Advanced Thermal Barrier Coatings for Operation in High Hydrogen Content Gas Turbines

Research Highlights

PI : Sanjay Sampath

Contributors: Prof. C. M. Weyant, Dr. G. Dwivedi, V. Viswanathan

Center for Thermal Spray Research AT STONY BROOK UNIVERSITY

Publication list

Dwivedi et al., Adv. Mater. Process, 2013, 8(2), 49

Dwivedi et al., JACerS, DOI: 10.1111/jace.13021

Viswanathan et al., JACerS, DOI: 10.1111/jace.13033

Dwivedi et al., JTST, DOI: 10.1007/S11666-014-0196-9

Viswanathan et al., JACerS, Under Review

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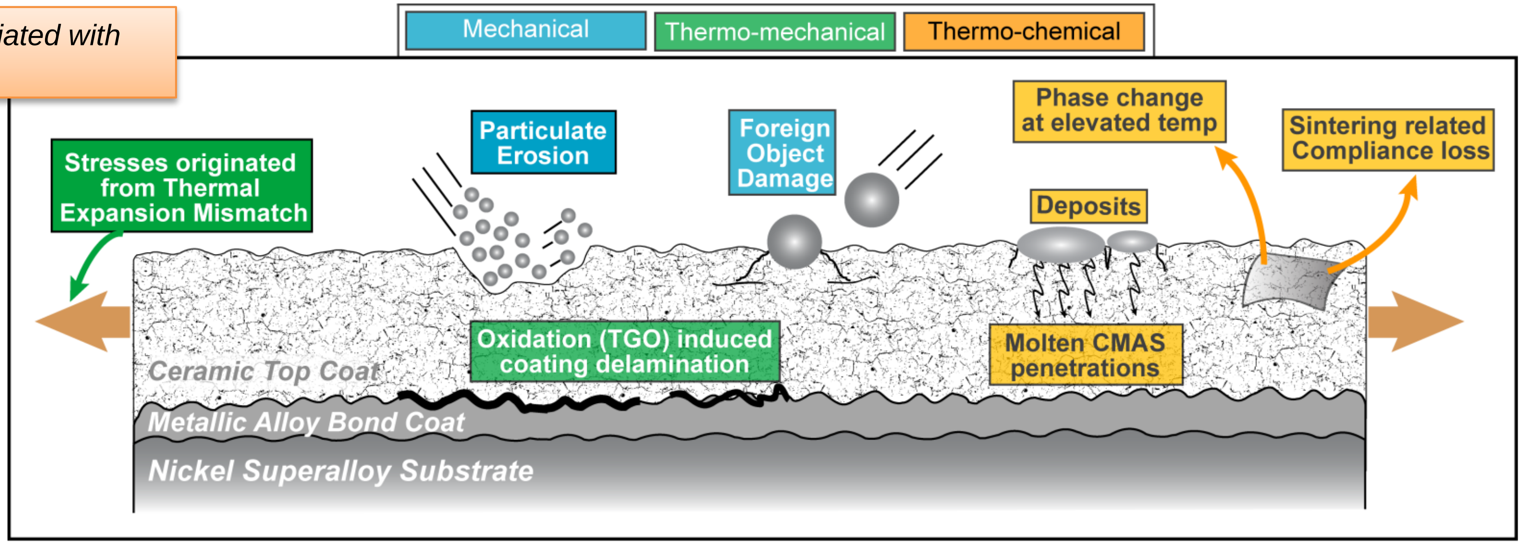
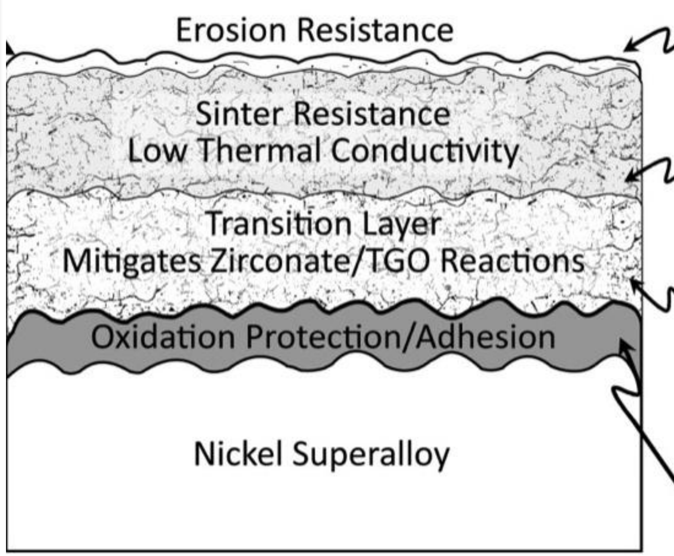
Program Manager: Dr. Briggs while

