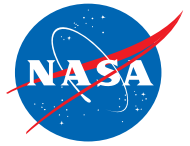

Foreign Object Damage in a $Yb_2Si_2O_7$ Environmental Barrier Coating

Leland Hoffman
HX5, LLC. at NASA Glenn
Brook Park, OH

Michael J. Presby, Bryan J. Harder, Jamesa L. Stokes
NASA Glenn Research Center
Cleveland, OH

ICACC Daytona Beach, FL
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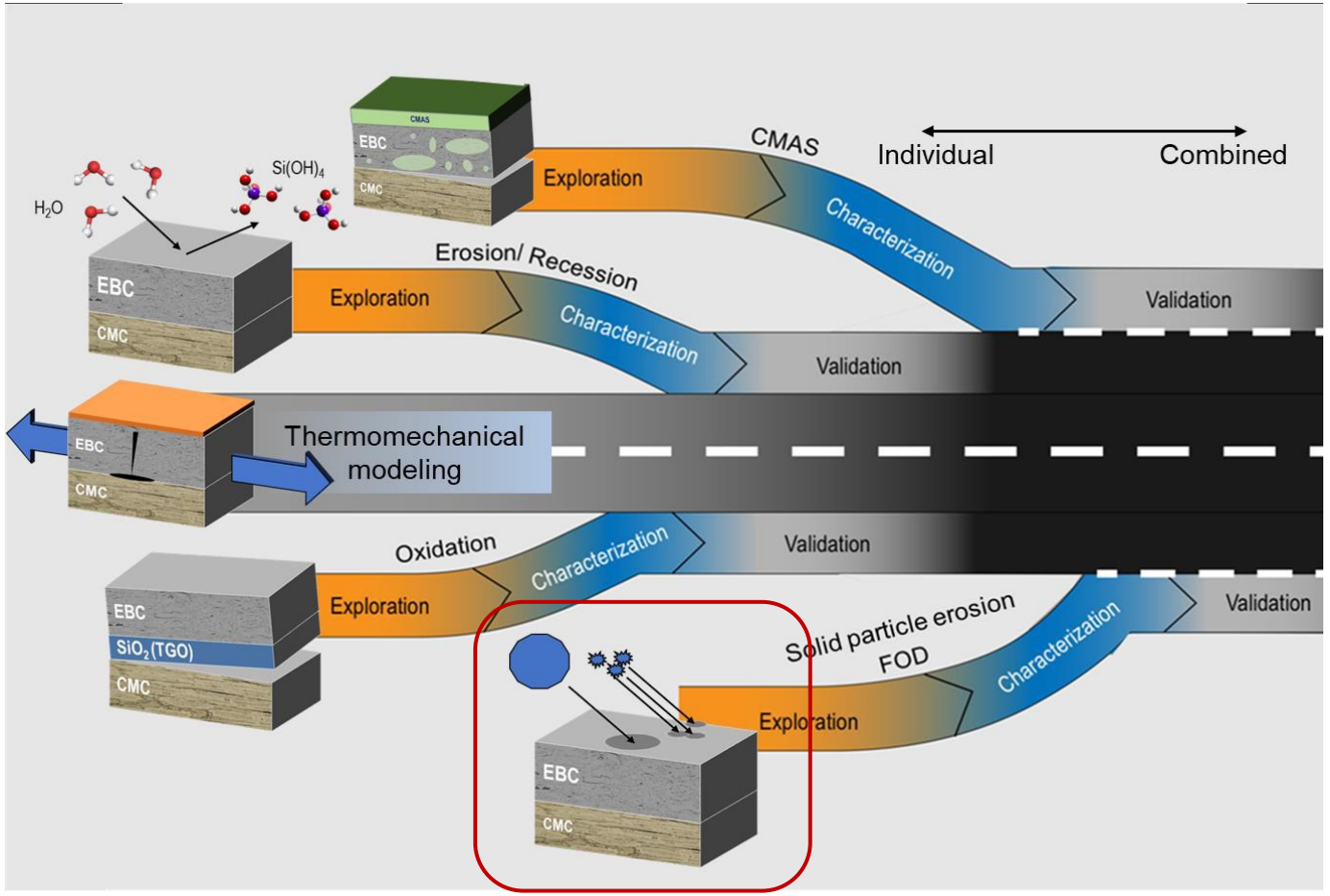
Foreign Object Damage (FOD) in Aero-Engines

