Residual Stress Distribution in a Thermally Oxidised RT22 Coated Superalloy

Dong Liu\textsuperscript{1,3} Peter EJ Flewitt\textsuperscript{1,2} Martyn Pavier\textsuperscript{3}

\textsuperscript{1}Interface Analysis Centre, University of Bristol, Bristol BS2 8BS, UK
\textsuperscript{2}School of Physics, H H Wills Laboratory, University of Bristol, Bristol BS8 1TL, UK
\textsuperscript{3}School of Mechanical Engineering, University of Bristol, Bristol BS8 1TR, UK
Contents

- Background
- Experimental
  - Specimens
  - Stress measurement procedure
- Results
  - After different thermal exposures
    - stress distribution
    - oxide morphology
- Concluding comments
Background

- Objectives
  - To investigate the distribution of residual stress in thermally grown oxides (TGO) after extended thermal exposures

- Technique
  - Photo-stimulated luminescence piezo-spectroscopy (PSPL): Renishaw System 2000 [λ = 514 and 633 nm]

\[
\sigma = \frac{\Delta \nu}{5.07}
\]

\(\Delta \nu\) - shift of \(R_2\) peak

TGO: \(\text{Al}_2\text{O}_3\)
Bond Coat: RT22
Substrate: CMSX-4
Experimental

- Specimens

Nominal composition of CMSX-4 (wt. %)

<table>
<thead>
<tr>
<th></th>
<th>Ni</th>
<th>Al</th>
<th>Ti</th>
<th>Cr</th>
<th>Co</th>
<th>Mo</th>
<th>Ta</th>
<th>W</th>
<th>Re</th>
<th>Hf</th>
<th>Fe</th>
<th>Nb</th>
<th>C</th>
<th>Si</th>
<th>Zr</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bal</td>
<td>5.64</td>
<td>1.03</td>
<td>6.4</td>
<td>9.6</td>
<td>0.59</td>
<td>6.5</td>
<td>6.4</td>
<td>2.9</td>
<td>0.10</td>
<td>0.045</td>
<td>0.03</td>
<td>0.0029</td>
<td>0.02</td>
<td>0.003</td>
<td>0.002</td>
<td></td>
</tr>
</tbody>
</table>

CMSX-4 / RT22 aging time and temperature

<table>
<thead>
<tr>
<th>Temperature (ºC)</th>
<th>Time (hours)</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
<th>10000</th>
</tr>
</thead>
<tbody>
<tr>
<td>850</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>✓</td>
</tr>
<tr>
<td>950</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>✓</td>
</tr>
<tr>
<td>1000</td>
<td>-</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1050</td>
<td>-</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
</tr>
</tbody>
</table>
Experimental

- Stress measurement procedure
• Stress measurement procedure
Experimental

• Optimising number of measurements (1000°C2000h)
Results

- Residual stress distribution: 850°C for $10^3$ hrs and $10^4$ hrs

![Graph showing stress distribution with Gauss fit](image)

- Centre: -0.19
- FWHM: 0.50
- R-square: 0.94

- Centre: -1.12
- FWHM: 1.07
- R-Square: 0.85

- Centre: -0.21
- FWHM: 0.46
- R-Square: 0.94
Results

- Specimens 850°C for $10^3$ hrs and $10^4$ hrs
  (a) Surface oxide in specimen 850C$10^3$h
  (b) Surface oxides in specimen 850C$10^4$h
Results

- Residual stress distribution: 950°C for $10^3$ hrs

![Graph showing stress distribution with Gauss fit, centre: -1.52 GPa, FWHM: 1.20 GPa, R-Square: 0.82.](image)
Results

- Residual stress distribution: 950°C for $2 \times 10^3$ hrs
Results

- Residual stress distribution: 950°C for $10^4$ hrs

![Graph showing residual stress distribution and images of cracks and oxides stacking over each other.](image)
Results

- Specimen: 950°C for $10^4$ hrs

Oxide spallation

Oxidation of bond coat
Results

- Residual stress distribution: 1050°C for $2 \times 10^3$ hrs and $4 \times 10^3$ hrs
Results

- Specimen 1050°C for $2 \times 10^3$ hrs and $4 \times 10^3$ hrs
Results

- Average residual stress in $2 \times 10^3$ hrs specimens
Concluding comments

- The average residual stress was observed to initially become more compressive and then relax with the increase in temperature for a given exposure time.
- The stress distribution in each specimen was found to related closely to the oxide type and coating degradation in terms of TGO growth and aluminium depletion.
- A single peak distributions of stress were found in initially oxidised specimens, bi-modal and tri-modal distributions were developed as the oxide morphology changed upon further thermal cycling. This also led to broader and more scattered stress distributions.
- Oxide delamination and failure followed by oxide healing can return the measured stress to a single distribution.
- When the healing exhausted, further oxidation due to cycling or rises in temperature, does not cause large variation in stresses.
Acknowledgements

We would like to acknowledge the support of The Energy Programme, which is a Research Councils UK cross council initiative led by EPSRC and contributed to by ESRC, NERC, BBSRC and STFC, and specifically the Supergen initiative (Grants GR/S86334/01 and EP/F029748) and the following companies; Alstom Power Ltd., Doosan Babcock, E.ON, National Physical Laboratory, Praxair Surface Technologies Ltd, QinetiQ, Rolls-Royce plc, RWE npower, Siemens Industrial Turbomachinery Ltd. and Tata Steel, for their valuable contributions to the project.