Permanent effect of a cryogenic spill on fracture properties of structural steels

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Outline

• Motivation
• Objective
• Materials
• Experimental
• Results
• Conclusion
Motivation

Failure due to cryogenic spill happens with a \textbf{\textit{Bang}}

Carbon steel platform deck exposed to liquid nitrogen $\rightarrow$ failure $\rightarrow$ flaw in a weld

Standard procedure:
- Visual and NDT testing
- Remove damaged material
- Replace with new material
Objective

Is it sufficient to only remove damaged material?

or

does a cryogenic spill affect the fracture properties of structural steels permanently?
Materials

Two structural steels:
NV E36 ← platform material
DOMEX S355 MCD

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>Cu</th>
<th>Al</th>
<th>Nb</th>
<th>V</th>
<th>Ti</th>
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</thead>
<tbody>
<tr>
<td>NV E36*</td>
<td>0.20</td>
<td>0.10-0.55</td>
<td>1.70</td>
<td>0.030</td>
<td>0.030</td>
<td>0.20</td>
<td>0.08</td>
<td>0.40</td>
<td>0.35</td>
<td>min 0.02</td>
<td>0.02-0.05</td>
<td>0.05-0.10</td>
<td>0.007-0.05</td>
</tr>
<tr>
<td>S355**</td>
<td>0.069</td>
<td>0.01</td>
<td>0.62</td>
<td>0.009</td>
<td>0.003</td>
<td>0.03</td>
<td>0.00</td>
<td>0.03</td>
<td>0.01</td>
<td>0.046</td>
<td>0.023</td>
<td>0.00</td>
<td>0.00</td>
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</tbody>
</table>

* Specification
** Certificate

<table>
<thead>
<tr>
<th></th>
<th>NV E36</th>
<th>S355</th>
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</thead>
<tbody>
<tr>
<td>Yield [MPa]</td>
<td>355</td>
<td>377</td>
</tr>
<tr>
<td>UTS [MPa]</td>
<td>470</td>
<td>450</td>
</tr>
<tr>
<td>Elongation [%]</td>
<td>21</td>
<td>39</td>
</tr>
</tbody>
</table>

NV E36: perlitic steel
large grain size
elongated sulphides

DOMEX: Low carbon steel
ferritic microstructure
small grains
low in S and P
offshore applications
Experimental setup – platform materials

NV E36
«Exposed» and «non-exposed» areas
• Charpy V-notch impact testing
• Notch perpendicular and parallel to the rolling direction
• Temperature: 0°C (32°F)
• Fractography
• Cross section examination
Experimental setup – simulated spill

Tensile testing in liquid nitrogen
Quasi-static: 1 mm/min
Reference samples tested at -196°C

Pre-stress in elastic region for 10 min:
DOMEX S355: 1000 N, 4000 N and 6500 N
NV E36: 5000 N

Tensile testing at room temperature

Metallographic investigation of cross sections of pre-stressed samples

<table>
<thead>
<tr>
<th>Material</th>
<th>Force [N]</th>
</tr>
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<tbody>
<tr>
<td>NV E36</td>
<td>Ref</td>
</tr>
<tr>
<td>NV E36</td>
<td>5000</td>
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<tr>
<td>S355</td>
<td>Ref</td>
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<tr>
<td>S355</td>
<td>1000</td>
</tr>
<tr>
<td>S355</td>
<td>4000</td>
</tr>
<tr>
<td>S355</td>
<td>6500</td>
</tr>
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</table>

Testing at -196°C

~1100 MPa
~900 MPa
Results – Charpy impact testing

Average: 38.68 J
Min: 24.47 J
Max: 76.49 J (instantaneous stress relief)
Required: ~ 64 J at 0°C
Too low

But still lower than expected

A few values >52 J acceptable

Average: 102.83 J
Min: 52.20 J
Max: 144.71 J
Required: ~ 74 J at 0°C

NTNU Norwegian University of Science and Technology
Platform material - microstructure

Sample 1-30:
- Brittle behavior
- Cracks only observed near the fracture surface

Sample 3-34:
- Mainly ductile
- Macro crack
- Shear behavior
- Small cracks near the fracture surface
Simulated spill – tensile testing

- No particular difference observed when tested at room temperature
- Upper yield point gradually decreases with increasing pre-stress
Simulated spill - microstructure

Two types of cracks observed in pre-stressed material:

- DOMEX S355 – micro cracks
- NV E36 – sulphide related cracks (difference in thermal expansion coefficient)
Conclusion

• Critical reduction in Charpy energy (NV E36)
  – Notch parallel to the rolling direction
  – Cracks related to sulphides (difference in thermal expansion coefficient)

• Simulated spill
  – Tensile testing at -196°C:
    • Increase in yield strength
    • OK ductility
    • no work-hardening → Lüders region → fracture
  – Room temperature tensile testing:
    • Decrease in upper yield point with increasing pre-stress
    • No particular difference when tested in the rolling direction

A cryogenic spill may cause permanent damage
Further work

- Charpy V-notch testing of DOMEX S355 MCD
- Tensile testing perpendicular to the rolling direction
- Bi-axial stress at -196 °C more accurate than uni-axial stress
Thank you for your attention