AEROSPACE TECHNOLOGY CONGRESS 2019
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Multilayered Thermal Barrier Coatings processed by Suspension Plasma Spraying

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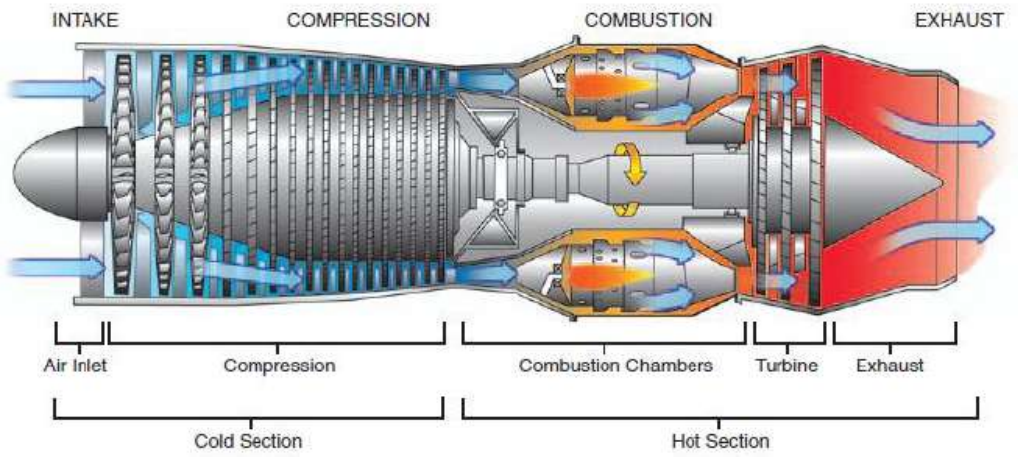
Gas Turbine Efficiency

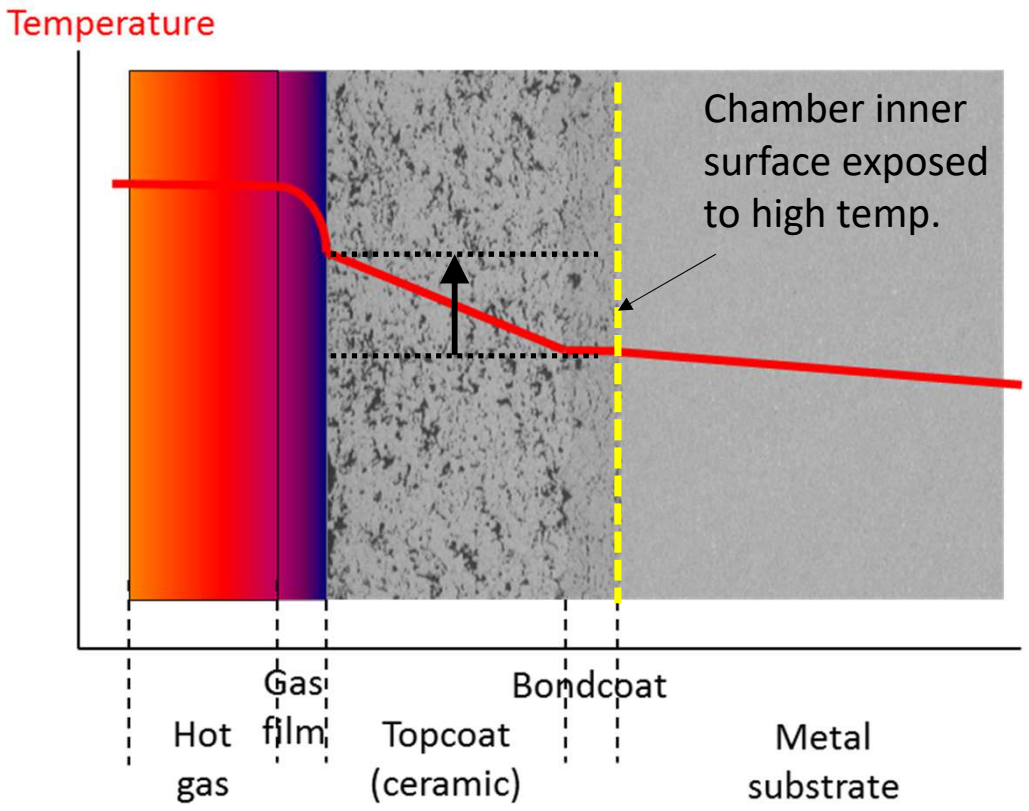
- 1% increase in engine efficiency of a power plant of 300 MW would result in savings of:
  - more than $ 2 M/year fuel costs
  - approx. 25 000 t/year reductions in CO_2
- How to increase efficiency? => Higher combustion temperature



