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Kinetic of crack propagation in hydraulic turbine runner material exposed to river water

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ABSTRACT

Hydraulic turbines are critical for Quebec's electricity production, as hydroelectricity accounts for 95% of its power generation. During operation, Francis turbines are subjected to cyclic loading and exposed to river water, leading to crack initiation and propagation. The integrity of these components is assessed through regular inspections, which provides updates on life predictions derived from damage tolerance models based on fatigue crack growth rate (*da/dN*) as a function of the applied stress intensity factor range (ΔK). This study investigates for the first time the influence of river water and material's microstructure on corrosion-fatigue crack growth (CFCG) behavior of 13Cr-4Ni low-carbon martensitic stainless steel. This research helps improve damage tolerance models by accounting for environmental effects. Fatigue crack growth tests were conducted in air and river water at two ΔK values of 8 MPa·m$^{0.5}$ and 15 MPa·m$^{0.5}$ on steels with minimal (S_M) and maximal (S_{RA}) reformed austenite (RA) fractions of 3% and 20%, respectively. To investigate the environment's influence, a setup was developed where the sample was partially immersed using an enclosure and the synthesized river water was circulated using a pump. The load frequency was varied from 10 Hz to 0.1 Hz and two load ratios (R) of 0.1 and 0.7 were applied. Measurements showed that CFCG rate (CFCGR) was mitigated by crack closure at frequencies of 10 Hz and 1 Hz, resulting in fatigue crack growth rates (FCGR) comparable to those in air. After accounting for crack closure, environmental effects on crack propagation kinetics were revealed. On average, fatigue cracks propagated faster in water for both microstructures. The scatter of data compromises the robustness of this conclusion for S_M. In S_{RA} material, significant environmental effect was observed below effective ΔK (ΔK_{eff}) of 9 MPa·m$^{0.5}$, attributed to longer crack tip exposure times due to slower crack propagation speed (*da/dt*). A comparison of CFCGRs between S_M and S_{RA} revealed that above ΔK_{eff} of 6.5 MPa·m$^{0.5}$, S_{RA} exhibited slower CFCGR due to greater crack closure, extensive crack branching, and RA-to-martensite transformation. Given the negligible environmental impact at high load frequencies, Hydro-Québec can safely use FCGR data from air tests. This experimental work correlating microstructure and crack propagation reveals that higher RA fractions led to slower CFCGR and FCGR. Developing RA-enriched alloys and optimizing hydraulic turbine manufacturing by new developed alloys could improve turbine runner durability. To complement this work, tests under variable R conditions better representing actual turbine loading should be performed.