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In Situ Characterization of Microstrain Partitioning in the Microstructures of Hydraulic Turbine Steels

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ABSTRACT *(MAX 400 WORDS):*

Hydro-Québec (HQ) aims to enhance the reliability of its hydroelectric facilities, which experience frequent start-stop cycles causing fatigue damage to the turbines. Current turbine models fail to consider the micro-mechanisms responsible for this damage, which are complex and microstructure dependent. Additionally, the stress distribution in welds and heat-affected zones is still not well understood. To address this, an experimental approach is proposed to characterize the mechanical behavior of hydraulic turbine steels at the microstructural scale. Three sub-objectives (SO) guide the study: the identification of suitable experimental techniques (SO1); the characterization of microscale deformation mechanisms (SO2); and the assessment of the precision of the experimental method developed in SO1 (SO3).

The materials studied are A516 carbon steel, similar to turbine steel, and E309L austenitic stainless-steel welds, used for repairs. The methodology combines in situ tensile testing within a scanning electron microscope (SEM) and micro-scale digital image correlation (µDIC) in order to obtain deformation map. Surface images of speckled specimens are acquired at various strain levels. Protocols are being developed to prepare specimens and define key parameters for deformation calculations. Results will enable a comparative analysis of deformation mechanisms in both materials and highlight dominant processes.

A literature review identified multiple techniques (T) for generating speckles required for µDIC. The weld microstructure is predominantly austenite with 10% delta-ferrite dendrites, ~1 µm thick. For accurate displacement calculations in the delta-ferrite zone, subsets in DIC analysis must be smaller than 1 µm. To ensure precision in the A516 steel, where ferrite and pearlite grains reach 16 µm in diameter, a 3x3 subset matrix must fit within individual grains. Based on these findings, the tests have led to the identification of two promising techniques: silver film reconfiguration (T1) and colloidal silica (SiO2) deposition (T2). Both techniques produce nanoscale speckles capable of characterizing a 121x91 µm² area in both materials. The speckles from T1 are particularly homogeneous and well-contrasted, potentially enabling finer local analyses. However, improvements to the test setup, including reduced working distance and enhanced image resolution, are required. Meanwhile, T2 speckles, while less dense, reveal microstructural details and could benefit from optimization.

In situ µDIC testing shows promise, though further refinements in experimental parameters and calculation settings are needed to ensure accurate results. These results will be compared with crystal plasticity models developed by HQ. This methodology could be extended to other microstructures, paving the way for broader industrial applications.