ENVIRONMENTAL BARRIER COATINGS FOR TURBINE ENGINES: A DESIGN AND PERFORMANCE PERSPECTIVE

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Ceramic thermal and environmental barrier coatings (TEBC) for SiC-based ceramics will play an increasingly important role in future gas turbine engines because of their ability to effectively protect the engine components and further raise engine temperatures. However, the coating long-term durability remains a major concern with the ever-increasing temperature, strength and stability requirements in engine high heat-flux combustion environments, especially for highly-loaded rotating turbine components. Advanced TEBC systems, including nano-composite based HfO_2-aluminosilicate and rare earth silicate coatings are being developed and tested for higher temperature capable SiC/SiC ceramic matrix composite (CMC) turbine blade applications. This paper will emphasize coating composite and multilayer design approach and the resulting performance and durability in simulated engine high heat-flux, high stress and high pressure combustion environments. The advances in the environmental barrier coating development showed promise for future rotating CMC blade applications.

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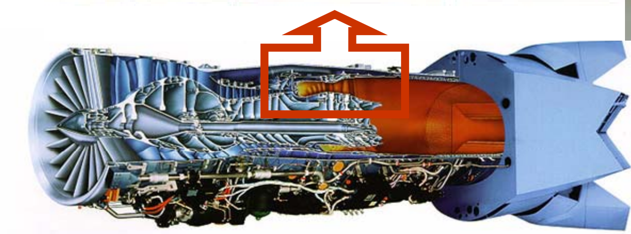
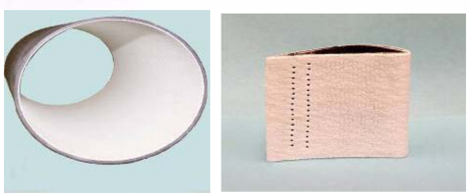
Revolutionary Ceramic Coatings Greatly Impact Turbine Engine Technology

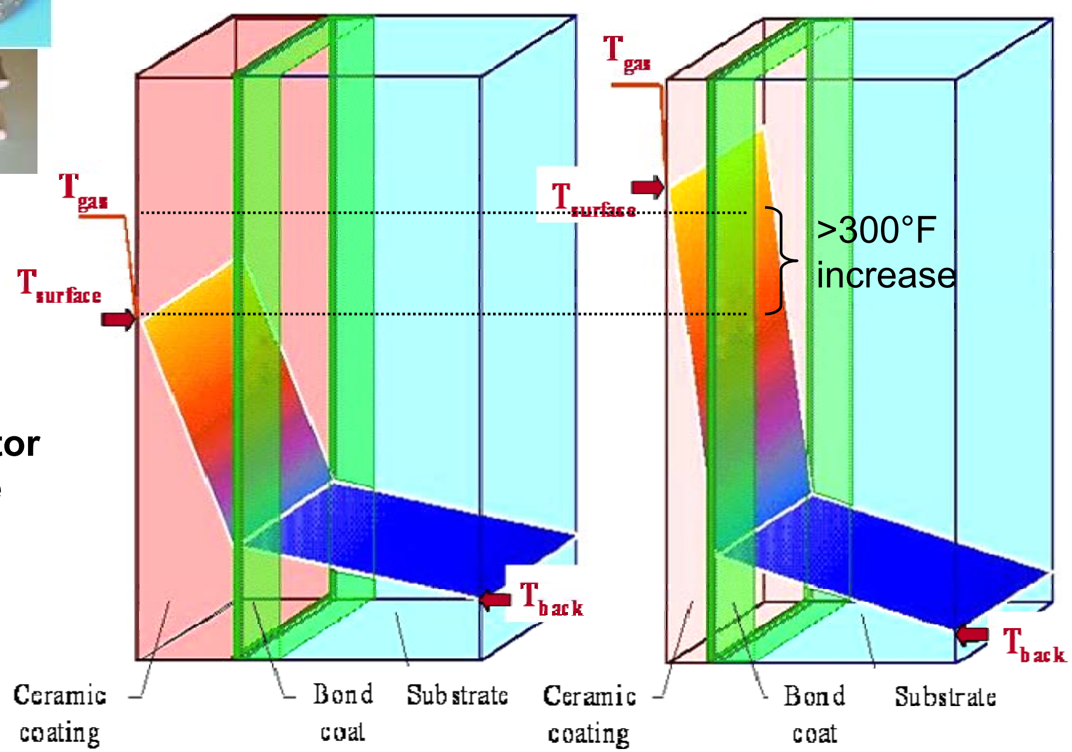
— **Ceramic barrier coatings can significantly increase gas temperatures, reduce cooling requirements, improve engine fuel efficiency and reliability**

