Molten Salt Corrosion Behavior of ferritic steels, austenitic steels and Ni-base alloys in solar energy applications

17th of May 2017, Madrid
Ali Soleimani-Dorcheh, Diana Fähsing, Mathias C. Galetz
<table>
<thead>
<tr>
<th>Galetz</th>
<th>Interdisciplinary Research for Sustainable Technologies</th>
</tr>
</thead>
</table>

- Non-Profit Foundation under public law
- Ca. 80 employees (22 in High Temperature Corrosion)
- Annual budget ca. 9 Mio € (2/3 from projects, 1/3 from donations and investment)
Harsh Environments at High Temperatures

Temperature (°C)

log Corrosion

Vanadates

Sulfidation

Metal Dusting

Chlorine/Chlorides

F, Cl

V

S

H₂O

O

Cl⁻

NO₂⁻
Objective of research

- Screening of high temperature corrosion behavior of steels and Ni-base alloys in molten salt environment
- Influence of salt impurity on corrosion behavior
- Development of a solar salt corrosion resistant coatings
<table>
<thead>
<tr>
<th>Galetz</th>
<th>Studied materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alloy</td>
<td></td>
</tr>
<tr>
<td>P91</td>
<td>X20CrMoV 11-1</td>
</tr>
<tr>
<td>347HSS</td>
<td>316SS</td>
</tr>
<tr>
<td>IN625</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Alloy type</th>
<th>Low-Cr Steels (ferritic-Mart.)</th>
<th>Stainless steel (austenitic)</th>
<th>Ni base alloy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mn</td>
<td>0.412</td>
<td>1.24</td>
<td>1.79</td>
</tr>
<tr>
<td>Cr</td>
<td>8.75</td>
<td>17.06</td>
<td>17.05</td>
</tr>
<tr>
<td>Ni</td>
<td>0.17</td>
<td>9.84</td>
<td>12.03</td>
</tr>
<tr>
<td>Mo</td>
<td>0.944</td>
<td>0.341</td>
<td>2.37</td>
</tr>
<tr>
<td>Fe</td>
<td>88.7</td>
<td>70.1</td>
<td>65.8</td>
</tr>
</tbody>
</table>

\[ T = 600°C \]
\[ t = 5000h \]
\[ (ca. 30 \text{ weeks}) \]
\[ \text{KNO}_3-\text{NaNO}_3 \ (40/60) \]
After 2500h, 600°C, molten salt

- **P91**
- **X20**
- **SS316**
- **SS347**
- **IN625**

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Cross-section investigation

- Low-Cr steels (9, 11%) show porous and multilayered scales with poor adherence to the metal

- Stainless steels and Ni-base alloy formed thin, compact and well adhered oxide scales - protective: Metal recession < 10 µm/a!!!
Corrosion products

Low Cr steel X20, After 1000h
Stainless steel 347H

Ni-base alloy, IN-625

Corrosion products

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T = 600°C
t = 5000h
(ca. 30 weeks)
KNO₃-NaNO₃ (40/60)
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- Screening of high temperature corrosion behavior of steels and Ni-base alloys in molten salt environment
- Influence of salt impurity on corrosion behavior
- Development of a solar salt corrosion resistant coatings
The influence of chloride impurities

<table>
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<tr>
<th>Impurity</th>
<th>Salt 1 (wt %)</th>
<th>Salt 2 (wt %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrite (NO\textsuperscript{2-})</td>
<td>&lt;0.01</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>Chloride (Cl\textsuperscript{-})</td>
<td>&lt;0.02</td>
<td>&lt;0.25</td>
</tr>
<tr>
<td>Magnesium (Mg\textsuperscript{2+})</td>
<td>&lt;0.0007</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Carbonate (CO\textsubscript{3}\textsuperscript{2-})</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Sulphate (SO\textsubscript{4}\textsuperscript{2-})</td>
<td>&lt;0.01</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Insolubles</td>
<td>&lt;0.01</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Moisture</td>
<td>&lt;0.2</td>
<td>&lt;0.1</td>
</tr>
</tbody>
</table>
• Accelerated corrosion of X20 Steel in high chloride salt

• 316 SS not really affected by salt impurities
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- Screening of high temperature corrosion behavior of steels and Ni-base alloys in molten salt environment
- Influence of salt impurity on corrosion behavior

![Material Cost Chart]

- Development of solar salt corrosion resistant coatings
Can low-Cr steels be protected in molten nitrates?

- P91
- X20Cr
- SS447H
- SS316
- IN625

Material Cost

Euro/ton

0 1,000 2,000 3,000 4,000 5,000 6,000 7,000 8,000
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Aluminizing process

Al- slurry coating

substrate

substrate

Al\textsubscript{2}Al_{5}

FeAl

crack

P91 substrate

20 \mu m

Heat treatment

Aluminized Surface

substrate

Slurry aluminizing process

RAISELIFE Dissemination Workshop, Madrid, 17\textsuperscript{th} of May 2017
A continuous thin Al-rich oxide formed on the surface

No sign of salt attack is observed on the aluminide

For details please look into:
A. Soleimani Dorcheh, R.N. Durham, M.C. Galetz
Corrosion behavior of stainless and low-chromium steels and IN625 in molten nitrate salts at 600 °C

A. Soleimani Dorcheh, R.N. Durham, M.C. Galetz
Effect of chloride contents on the corrosion behavior of ferritic and austenitic steels in molten solar salts in "Proceedings of Corrosion 2016" (2016), NACE

A. Soleimani Dorcheh, M.C. Galetz
Slurry aluminizing: A solution for molten nitrate salt corrosion in concentrated solar power plants
Solar Energy Materials and Solar Cells 146 (2016), 8-15

A. Soleimani Dorcheh, R.N. Durham, M.C. Galetz
High temperature corrosion in molten solar salts: the role of chloride impurities
Materials and Corrosion, accepted

Thank you for your attention