MECHANISTIC INFLUENCE OF SUB-MICROMETER POROSITY ON THE HYDROGEN ENVIRONMENT-ASSISTED CRACKING BEHAVIOR OF ADDITIVELY MANUFACTURED 17-4PH STEEL

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Key Words: porosity, 17-4PH, stainless steel, HEAC, additive manufacturing

Metal additive manufacturing (AM) offers the potential for significant cost and logistical advantages over conventional manufacturing techniques, especially for complex component production. While significant attention has been given to evaluating first-order properties like yield strength in AM materials, understanding of higher-order properties, such as hydrogen environment-assisted cracking (HEAC), in AM alloys remains poorly understood. Given the known microstructural differences between wrought and AM alloys, and the fact that HEAC is highly sensitive to subtle microstructural changes in wrought alloys, it is critical to develop specific understanding of the HEAC behavior of AM materials to ensure their safe use in aggressive environments.

In this study, the HEAC behavior of AM 17-4PH stainless steel heat-treated to exhibit similar microstructure and yield strength as comparable wrought 17-4PH is assessed via full immersion in 0.6 M NaCl while exposed to varying levels of cathodic polarization. Results demonstrate that, despite strong similarities in first order microstructural and mechanical parameters, AM 17-4PH exhibits (1) the onset of HEAC at less severe cathodic polarizations and (2) up to 10-fold faster crack growth rates for a given polarization relative to conventional 17-4PH. A detailed analysis of the alloy microstructure, hydrogen-metal interactions, and near-crack deformation behavior collectively demonstrates that this enhanced HEAC susceptibility is driven by homogeneously distributed sub-micrometer porosity in the AM material. In particular, characterization of the crack tip region revealed strongly enhanced strain localization around pores located on a grain boundary directly ahead of the crack tip.

To better understand the mechanistic role of this sub-micrometer porosity, additional hydrogen-metal interaction and near-crack characterization experiments were performed. Follow-on thermal desorption spectroscopy studies strongly suggest that the pores themselves are not acting as hydrogen traps; this observation, along with the resistance of the pores to conventional hot isostatic press treatments, implies that the pores are filled with Ar from the build process. Conversely, comparative characterization of the crack tip region for specimens subjected to the same stress intensity while tested in laboratory air versus full immersion under cathodic polarizations revealed notable differences in the pore size distribution. Specifically, the near-crack pores in the hydrogen-exposed specimens were tangibly larger than those observed in the near-crack region of the specimen tested in laboratory air. Critically, both samples exhibited the same nominal pore size away from the crack tip region. These results indicate that hydrogen is acting to accelerate pore growth proximate to the crack tip, which has two important mechanistic implications. First, these findings suggest that hydrogen is modifying the hydrostatic stress field ahead of the crack since pore dilatation is driven by hydrostatic stresses; such an effect is speculatively related to hydrogen increasing the yield strength of the near-crack material volume. Second, since porosity is generally considered initial damage that degrades the local fracture resistance, it is speculated that this hydrogen-facilitated increase in pore size proximate to the crack tip intrinsically weakens the material against HEAC. The implications of these findings on the broader adoption of AM materials for hydrogen service and materials acceptance/inspection requirements are then discussed.