Combustor **Vane** **Blade** **Ceramic nozzles**





CMC combustor liner and vane

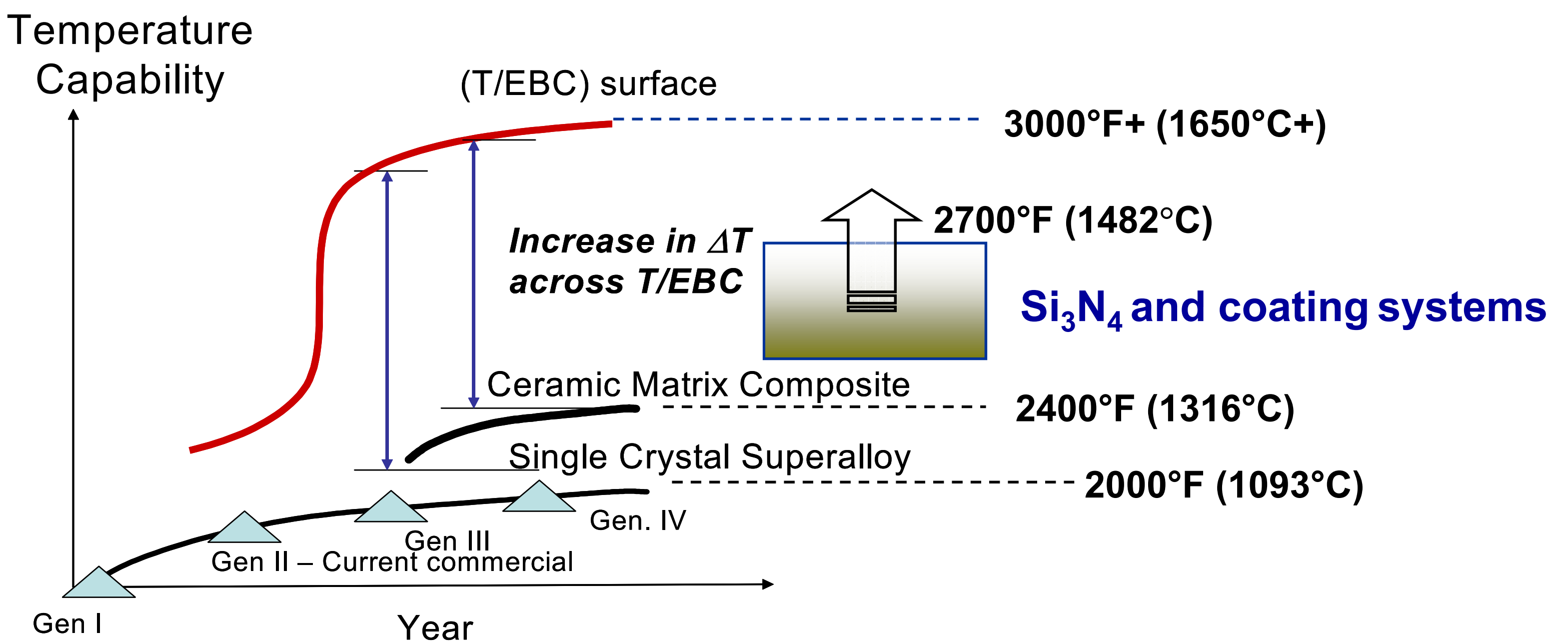


(a) Current T/EBCs **(b) Advanced T/EBCs**

Revolutionary Ceramic Coatings Greatly Impact Turbine Engine Technology

— **Ceramic barrier coating system development goals**

- Meet next generation engine temperature, performance and durability requirements
- Help fundamental scientific understanding, database and design tool development
- Increase the coating Technology Readiness Levels (TRL)



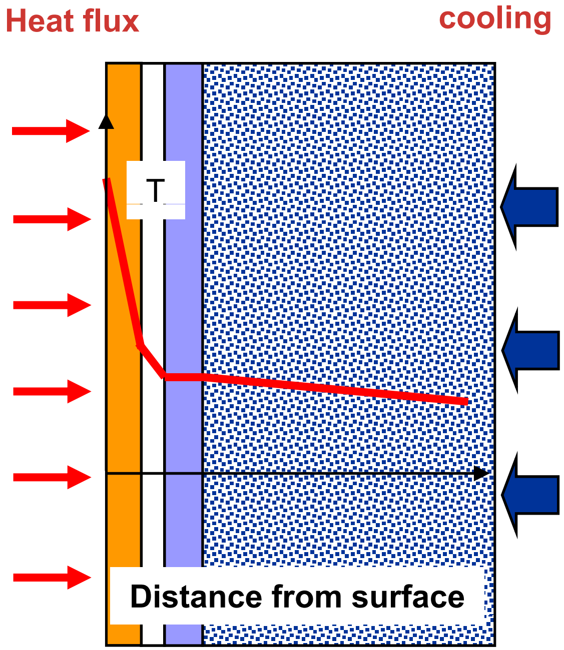
Outline

- **High-heat-flux and simulated engine test approaches for ceramic coating development**
- **The 2700°F thin turbine TEBC systems for SiC/SiC CMCs and Si_3N_4**
- **Coating durability and stability evaluations**
- **Summary and directions**

