

Quantitative evaluation of hydrogen effect on dislocations in iron

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As various hydrogen technologies are being developed and tested (fuel cells, hydrogen gas turbines), the need for a deeper understanding of hydrogen effects on the mechanical properties of structural materials is as strong as ever. Such materials include stainless steels, especially with an austenitic structure, as well as nickel alloys, but for larger scale or lower cost applications, low-alloy steels or pipeline steels are used. The formers have a face-centered cubic (fcc) structure, and nickel is one of the model materials for hydrogen embrittlement of fcc crystals. For the body-centered cubic structure (bcc), pure iron is the model material.

While a lot of effort has already gone into the now century-old hydrogen embrittlement research field, quantitative analysis remains difficult. The effect of hydrogen concentration on material strength can be obtained rather straightforwardly, albeit with some dedicated machinery for high-pressure hydrogen gas exposure. But smaller scale results, the effect of hydrogen on lattice defects, such as dislocations or vacancies, are still lacking. Most of the work on hydrogen-dislocation interactions has been done with transmission electron microscopes (TEM), showing how dislocation structures evolve with hydrogen and deformation. First principle and density functional theory calculations have also been used to model those interactions. They remain however limited in scale (low strain, short time periods, small volumes).

On the other hand, X-ray diffraction is also a relatively old method that can be used for quantitative measurements of such interactions. Issues remain of the effect of hydrogen on lattice expansion and how this affects the data processing, when comparing samples with and without hydrogen, but for bcc structures, with little elastic anisotropy, the data analysis, although relatively time-consuming, gives reliable results. Here, we focused on the analysis of pure iron, strained at room temperature and low temperature, with and without hydrogen. The evolution of dislocation density, and dislocation character, could then be discussed in comparison with the established models for both hydrogen-dislocation interactions, and the dislocation-strain relationship.