AGENDA

• Development of Crevcorr crevice former
• HISC – Hydrogen Induced Stress Cracking of duplex stainless steels
CREVCORR
CREVCORR

• The working party "Marine corrosion" in EFC had performed two round robins testing programs and one EU funded project for crevice corrosion testing in seawater
  – The reproducibility was bad
  – The results did not correspond to service practice
    • 316L did not experience crevice corrosion in all testing
• An EU funded project were initiated in the working party – Crevcorr
  – One task was to develop crevice corrosion testing techniques for stainless steels – both for flat and curvature specimens
**DISC SPRING LOADING**

**SPECIMEN DESIGN**

- Using disc springs to control the crevice gap gives good reproducibility

- Use of PVDF for the crevice former
  - PTFE deforms during loading
  - PTFE relaxes at higher temperatures
  - PVDF is suitable as crevice former up to at least 90°C
IMPROVED RESULT

RESULTS FROM 6 MONTHS AMBIENT TEMPERATURE SEAWATER TEST PROGRAMS FOR 316L

- Experiences shows that 316L is prone for crevice corrosion in ambient seawater
- Improved prediction with the Crevcorr set up

<table>
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<th>Laboratory</th>
<th>EFC Test I</th>
<th>EFC Test II</th>
<th>MAST test</th>
<th>Crevcorr test</th>
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T. Ronge, EFC Publication no 60, 2010, pp. 67-87
TUBULAR TEST SPECIMENS

SPECIMEN DESIGN

- Based on the Crevcorr set-up for flat specimens
- Curvature crevice formers with the same radius as the tube
- The applied clamping force must be adjusted in order to have constant pressure
  - Based on FEM-modeling in order to have similar pressure as for flat specimens

\[ y = 251.51 \ln(x) - 216.39 \]
\[ R^2 = 0.9943 \]

U. Kivisäkk, EFC Publication no 60, 2010, pp. 21-29
ISO 18070

CREVICE FORMER DEVELOPED IN CREVCORR

• Based on the work in Crevcorr standardisation within ISO were initiated for the developed crevice former

• In 2015 publication of ISO 18070 was made
HISC OF DUPLEX
INTRODUCTION

• Failures due to hydrogen induced stress cracking (HISC) have occurred
• Occurs when subject to both cathodic protection and tensile load
• The failures of duplex stainless steels have in common
  – Coarse material, austenite spacing above 30 µm
  – Involvement of plastic deformation
MATERIAL

• Two product forms
  – Extruded tube - austenite spacing of 10 µm
  – Bar material - austenite spacing of 42 µm

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<tr>
<th>Grade</th>
<th>UNS</th>
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<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
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<td>7</td>
<td>4</td>
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<td>&gt;42.5</td>
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</table>
RESULTS FROM HISC-TESTING

MAXIMUM TESTED LOAD WITHOUT CRACKING

Percentage of the yield strength ($R_{p0.2}$)
INHOMOGENOUS DEFORMATION OF DUPLEX STAINLESS STEELS

- At 90% of the yield strength, austenite is softer than the ferrite.
- The deformation takes place in the austenite.
- In order to have the same strain, the ferrite creeps, dislocations are generated.
- The coarse duplex experiences creep but not the tube with small austenite spacing at 90% of the yield strength.
EBSD for HISC-tested specimens at 90% Rp_{0.2}

**TUBE:** NO LOW ANGLE GRAIN BOUNDARIES IN FERRITE

**BAR:** MANY LOW ANGLE GRAIN BOUNDARIES IN FERRITE

White lines represent low angle grain boundaries with dislocations

Ferrite = Blue

Austenite = Red
PROPOSED MECHANISM FOR HYDROGEN INDUCED STRESS CRACKING IN A TWO PHASED MATERIAL
CONCLUSIONS

• Reproducible crevice corrosion test procedures for stainless steels in seawater have been developed and consistent results between laboratory testing and field testing has been achieved

• The crevice forming technology has been standardised in ISO 18070

• A mechanism for HISC on duplex stainless steels subject to cathodic protection based on inhomogeneous deformation has been proposed

• The mechanism explains why coarse material cracks when duplex with fine microstructure don’t
ACKNOWLEDGMENTS

- Co workers at Sandvik Materials Technology
- Project members of Crevcorr
- Members of EFC working party “Marine Corrosion”
- Dr Marie Sparr at Swerea KIMAB of standardisation of crevice former