High-Heat-Flux Testing Approach

– **High-heat-flux tests crucial for the coating development**

- Temperature gradient requirements: 400-600°F across 5-10 mil coatings

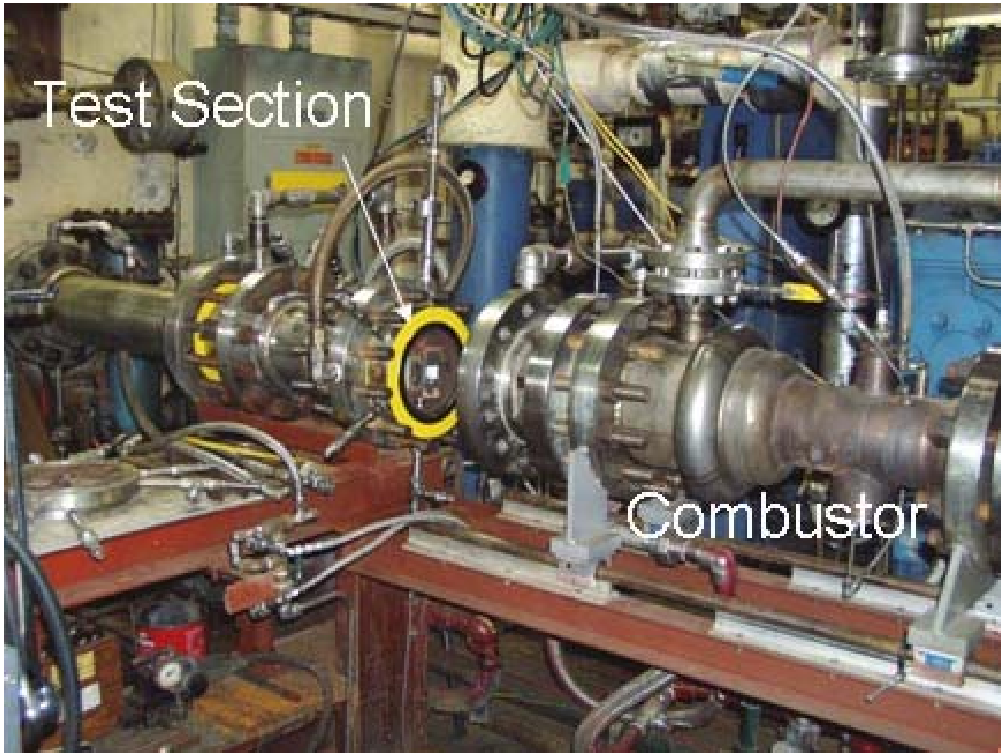


NASA CO_2 Laser Rig

Current capability up to 315 W/cm^2 for TBCs

High Pressure Burner Rig for Thermal and Environmental Barrier Coating Development

– **Realistic engine combustion environments for specimen and component testing**