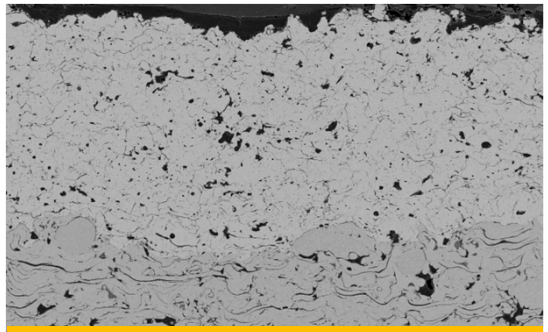
6,5€/GJ fuel cost, 8000 h/a
Ref: M. Oechsner, Siemens, TBC - Conference, Irsee, 2012

Thermal Barrier Coatings (TBCs)

- TBCs used in combustion and exhaust chamber for insulation
- Combustion temp. increased by 200-300°C
- Lower thermal conductivity and strain tolerance are desired

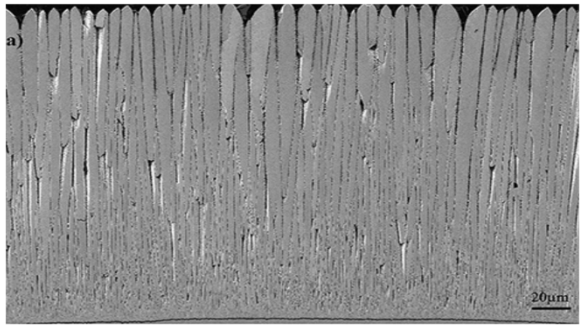


Why Suspension Plasma Spray (SPS)???



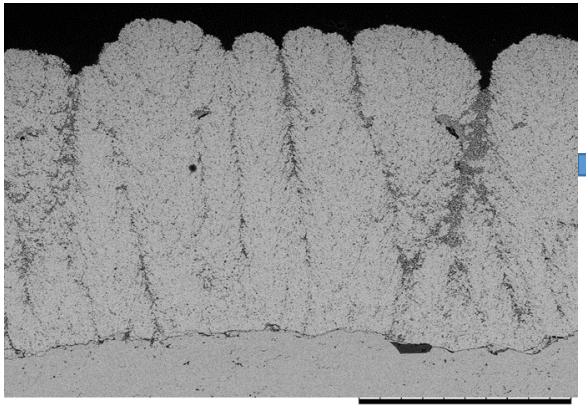
Courtesy: N. Curry, University West.

APS Microstructure



Munawar .et.al, J. Engineering for Gas Turbines & Power, 2013

EB-PVD Microstructure



SPS Microstructure

SPS makes it possible to mimic EB-PVD to obtain columnar microstructure and SPS can also produce a large variety of microstructures

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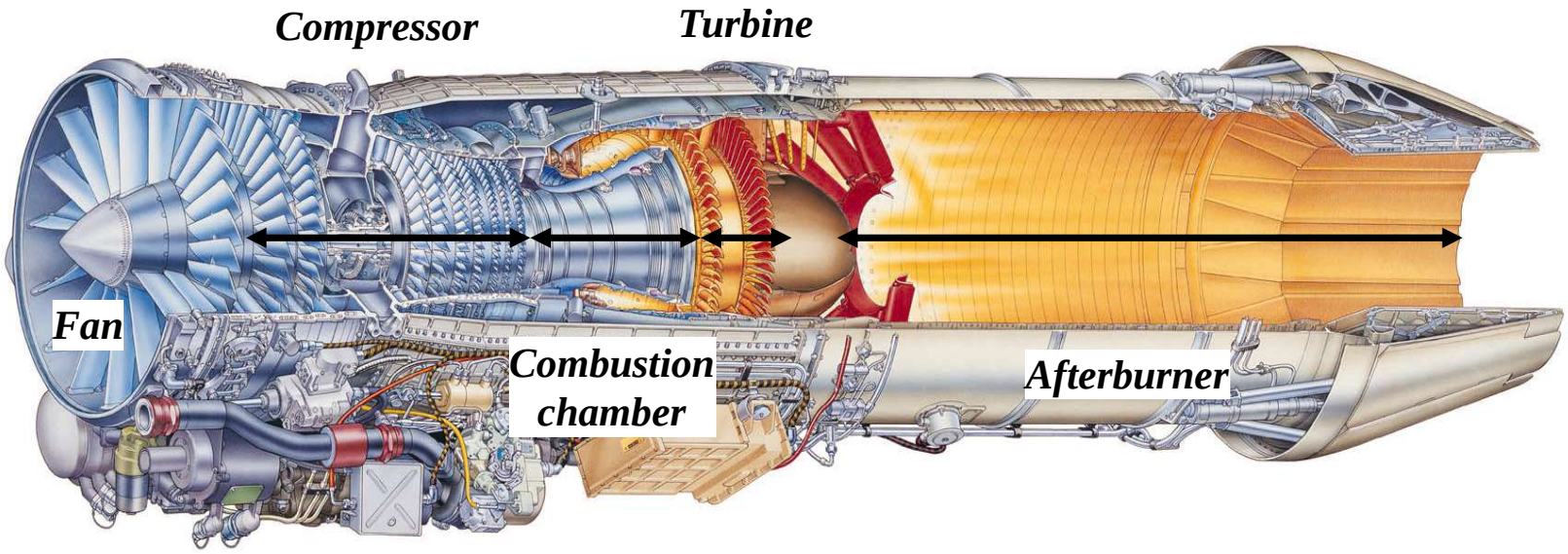
Example: RM 12