Multifunctional requirements of TBCs requires Multilayered architecture

Challenges associated with new gen TBCs



Multilayer, Multifunctional Coating Solution



Erosion, FOD, CMAS/Ash

Low-K material, Porosity, Lower sintering rate

Remains complaint

Compatibility with Bondcoat

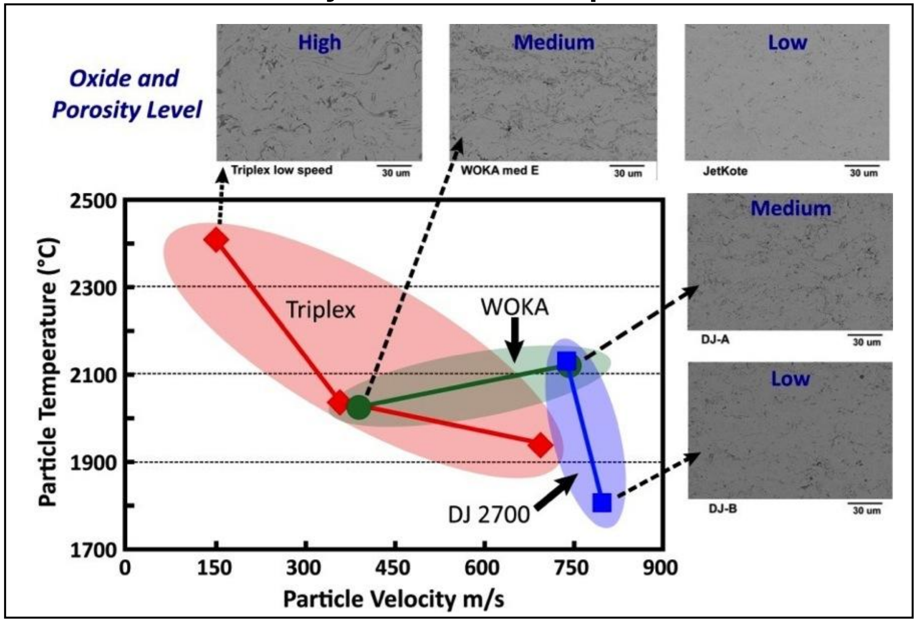
Mostly traditional TBC, High toughness

Adequate roughness, oxidation resistant (dense), environmental effects

Layer-by-layer optimization of multilayered TBCs is naturally suited for Thermal Spray

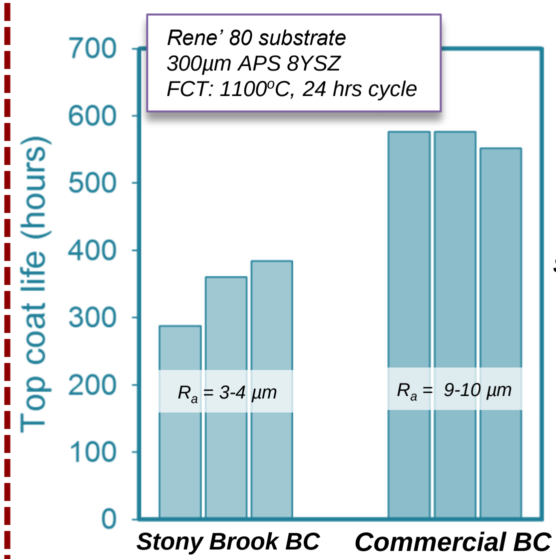
Bond coat processing and performance

Process selection and mapping strategy for the density and oxidation optimization

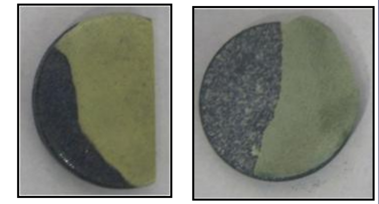


- Prior work conducted at Stony Brook has explored the process-property relationship of bond-coat material deposited using Atmospheric plasma Spray and High Velocity Oxy-fuel (HVOF) processes.
- The selection of HVOF process was to obtain dense bond-coat microstructure with minimum oxide inclusion (WOKA and DJ2700 in the above figure).
- Such coatings offer requisite oxidation resistance to the substrate.
- For material selection, concurrent study was conducted at ORNL (coating prepared by Stony Brook), on two different bond-coat chemistries- SM AMDRY 386-2 (NiCoCrAlYHfSi) and SM XPT 449 (NiCoCrAlY). Results suggested superior performance of AMDRY 386-2.
- Therefore, the bond-coat study at Stony Brook, focused on the same (AMDRY 386-2) material. The coating was deposited using liquid fuel HVOF process.

Initial performance evaluation with HVOF bond coats



Photographs of failed specimens



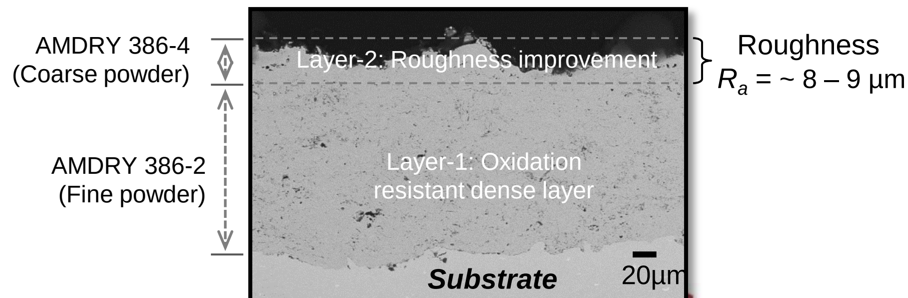
Stony Brook's BC *Poor adhesion* | ***Commercial BC*** *Good adhesion*

Initial results exhibited significantly poor life of TBC sprayed on Stony Brook's bond-coat, compared to those sprayed on commercially obtained bond-coat.

Initial observations on failed specimens indicated that the poor FCT life in Stony Brook's bond-coat specimen was primarily due to lower bond-coat roughness.