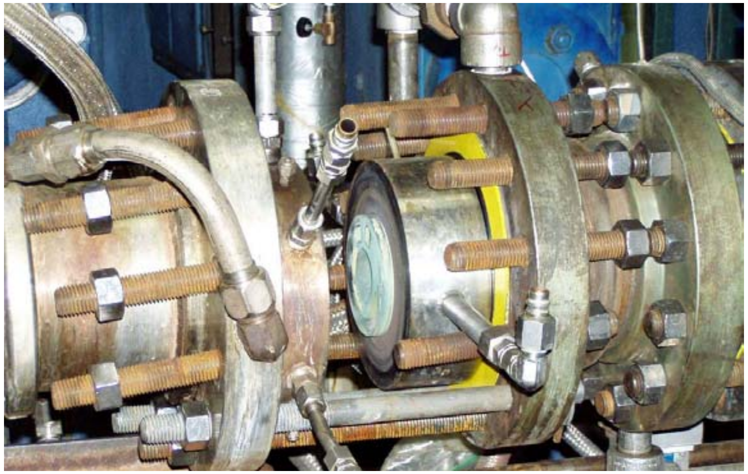


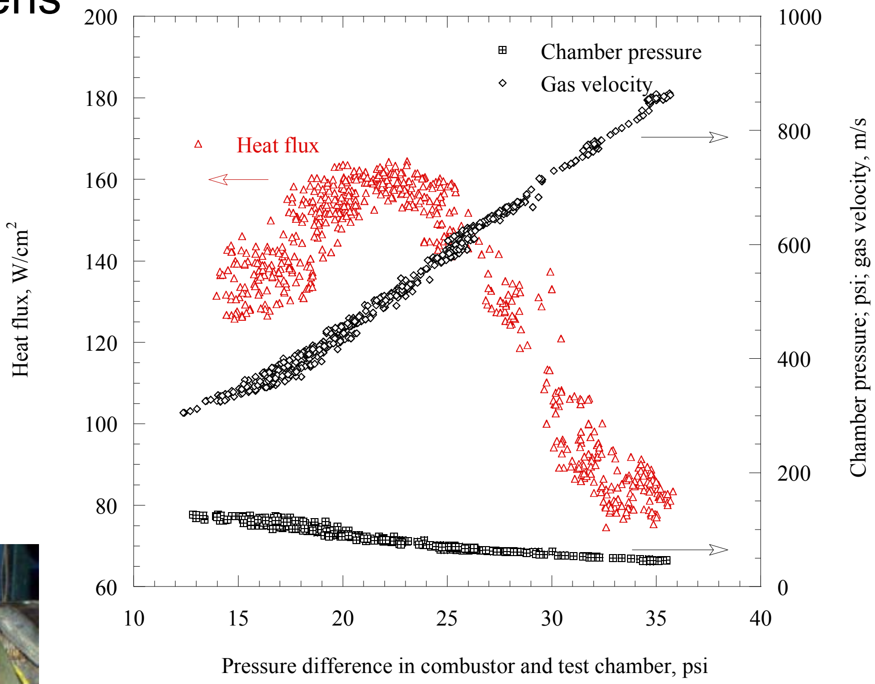
High Pressure Burner rig (6 to 12 atm)

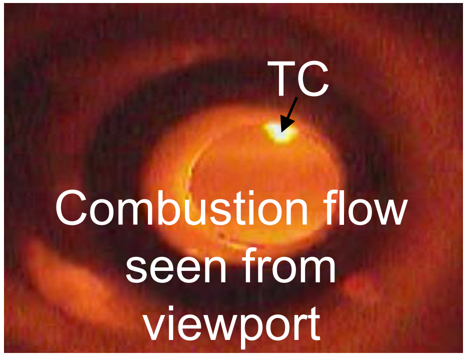
Coated turbine vane test fixtures

High Pressure Burner Rig for Thermal and Environmental Barrier Coating Development

- **High Velocity and High Pressure Burner Rig Testing**
  - High velocity testing for ceramic specimens
  - Optimum heat flux regime determined



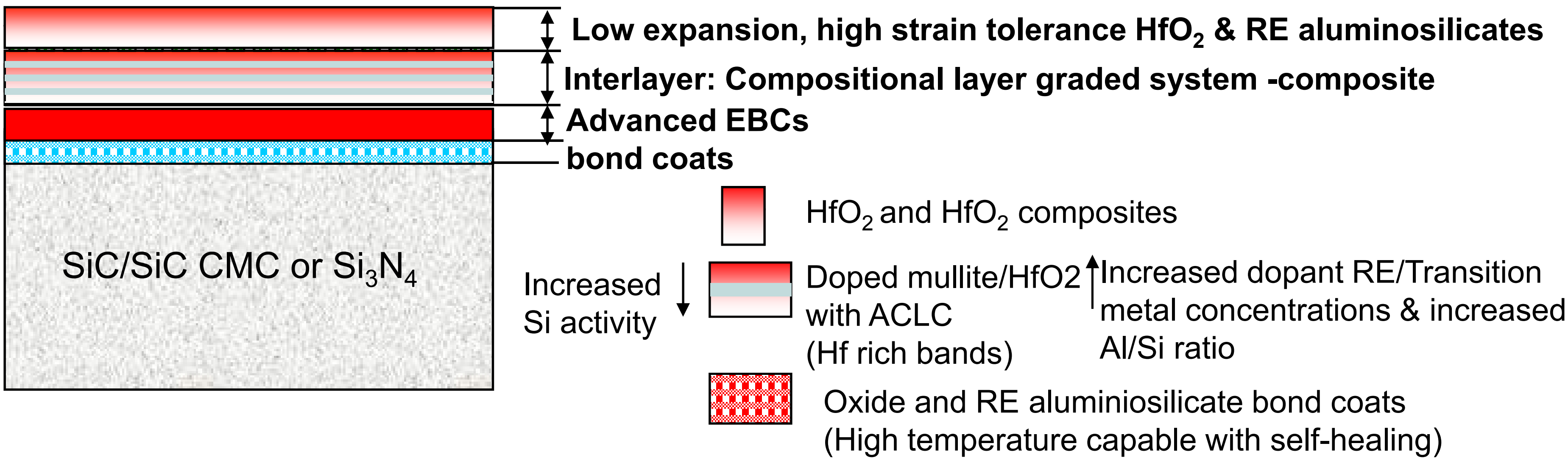




Multi-Functionally Graded Environmental Barrier Coatings for Si-based Ceramic Components

