Modeling fracture in steels exposed to hydrogen

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The diffusion of hydrogen into metal components causes a dramatic reduction in their strength. This hydrogen embrittlement poses a significant challenge in the oil and gas industry as well as in many other fields.

We present a theoretical framework for predicting hydrogen assisted fracture in elastic-plastic solids, without the need for experimental calibration, based on the following: (i) Stress-assisted diffusion of solute species, (ii) strain gradient plasticity, and (iii) a hydrogen-sensitive phase field fracture formulation, inspired by first principles calculations.

The model is implemented in a finite element framework, for use with the commercial finite element package Abaqus. A series of 2D boundary value problems have been studied, revealing that the combination of hydrogen and strain gradient plasticity successfully captures the ductile to brittle transition, which is observed in hydrogen-assisted fractures. Steady state fracture toughness curves have been computed for realistic material values, demonstrating that typically ductile materials can display quasi-cleavage at modest hydrogen concentrations. Furthermore, a wide range of computations show that the model appropriately captures the influence of plastic and fracture length scales, as well as loading rate.

Finally, the modelling framework has been applied to the 3D problem of a riser pipeline with internal pit corrosion damage, based on in-line inspection data from the literature. This complicated large-scale problem showcases the capabilities in delivering predictions of engineering relevance, while appropriately capturing the underlying physics at the micron-scale.