Strain Rate Effects on the Stress Corrosion Cracking Behavior of Ni- and Co-Based Superalloys for Marine Applications

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Introduction and Motivation

Marine fastener materials have exhibited IG-SCC failures in seawater environments when exposed to polarization from cathode protection systems. Fracture mechanics characterization and life estimations offer a next-generation means by which to manage these long life failures. Specifically, IG-SCC metrics threshold I stress intensity (Kth) and Stage II crack growth rate (da/dt) can be established using laboratory testing and used to inform engineering decisions via the similitude concept. Critically, prior efforts have established that Kth and da/dt can be a strong function of loading rate. An understanding of this behavior is necessary for accurate characterization and structural management of marine alloys (MP98t and Monel K-500) susceptible to IG-SCC. Specifically, it is necessary to ensure that IG-SCC metrics established via laboratory testing are pertinent to in-service loading rate conditions.

Objectives

1. Use LEFM experiments to quantify the effect of da/dt on the Kth and da/dt for different marine alloys at relevant electrochemical polarization/s.
2. Use experimental data to provide mechanistic insight for the any da/dt dependent SCC behavior.
3. Inform practical testing protocols to ensure accurate and conservative quantification of the SCC behavior.

Materials

Experimental Approach

Sample Description: Single edge notch tension (SENT) specimen. The load was applied longitudinally, along the rolling direction of MP98t.

Measurement Method: Direct current potential difference (dCPD) is used to measure active crack growth.

Environment: 0.6 M NaCl with a constant applied electrical potential (V SCE).

Management: A stress ratio displacement test with a constant K range. The applied load changes with each test.

Fractography: The fracture surface is analyzed in the SEM.

Data Analysis: The crack growth rate (da/dt) is determined. Material corrections are applied. NRL HS creates a large plastic zone relative to the specimen size so elastoplastic K is used.

Comparison: Test results are compared to each other and computational models to determine trends.

Possible Mechanisms

Crack Tip Strain Rate with Barrier Rutlature: Some barrier at the crack tip develops and blocks additional H from entering. At a sufficiently high loading rate, this barrier is continually ruptured, creating a fresh receptive surface.

Concurrent Plasticity: Increased crack tip work hardening due to simultaneous H adsorption and strain induced plasticity.

These mechanisms may have some limited step that causes the da/dt plateau.

Results

Monel K-500

Monel K-500 was tested at -950 mV SCE with da/dt = 0.33 MPa√m/hr. SCC only occurred at this potential so further testing was pursued. To remove the additional increase due to plastic effects, the resolution limit (RL) for each da/dt was subtracted from the data. The scaling plasticity effects must be removed in order to see true crack growth trends.

The plastic collected in conjunction with crack growth by dcPD must further analyzed for true crack growth rates to be determined.

This work is in progress and has thus far seen that the resolution limit does not scale linearly with da/dt > 1.0 MPa√m/hr in Monel K-500.

MP98t

MP98t shows mixed IG and transgranular cracking (TG-SCC). After a short Mode I crack extension, the crack deflected to γ = 45°, this occurred on all samples tested at -1.30 V SCE. Post-test corrections were made to the K and da/dt calculations to reflect the changes due to mode fracture. Discontinuities in the graph below depict the K of deflection.

The reason for deflection is not conclusively established, but is directionally consistent with anisotropy in grain size (EBSD) and tensile properties.

Conclusions

1. MP98t shows decreases in Kth trends with increasing da/dt. The magnitude is material dependent.
2. NRL HS and MP98t show IGSCC and IG/TG-SCC, respectively. These mechanisms are consistent over the full range of da/dt values examined. This suggests that there is not a fundamental change in the mechanism as da/dt varies.
3. The plastic resolution limit for dcPD does not scale linearly across all K-rates.

Future Work

1. Further quantify effects, focusing on very high and low da/dt values to determine if plateaus exists.
2. Preliminary testing of NRL HS at -850 mV SCE shows no evidence of SCC at a da/dt = 0.33 MPa√m/hr. However, this potential could be useful for determining if a cracking can be induced at different da/dt.
   This testing could give insight into what mechanism governs hydrogen environmentally assisted cracking (HEAC).
3. Use the quantitative data and mechanistic insights to inform experimental testing protocols for engineering relevant loading rate conditions.

Acknowledgements

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References


Appendix: Table of Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Environment</th>
<th>Stress Intensity (MPa√m)</th>
<th>CR</th>
<th>IT</th>
<th>RL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monel K-500</td>
<td>-950 mV SCE</td>
<td>0.33 MPa√m/hr</td>
<td>0.19</td>
<td>0.17</td>
<td>0.12</td>
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<tr>
<td>MP98t</td>
<td>-1.30 V SCE</td>
<td>0.33 MPa√m/hr</td>
<td>0.20</td>
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