Modelling Based Detection of Early Stage Corrosion Degradation of Pipeline Steels

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Main Objective

This project was awarded to Iowa State University to develop experimental protocols to detect early stage degradation associated with stress corrosion cracking (SCC) in pipeline steels in high-pH bicarbonate solution, based on a combined modeling – experimental approach.

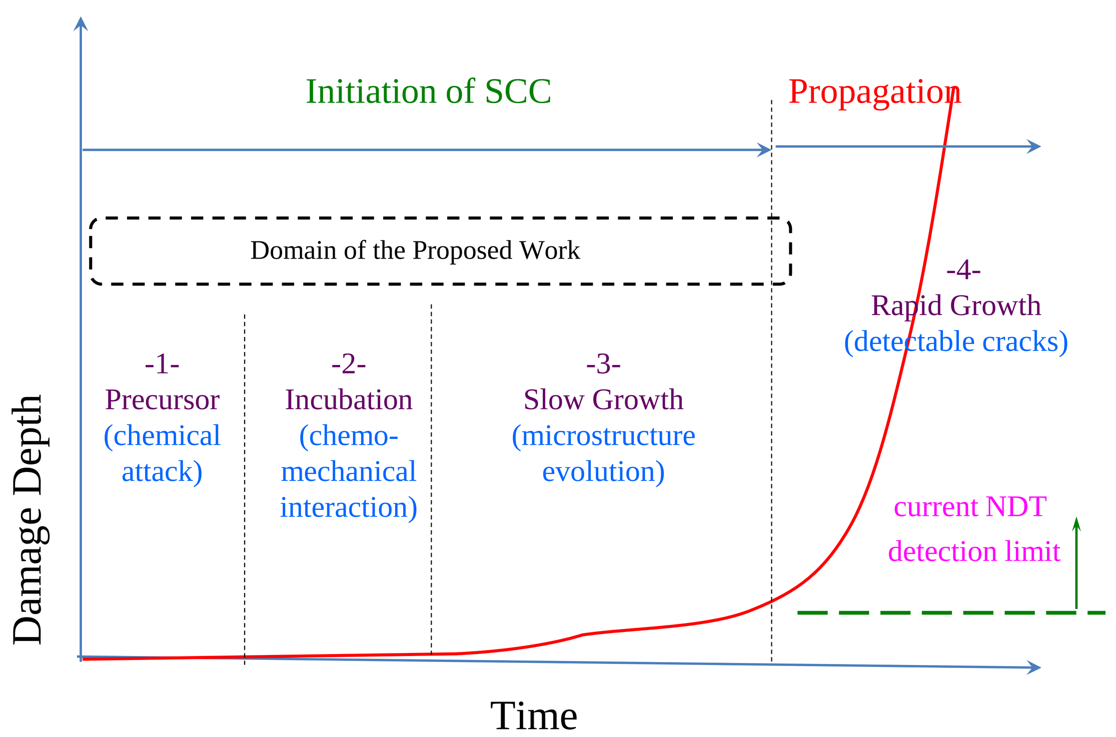

Figure 1. Scope of the present work

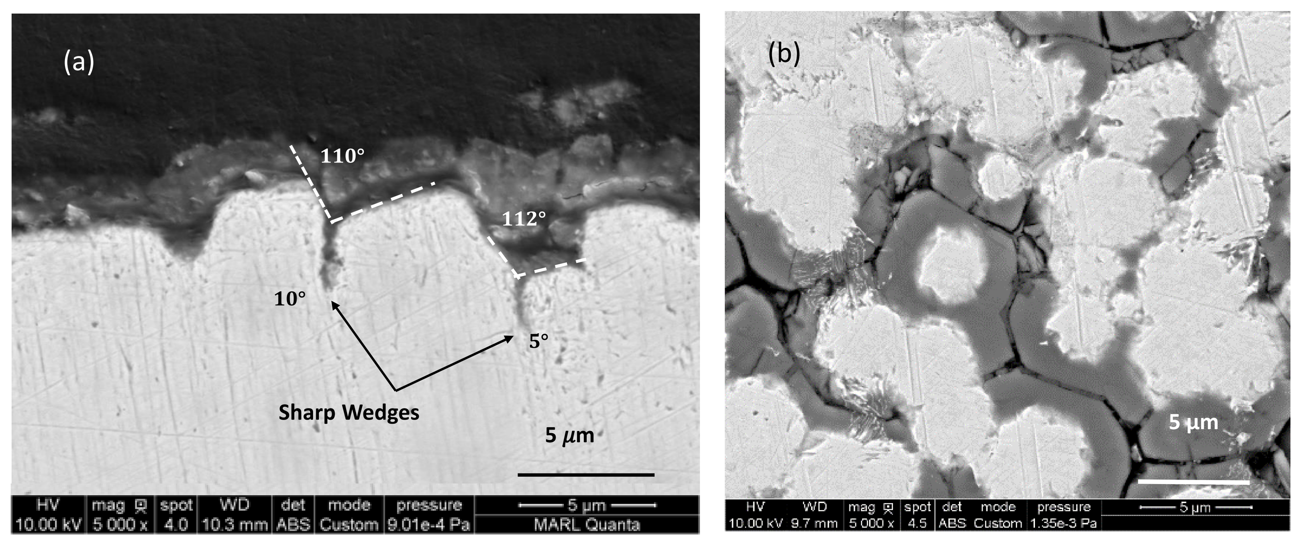

Figure 2. SEM images showing grain boundary (GB) corrosion product wedges. (a) Vertical cross section (b) horizontal cross section

Project Approach/Scope

Develop predictive model for early stage intergranular corrosion damage (IGC) preceding SCC. Model is based on our experimental findings:

- Layer of reduced hardness near corroded GBs suggests nonequilibrium vacancies
- Preferential Si oxidation at GBs can explain vacancy formation.
- Triangular corrosion product wedges indicate uniform steel dissolution rate V_s on grain faces, slightly higher GB dissolution rate V_{gb}