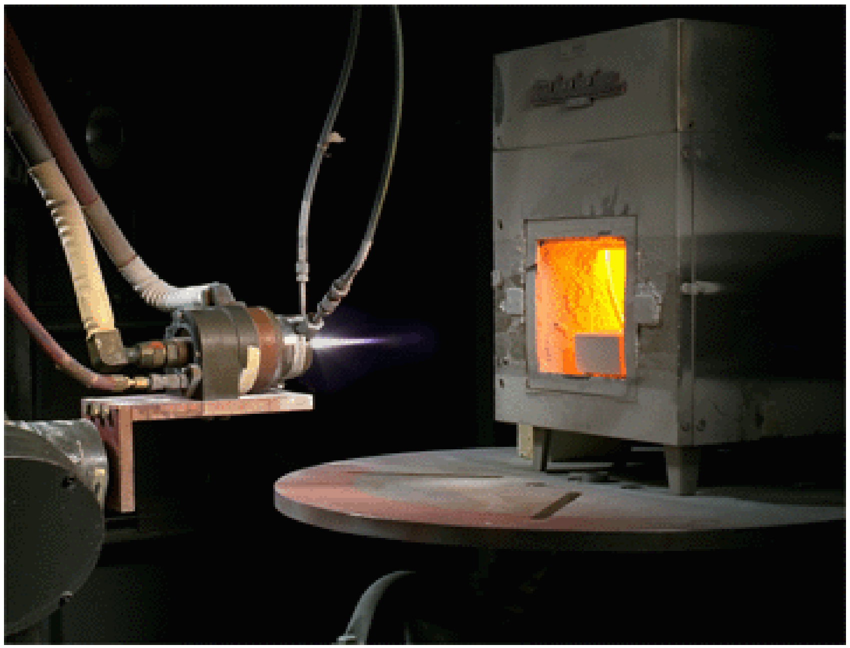
– Multifunctionally Graded Materials for SiC/SiC CMC and Si_3N_4 applications

- High stability oxide composite layer with graded interlayer, environmental barrier and advanced bond coats
- Alternating composition layered coatings (ACLCs) and nano-composite coatings

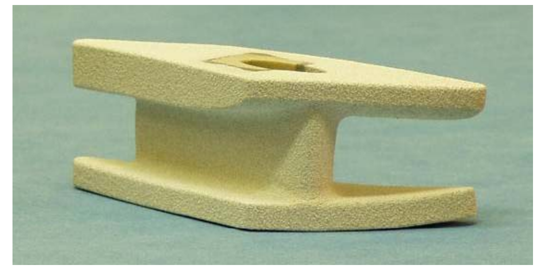


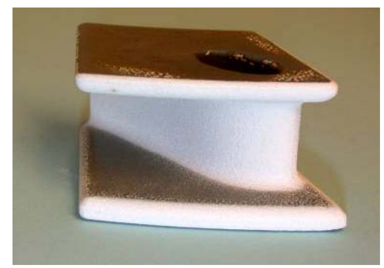
Environmental Barrier Coatings Processed on Complex-Shaped Specimens

– Thinner coating processing technologies developed for complex shaped components



Plasma-spray processing of Environmental barrier coatings for various components





Thin Turbine Blade CMC Coatings will be Pursued using Hybrid Plasma Vapor Deposition Technique

