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Influence of the Microstructure on Stress Concentration due to Localized Corrosion

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Pitting corrosion is an electrochemical process that depends upon the composition and microstructure of the corroding metal, and the formulation of the electrolyte. Under favorable circumstances, a stable pit growth can transition into stress corrosion cracking in a structural component under mechanical load leading to catastrophic failure [1,2]. It is intuitive to assume that like notches, cavities and cracks in structural components, growing pits could cause areas of stress concentration; and thus, cracks near the electrolyte-metal interface with the exact location of the highest stresses being dependent upon the part dimensions, loading mode, material behavior and pit morphology [3].

Along with other aspects of pit kinetics, the growing pit shape is also affected by the evolving electrochemistry in the pit as well as the exposed microstructure at the corrosion front. In fact, at the microscale--the typical scale of pit initiation and growth--these two aspects are strongly coupled. The microstructural features at the corrosion front, such as precipitates, secondary particles and phases, and grain boundaries, effectuate changes in the observed electrochemical (dissolution) behavior. Therefore, it is the microstructure that dominates the formation of irregular pit shapes that are commonly observed experimentally. It is again intuitive to assume that the more tortuous shapes, those with much local variation in geometry, may lead to relatively higher stresses than the smoother shapes.

Therefore, the objective of the current study is to determine the effect of the microstructure on stress concentration near corrosion front due to the formation of irregular pit shapes. Another objective is to quantify the irregularity in terms of robust tortuosity measures. The goal is to be able to relate these parameters to actual calculations of stress concentration in pitted samples to acquire efficient predictive capability. The objectives are achieved through the modeling of stable pit growth in 316 stainless steel microstructure with focus on the variation in polarization behavior with respect to the crystallographic orientation of the exposed metallic surface at the front (e.g., see [4]).

The approach is to perform 2D image-based modeling of the corrosion process in the commercial software COMSOL. High-resolution voxel-based microstructural reconstruction obtained through orientation image microscopy is included in the models through a sophisticated interpolation scheme based on spatial description of the crystallographic orientation of the underlying microstructure. Maximum corrosion conditions are assumed, which are described with the Laplace equation for the electric potential in the electrolyte. Arbitrary Lagrangian-Eulerian meshing method is used to track the corrosion front.

The following steps are taken for a each numerical experiment (see Figure 1): Idealized initial pit shapes are chosen randomly at locations throughout the microstructure and stable pit growth is simulated; b) The pit interface is digitally identified with an image-processing utility in Matlab; c) The solid domain is separated from the electrolyte at the corrosion front; d) Additional solids sub-domains are added to the original domain to create a larger mechanical specimen, and the resulting model is meshed and loaded in Mode I; e) The stress concentration factor is numerically calculated. Moreover, four quantitative descriptions of tortuosity that have been pioneered in the medical industry for retinal diseases are used to describe the shape of the resulting pits. Two of these parameters, the normalized integrated curvature over the pit perimeter and integrated square of curvature over the pit perimeter are plotted in Figure 2 for 10 locations. Currently, additional parametric simulations are being performed to be able to correlate the tortuosity measures with the calculated stress concentration factors.

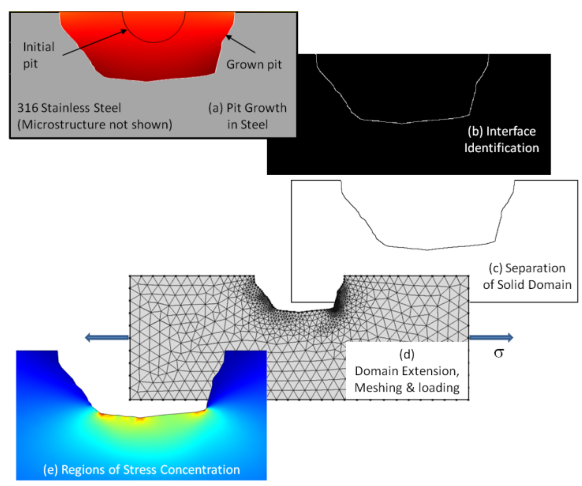

Figure 1. Simulation steps from pitting to mechanical loading.

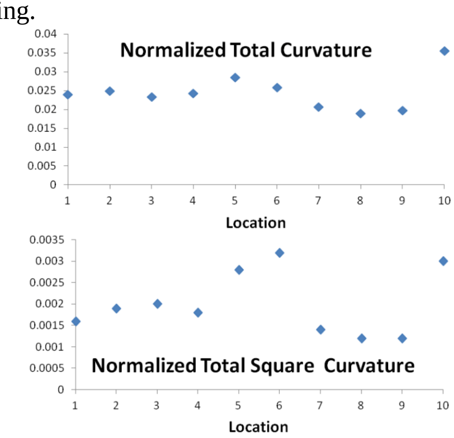

Figure 2. Variation in pit shapes as described by two tortuosity parameters across ten random locations in the microstruture.

References:
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