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QUARTERLY REPORT

Guidelines for the Identification of Stress Corrosion Cracking Sites and the Estimation of Re-Inspection Intervals for Stress Corrosion Cracking Direct Assessment

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Prepared For: United States Department of Transportation
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Prepared By: Fraser King
Principal Investigator
NOVA Research & Technology Corporation
2928 16th Street, N.E.
Calgary Alberta T2E 7K7
fraser.king@shaw.ca

Mark Piazza
Program Manager and Technical Coordinator
Pipeline Research Council, International
1401 Wilson Blvd., Suite 1101
Arlington, VA 22209
703-387-0190
mpiazza@prci.org

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PRCI LEADING PIPELINE RESEARCH

Pipeline Research Council International, Inc.
1401 Wilson Boulevard • Suite 1101 • Arlington, VA 22209 • USA
Main 703-387-0190 • Fax 703-387-0192 • www.prci.org

Project Background

The objective of this project is to develop a set of quantitative guidelines for predicting where and when Stress Corrosion Cracking (SCC) might be an integrity threat for gas and liquid hydrocarbon pipelines. These objectives will be achieved over 24 months through the following tasks:

- Task 1: Data Collection – Data will be collected from the literature, company or field records, pipeline operators, and regulators;
- Task 2: Data Analysis – Analysis of field and laboratory data to derive relationships describing susceptibility to SCC, crack initiation, crack growth and dormancy, and crack growth to failure;
- Task 3: Documentation – Document the results of the data analysis task;
- Task 4: Technology Transfer – Disseminate the results of this work to the industry; and
- Task 5: Administration and Reporting – Direct and document the research and report on project progress and results.

Technical Status

Progress in the quarter was made on a number of the scheduled tasks. In particular, progress was made on Task 1: Data Collection and Task 2: Data Analysis. Limited progress was made on Task 3: Documentation and Task 4 Technology Transfer.

Task 1: Data Collection

Sub-task 1.1 Data Collection from Literature

Formal data collection from the historical literature has been completed as reported in the Q5 quarterly report (August 31, 2007). Copies of more than 200 papers, reports, proceedings, and industry guidelines have been collected. Although the formal literature data collection has been completed, the literature is still being monitored for new publications in this area. This monitoring involves monthly review of the Table of Contents of 5-10 relevant journals, periodic review of the agendas of relevant topical meetings, and discussions with colleagues to monitor areas of active research on pipeline SCC. The PI is also involved in company-specific SCC research and these activities are also being monitored. Developments from pipeline industry groups (e.g., the Canadian Energy Pipeline Association, CEPA) are also being reviewed. Finally, discussions and feedback from workshops will be incorporated into the SCC guidelines where applicable (e.g., discussions at the Banff Pipeline Workshop).

Sub-task 1.2 Data Collection from Pipeline Operators

This sub-task has been on-hold for the past three quarters because of a delay in the coordination of activities with other PRCI SCC projects. PRCI-member companies have requested that the data collection for this project be coordinated with that from other similar PRCI SCC projects in order to avoid multiple requests for the same data.

As reported in the last two monthly progress reports (September and October 2007), it is understood that the cause of the delay in coordinating the collection of field SCC data from pipeline operators has been resolved, and that such data collection activities will begin in December 2007. It is expected that the data collected should be available for validation of the guidelines in time for completion of this project.

Sub-task 1.3 Data Collection: Foreign SCC Mitigation Practices

Collection of SCC data from non-US operators was part of the overall coordinated strategy with PRCI. This task has been delayed because of the same issues with data collection from domestic pipeline companies. As noted above, this issue should have now been resolved.

Task 2: Data Analysis

Analysis of the data has been proceeding simultaneously with data collection.

Sub-task 2 Data Analysis: Categorizing Data

Categorization of the data involves reading the assembled literature and determining to which stage of crack growth the results refer. The four stages or modules of the guidelines are:

1. SCC susceptibility
2. Crack initiation
3. Crack growth and dormancy
4. Crack growth to failure

The major focus of this project is the development of guidelines based on an analysis of literature pertaining to SCC Research & Development studies, with the conclusions validated by comparison with field data from operating pipeline companies.

Categorization of the data was completed early in this quarter and examples of the types of information available from the literature were presented in the previous quarterly report.

The following discussion provides detailed examples of R&D information that describes different phases of the guidelines, which are consistent with the stages of crack growth, namely: susceptibility, initiation, crack growth and dormancy, and crack growth to failure.