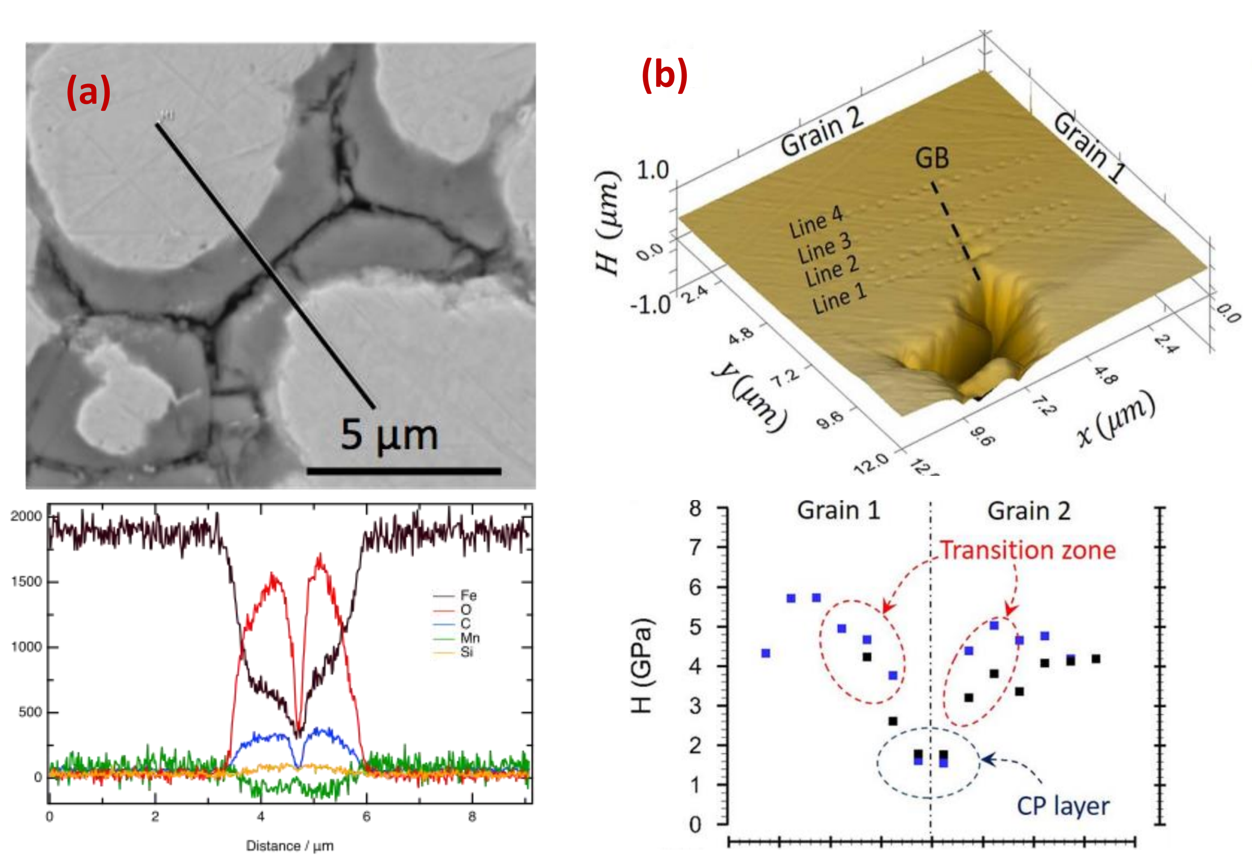

Figure 3. Experimental findings: (a) elevated Si in corrosion product (b) reduced-hardness layer near grain boundaries

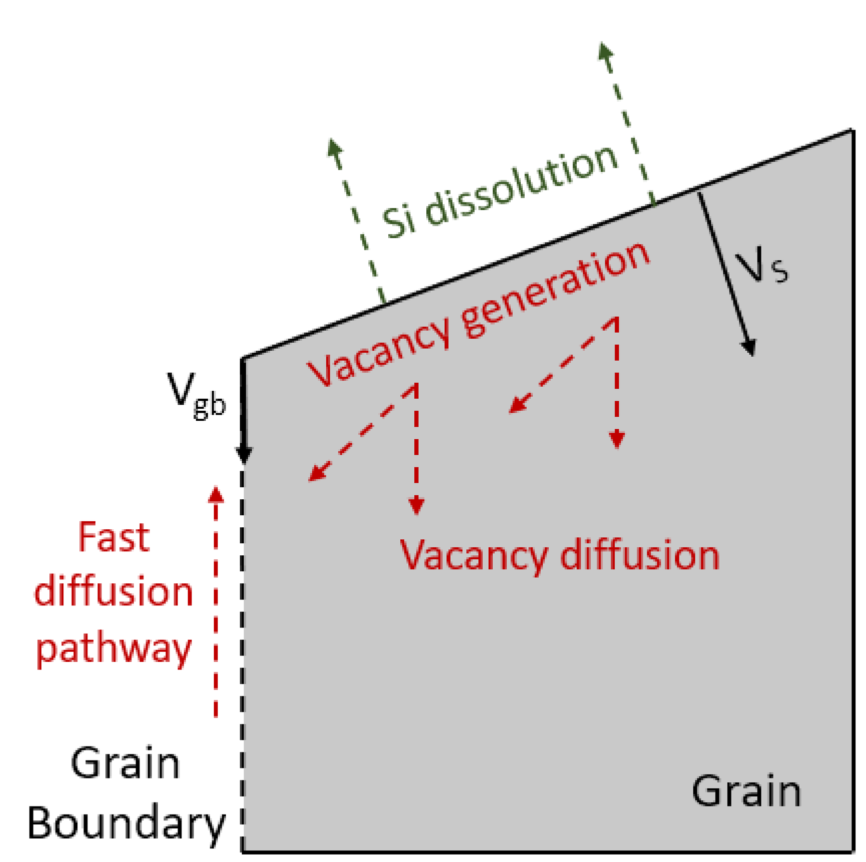

Figure 4. Diffusion model for vacancies introduced by selective Si oxidation. Vacancy diffusion along GB enhances V_{gb} relative to V_s, accounting for triangular wedge shape.