Two-layer bond-coat deposition: Improved roughness

NiCoCrAlYHfSi



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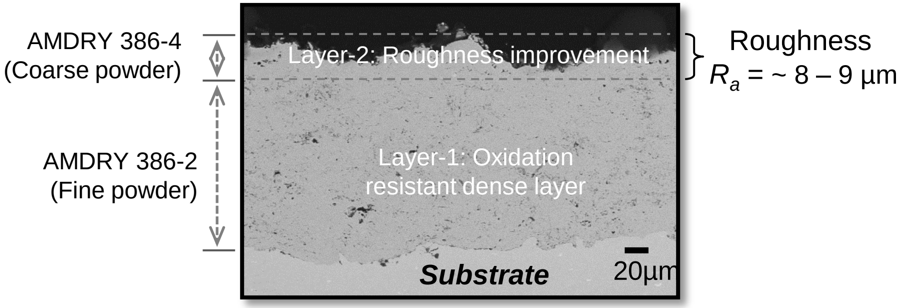
Bond coat processing and performance

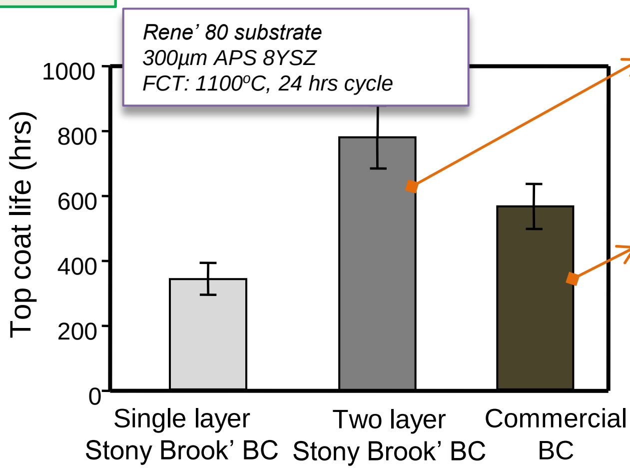
Two-layer bond-coat deposition: Improved roughness

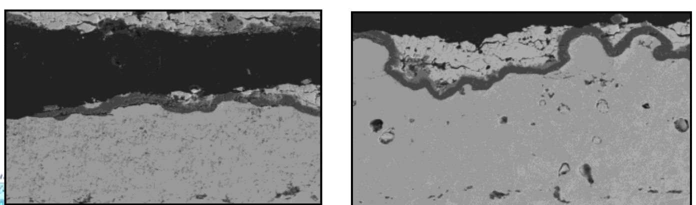
Microstructure

<u>*NiCoCrAlYHfSi*</u>



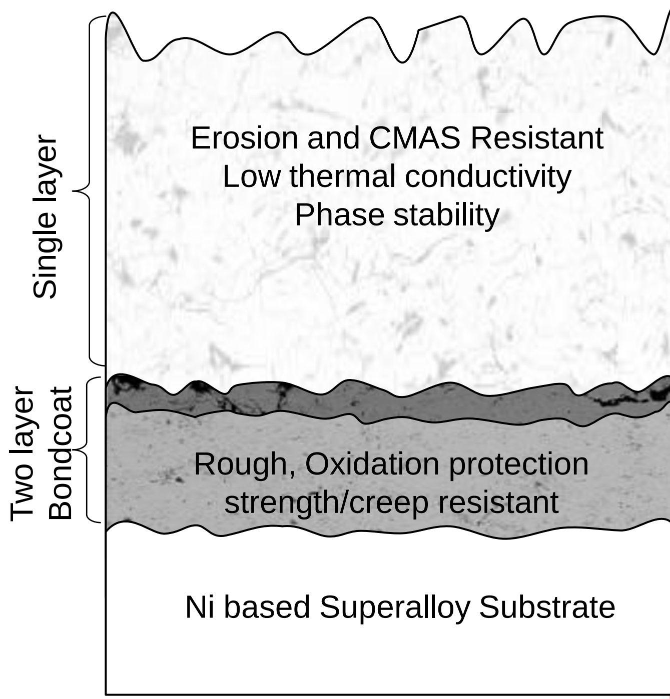
FCT life





- Processing strategies leveraged for the development of improved HVOF bond coats
- Based on process diagnostic and coating property measurements a two layered HVOF coating was designed, fabricated and tested.
- First layer would consist of a dense oxidation resistant coating comprising of majority of the thickness while the second layer would serve to enhance the surface roughness of the HVOF coatings
- A significant improvement in FCT life obtained with the two layered bond coat architecture compared with initial single layered coating
- Processing strategies were utilized to provide significant performance benefits for a chosen feedstock chemistry

