Characterization and Modeling of Material Damage Mechanisms by Cavitation

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Supervised by Marc Fivel (SIMaP), Pierre Lhuissier (SIMaP) and Sylvain Gaudion (General Electric)

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K118 amphitheater of LEGI, 1209 Rue de la Piscine, 38610 Gières

Jury :

Sébastien ALLAIN, Professor, IJL University of Lorraine, reviewer
Sébastien MERCIER, Professor, LEM3 University of Lorraine, reviewer
Eva HÉRIPRÉ, CNRS Research Engineer, PIMM Arts et Métiers, examiner
Frédéric AYELA, Professor, LEGI University Grenoble Alpes, examiner
Marc FIVEL, CNRS Research Director, SIMaP University Grenoble Alpes, thesis supervisor
Pierre Lhuissier, CNRS Researcher, SIMaP University Grenoble Alpes, invited, co-supervisor
Sylvain Gaudion, Engineer, General Electric Renewable Energy, invited, co-supervisor

Abstract : Martensitic stainless steels X3CrNiMo13-4 and X4CrNiMo16-5-1 are widely used in the production of hydroelectric turbines due to their excellent mechanical strength and intriguing corrosion resistance. Although these materials have been extensively studied from both a mechanical and microstructural standpoint, the relationship between these properties and damage mechanisms is not yet clearly established. However, in certain scenarios, operators are required to operate under cavitation flow conditions that can damage the turbines to the extent of causing mass loss, noise issue and decreased efficiency. In such situations, for turbine engineers to predict the lifespan of components exposed to cavitation, they must rely on modeling. These models crucially depend on a key aspect of the mathematical framework: the damage law. The aim of the research presented in this manuscript is precisely to characterize and model the damage mechanisms induced by cavitation.

In this study, the materials were exposed to cavitation using two complementary experimental setups, MUCEF and PREVERO, which respectively generate acoustic and hydrodynamic cavitation. To identify the damage mechanisms, temporal tracking of crack initiation and propagation was performed on the material's surface through electron microscopy and within the volume using X-ray tomography. The observations highlight that crack initiation occurs in the vicinity of non-metallic elements, along persistent slip bands, which are indicative of very low-cycle fatigue loading. The cracks propagate from the surface into the volume and then parallel to the surface, no longer influenced by the presence of intermetallics. We have demonstrated that this damage mechanism is the same for the two selected materials, for two tested microstructural states and for the two experimental conditions.