Motivation

To improve efficiency of gas turbine engines in order to lower harmful emissions (CO_2) and fuel costs

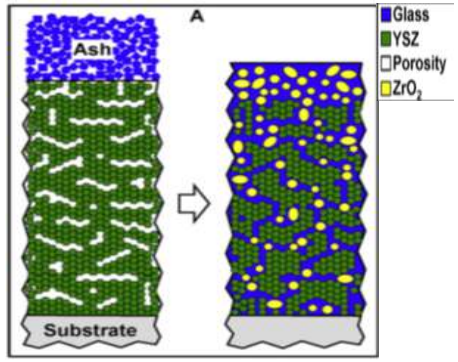
Challenges

Standard thermal barrier coating (TBC) material YSZ has limitations above 1200°C

1. Phase stability issues
2. High sintering rates
3. CMAS infiltration

Saudi Arabian desert sand

Icelandic Volcano



Schematic of CMAS degradation, Padture et al.

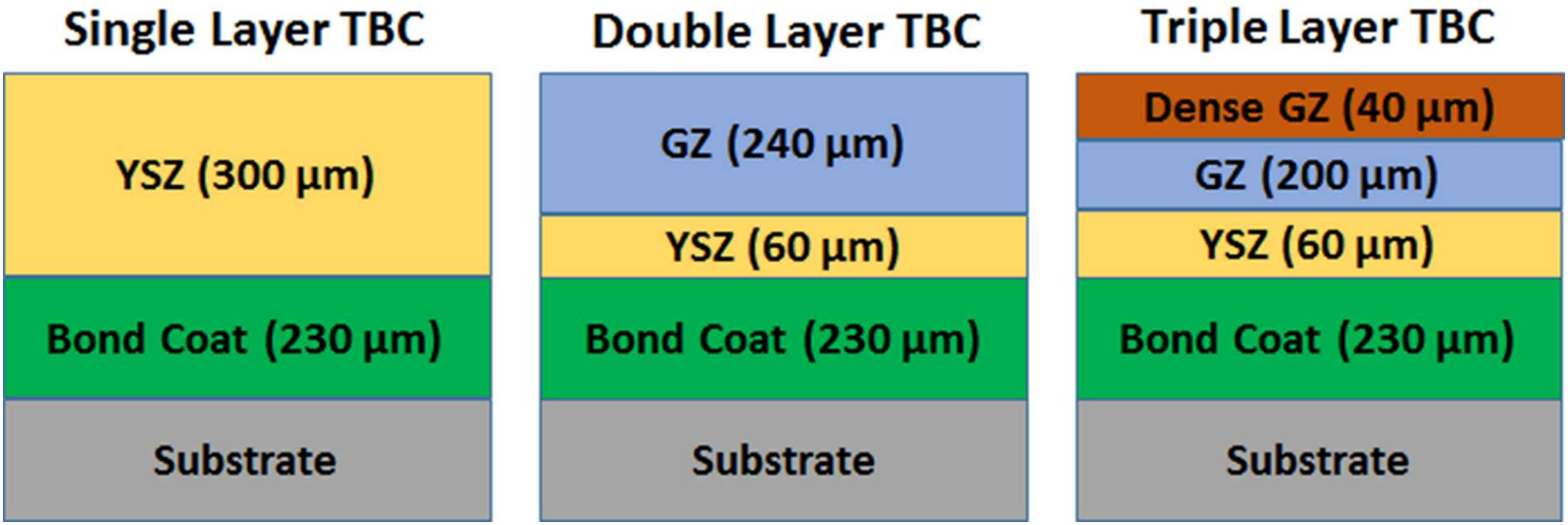
❖**Need for new ceramic materials which can overcome these drawbacks**