Summary



~100% improvement in FCT life with two-layer bondcoat

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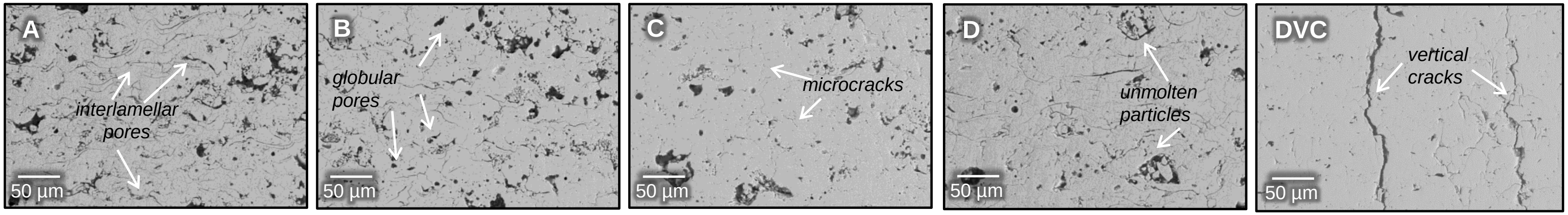
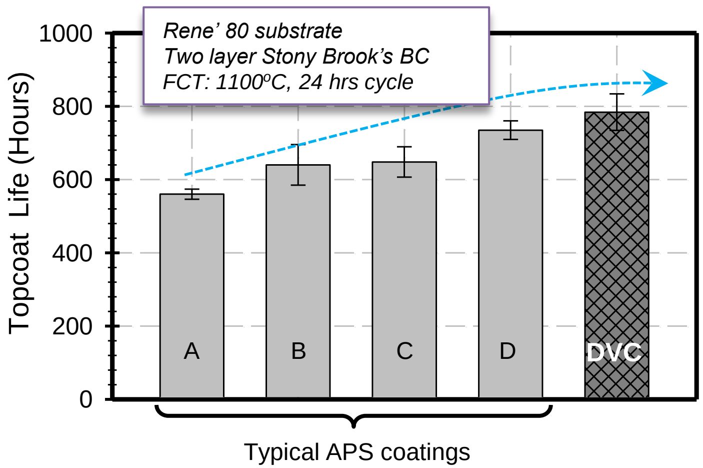
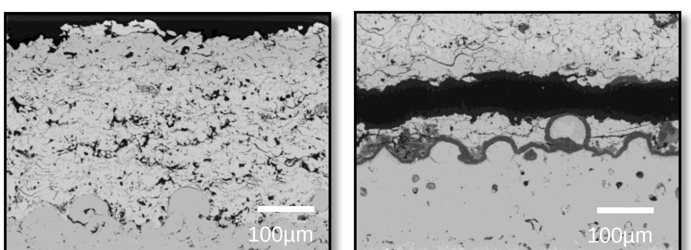
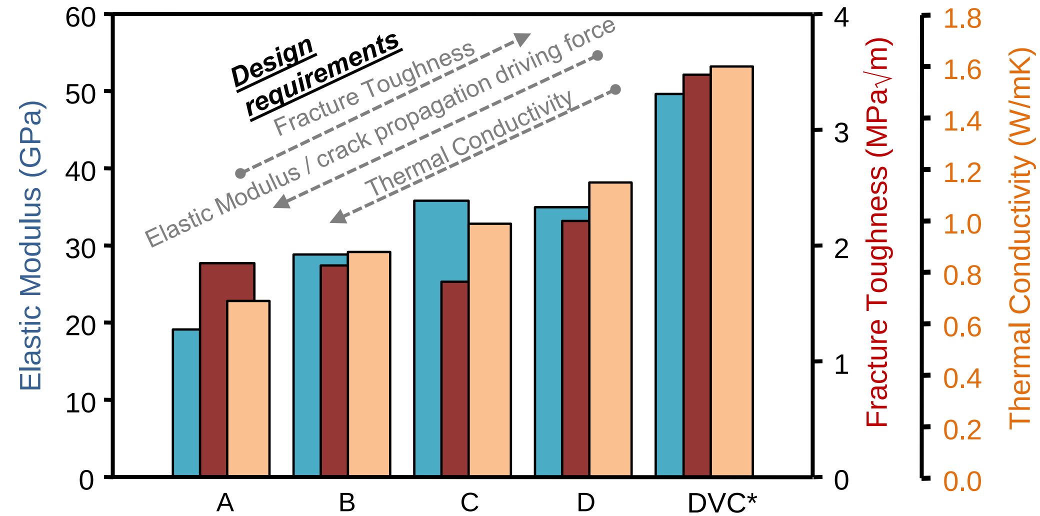
Performance assessment of various APS YSZ architectures





As-deposited TBC **Failed (~600 hrs)**





- Five top coat architectures with decreasing porosity from A to DVC, were sprayed on identical bond-coated superalloy substrates, and were subjected to FCT.
- The FCT results indicated higher top coat life for coatings with lower porosity .
- The measured elastic modulus and thermal conductivity of coatings also increases with decreasing porosity.
- The fracture toughness (measurement details are in next page) of coatings appears to be the operating mechanism with higher toughness coatings resulting in higher FCT durability

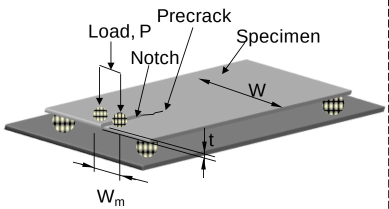
FCT life of coatings is higher with higher fracture toughness coatings. However, these coatings also have higher thermal conductivity, which is not desirable for TBCs.

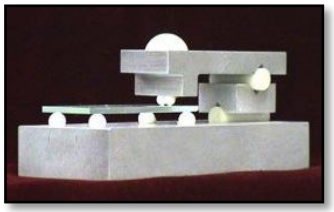
The high fracture toughness requirement only seems to be at the bond-coat and top-coat interface. Can we design a multilayer top-coat with low overall thermal conductivity and high toughness at the interface

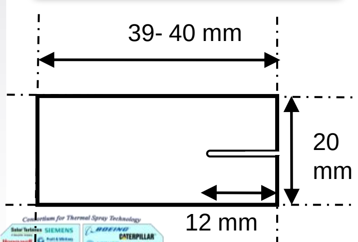
Microstructural dependence of fracture toughness of TBCs

