Development of Spallation-Resistant Coatings: Preliminary Results

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Project Overview

• University of North Dakota Mechanical Engineering and the UND Energy & Environmental Research Center (EERC) are working with Siemens Power Generation to test a new method for joining high-temperature alloys for use in advanced high-hydrogen-gas-burning turbines.

• Will bond thin plates of oxidation- and spallation-resistant Kanthal APMT™ to high-strength CM247LC and Rene® 80 using evaporative metal (EM) bonding.

• Bonded parts, with and without thermal barrier coatings (TBCs), will be tested for oxidation, corrosion, and spallation resistance.
## Alloy Compositions

<table>
<thead>
<tr>
<th>Composition of Kanthal APMT in wt % – Dispersion-Strengthened</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metals</td>
</tr>
<tr>
<td>APMT</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Composition of CM 247 LC in wt % – Gamma Prime-Strengthened</th>
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</thead>
<tbody>
<tr>
<td>Metals</td>
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<tr>
<td>CM247LC</td>
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</table>

<table>
<thead>
<tr>
<th>Composition of Rene 80 in wt% – Gamma Prime-Strengthened</th>
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</thead>
<tbody>
<tr>
<td>Metals</td>
</tr>
<tr>
<td>Rene 80</td>
</tr>
</tbody>
</table>
Prior Work:
TBC Spallation Lifetimes

Testing at Siemens Energy Inc. shows that the spallation lifetime of TBCs on APMT is three times that of a similar coating on Rene 80 or CM247LC.
Prior Work: 
Alloy Oxidation Rates

The oxidation rate of APMT is much lower than for CM247LC or Rene 80.
Prior Work:
Transient Liquid Phase (TLP) Bonding

- Welding of advanced alloys is not possible because critical structures are destroyed.
- TLP bonding uses a reactive braze that diffuses away from the joint.
- Bonding alloys need to have low melting points, be soluble, and not form intermetallics.
- Evaporative metal (EM) bonding is an alternative
Prior Work: Joining Complex Geometries

- Scanning electron microscopy photo top, x-ray map on bottom.
- Needle growth and interdiffusion create a joint stronger than the APMT.
- Nickel diffuses up to 700 µm into APMT.
- Iron diffuses 200 µm into the CM247LC.
Prior Work:

Room Temperature Joint Strengths

- Room-temperature ultimate tensile strength results for joints made with four joining alloys.
- All samples broke within the APMT, showing the joints are stronger than the APMT.
Prior Work:

950°C Stress Rupture Test

- Stress rupture tests done at 950°C using 20 MPa, the 100-hour APMT rupture stress.
- Samples broke within the APMT, not the joint.
- APMT was much weaker than anticipated.
Prior Work: Joining Complex Geometries

- Joined actual turbine ring segments of CM247LC with APMT sheet in between.
- Demonstrates the ability to cover large areas of superalloys with oxidation- and spallation-resistant APMT using EM bonding.
- Joints were stronger than the APMT.
Articulated Clamping System

- Specimens electro-discharge machined to shaped and then polished
- Bonding surface blasted with silica beads.
- Clamp made from low-CTE metal (Mo).
- Steel hemispheres (E52100) used to articulate the pieces, which is necessary because of the thinness of the foils. Steel used to facilitate modeling.
- Joints of APMT to CM 247 and APMT to Rene 80
Articulated Clamping System
UTSR 2011 Award – Task 1

• Task 1 – Determine diffusion rates of evaporative metal through APMT, CM247LC, and Rene 80 as functions of temperature.
  – Prepare bonded rods at different temperatures and times.
  – Cross-section bonded rods, and measure bonding metal concentration gradients.
  – Develop diffusion rate equations as functions of temperature.
  – October 2011 - March 2013
Elemental Map of Zn – CM 247 bonded at 1214°C for 1 hour (joint edge)
UTSR 2011 Award – Task 1

Elemental Map of Zn – CM 247 bonded at 1214°C for 1 hour (joint center)
Elemental Map of Zn – CM 247 bonded at 1214°C for 3 hours (joint center)
Elemental Map of Zn – APMT bonded at 1214°C for 1 hour (joint center)
Elemental Map of Zn – APMT bonded at 1214°C for 3 hours (joint center)
Elemental Map of Zn – Rene 80 bonded at 1214°C for 1 hour (joint center)
UTSR 2011 Award – Task 2

• Task 2 – Model bonding pressure distributions in complex joints.
  – Measure bonding pressures in actual joints.
  – Measure high temperature properties of substrate metals (E, $\alpha$)
  – Model pressures at the bond line at temperature.
  – Design clamping system.
  – October 2011 - March 2013
UTSR 2011 Award – Task 2
Comparison of strains in the bonding assembly when loads applied at a) joint center or b) joint ends.
Task 3 – Characterization of combusted syngas contaminants.

