High Pressure Burner Rig Testing of Advanced Environmental Barrier Coatings for Si$_3$N$_4$ Turbine Components

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Abstract

Advanced thermal and environmental barrier coatings are being developed for Si₃N₄ components for turbine engine propulsion applications. High pressure burner rig testing was used to evaluate the coating system performance and durability. Test results demonstrated the feasibility and durability of the coating component systems under the simulated engine environments.
Revolutionary Ceramic Coatings Greatly Impact Turbine Engine Technology

— Ceramic barrier coating system development goals
  - Meet temperature and performance requirements
  - Help fundamental scientific understanding
  - Increase Technology Readiness Levels (TRL)

Temperature Capability

(a) Current T/EBCs (b) Advanced T/EBCs

- 3000°F (1650°C+)
- 2700°F (1482°C)
- 2400°F (1316°C)
- 2000°F (1093°C)

Increase in $\Delta T$ across T/EBC

Si$_3$N$_4$ and coating systems

Gen I  Gen II – Current commercial  Gen III  Gen IV
High Pressure Burner Rig for Thermal and Environmental Barrier Coating Development

— Realistic engine combustion environments for specimen and component testing

High Pressure Burner rig (6 to 12 atm)

Coated turbine vane test fixtures
Multi-functionally Graded Environmental Barrier Coatings for Si-based Ceramic Components

- Advanced TEBC System
  Multifunctionally Graded Materials for SiC/SiC CMC and Si₃N₄ applications
  
  - High stability HfO₂ layer with graded interlayer, environmental barrier and advanced bond coats
  - Alternating composition layered coatings (ACLCs) and nano-composite coatings

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  \text{SiC/SiC CMC or Si}_3\text{N}_4
  \]

  - Low expansion HfO₂
  - Interlayer: Compositional layer graded system
  - Doped mullite-HfO₂/Si, with and rare earth silicate EBCs
  - Ceramic composite bond coat

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  \text{Increased Si activity}
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  \text{Increased dopant RE/Transition metal concentrations & increased Al/Si ratio}
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  \text{Doped mullite/Si (SiC/Si}_3\text{N}_4) \text{ composite bond coat}
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  \text{(High temperature capable with self-healing)}
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  - Nano-composite coating (ACLCs)

  - Plasma-sprayed coating
  - EB-PVD coating
Environmental Barrier Coatings Processed on Complex-Shaped Specimens

The coating processing technologies developed for complex shaped components

Plasma-spray processing of Environmental barrier coatings for various components
Advanced Environmental Barrier Coatings Development for Si₃N₄ components

- The coatings tested using cyclic furnaces, laser rig and the high pressure burner rig at the temperatures up to 2650°F (1450°C)
- Coating temperature capability, water vapor stability and durability emphasized

Furnace/laser heat flux/high pressure burner rig testing

Fracture strength and high temperature rupture testing

High Pressure Burner Rig Sub-Component Testing
Dynamic Fatigue Testing of Advanced Environmental Barrier Coatings Coated Si$_3$N$_4$ Materials

The coated specimens demonstrated significantly improved slow crack growth resistance at high temperatures.

Composite EBC coated AS 800 Si$_3$N$_4$ rupture testing (completed 691 hrs at 2500ºF (1371°C), 250 MPa without failure).

EBC coated SN 282 rupture testing (completed 815 hr testing at 2500ºF (1371°C) at 200MPa without failure).
Advanced Environmental Barrier Coatings for Si$_3$N$_4$
Demonstrated High Temperature Capability

— The coated SN 282 bend bar specimens demonstrated 50hr durability at 2500°F in the high pressure burner rig
Advanced Environmental Barrier Coatings for Si$_3$N$_4$
Demonstrated in High Pressure Burner Rig

The coated miniature Si$_3$N$_4$ vanes demonstrated 50hr durability in the high pressure burner rig test at up to 2500°F
Advanced Environmental Barrier Coatings for Si$_3$N$_4$
Demonstrated in High Pressure Burner Rig

— A coated Si$_3$N$_4$ vane also demonstrated 50hr durability in the high pressure burner rig test at up to 2700°F

Coated Si$_3$N$_4$ vane

Tested coated Si$_3$N$_4$ vane

Modeled temperature distributions
Summary

- Advanced multi-functionally graded thermal and environmental barrier coatings developed and processed on complex-shaped components

- The coated specimens showed significantly improved high temperature strength and slow crack growth resistance

- Coated Si$_3$N$_4$ vanes have been successfully demonstrated in the high pressure burner rig

- The coating systems showed promising performance in the burner rig simulated engine environments