Double Torsion Technique

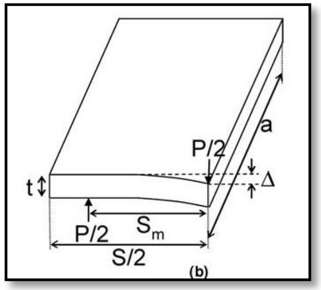
Test method

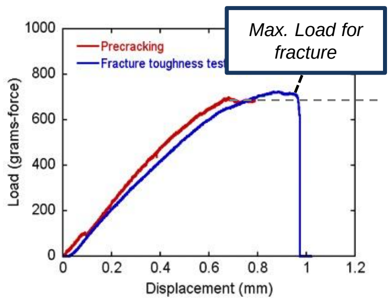






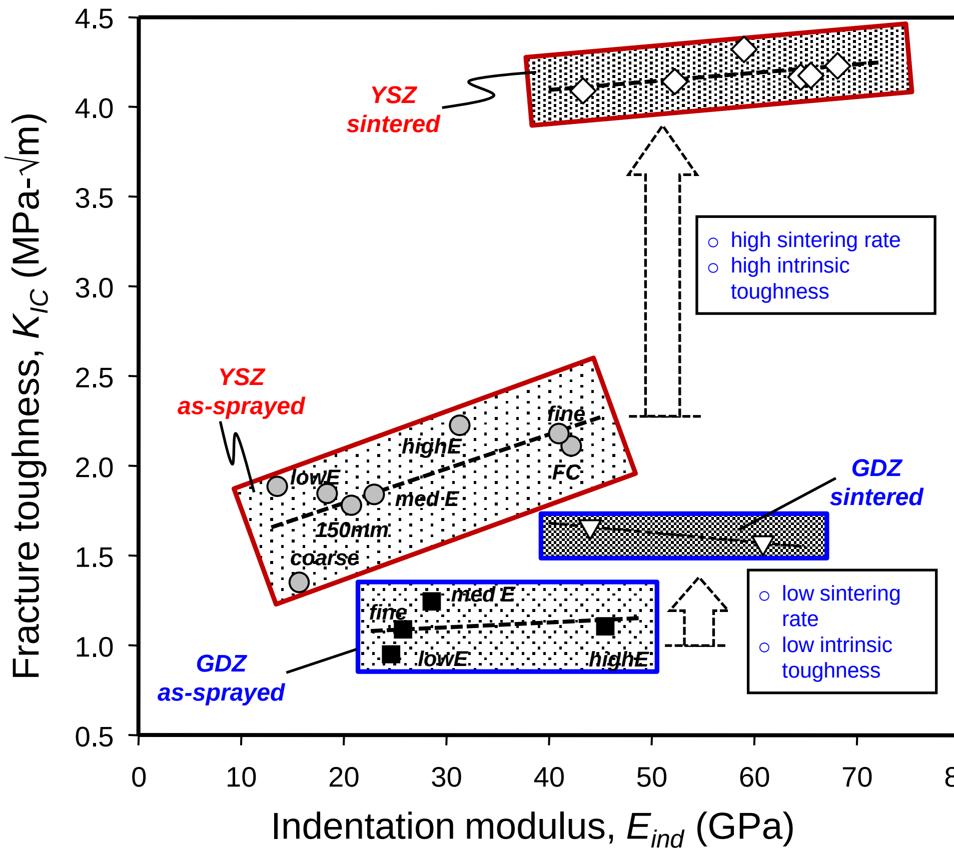
K_{IC} extraction





$$K_{IC} = P_{IC} S_m \left[\frac{3(1+\nu)}{St^4 \xi} \right]^{1/2}$$

P_{IC} - Maximum load at failure
ν – Poisson's ratio
S - specimen width
S_m – moment arm
t - specimen thickness
ξ - thickness correction factor
$\xi = 1-1.26(t/S)+2.4(t/S)\exp(-\pi S/2t)$



1. Fracture toughness of coatings sensitive to their processing conditions
2. Coatings with higher degree of porosity have both lower modulus and fracture toughness
3. YSZ coatings shows better fracture toughness than $Gd_2Zr_2O_7$ (GDZ) coatings.
4. With sintering, the improvement in fracture toughness of YSZ coatings is larger than that of GDZ coatings
5. The map allows us to down select the coating material and processing conditions to meet fracture toughness requirement for coating design

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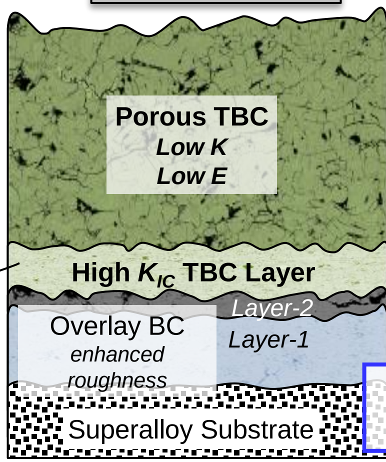
Revised TBC Architecture: Strategic approach for multi-functionality

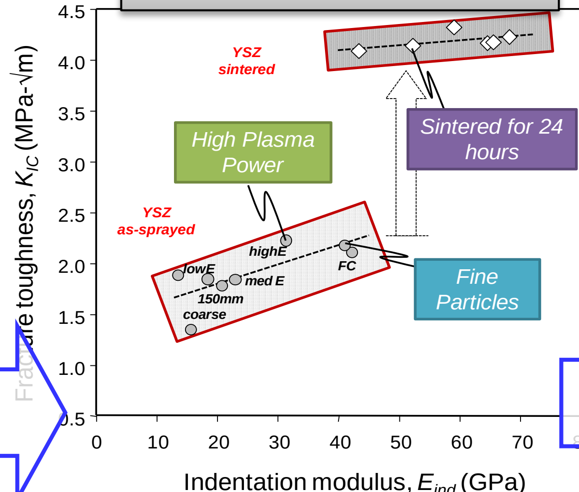
Functionally Optimized TBC with high fracture toughness interface layer