Background

- Environmental barrier coatings (EBC) are being developed to protect SiC based ceramic matrix composites (CMC) from oxidative degradation
- Oxidative growth of a SiO_2 thermally grown oxide (TGO) layer reduces the lifespan of the material system
- FOD is a key failure mechanism of interest in gas aero-engine materials

Present Study

- Previous study on YbDS showed FOD caused delamination in the TGO layer
- Recent EBC advancements showed that oxide modifiers reduced TGO growth rates

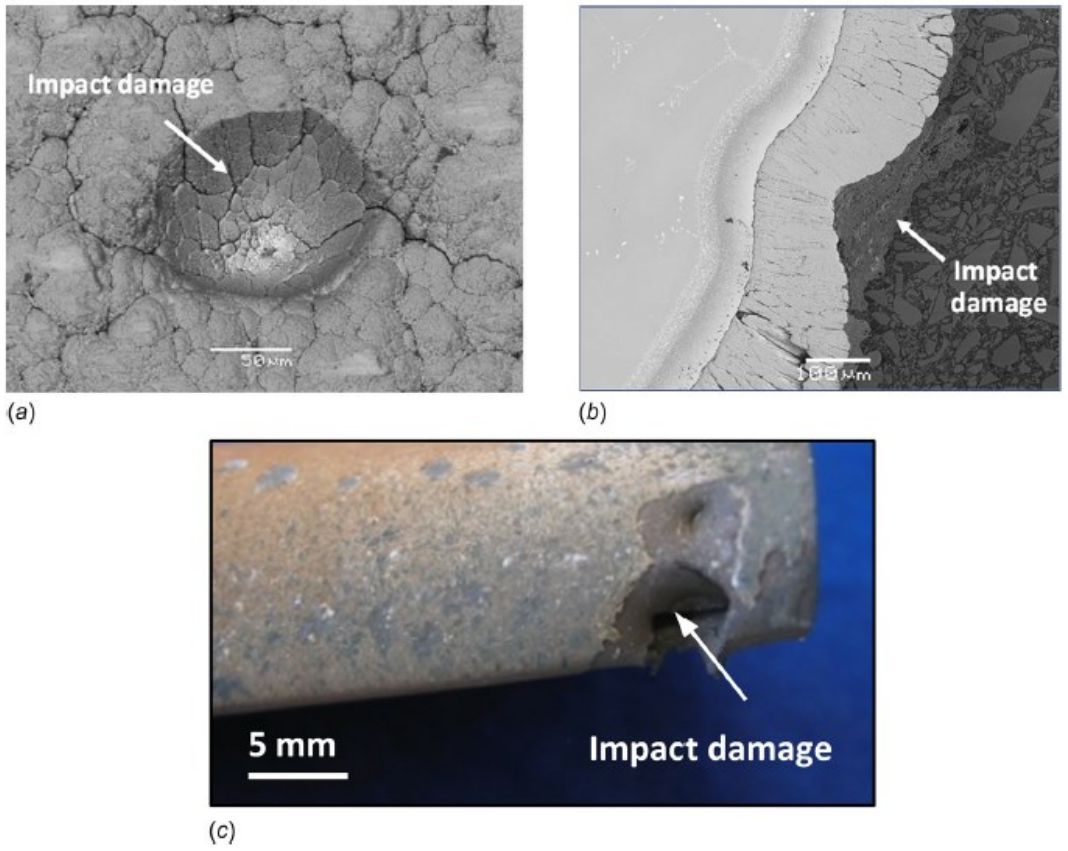


Foreign Object Damage (FOD) in Aero-Engines

Foreign Object Damage
- Any object traveling into or downstream an engine causing impact damage
- Limited studies on FOD in EBCs

External FOD:
- Ice, pebbles, runway debris, and birds can be ingested into the engine

Internal FOD:
- Spalled coatings, metallic particles, and nuts/bolts can cause downstream damage



Examples of FOD in US Navy TBC airfoils:
S. Choi, (2014) ASME J. Eng. Gas Turbine Power

Experimental Procedure

Materials

- α-SiC Hexoloy SA substrate (25.4 x 12.7 x 3mm)
- Si bond coat (~125 μm)
- Modified Ytterbium Disilicate (M2Y) EBC (~250 μm)
  - 1.39 wt.% mullite ($3Al_2O_3 \cdot 2SiO_2$)
  - 2.33 wt.% YAG ($Y_3Al_5O_{12}$)
  - Balance ($Yb_2Si_2O_7$)