In this quarter, most emphasis has been placed on analyzing data that are relevant for the susceptibility and initiation phases of the guidelines. The other two phases, crack growth and dormancy and crack growth to failure, were the focus of the previous quarters analysis, as reported in the last quarterly update.

Sub-task 2.1 Data Analysis: Pipeline Susceptibility to SCC

A significant number of R&D studies have either focused on, or the results can be used to inform, the question of factors determining SCC susceptibility.

There have been a number of studies on the potential inhibiting effects of organics on crack initiation and growth. The aim of these studies has been to identify particular soils or soil components which may inhibit SCC. If such a component could be identified, then there is the possibility of identifying soils that will not support SCC. Identifying locations not susceptible to SCC is, in many ways, as valuable as identifying locations that are susceptible.

Figure 1 shows the results of a PRCI-funded project examining the effect of different soil components on the susceptibility to SCC. The soil tested was from a site on a pipeline right-of-way at which near-neutral pH SCC has been previously discovered. Slow strain rate testing is a severe mechanical test and is believed to indicate susceptibility to SCC and to provide information about crack initiation and, possibly, early-stage growth.

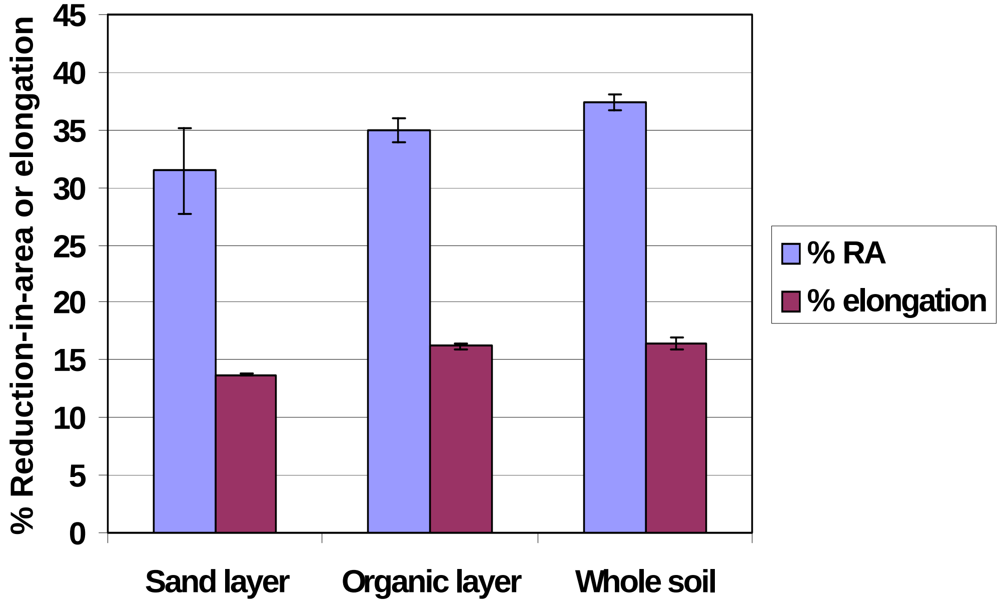

Figure 1: The results of slow strain rate tests in soil solutions from separate sub-components of a stratified soil from a near-neutral pH SCC site and from the mixed soil solution.

The soil at this SCC site is described as organics-over-sand, and comprises an organic layer 1-2 feet thick overlying a sand or clay layer in which the pipe is located. Soil solutions were prepared from the two layers separately which were then combined into a third single soil solution mixture. Greatest susceptibility (greatest brittleness) was observed in the sand soil solution, with the least susceptibility (greatest ductility) in the organic soil solution. Interestingly, when added to the sand soil solution, the organic soil solution inhibited the aggressiveness of the sand layer, indicating a distinct inhibitive effect of some component of the soil solution.

Sub-task 2.2 Data Analysis: Initiation

The other topic considered in some detail during the past quarter is the evidence in support of initiation available in the technical literature. Parkins and co-workers studied the factors leading to the initiation of high-pH SCC in some detail in the 1970's. One of the factors considered was the role of millscale in poising the potential in the appropriate range for cracking. Some recent work has shed more light on the role of millscale and has suggested an additional effect on the initiation process.

