NEW FILLER ALLOYS FOR OXIDATION DAMAGE REPAIR

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Problem analysis

Want to repair oxidized squeeler tips - SX aero alloy CMSX-4.

Coatings were not able to protect the base alloy
-> They will not be able to protect it after repair
-> The filler must have at least 'CMSX-4 level' oxidation resistance
-> The filler must form alumina scale with a very low level of active Sulphur

Cannot assume ultra clean casting Sulphur levels for a welding process
-> Need more elaborate Reactive Elements in the filler than in CMSX-4

Creep analysis with significantly reduced creep strength in squeeler tip showed 'almost no' creep deformation
-> Can trade creep strength for weldability compared to base alloys when choosing a filler
Fillers in the CrAl plane - Evaluation of 'state-of-the-art'

Aero alloys:
- Oxidation - Good
- Weldability - Very poor
  -> *not appropriate filler*

Industrial Gas Turbine alloys:
- Oxidation - Moderate *(chromia)*
  -> *not appropriate filler*
- Weldability – Poor
  -> *not appropriate filler*

'New IGT' SCA425+
- Oxidation - Good
- Weldability – Poor ?
  -> *not appropriate filler ?*

IN625
- Oxidation - Moderate
  -> *not appropriate filler*
- Weldability - Good

Ni-122, sold as NiCrAl for repair

*No Reactive Elements*
New trial fillers

We needed something new…

**Ni122EC**  
*Ni-18Cr-6Al-0.9Si-0.1Hf-0.1Y*  
Clean Ni-122 with Hf and Y added for RE effect.

**SCA425+**  
*Ni-5Co-15.5Cr-1Mo-4W-4.55Al-8Ta-0.1Hf-0.03Ce*  
New IGT blade alloy

**STAL18**  
*Ni-5Co-18Cr-0.8Mo-2.5W-4.5Al-4.5Ta-0.1Hf-0.1Si-0.05C-0.05Zr-0.03Ce*  
‘Weak SCA425+’

**STAL18Si**  
STAL18 with Si increased to 0.5 wt%

**STAL185**  
*Ni-5Co18.5Cr-1.6W-5.3Al-3.2Ta-0.3Hf-0.1Si-0.05Zr-0.05C-0.03Ce*  
‘weak STAL18, more Al’

**STAL185LaY**  
STAL185 with 0.03 wt% Ce replaced by 0.1 wt% La + 0.1 wt% Y

Our hypothesis: Successful suppression of spallation require;

• Catch as much sulphur as possible in the molten state - *La or Ce*

• Guard diffusion paths to the metal/scale interface
  
  • Zr against grain boundary diffusion, and
  
  • Y against diffusion through the gamma matrix

  \[ Sulphur \text{ tends to migrate to the interphase and reduce the metal/scale adhesion.}\]

• Make the scale thinner to reduce thermal stresses, e.g. using Si to speed up selective oxidation of Al.
Trial weldings and subsequent analysis

Machine of the squeeler tips

Rebuild them with laser welding layers, ~0.25mm per layer

New tips: ~2mm in width, 3mm in height before machining

Do several cuts, look for weld cracking

Do cyclic oxidation tests to 1100°C, look for
- oxidation resistance
- extensive microstructure analysis
- post-weld cracking

Do isothermal oxidation tests to 1000°C and 1050°C
Look for post-weld cracking
## Results - Overview

<table>
<thead>
<tr>
<th>Material</th>
<th>Weld Cracks</th>
<th>Cyclic Oxidation</th>
<th>Post Weld Cracking</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCA425+</td>
<td>Severe</td>
<td>Good</td>
<td>Moderate</td>
</tr>
<tr>
<td>STAL18</td>
<td>Moderate</td>
<td>Good</td>
<td>Moderate</td>
</tr>
<tr>
<td>STAL18Si</td>
<td>None</td>
<td>Excellent</td>
<td>None</td>
</tr>
<tr>
<td>STAL185</td>
<td>Moderate</td>
<td>Good</td>
<td>Moderate</td>
</tr>
<tr>
<td>STAL185LaY</td>
<td>Moderate</td>
<td>Excellent</td>
<td>Moderate</td>
</tr>
<tr>
<td>Ni-122</td>
<td><em>material gone</em></td>
<td>Very poor</td>
<td><em>not tested</em></td>
</tr>
<tr>
<td>Ni-122EC</td>
<td>Minor</td>
<td>Excellent</td>
<td>Severe</td>
</tr>
<tr>
<td>CMSX-4</td>
<td></td>
<td>Good</td>
<td></td>
</tr>
</tbody>
</table>
Weld cracking in SCA425+.