Design Strategy

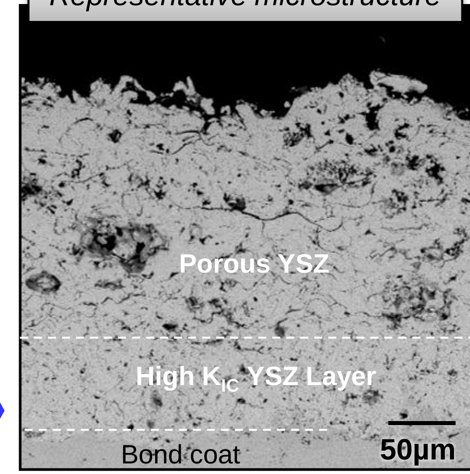
- Structural Compliance
- Low Th. Conductivity
- High fracture toughness



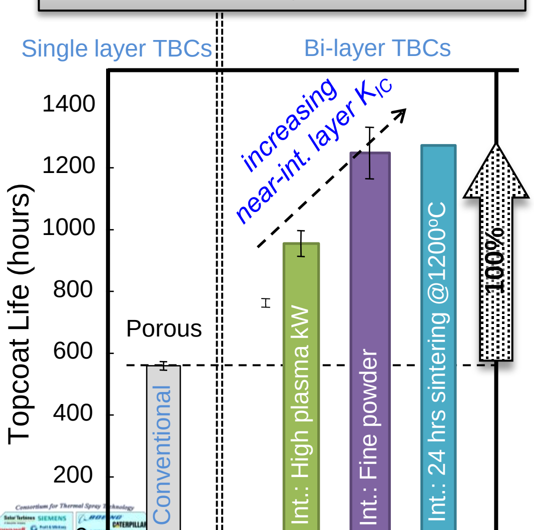
Processing condition selection



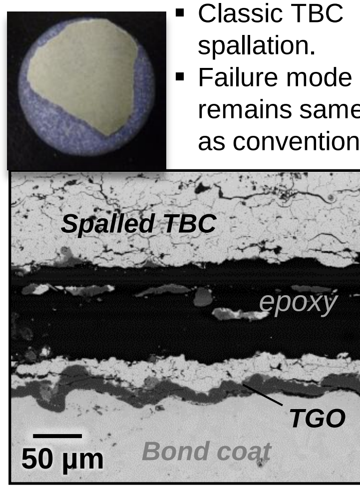
Representative microstructure



FCT Life: 24 hrs cycles @ 1100ºC

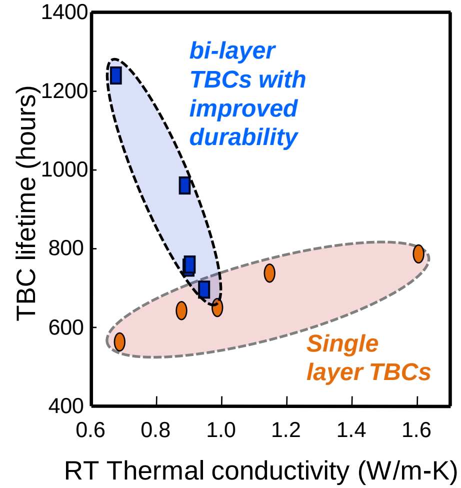


Failed specimen analysis



- Classic TBC spallation.
- Failure mode remains same as conventional.

Coating with high durability and low k



Summary

- Simultaneous optimization of coating durability and functionality
- 100% improvement in life while maintaining low Thermal Conductivity

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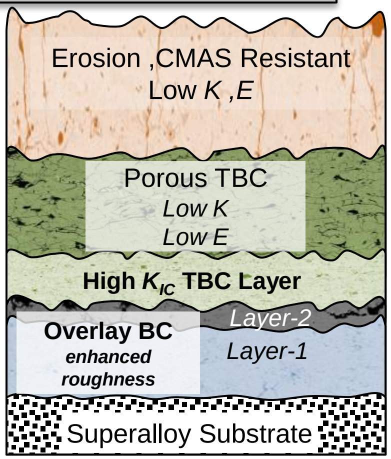
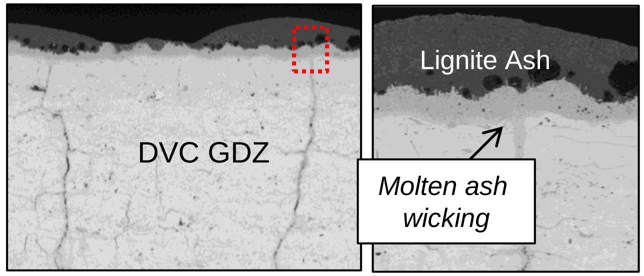
Multilayer TBC architevure: Strategic approach for multi-functionality

Functionally Optimized TBC with high durability as well as erosion and CMAS resistance