Results to Date

- The vacancy diffusion-based mechanism was implemented in a finite element simulation of intergranular corrosion.
- Experimentally measured GB corrosion rates and wedge angles are quantitatively consistent with the independently determined vacancy diffusivity D_v in steel of ~ 10^{17} m^2/s.
- Model predicts formation of sharp wedges during long corrosion exposures leading to low corrosion rates (prediction currently being tested by SEM). Narrow-angle wedges can concentrate external stresses and act as precursors for SCC.
- Inhibition of SCC may be possible by reducing the Si content of steel. Electrochemical impedance spectroscopy is being developed to detect corrosion crevices and cracks.

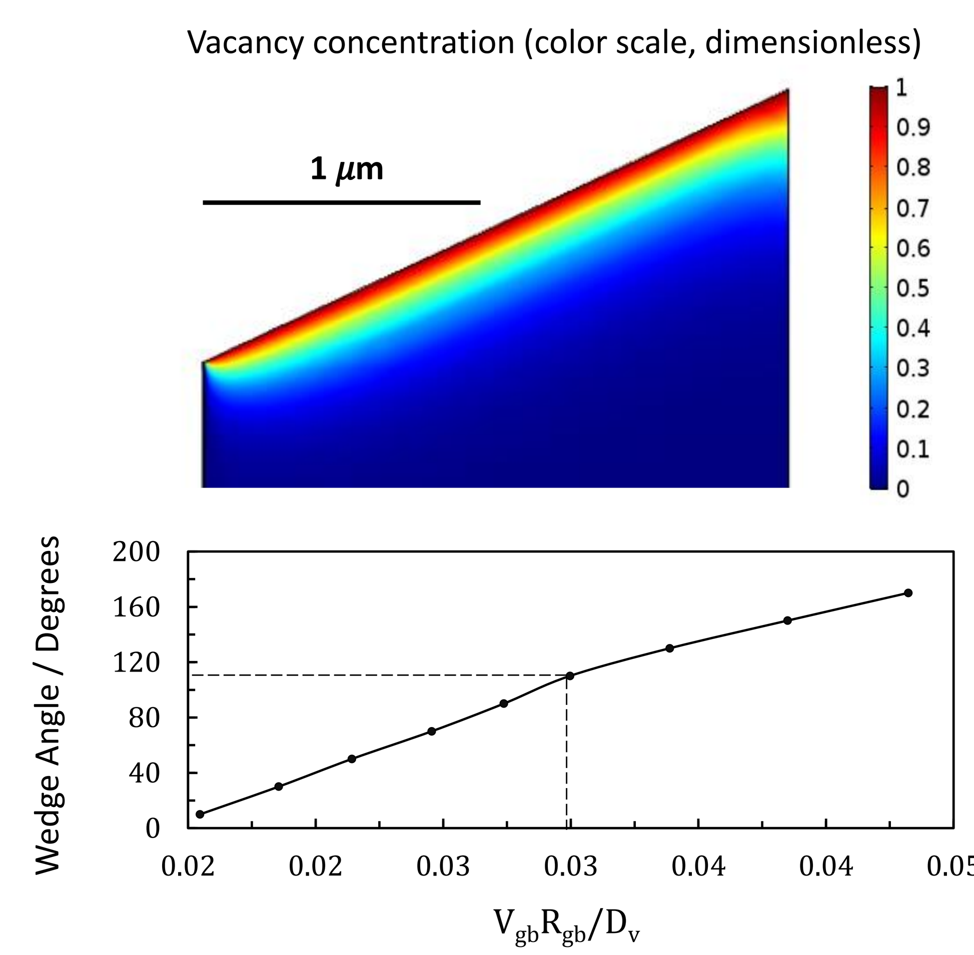

Figure 5. Results from implementation of the vacancy diffusion mechanism in finite element simulation.

