Critical experiments to unravel metal corrosion

Corrosion damage phenomena such as pitting or stress corrosion cracking are a major concern for the nuclear industry. From atmospheric stress corrosion cracking of dry store canisters to ageing degradation of water reactor components. Predicting these phenomena is challenging, from both engineering and scientific perspectives. Existing academic models are rarely used due to the empirical nature; they require extensive calibration and are unreliable beyond the calibration regimes. However, there is an opportunity now to develop a new generation of physically-based models that can resolve the physical mechanisms and thus deliver reliable predictions over space and time scales of interest. These models build upon the success of phase field algorithms, which enable (for the first time) to simulate explicitly the nucleation of pits, the pit-to-crack transition and the subsequent crack growth [1-4].

Figure 1. Phase field models can predict pitting, stress corrosion cracking at large scales.

The coupling of phase field models for corrosion and environmentally assisted cracking with multi-physics finite element analysis has enabled predicting pitting and stress corrosion cracking over very large time scales. This methodology has been successfully benchmarked against laboratory experiments and field measurements from industrial partners in the offshore energy sector (Wind, Oil&Gas). Its potential in bringing down maintenance and fitness-for-service assessment has been demonstrated in offshore engineering and the aim of this project is to extend this success to the nuclear energy sector.

Two PhD projects will be carried out in parallel to bring this ambition to fruition. One, provided in-kind by Imperial College, will use this new generation of models by predicting pitting and pit-to-crack transitions in dry store canisters made of austenitic stainless steel, which are susceptible to atmospheric stress corrosion cracking. The other one, supported by EDF Energy, will carry out the necessary experimental testing to validate model predictions and provide the necessary input. As shown in Fig. 2, the model will resolve the microstructural nature of the problem by using crystal plasticity formulations, enhancing fidelity. Simulations will be benchmarked against experiments and EDF data, including sensor measurements and the role of variables such as defect size or humidity. Verified models will then be used to
predict defect evolution over long time periods (years), assisting nuclear fuel storage decision-making.

Figure 2. Evolution over time of a pit corrosion defect in a polycrystalline stainless steel structure.

The modelling framework developed is expected to be useful in (1) optimizing monitoring of current dry store canisters, bringing down operational costs, and (2) material selection and design of future generation storage. The work is well-aligned with other research efforts supported by EDF (e.g., EPSRC Prosperity Partnership) and complementary to the activities at Modelling and Simulation Centre (MaSC) in Manchester, part of the work will be devoted to integrating this new generation of promising models into the open-source platforms developed by EDF over the past three decades (Code Aster, Salome Meca); ensuring a significant impact for EDF activities during and beyond the PhD project.

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**References**