Multilayer-multifunctional architecture

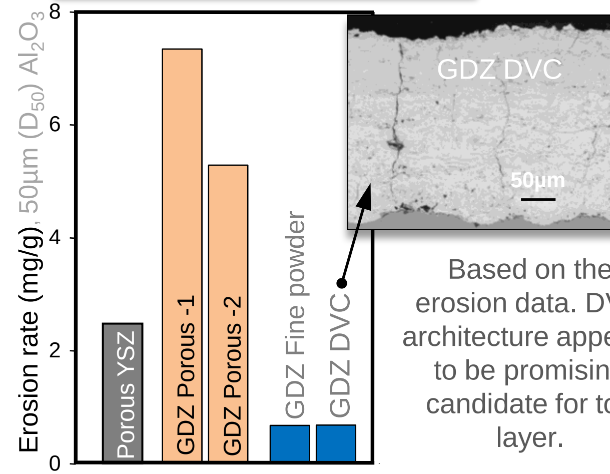


CMAS resistant layer

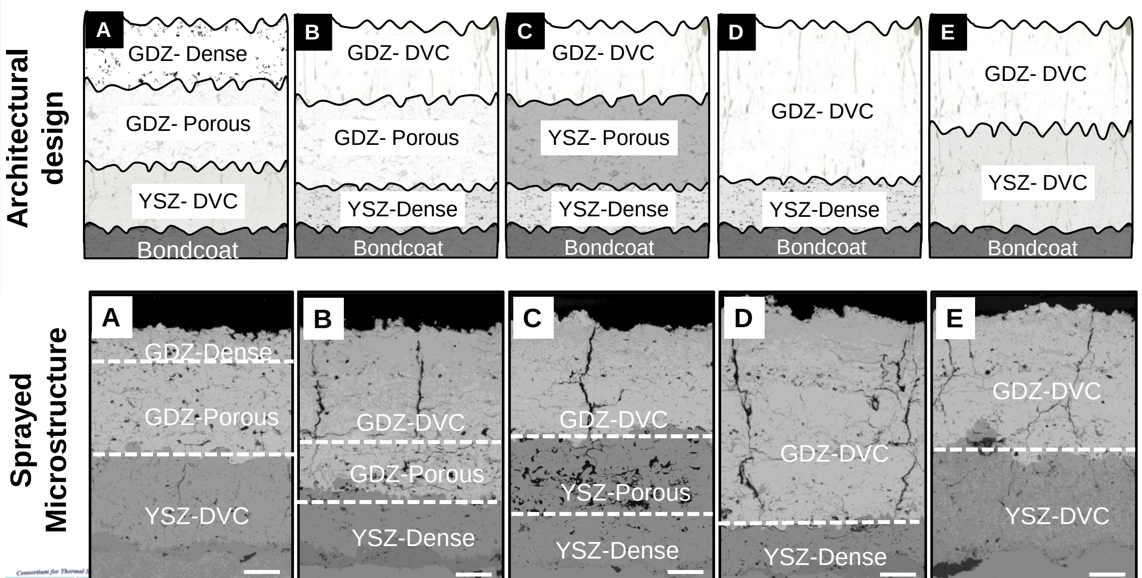


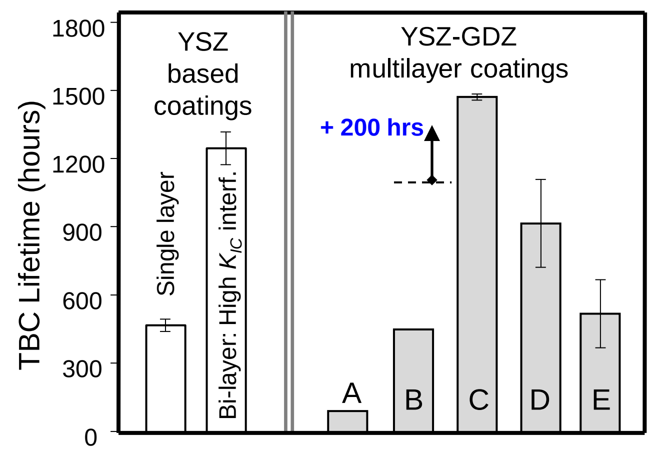
DVC architecture of GDZ material was evaluated. Lignite ash was spread onto the topcoat (35 mg/cm^2). Heat treatment: 1200ºC for 24 hours. The coating exhibited resistance to CMAS, and the average penetration depth was ~ 25 microns

High erosion resistance layer



Based on the erosion data. DVC architecture appears to be promising candidate for top layer.





Coating 'C' shows high FCT life, even better than the Bi-layer YSZ, simultaneously addressing the issues of CMAS and erosion.

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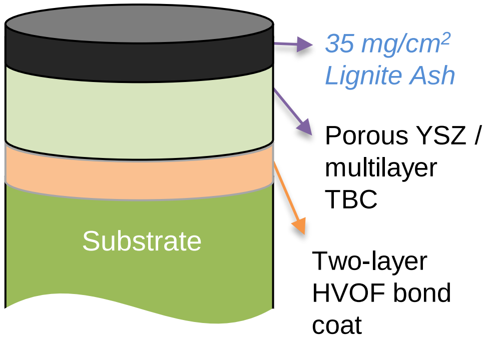
Multilayer TBC architevure: Strategic approach for multi-functionality

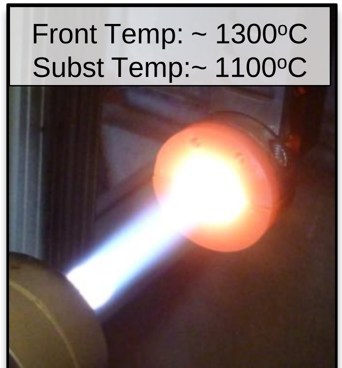
Functionally Optimized TBC with high durability and low thermal conductivity

Preliminary Gradient Testing

Specimen preparation

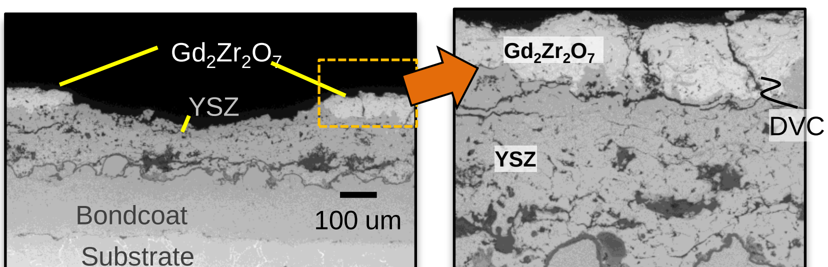


Gradient test rig



Lignite ash was adhered to the coating by baking it onto the topcoat at 1000ºC. Cycles with10 minutes heating and 2 minutes air cooling were performed

