Hydrogen-Induced Fracture: From Fundamentals to Prognosis

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Development and validation of a lifetime prediction methodology for failure of materials used for hydrogen containment components are of paramount importance to the planned hydrogen economy. In this presentation, we summarize recent developments on fracture prognosis for various materials by accounting for the deformation mechanisms at the microscale.

Recent experimental studies of the microstructure beneath fracture surfaces of ferritic steel, lath martensitic steel, stainless steel and nickel specimens fractured in hydrogen suggest that the dislocation structure and hydrogen transported by mobile dislocations play important roles in the evolution of the fracture process/event. After reviewing this plasticity-mediated hydrogen-induced failure, we present a revised model for hydrogen/deformation interactions in order to account for dislocation transport along with stress driven diffusion and trapping at microstructural defects.

Arguably the most devastating mode of hydrogen-induced degradation is the hydrogen embrittlement of high-strength steels which results in a sharp transition from a high-toughness ductile (microvoid coalescence) fracture to a low-toughness brittle intergranular fracture. We present an approach to quantify this effect of hydrogen on the fracture resistance of a low alloy martensitic steel through the use of a statistically-based micromechanical model for the critical local fracture event which relates the influence of hydrogen adsorbed at internal interfaces in affecting decohesion to the onset of macroscopic failure.

Lastly, we present an approach to mitigate the hydrogen effect on ferritic systems subjected to cyclic loading. Based on experiments, materials physics, and applied mechanics methodology, we have recently found and quantified that a few molecules of oxygen per million molecules of hydrogen can markedly increase the magnitude of the stress intensity factor range at which hydrogen-accelerated fatigue commences.

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Fields of Research

Environmental degradation of materials, solid mechanics, finite element methods.

Publications

1. Dadfarnia, M., Martin, M. L., Nagao, A., Sofronis, P. and Robertson, I. M.,*J. Mech. Phys. Solids*, In Print.
2. Nagao, A., Martin, M. L., Dadfarnia, M., Sofronis, P. and Robertson, I. M.,*ActaMaterialia*, **74**, 244 (2014).
3. Somerday, B. P., Sofronis, P., Nibur, K. A., San Marchi, C. and Kirchheim, R. *ActaMaterialia*, **61**, 6153 (2013).
4. Martin, M. L., Somerday, B. P., Ritchie, R. O., Sofronis, P., Robertson, I. M., *ActaMaterialia*, **60**, 2739 (2012).
5. Novak, P., Yuan, R., Somerday, B., Sofronis, P. and Ritchie, R. O., *J. Mech. Phys. Solids*,**58**, 206 (2010)