# The synergistic interplay of the localized plasticity (HELP) and decohesion (HEDE) mechanisms of hydrogen embrittlement in steels: effects on macromechanical properties

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**Abstract**

Hydrogen damage includes a wide range of environmental types of failure, hydrogen assisted mechanical degradation processes - hydrogen embrittlement (HE), and hydrogen-material interactions, including material microstructural changes, caused by the presence of hydrogen in metals. The connection between microstructure-based behaviors of materials and the effects of hydrogen on its macroscopic measurable properties is of the utmost importance in order to provide a unified model for HE in metallic materials, including steels.

The simultaneous activity and synergistic interplay of the hydrogen-enhanced localized plasticity (HELP) and hydrogen-enhanced decohesion (HEDE) mechanisms of HE (HELP+HEDE) was recently detected and confirmed trough simulations (modeling), and also experimentally, in the case of different materials, such as low carbon steels, dual-phase steels, ultra high strength steels, advanced high-strength steels, martensitic steels, martensitic stainless steels, nickel, and nickel-based alloys. This complex interaction dependence between the simultaneously active micro-mechanisms of HE, degree of mechanical properties degradation, hydrogen concentration/distribution, and temperature is particularly pronounced in the case of industrial components that are exposed to hydrogen during operation at different temperatures and from different sources.

This paper presents an overview about the simultaneous activity and synergistic interplay of HELP+HEDE mechanisms in metallic materials and an in-depth study of the model based on the correlation of mechanical properties to scanning electron microscopy fractography analysis of fracture surfaces in the presence of simultaneously active hydrogen embrittlement micro-mechanisms (HELP+HEDE) in a low carbon steel.

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