- EBC and bond coat deposited via air plasma spray
- Results will be compared to previous study on 100% YbDS

Steam Oxidation Exposure

- Some samples were steam oxidized to form a thermally grown oxide layer at the bond coat – EBC interface
- 1316˚C for 100, 200, or 300 hours in a vertical tube furnace with flowing steam

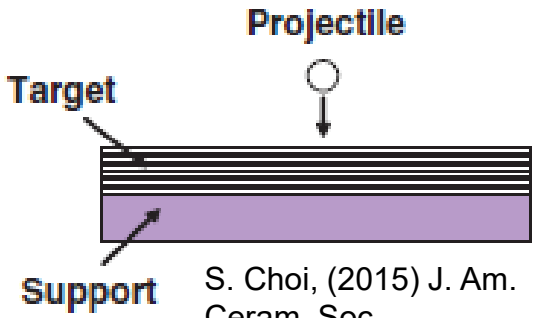
Foreign Object Damage Test Facility

Test Conditions

- As-processed samples impacted at 50-300 m/s
- Steam-oxidized samples impacted at 50-100 m/s

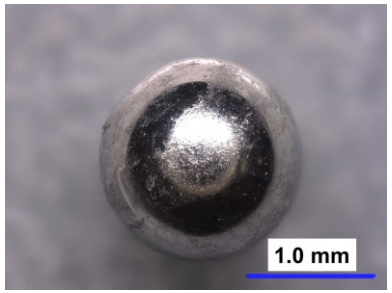
- Normal incidence angle
- Fully supported configuration
- Hardened steel BB projectile (1.59 mm)

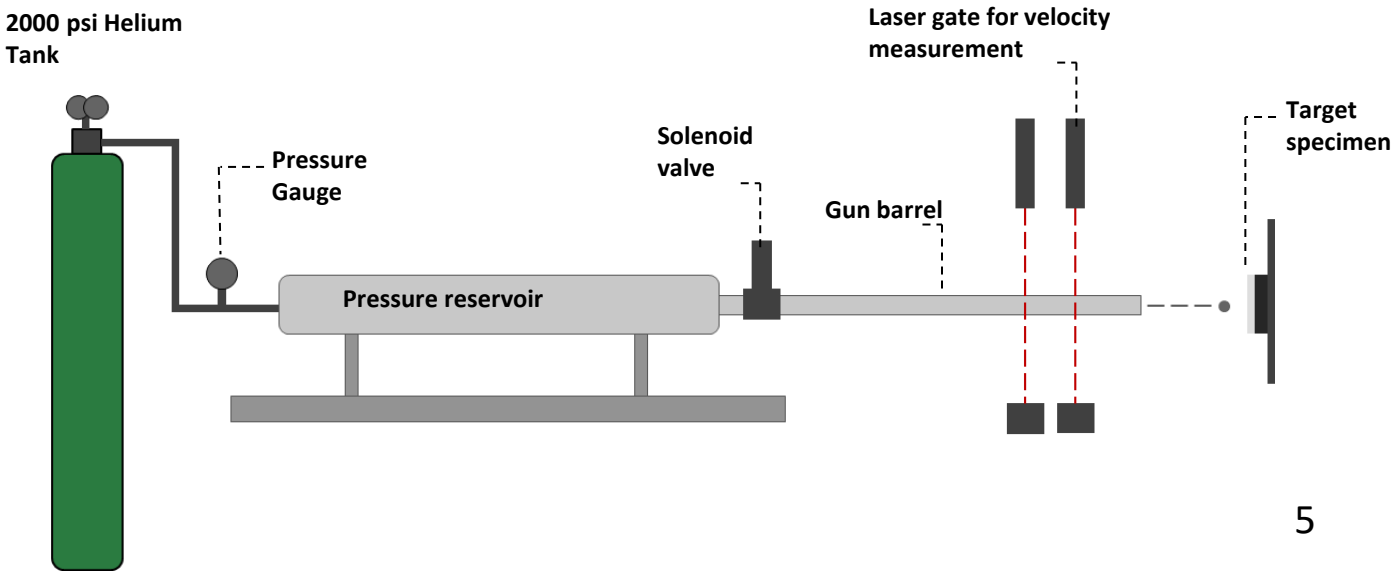
Fully Supported:



S. Choi, (2015) J. Am. Ceram. Soc.

Steel Projectile:

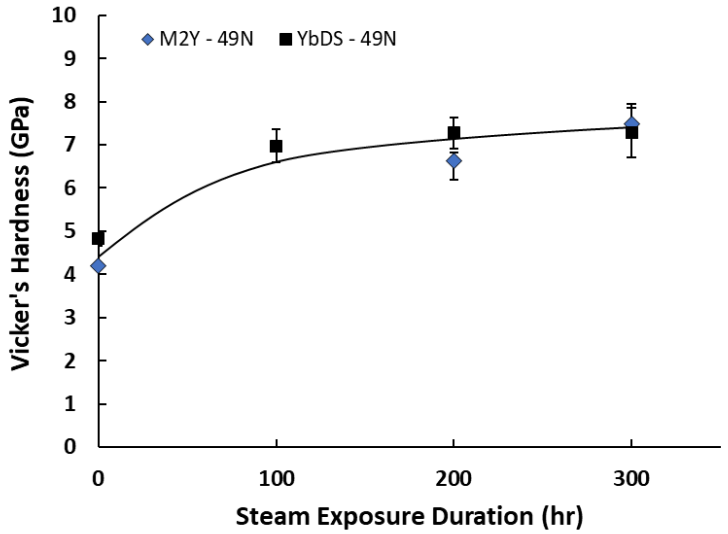


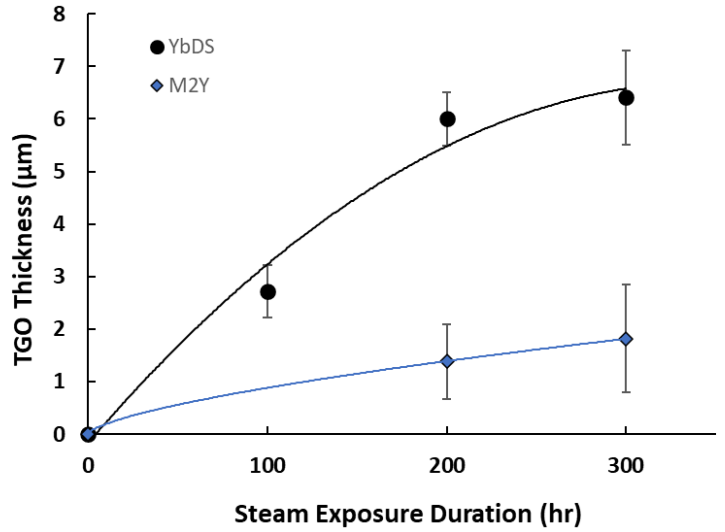


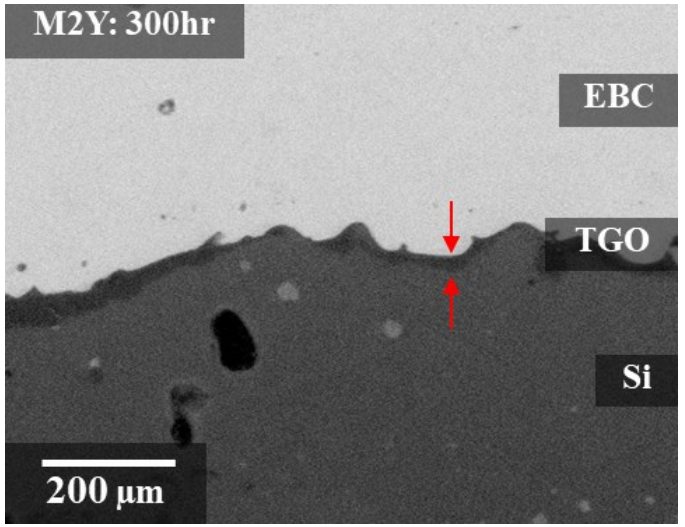
Results: Material Characterization

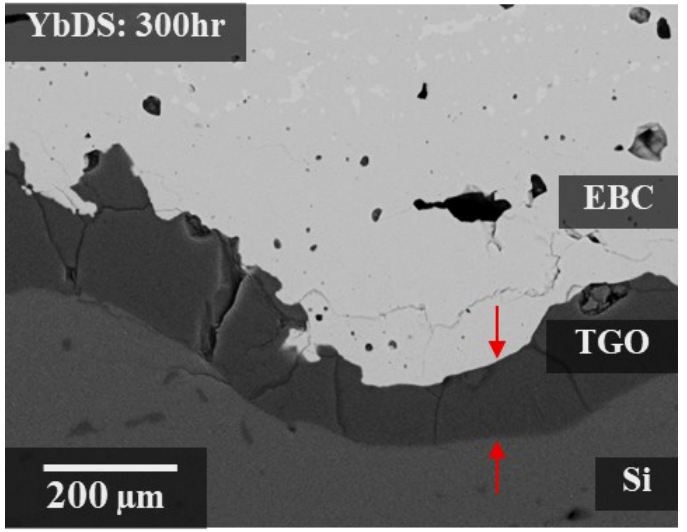
- EBC hardness increased with steam exposure (Vicker's 49N)
  - Coating densification and microstructural changes
  - M2Y 0hr – 4.21 GPa
  - M2Y 300hr – 7.49 GPa
- SiO_2 TGO at EBC – bond coat interface
  - M2Y - 300 hour: 1.8±0.9 µm
  - YbDS - 300 hour: 6.4± µm