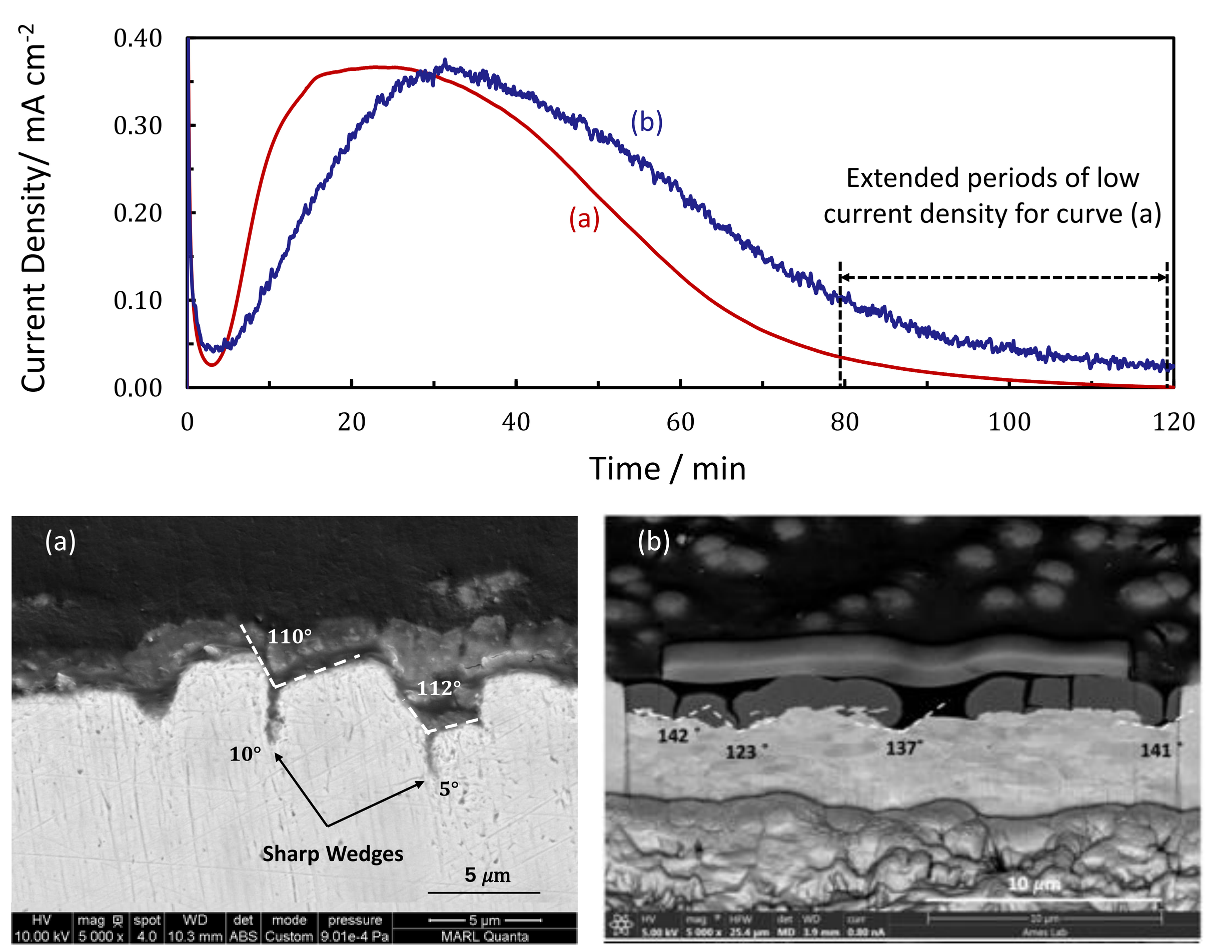

Figure 6. Formation of narrow and wide angle wedges corresponding to lower and higher current density regions, respectively.

Acknowledgments

This project is funded by DOT/PHMSA's Competitive Academic Agreement Program (No. DTPH5614HCAP03 and DTPH5614HCAP01).

References

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2. D. Yavas, P. Mishra, A. Alshehri, P. Shrotriya, K.R. Hebert, A.F. Bastawros, "Nanoindentation study of corrosion-induced grain boundary degradation in a pipeline steel", Electrochemistry Communications, 88, 88-92, 2018.

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