Cracking Thresholds and Fracture Toughness Properties of Tritium-Charged-and-Aged Stainless Steels

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Cracking thresholds and fracture toughness properties were measured for tritium pre-charged Types 304L and 21-6-9 stainless steels. The purpose of the experiments was to measure the effect of decay helium on the fracture properties of stainless steels and to evaluate fracture toughness values determined under falling-load and rising-load conditions. Arc-shaped fracture toughness samples were prepared from stainless steel forgings and equilibrated with tritium gas at 34 MPa and 623 K for three weeks. After pre-charging, the samples were aged for a period of years in air at 223 K to build in decay helium (up to ~800 atomic parts per million). Falling-load cracking threshold tests were conducted by step-loading and holding the samples at a fixed displacement until the pre-existing fatigue pre-crack began to propagate under a falling load. After the crack arrested, the samples were unloaded and critical value of the stress intensity for cracking was determined from the final load, the arrested crack length, and geometric factors for the arc-shaped specimen. Threshold stress intensity values were compared to rising-load J-Integral fracture toughness values as determined from the ASTM E1820 procedure, "Standard Test Method for Measurement of Fracture Toughness".

The results show that cracking thresholds and fracture toughness properties decrease with increasing He^3 content. Cracking apparently occurs by a hydrogen embrittlement process that is made worse over time because of the hardening effects of the nanometer-sized helium bubbles in the microstructure. Falling-load cracking thresholds were lower than thresholds determined from the rising-load J-Integral test. However, falling-load tests took much longer to perform and the results were obscured by uncertainties associated with the time required for the crack propagation event. An analysis shows that conservative and more consistent cracking threshold values can be determined from the J-Integral tests provided that the threshold values are determined from the actual point of crack initiation rather than the values associated with the point of significant crack extension as specified in the ASTM procedure.