Crack initiation tests with tapered high Si stainless steel specimens

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Stainless steels are extensively used in the internal components of nuclear power plants because of their universal corrosion resistant qualities at increased temperatures. Normal pressurized water reactor (PWR) operating conditions lead to material degradation through stress corrosion cracking (SCC) [1]. An accelerated test method based on tapered tensile specimens is applied to determine the stress threshold for crack initiation in a corrosive environment. Metallic specimens with variable cross-sections are exposed to nominal strains in constant elongation rate tests (CERT) while being subjected to a simulated PWR environment. The tapered geometry allows for a stress gradient at each cross-section along the gauge length of the specimen. Individual stress thresholds for SCC are derived from a number of samples exposed to different strain rates. An extrapolation of these stress thresholds to an infinitesimal strain rate yields the stress threshold under constant load conditions.

The tensile specimens consist of an austenite-ferrite duplex matrix structure made from high Si stainless steel. The inclusion of high concentrations of Si in the matrix simulates radiation effects such as radiation induced segregation (RIS) and radiation hardening (RH) in an otherwise unirradiated specimen. The CERT tests were executed in an autoclave with an internal loading unit that simulates the PWR environment (2ppm of Li, 1000ppm of B, 35 cc/kg H2).

Scanning electron microscopy (SEM) is utilized to investigate crack distributions along the gauge length of the tapered specimen after testing. It is found that the austenite phase is much more susceptible to SCC due to the Si stabilization of the ferrite phase. The crack density decreases along the gauge length and is the highest near the edge of the fracture surface at the smallest cross-section. Crack analysis is carried out using the powerful built-in ridge detector tool of the image processing software Fiji based on the detection of curvilinear structures [2]. Cracks on the fracture surface are detected by approximating the image pixel values with a second order Taylor expansion and calculating eigenvalues of the second order derivative Hessian matrix.

High resolution SEM images examined with an effective, subpixel accurate, analysis tool like Fiji accurately estimates crack densities and crack angle distributions of the SCC cracks. In addition, special consideration is given to the investigation of the significant scatter which is observed in the stress threshold data. Optimization of the methodology to reduce this scatter is openly discussed.

[1] P. M. Scott, “2000 F. N. Speller award lecture: Stress corrosion cracking in pressurized water reactors- Interpretation, modeling, and remedies," Corrosion, vol. 56, no. 8, pp. 771-782, 2000.

[2] C. Steger, “An unbiased detector of curvilinear structures," IEEE Transactions on Pattern Analysisand Machine Intelligence, vol. 20, pp. 113-125, Feb 1998.