Supporting Information

Jet Engine Coatings for Resisting Volcanic Ash Damage

Julie M. Drexler, Andrew D. Gledhill, Kentaro Shinoda, Alexander L. Vasiliev, Kongara M. Reddy, Sanjay Sampath, and Nitin P. Padture *
Supporting Information

Jet Engine Coatings for Resisting Volcanic Ash Damage

By Julie M. Drexler, Andrew D. Gledhill, Kentaro Shinoda, Alexander L. Vasiliev, Kongara M. Reddy, Sanjay Sampath and Nitin P. Padture

Experimental

1. TBCs Preparation

All thermal barrier coatings (TBCs) used in this study were deposited on Ni-based superalloy substrates (Grade 214, Haynes International, Kokomo, IN) machined in the form of “buttons” (25.4 mm diameter, 3.2 mm thickness). One circular surface of each “button” substrate was roughened by grit-blasting prior to coating deposition. All TBCs were deposited by the air plasma spray (APS) method using an atmospheric direct-current plasma torch with an 8-mm diameter nozzle and a swirl flow gas distribution ring (Model F4-MB, Sulzer Metco Inc., Westbury, NY). The APS method uses granulated powder as feedstock. In the case of conventional 7YSZ TBCs, a commercially available powder was used (Grade 9204, Saint-Gobain, Worcester, MA). The Gd$_2$Zr$_2$O$_7$ TBCs were deposited using a special order powder from a commercial vendor (TransTech, Adamstown, MD). In the case of the YSZ+Al+Ti TBCs, an in-house prepared powder of the composition 71.4 mol% (73.0 wt%) ZrO$_2$, 3.6 mol% (6.8 wt%) Y$_2$O$_3$, 20.0 mol% (16.9 wt%) Al$_2$O$_3$, and 5.0 mol% (3.3 wt%) TiO$_2$ was used. In all
three cases APS deposition parameters were determined through optimization studies to produce high quality TBCs of similar microstructures. \cite{2}

2. Volcanic Ash-TBCs Interactions

An ash sample from the Icelandic Eyjafjallajökull volcano eruption, and its chemical composition, was provided by Mr. Níels Óskarsson (Institute of Earth Sciences, University of Iceland, Reykjavik). \cite{3} The melting point of the ash was determined using differential thermal analysis (Orton Materials Testing and Research Center, Westerville, OH) at 10 °C.min^{-1} heating rate. The ash was ball-milled into a finer powder in an attempt to simulate airborne ash fines, which was then mixed with ethanol to produce a thick paste for application on the TBCs.

Top surfaces of the as-deposited TBCs (7YSZ, Gd_2Zr_2O_7, and YSZ+Al+Ti) were coated with a uniform layer of the ash paste by hand and dried so as to achieve an ash loading of ~15 mg.cm^{-2} on all TBCs. These specimens were then placed in a box furnace (CM Furnaces Inc., Bloomfield, NJ), with the ash-coated surface facing up, and heat-treated at 1200 °C for 24 h in air.

3. Characterization

As-deposited TBCs and heat-treated (with ash) TBCs were cross-sectioned and polished to a 1-μm finish using routine metallographic techniques. These cross-sections were then observed in a scanning electron microscope (SEM; Sirion, FEI Company, Hillsboro, OR), equipped with an energy dispersive spectrometer (EDS; EDAX, Mahwah, NJ) capable of determining elemental distributions in the microstructure. Porosities of the as-deposited TBCs were estimated from the SEM micrographs in conjunction with image analysis.
Transmission electron microscopy (TEM) specimens from specific locations within the heat-treated (with ash) TBC cross-sections (7YSZ, Gd$_2$Zr$_2$O$_7$, and YSZ+Al+Ti) were extracted using focused ion beam (FIB; Helios 600, FEI, Hillsboro, OR) and in situ lift-off. These specimens were observed in two different types of TEMs (FEI Company, Hillsboro, OR): Tecnai F20 or Titan 80-300 operated at 200 kV or 300 kV, respectively. Both TEM are equipped with EDS for elemental analysis. Indexing of the selected area electron diffraction patterns (SAEDPs) and phase identification was performed using standard procedures.

Table 1.

Chemical composition (wt%) of the Eyjafjallajökull volcano ash sample used in this study. [3]

Trace amounts of various other elements are not included. The CMAS composition is from an earlier study. [4]

<table>
<thead>
<tr>
<th>wt%</th>
<th>SiO$_2$</th>
<th>Al$_2$O$_3$</th>
<th>FeO</th>
<th>CaO</th>
<th>Na$_2$O</th>
<th>MgO</th>
<th>K$_2$O</th>
<th>TiO$_2$</th>
<th>P$_2$O$_5$</th>
<th>MnO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash</td>
<td>58.0</td>
<td>14.9</td>
<td>9.8</td>
<td>5.5</td>
<td>5.0</td>
<td>2.3</td>
<td>1.8</td>
<td>1.8</td>
<td>0.5</td>
<td>0.2</td>
</tr>
<tr>
<td>CMAS</td>
<td>49.7</td>
<td>6.7</td>
<td>2.4</td>
<td>35.3</td>
<td>1.0</td>
<td>3.3</td>
<td>1.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

References


