A NEW APPROACH FOR CHARACTERIZATION OF STEEL WELD METAL HYDROGEN CRACKING SUSCEPTIBILITY

Aaron Dinovitzer, Vice President, BMT Canada Limited, Ottawa ON, Canada
adinovitzer@fleetech.com
Stuart Guest, Welding Engineering Specialist, BMT Canada Limited, Ottawa ON, Canada
Vlad Semiga, Materials & Structures Specialist, BMT Canada Limited, Ottawa, ON, Canada
Marie Quintana, Welding & Materials Consultant to BMT Canada Limited, Twinsburg OH, USA

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Historically, managing the risk of hydrogen embrittlement (HE) and hydrogen assisted cracking (HAC) in arc welded steel construction has been governed by crack/no-crack criteria in empirical tests that generally consider a limited number of individual risk factors in isolation. Most, if not all, such tests predate our current understanding of hydrogen in steel as ductility loss. The fact that HAC still occurs indicates that research has not yet bridged the gap between fundamental mechanisms and mitigation strategies deployed in practice and that ensure welded systems and structures perform as intended.

This paper presents the initial effort to develop a comprehensive measure of susceptibility that is needed for effective hydrogen risk management as materials evolve over time [1, 2]. Understanding HE and HAC susceptibility in welds is challenging because of microstructural heterogeneity that results from multiple reheat cycles and multiple processes/consumables used in the same weld deposit. Thus, a three-point bend test was developed for weld metal susceptibility that considers the combined effects of process variables at the point of crack initiation in the specific region of interest (i.e. weld metal, heat affected zone or base material).
Initial work studied a broad range of steel weld metals used for transmission pipeline construction, each over a range of diffusible hydrogen levels, using transverse bend specimens with notches placed in as-deposited microstructure. Diffusible hydrogen was varied from a peak level to near zero prior to loading. For each weld metal, critical displacements at failure initiation were normalized against the response for the fully aged test and plotted as a function of aging time. Numerical methods were used to replace aging times with estimates for local hydrogen concentrations at point of initiation and to replace normalized critical load line displacement with normalized critical strain.The test offered more than simple crack/no crack criteria and the relative risk of HAC among the weld metals was largely consistent with experience. However, results still lacked the precision sought.

The resulting characteristic hydrogen embrittlement curves derived from nonlinear finite element modeling, took the form εcrit = A (Hconc)B wherein A and B are the regression curve fit constants referred to as ductility index and embrittlement index, respectively. Figure 1 presents six examples of these hydrogen susceptibility relationships that define the critical combinations of hydrogen concentration and local strain.

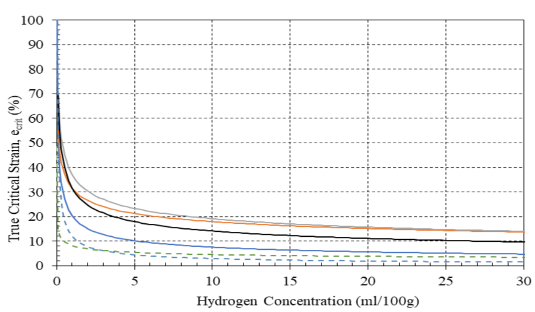

Fig. 1: Hydrogen Cracking Susceptibility Relationships for Six Weld Metals

This methodology makes it possible to characterize the interaction among three risk factors for hydrogen cracking quantitatively – local hydrogen concentration, strain and microstructure at the point of brittle crack initiation. This makes it possible to evaluate the influence of practical materials and welding variables in a more robust manner than has been possible historically. This paper also presents thoughts regarding the use of this test specimen with hydrogen charged samples to evaluate HAC susceptibility or the impact of strain concentration on hydrogen concentration distribution and hydrogen crack formation.

References:
[1] 1) BMT Canada Limited, “Weld Hydrogen Cracking Risk Management Guide”, Pipeline Research Council (MAT-1-1) Contract PR-214-134502
[2] BMT Canada Limited, Weld Hydrogen Cracking Susceptibility Characterization”, Pipeline Research Council (MAT-1-3) Contract PR-214-14450