• Information to be used in designing later corrosion testing – contaminants will not be similar to gasifier fly ash.
• Collection of microcontaminants in combusted syngas created in a pilot-scale gasifier.
• Analysis of captured microcontaminants by SEM.
• Data will be made available to other researchers.
UTSR 2011 Award – Task 3

EERC entrained flow gasifier test rig

EERC fluidized bed gasifier test rig
UTSR 2011 Award – Task 3

- Sampling method follows EPA methods 26A and 29
- Flow enters probe at about 750°C and cools to 100°C
- Flow passes through a polycarbonate filter (0.1 micron diameter holes)
- Flow enters water-filled impingers

<table>
<thead>
<tr>
<th>Trace Metal</th>
<th>As</th>
<th>Be</th>
<th>Cd</th>
<th>Co</th>
<th>Cr</th>
<th>Mn</th>
<th>Ni</th>
<th>Pb</th>
<th>Sb</th>
<th>Se</th>
<th>Hg</th>
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<tbody>
<tr>
<td>LLQ (µg/L)</td>
<td>0.5</td>
<td>0.1</td>
<td>0.1</td>
<td>0.5</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
<td>1.0</td>
<td>0.02</td>
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<tr>
<td>Conc.(µg/L)</td>
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<td>0.2</td>
<td>0.2</td>
<td>0.4</td>
<td>8.2</td>
<td>63.8</td>
<td>7.53</td>
<td>0.76</td>
<td>0</td>
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<td>0.06</td>
<td>0.06</td>
<td>0.12</td>
<td>2.39</td>
<td>18.58</td>
<td>2.19</td>
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<table>
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<tr>
<th>Trace Metal</th>
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<th>Mg</th>
<th>Ca</th>
<th>Na</th>
<th>Fe</th>
<th>Ti</th>
<th>V</th>
<th>Mo</th>
<th>Zn</th>
<th>Ge</th>
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<tr>
<td>LLQ (µg/L)</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
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<td>20</td>
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<tr>
<td>Conc.(µg/L)</td>
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<td>128.8</td>
<td>670.4</td>
<td>243.5</td>
<td>354.6</td>
<td>15.84</td>
<td>0.777</td>
<td>3.959</td>
<td>13.42</td>
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### UTSR 2011 Award – Task 3

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<tr>
<th>Spectrum</th>
<th>O</th>
<th>Si</th>
<th>S</th>
<th>Cr</th>
<th>Fe</th>
<th>Ni</th>
<th>Total</th>
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<td>Spectrum 4</td>
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<td>19.45</td>
<td>2.54</td>
<td>12.47</td>
<td>1.06</td>
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<tr>
<td>Min.</td>
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<td>2.68</td>
<td>17.11</td>
<td>2.01</td>
<td>10.41</td>
<td>1.06</td>
<td></td>
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</tbody>
</table>

**Composition of 316L Stainless Steel in wt % (max)**

<table>
<thead>
<tr>
<th>C</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Al</th>
<th>Mo</th>
<th>Mn</th>
<th>Si</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.03</td>
<td>0.045</td>
<td>0.03</td>
<td>16-18</td>
<td>10-14</td>
<td>2-3</td>
<td>2</td>
<td>0.75</td>
<td>Bal.</td>
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</table>
UTSR 2011 Award – Tasks 4-6

• Task 4 – Preparation of APMT-plated superalloy turbine parts.
  – Use data from Tasks 1 and 2 to design clamping system and time–temperature heat treatment.
  – April 2013 – September 2014

• Task 5 – Environmental testing of plated turbine parts.
  – Oxidation and spallation testing at Siemens Energy.
  – Corrosion testing at the EERC.
  – October 2013 – September 2014

• Task 6 – Reporting (ongoing).
Acknowledgements

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