Millscale is residual oxide and deposit that remains on the pipe following manufacture. These days the millscale is removed from the pipe surface immediately prior to application of a mill-applied coating. However, for much of the pipe now experiencing SCC problems, the coating was applied in the field and the millscale was not removed prior to coating application. When this coating inevitably disbonded, the surface exposed to the soil solution was not a polished steel surface, as is commonly used in laboratory experiments, but a millscale-covered surface.

Millscale is a mixture of magnetite (Fe_3O_4), maghemite (gamma-FeOOH), iron carbonate ($FeCO_3$), and other mineral impurities from the steel-making process. This complex oxide acts as a semi-conductor and is electrochemically active. Therefore, it is not an inert surface when expsoed to the groundwater when the coating disbonds.

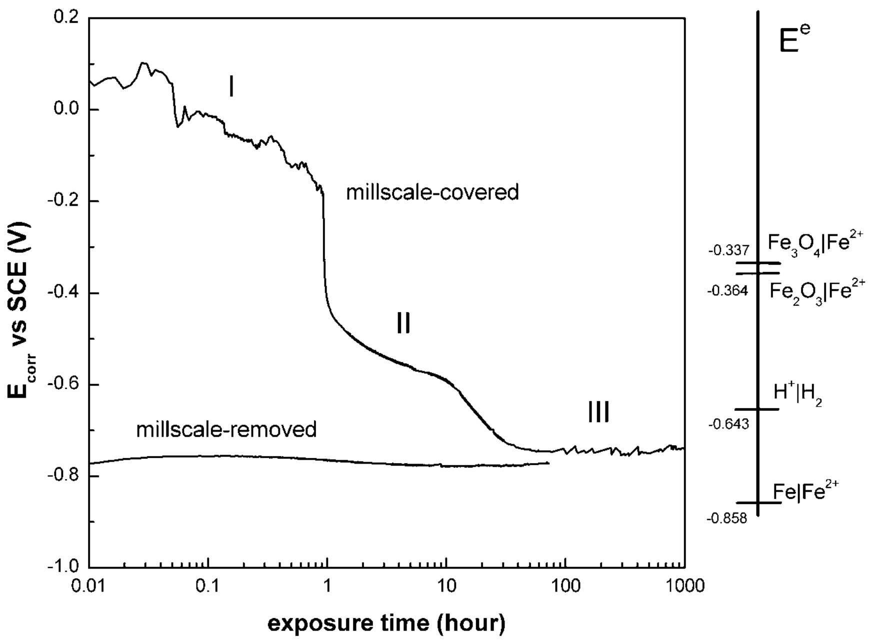

Figure 2: Time dependence of the open-circuit potential of a millscale-covered steel electrode when exposed to a simulated near-neutral pH SCC environment.

Figure 2 shows the time dependence of the open-circuit potential of a millscale-covered C-steel electrode when exposed to a simulated near-neutral pH SCC solution. The open-circuit potential, which is representative of the surface of the pipeline under a shielding coating, evolves through a number of phases. Initially the potential is quite positive, but gradually shifts to more-negative values as the millscale layer is slowly dissolved in the acidic CO_2-purged solution. However, as the potential evolves, the underlying C-steel surface, which is galvanically coupled to the millscale layer, is polarized by the millscale layer. As a consequence, there is a period of time during which the C-steel is maintained at a positive potential and dissolves rapidly. This dissolution, however, is localized as much of the surface is protected by the remaining millscale layer. In fact, the C-steel only dissolves at the base of defects in the brittle millscale layer. However, the millscale is preferentially defected in a direction perpendicular to the major stress on the pipe, i.e., the hoop stress. Thus, preferential dissolution of the C-steel occurs in a longitudinal orientation, resulting in the growth of elongated pits aligned in an ideal direction for the initiation of cracks.

This mechanistic understanding could be used to identify pipelines that are more or less susceptible to crack initiation. For example, pipelines that operate at relatively constant pressure with only small pressure fluctuations might not suffer much crack initiation as the millscale does not become excessively defected due to the fluctuating hoop stress. Alternatively, some forms of millscale may be either more-resistant to cracking or may not possess the electrochemical properties necessary to support the form of galvanic coupling required to drive dissolution of the underlying C-steel. One pipeline company has speculated that its observation of different behaviour of two seemingly identical pipelines the same sort of terrain which exhibit totally different SCC susceptibility may be due to differences in the properties of the millscale.