- APS

- VPS/LPPS

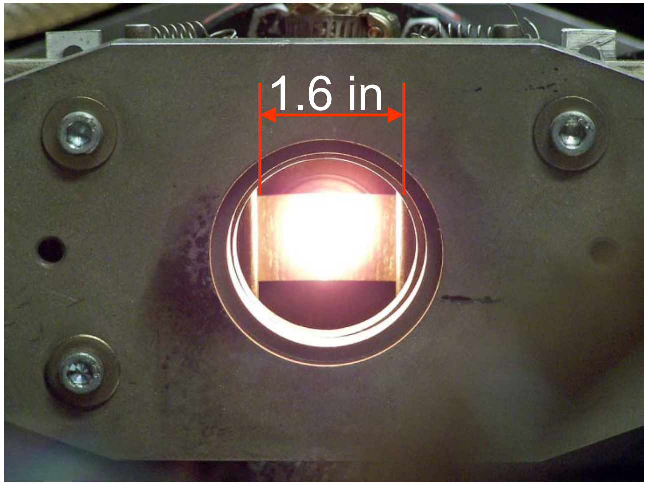
- LPPS-Thin Film

Sulzer plasma vapor deposition

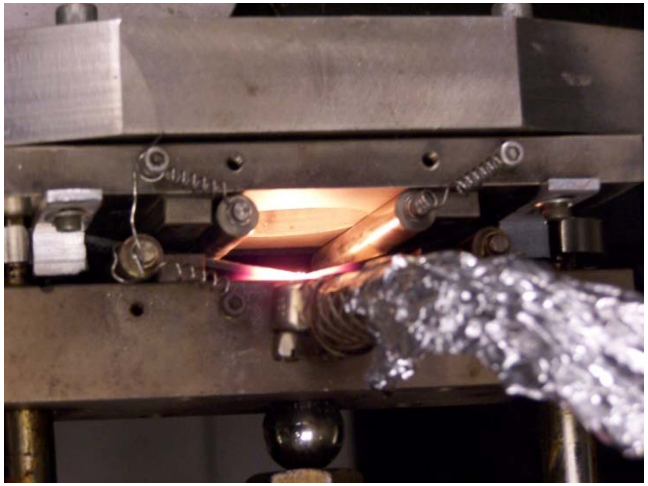
- Standard APS
- Standard LPPS:
  - Well established process for high quality functional coatings
  - Various gas-turbine, aero, medical and special applications
  - Pressure range typically 50 - 200 mbar
- LPPS-Thin Film:
  - High flexibility of operation conditions
  - Pressure range down to 1 - 2 mbar
  - High enthalpy plasma stream (up to 180 kW)
  - Special applications in film thickness range of 5 - 200 µm
  - Use of fine powders and suited injection (modified nozzles)
  - Fast coverage on large surfaces with thin & dense layers
  - Capable for deposition from vapor phase
  - Non line-of-sight coating due to highly forced gas stream

TEBCs Evaluated for Thermomechanical Fatigue (TMF) Resistance

-10 Hz, R ratio ~0, maximum mechanical load 250 MPa (36ksi) at 2200°F
- Coating achieved excellent durability without failure after 250 hour testing
- The system durability is currently limited by the CMC TMF capability and variability

