the microstructure, phase fractions, and hydrogen diffusion associated with the various strain levels in this steel. Contact potential differences (CPD) measured in the SKPFM potential maps show a bimodal distribution, which has been interpreted as the two phases. Figure 2 shows a histogram analysis of the potential landscape from an un-strained 4130 sample suggesting a similar weight fraction of the two phases determined by neutron diffraction (see Figure 1). These results not only demonstrate the utility of SKPFM, but also indicate it is a suitable method for identifying steel phases that possess similar crystal structures that may be difficult to detect using conventional methods such as electron back-scattered diffraction (EBSD).

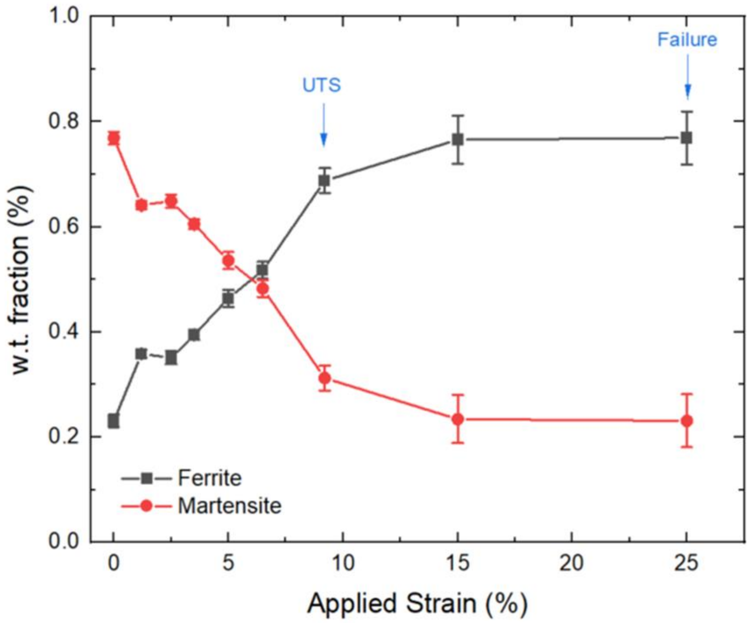

Figure 1. Strain-induced phase transformation of a 4130 pressure vessel steel determined from analyzing neutron diffraction patterns. Weight fractions of ferrite (black) and martensite (red) are shown as a function of applied strain. The ultimate tensile strength (UTS) sample and failure sample are indicated by blue arrows.

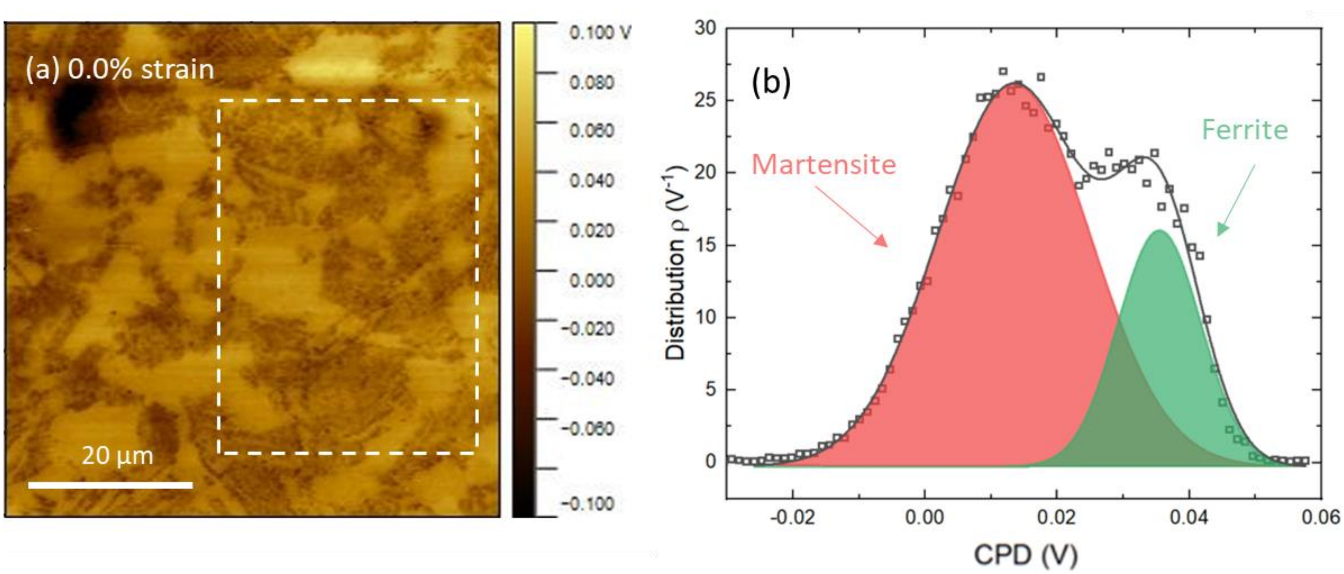

Figure 2. (a) Scanning Kelvin probe force microscopy (SKPFM) image of an un-strained 4130 steel sample. (b) Histogram of the potential landscape measured from the area indicated by the white-dashed line box in the SKPFM image. Analysis of the bimodal histogram reveals a ferrite / martensite ratio similar to what was observed from neutron diffraction (77% / 23%).

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