Figure 4  Left: Visible layer-by-layer structure and a significant crack for SCA425+. There seems to be an ‘imperfect DS structure’, and the crack follows a grain boundary. The grain boundary initiated at one of the layers.
No weld cracking in STAL18Si

Figure 5  Left: Faint layer-by-layer structure for STAL18Si and a less pronounced dendrite structure. There seems to be a SX structure with some LAB.
Cyclic oxidation testing - CMSX-4

Figure 7  The CMSX-4 after 550 cycles of cyclic oxidation. A continuous alumina layer is seen on most parts but seems to have spalled locally during preparation.
Cyclic oxidation testing - SCA425+

Figure 10   SCA425+ after 550 cycles. A continuous alumina scale was seen.

SCA425+ appeared similar to CMSX-4, i.e. it showed a high cyclic oxidation resistance interpreted as a consequence of a very low level of S, and RE effects from Hf and possibly also from traces of Ce, see Figure 10.
Cyclic oxidation testing - STAL18Si

Figure 11  STAL18Si after 550 cycles of cyclic oxidation. An internal continuous alumina layer with what could be roots of silica with a spinel layer on top.

STAL18Si showed excellent cyclic oxidation resistance despite an S content of 9ppm and the fact that there are probably at most traces left of Ce. Our interpretation is that the Si addition has been beneficial, and that we also have a positive RE effect from the presence of Hf and Zr.
Cyclic oxidation testing - Ni122 versus Ni122EC

**Figure 9** Aluminium nitride below a non-protective scale in the remaining material after 550 cycles for Ni-122.

**Figure 8** Ni-122EC after 550 cycles of cyclic oxidation. A continuous alumina scale with what appear to be roots of silica was seen.
More on oxidation – Chromia and alumina formation ranges

\[ \gamma/\gamma' \text{IGT alloys like IN792} \]

- RT Chromia
- Higher gas velocity
- More Cr
- More Si
- 1000°C Temperature

\[ \gamma/\gamma' \text{Aero alloys like CMSX-4} \]

- RT Poor resistance to influx of corrosive species
- More Al
- More Si
- Alumina
- Clean casting RE recipe
- Temperature

Ideal response for a repair alloy

- RT Chromia
- Alumina
- Temperature
More oxidation testing – Checking for chromia/alumina overlap

About the alumina formation range

While the most important property for a filler to be used for repair of oxidation damage in alumina formers such as CMSX-4 is oxidation resistance at very high temperatures, it would be a nice bonus if it was also able to provide a seamless overlap between formation of a protective chromia layer at low and intermediate temperature, and a protective alumina layer at high temperature, compare Figure 2. This was tested with isothermal oxidation tests at 900°C for 1000h on STAL18Si.

Figure 14 STAL18Si weld material after 1000h static oxidation at 900°C.
Discussion

STAL18Si can be assumed to be the strongest of the designated filler alloys (SCA425+ was included as a reference) and so it was a pleasant surprise that the effect of Si on wetting was so beneficial that the weldability was nevertheless the best. This implies that we only needed to sacrifice creep strength for weldability to a limited extent, which will increase the area of applicability for the filler.

It should be noted that we did not set out specifically to preserve the SX structure, i.e. it was not an initial requirement. It did turn out to be a large bonus and possibly the key to the success. Future development work will focus on development of test methodology for notch TMF testing of weld repairs, and on welding of CC alloys.