*Previously reported data using 100% Ytterbium Disilicate EBC (YbDS) shown for comparison









Results: FOD of As-Deposited M2Y EBC

Low Velocity (<100 m/s)

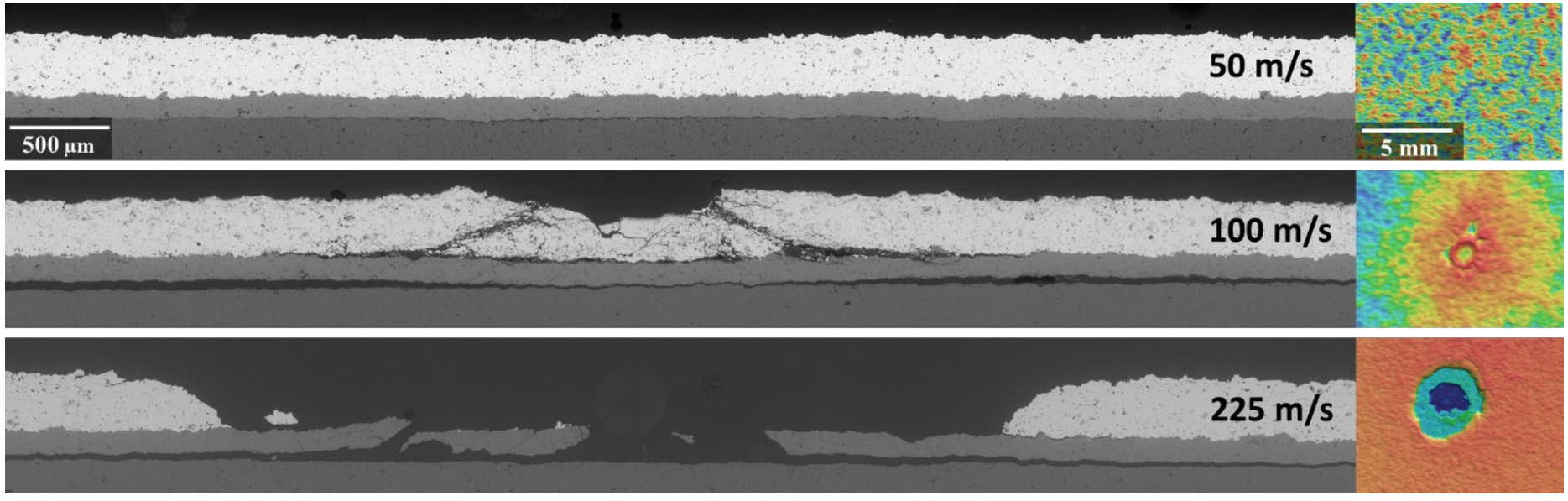
- Minimal surface damage
- Delamination at bond coat – substrate interface
- EBC microcracking

Intermediate Velocity (100-150 m/s)

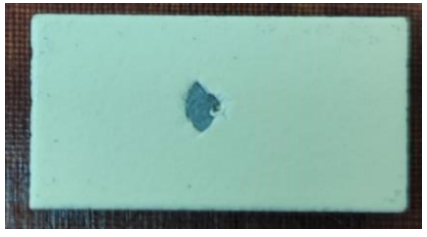
- Simple crater formation
- EBC crushing and cone cracking
- EBC protrusion and ejection