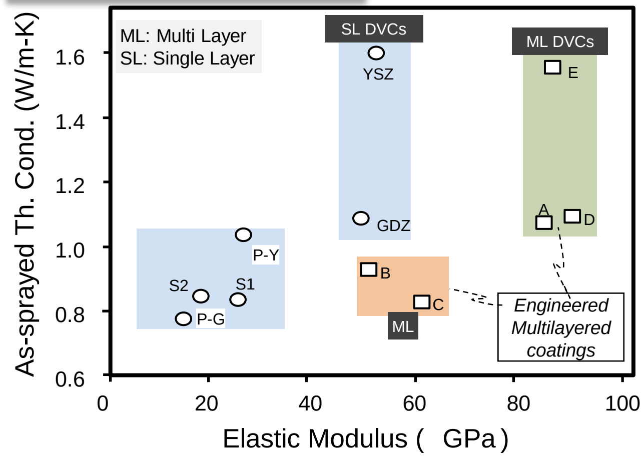
Failed coatings microstructures



The microsturctures from this preliminary test suggest that the top GDZ-DVC layer can mitigate CMAS penetration to the GDZ-YSZ coating architecture.

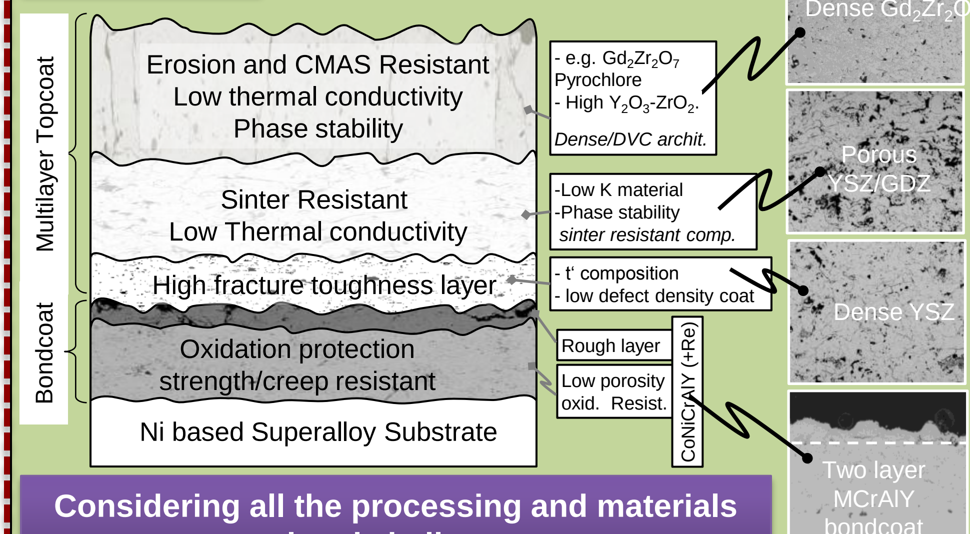
Multilayered TBC (C) lasted ~ 20 times more than conventional YSZ TBC.

Functional property map



The as-sprayed thermal conductivity and elastic modulus map shows that the new multilayer GDZ-YSZ coating architecture **(C)** has thermal conductivity as low as conventional YSZ coating. However the elastic modulus is somewhat higher due to the inclusion of DVC structure in the new TBC design.

Summary



Considering all the processing and materials related challenges

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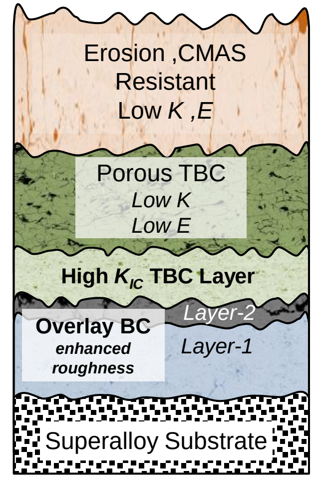
Systematic progress over past four years

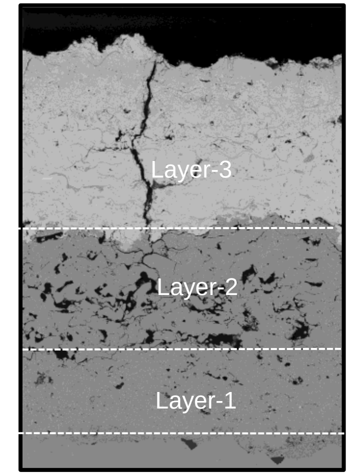
Y1
- YSZ and GDZ process property relationships
  - **Process Map development**
  - ***Toughness, Lignite ash penetration depth, erosion***

Y2
- Rough bond coat process optimization with 40% increase in FCT life
  - **Two layer Bond coats**

Y3
- Bi-layer YSZ coating with two fold increase in FCT life, and maintaining low *K*
  - **High toughness interface layer, Elastic energy model**

Y4
- Multilayer YSZ-GDZ coating system
  - **Enhanced life, Lignite ash penetration minimization, erosion resistance**





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Dr. Briggs While, Program Manager

Prof. Toshio Nakamura, Stony Brook University

Dr. Curtis Johnson, Rtd. GE GRC

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