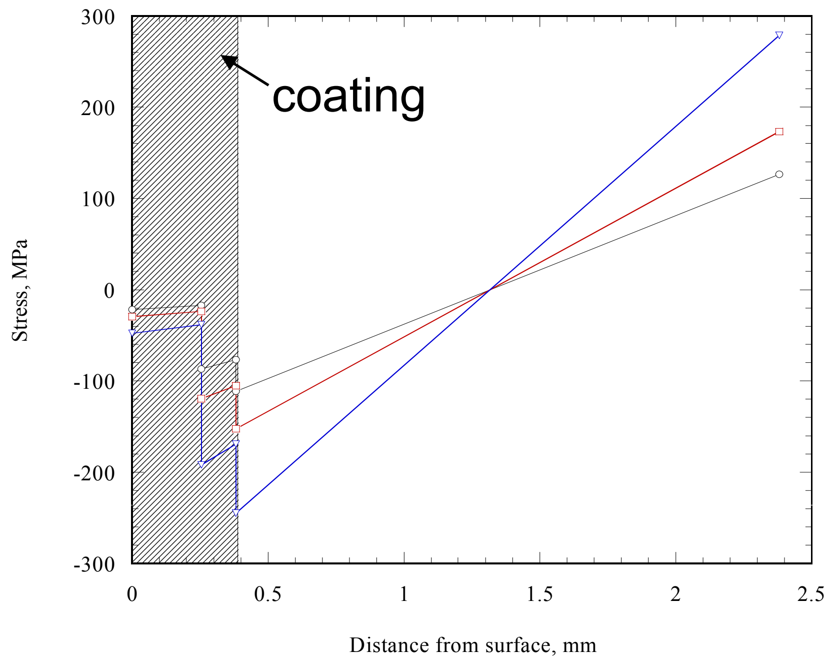


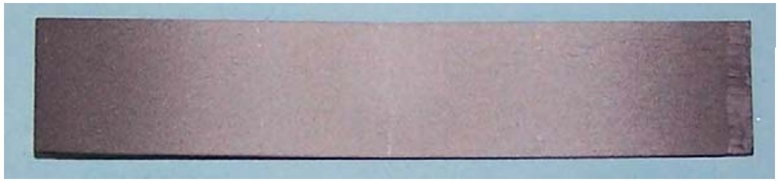
(a) Specimen testing



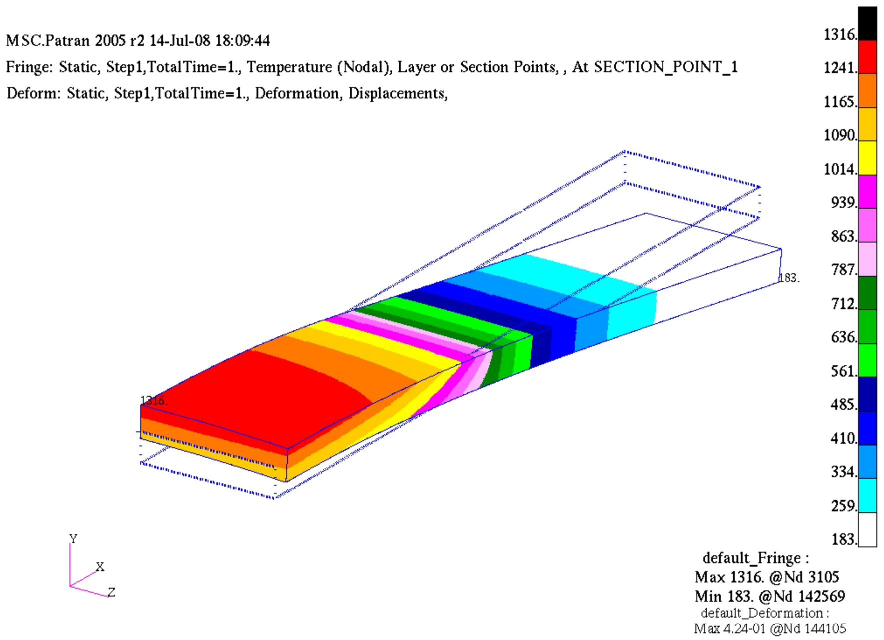
(b) Specimen failure

TEBCs Evaluated for ThermoMechanical Fatigue (TMF) Resistance - Continued





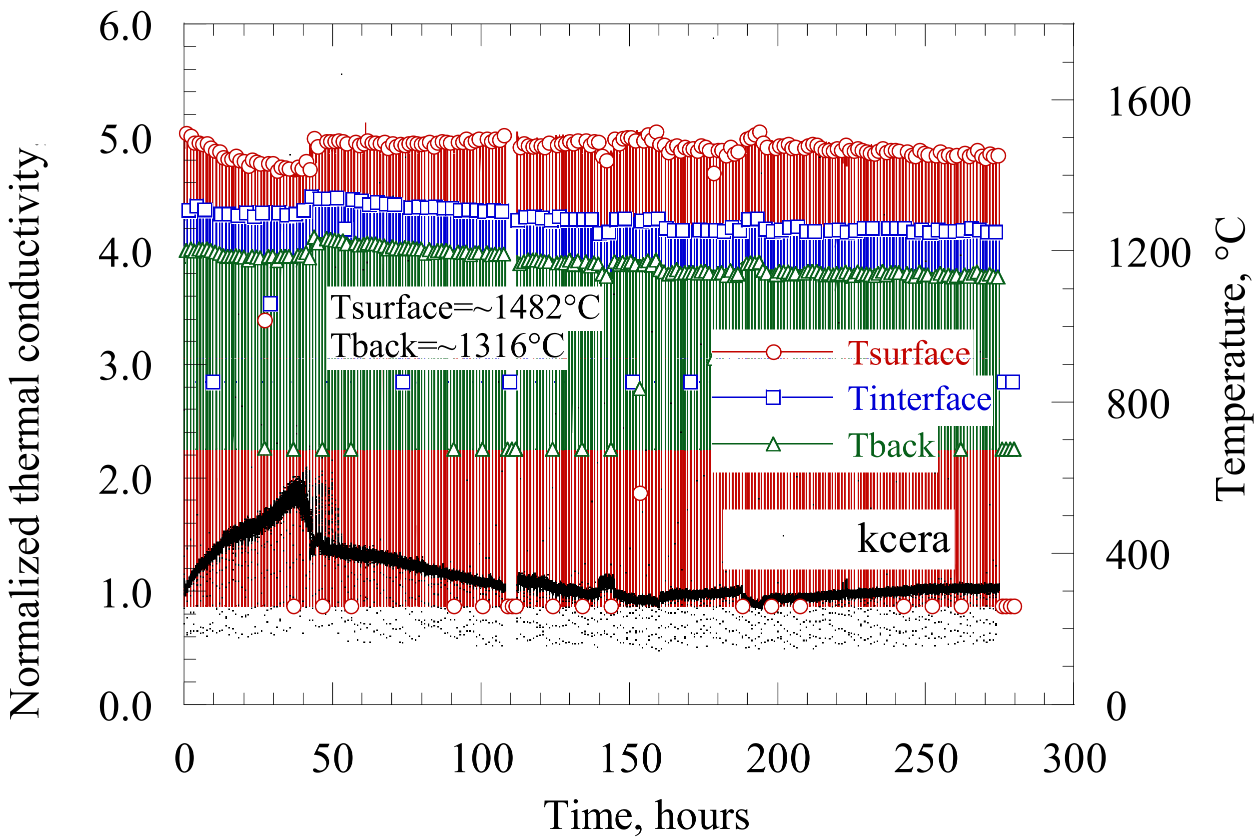
Max 250 CMC MPa@2200°F, cyclic; Failed at $5x10^5$ cycles



