Water vapor corrosion of EBC candidate materials

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Motivation:
One of the major goals for gas turbine engines is to increase the engine efficiency which necessitates operating at higher temperatures. Increased engine temperatures have been addressed through silicon-based ceramics and composites which have shown great promise as replacements for hot-stage alloy components of gas turbine engines. However, these Si-based materials are susceptible to the effects of water vapor, (Ca-Al-Mg-Si-O) CMAS interaction, and oxidation, among other issues at high temperature. Hence, environmental barrier coating (EBC) materials are sought after to protect next generation high temperature engine components. This study focuses on one aspect of high temperature degradation in EBC materials, namely the recession caused by the interaction of the coating with water vapor.

Background:

• In 1997, Opila et al demonstrated that Si-based composites were vulnerable to recession by water vapor at elevated temperature (i.e. oxidation and hydroxide formation. See Eqs. at right)
• A protective layer, composed of rare earth silicates (RES), was proposed to protect against recession.
• It was found that mono-silicates (i.e. RE_2SiO_5) tended to have better protection against recession over di-silicates (i.e. RE_2Si_2O_5) which led to their use in the current study.

Sample preparation and experimental methodology:

• To replicate water vapor conditions in an engine and measure recession, thermogravimetric analysis (TGA) was used under the conditions listed to the right.
• Samples are cut into rectangles, polished to remove carbon, and a hole is then drilled for their use in the current study.

Recession at high temperature due to water vapor

\[ SiC + 3/2O_2(g) = SiO_2 + CO(g) \] (1)

\[ SiO_2 + 2H_2O(g) = Si(OH)_4(g) \] (2)

Experimental setup:

• Test temperature: 1300°C
• Carrier gas: O_2
• 50%/50% O_2/H_2O
• 33 mm ID. Al_2O_3 tube
• Rectangular samples

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X-ray diffraction:

• XRD measured on surface of Pre- and Post-TGA without polishing

Exposure to water vapor:

• Solid lines are from TGA; Dashed lines are from modeling

Modeling:

Free Stream Gas Velocity \( v_s \) (m/s)

\[ v_s = \frac{1.5 \times 10^{-3} \text{ m/s}}{(2500 \text{ K})^2} \]

\[ f = \frac{\rho_{\text{gas}} \cdot L \cdot T}{\mu \cdot R \cdot T} \]

Reynolds number, \( Re \)

Interdiffusion coefficient, \( D \)

Density of gas, \( \rho_{\text{gas}} \)

Pressure of hydroxide, \( P \)

Viscosity, \( \mu \)

Gas constant, \( R \)

Temperature, \( T \)

Scanning electron microscopy:

• To investigate Lu_2Al_2O_7 at the surface, the weight change of a half Pt coated sample of Lu_2SiO_5 was measured in TGA.
• SEM images were then taken of a polished surface to determine Al infiltration depth.
• At % ratios are shown for Lu:Si.

References:


Conclusion:

• EBC candidate materials were tested under high temperature, water vapor conditions with a TGA.
• SiO_2 reacts to form Si(OH)_4 as expected (Eq. 2). HfSiO_3 and HfO_2 are relatively stable in the water vapor environment.
• However, Lu_2SiO_5 exhibits complex behavior due to the presence of Al_2O_3 in the TGA tube.
• Model predicts recession through water vapor, but does not account for surface reactions from contaminants.