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Numerical Prediction of Fatigue Crack Propagation in E410NiMo and 13Cr-6Ni Using Finite Element Methods

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ABSTRACT

Francis turbines are widely used in Hydro-Québec's hydropower plants, playing a crucial role in energy production by efficiently converting hydraulic energy into mechanical power. These turbines operate in submerged conditions within dams where access for inspection, maintenance, and repair is highly restricted. One of the primary concerns in these turbines is fatigue cracking, particularly in the welded connections of the turbine blades, which can compromise the structural integrity, leading to costly failures and unplanned shut down. Therefore, accurate fatigue life prediction and material optimization are essential to enhance the reliability and longevity of turbine components, reducing downtime and maintenance costs.

Currently, Hydro-Québec employs E410NiMo (13Cr-4Ni) as the filler material for martensite stainless steel CA6NM turbine runners. A modified composition with enriched Ni and Mn content (13Cr-6Ni) has been proposed to enhance fatigue resistance. This study compares the fatigue crack propagation life of these two materials in a laboratory-scale compact tension specimen using a numerical approach. A finite element-based incremental crack propagation simulation was developed using ABAQUS for stress analysis and Franc3D for fatigue life prediction. The fatigue crack growth properties were derived from experimental data, ensuring accurate representation of material behavior. The numerical model evaluates fatigue life under various loading conditions, including different load ratios, applied load magnitudes, and simplified residual stress states.

This study aims to quantify the extent of this improvement across different loading scenarios, providing insight into the material's performance under realistic service conditions. By numerically evaluating the fatigue life of these materials, this study offers a foundation for understanding the benefits of 13Cr-6Ni in Francis turbine applications. The findings contribute to the ongoing development of optimized filler materials for turbine blade fabrication. Future work will extend this methodology to real-scale turbine geometries and load conditions derived from operational data, providing a more comprehensive assessment of fatigue behavior in service.

Keywords: Fatigue crack growth, Francis turbine runner, finite element methods, and numerical simulation