Syntactic YSZ TBC for improved thermal resistance of turbine components

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Introduction

This project is currently being completed under Phase I SBIR funding from the U.S. Department of Energy.

The current turbine thermal barrier coating (TBC) materials (thermal sprayed yttria-stabilized zirconia seals) are limited to 1200 °C As next-generation aerospace and power generation turbines come online it is desired to increase internal engine temperature to improve engine efficiency by 1-2%, lowering fuel consumption and increasing performance.

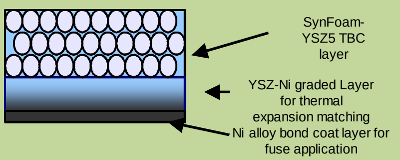
In order to improve efficiency in turbines by allowing for increased operating temperature and longer lifespan, Powdermet is developing an integrated TBC-graded structure with integral bond coat (BC). The resulting TBC coating can then be bonded directly to the substrate.

The multi-layer YSZ TBC-graded BC materials are ideal for TBC/BC applications in high temperature (1300 °C+) for the following reasons:

Â Engineered microballoon porosity is constant though the layer and along the part adding to its strength (compression) without sacrificing performance.

Â The consistency of engineered porosity also adds a benefit that the total area of the TBC will be a consistent hardness and less likely to break away in chucks or damage rotor parts during initial seating and will be less likely to scar by breaking away a large chunk and dragging it through the rest of the coating.

Â The thermal conductivity of the layer can be controlled and modified and can range from about 0.3-1.0W/m-K.



Objectives

Develop SynFoamÊ YSZ TBC to exceed current SOA TBC performance:
- ÂAt least greater than 1400°C operating temperatures, with a goal of exceeding 1500°C
- ÂMaintain mechanical properties at high temperature
- Â>300°C decrease in temperature across substrate for a 300 micron thick TBC

Achieve low thermal conductivity with SynFoamÊ YSZ:
- ÂClosed-cell structure reduces densification at higher temperatures
- ÂGoal thermal conductivity: <0.5 W/m-K (2 W/m-K max)

Develop a thermal mechanical model using Finite Element Analysis Software

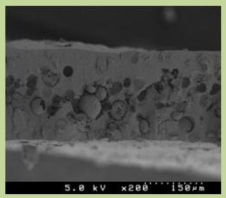
Based on thermal mechanical model, develop optimal system and fabricate:
- ÂAchieve coating of TBC material onto substrate
- ÂAdhesion comparable to APS TBC

Material Development

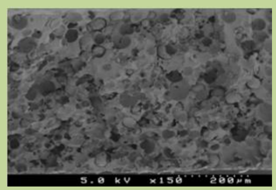
Syntactic YSZ films were developed by casting with a polymer binder

The green films were then processed through a de-bind and sinter profile

Sintered films showed little open-cell porosity and exhibited the closed-cell syntactic structure



Cross-section of film with ~40% porosity



Cross-section of film with ~70% porosity

Coatings were applied directly to an Inconel substrate with bond coat and sintered

The coating did not delaminate upon handling

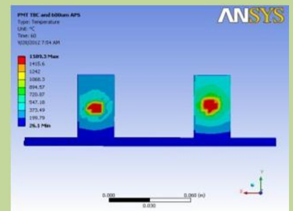
Processing is still underway to determine adhesive properties

Cast coated (left) and sintered (right) YSZ on bond coat/substrate

Modeling of System

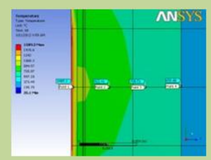
Material was modeled using ANSYS FEA software as a ñburner rigò setup

Burner rig ï samples placed on stand and exposed to high temperature (1500 °C) torch for 60 second cycles



Model of Burner Rig (Left: 600 µm and Right: 300 µm)

Temperature measurements were taken at four points within each sample (1, 2, 3, and 4). Compare proposed material (0.5 W/m-K) to current TBCs (~1W/m-K)

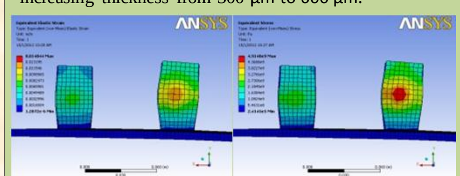


Temperature profile and data points in model

Summary of Temperature Data

Thermal Conductivity (W/m-K)	Thickness (µm)	Temperature (°C) 1	2	3	4
0.5	300	1503	1374	1180	1077
0.5	600	1487	822	708	659
1.0	300	1501	1358	1193	1100
1.0	600	1496	1014	849	779

The model showed a significant reduction in thermal stress and strain at the TBC/Bond Coat interface when increasing thickness from 300 µm to 600 µm.



Thermal strain model (left) and thermal stress model (right) of TBC/bond coat interface for 300 µm and 600 µm coatings.

Conclusions

Syntactic YSZ films can be cast and successfully adhered to a substrate with bond coat

Â Enables alternative methods of adhesion (furnace sintering, IR sintering, etc.)

Â Shows potential as alternative to APS

Â Would be less expensive than APS due to reduced material loss upon application

Based on a burner rig model, thicker coatings and increased porosity (decreased thermal conductivity) significantly reduce the thermal stress and strain at the TBC/bond coat interface.

Future Plan

Test coated substrates in experimental burner rig to test effectiveness and verify model

Obtain thermal conductivity data of casted films
- Â Goal will be to validate theoretical values
  - Â 0.3-0.5 W/m-K goal, 2 W/m-K maximum

Test IR fusion adhesion method
- Â Sintering parameters determined in oven, need to convert to IR lamp parameters

Develop gradient TBC-Bond Coat layer
- Â Will reduce thermal mismatch
- Â Will improve adhesion between TBC and substrate

Phase II:
- Â Scale up to produce larger parts
- Â Improve on Phase I properties
  - Â Thermal Conductivity
  - Â Strength of Adhesion
  - Â Ablation Resistance
  - Â Test in a relevant environment
- Â Full development and implementation of IR fusion techniques

Acknowledgments

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