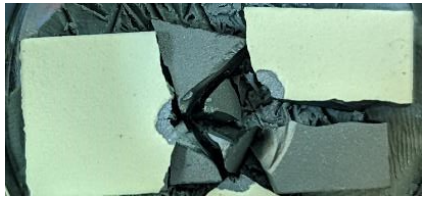
High Velocity (>150 m/s)

- EBC spallation at impact site
- Hairline substrate cracking
- M2Y fracture above 275 m/s
- YbDS fracture above 200 m/s
  - Demonstrates the need to study FOD in CMC substrates




100 m/s


200 m/s

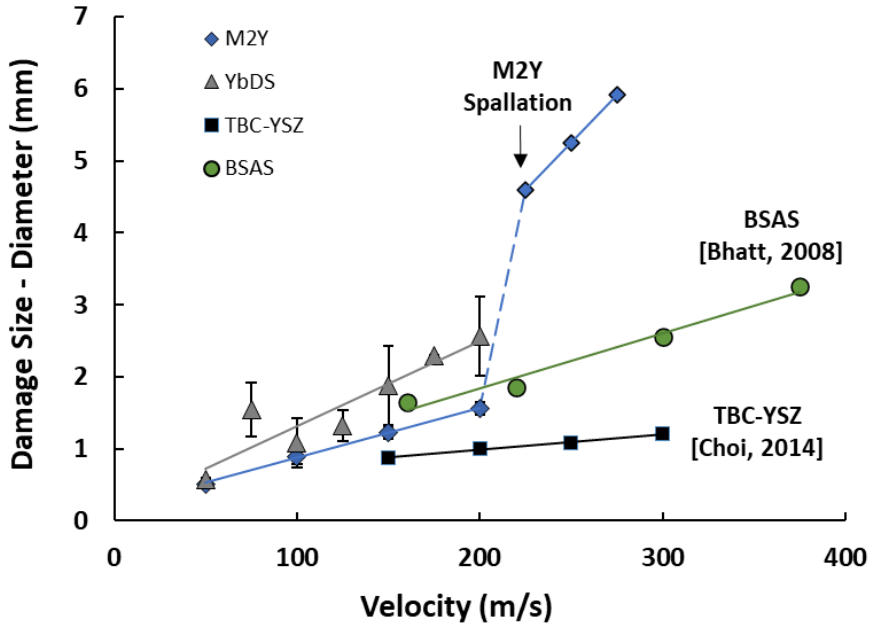

300 m/s

Results: FOD of As-Deposited EBCs

Surface Damage

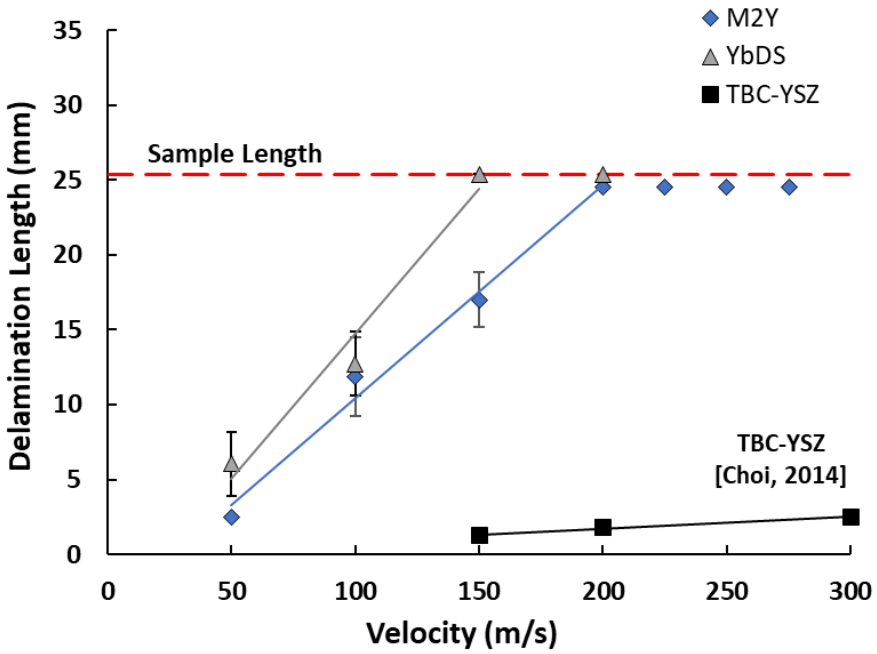
- Crater diameter increased with velocity
  - Less severe damage in M2Y
- Spallation of EBC ~225 m/s in M2Y