CMC temperature modeling

Long-Term High Heat Flux Thermal Gradient Cyclic Testing of an Advanced TEBC Coating on SiC/SiC Ceramic Matrix Composite

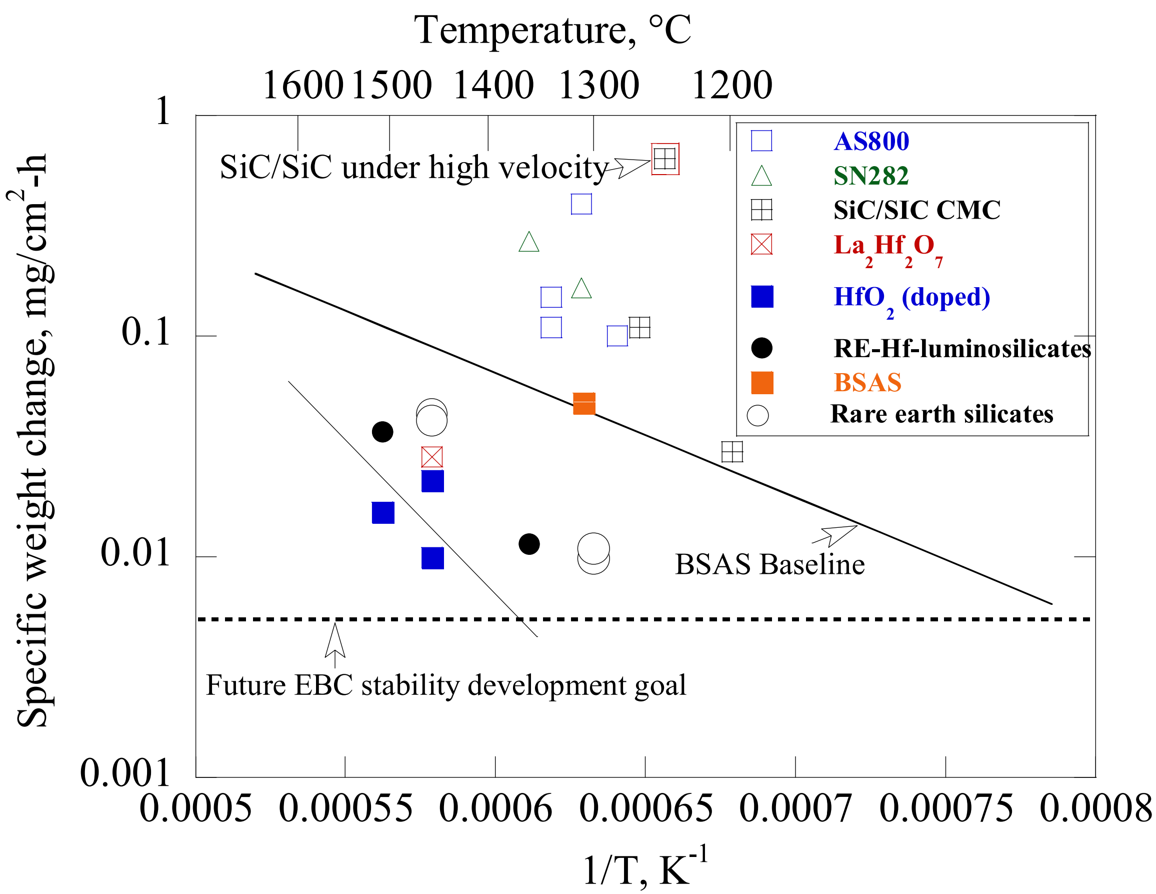
- Coating successfully tested at Tsurface 2700°F and Tinterface 2400°F 250 hrs (1 hr hot hour cycles in air)



Thin coating turbine CMC demonstrated high-heat-flux cyclic durability at 2700˚F

High Pressure Burner Rig Durability Evaluations

- High Pressure Burner Rig Stability being evaluated for TEBCs on SiC/SiC
- High stability coatings being down-selected



Summary

- Advanced ceramic turbine component testing capabilities established
- Advanced thermal and environmental barrier coatings developed and processed on complex-shaped components
- Coating stability demonstrated in high velocity-high pressure burner rig simulated engine environments
- Coated CMC system low cycle fatigue durability demonstrated at 2700˚F
- Coated CMC system TMF evaluated at 2200°F
- Heat transfer, fracture mechanics and stochastic approaches being established to develop coated CMC life prediction models

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