*BSAS EBC and YSZ TBC data included for comparison



Delamination

- At the bond coat-substrate interface
- Length increased with velocity and was less severe in M2Y EBC
- Delamination in TBC airfoil at TBC – bond coat interface included for reference



Results: FOD of Steam-Oxidized EBCs

Surface Damage

- Minimal EBC surface damage
- M2Y substrate fracture at 125 m/s
- YbDS fractured at 75-100 m/s

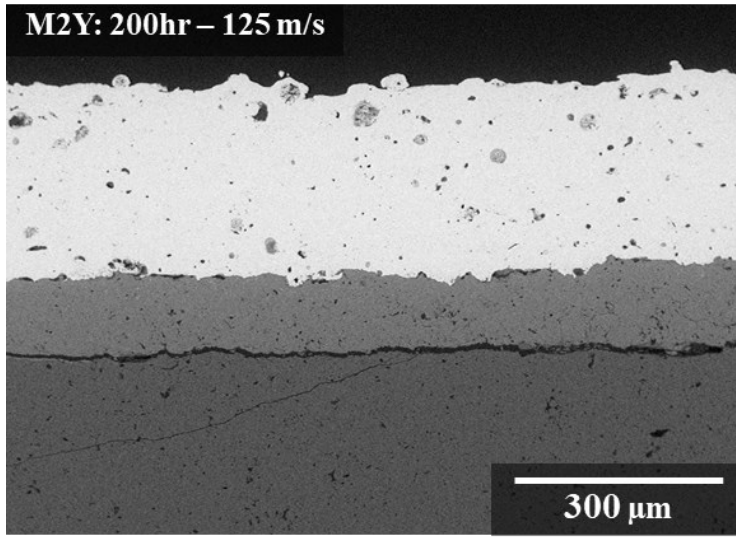
Internal Damage

- There was very little EBC deformation (crushing/cracking, protrusion, ejection).
- Brittle damage morphology
- M2Y: delamination at the bond coat – substrate interface
- YbDS: short delamination in the TGO layer (2±1 mm at 75 m/s)

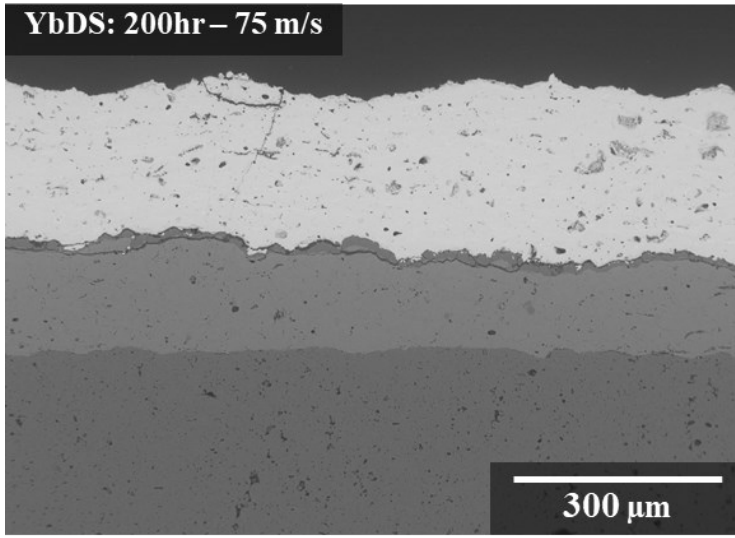
Implications

- Lack of surface/internal damage likely due to increased hardness and EBC densification
- Embrittlement reduced the critical fracture velocity

M2Y delamination at substrate interface



YbDS delamination in TGO layer



Conclusions

Summary:

- FOD in as-deposited M2Y samples resulted in EBC crushing, protrusion, and ejection as well as delamination at the bond coat - substrate interface.
  - Slightly improved FOD resistance compared to 100 % YbDS EBC
- FOD in steam-oxidized samples resulted in more brittle damage mechanisms and fractured at half the velocity of the as-deposited samples.
  - True in M2Y and YbDS EBCs
- Steam-oxidized M2Y samples delaminated at the Si-SiC interface
- Steam-oxidized YbDS samples delaminated in the TGO layer

Future Work:

- FOD on EBCs deposited on SiC/SiC CMCs
- FOD at elevated temperature – isothermal furnace or burner rig

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