Talk Focus

To investigate the Volcanic Ash (VA) infiltration resistance of new TBC materials and compare with standard 8YSZ TBC

Approach

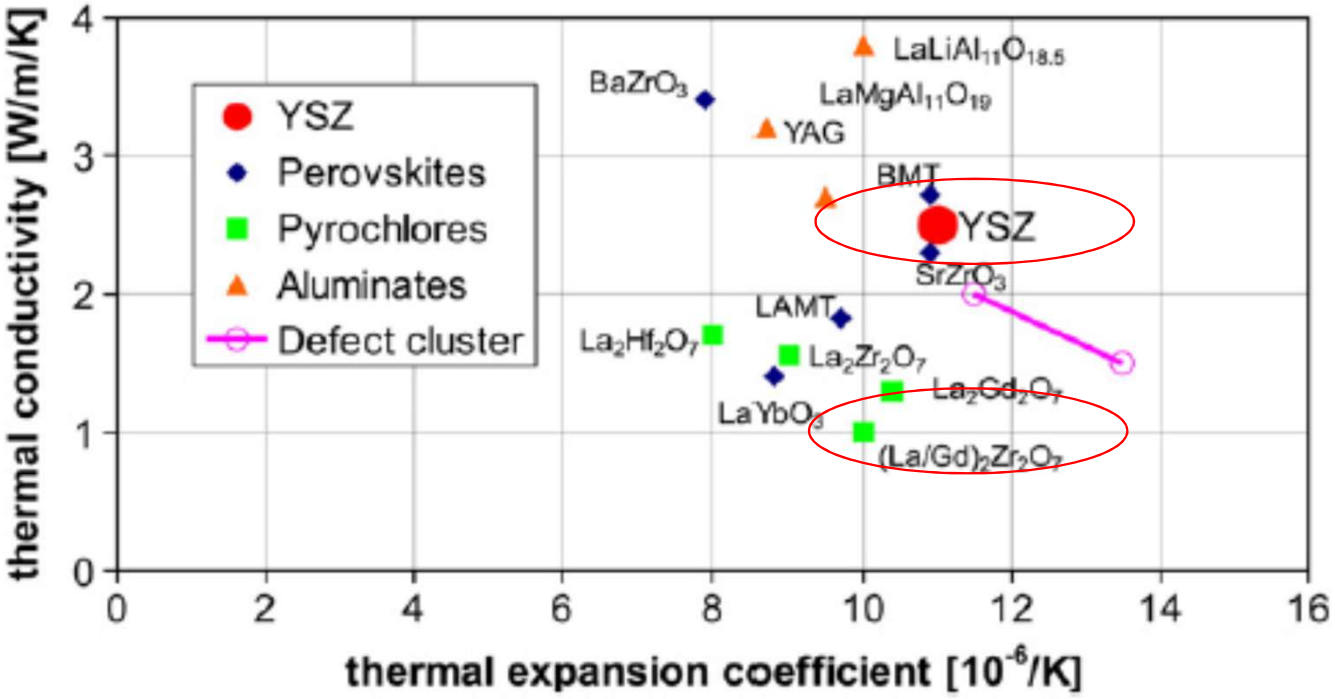
Multilayered TBCs



Why Pyrochlores ???

Pyrochlores are promising TBC candidates due to :

1. Lower thermal conductivity than YSZ
2. Phase stability up to the melting temperature
3. CMAS infiltration resistance



Vassen et al. 'Overview on advanced thermal barrier coatings' Surf. Coat technol, Vol. 205, 2010

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Experimental Work

- **Substrate**: Hastelloy-X plates (25 mm X 25 mm)
- **Bond coat**: NiCoCrAlY powder (AMDRY 386) using HVAF process (M3 Gun, UniqueCoat, U.S)
- **Top coat**: Axial III Plasma Gun (Mettech Corp., Vancouver, Canada) and suspension feeder Nanofeed 350 ™
- **Suspension properties:** Ethanol based GZ, 8YSZ and 48YSZ suspension with D_{50} of 550nm provided by Treibacher Industrie AG, Austria. Solid load was kept at 25wt.% in all the three suspensions
- All the TBCs were processed using same spray parameters

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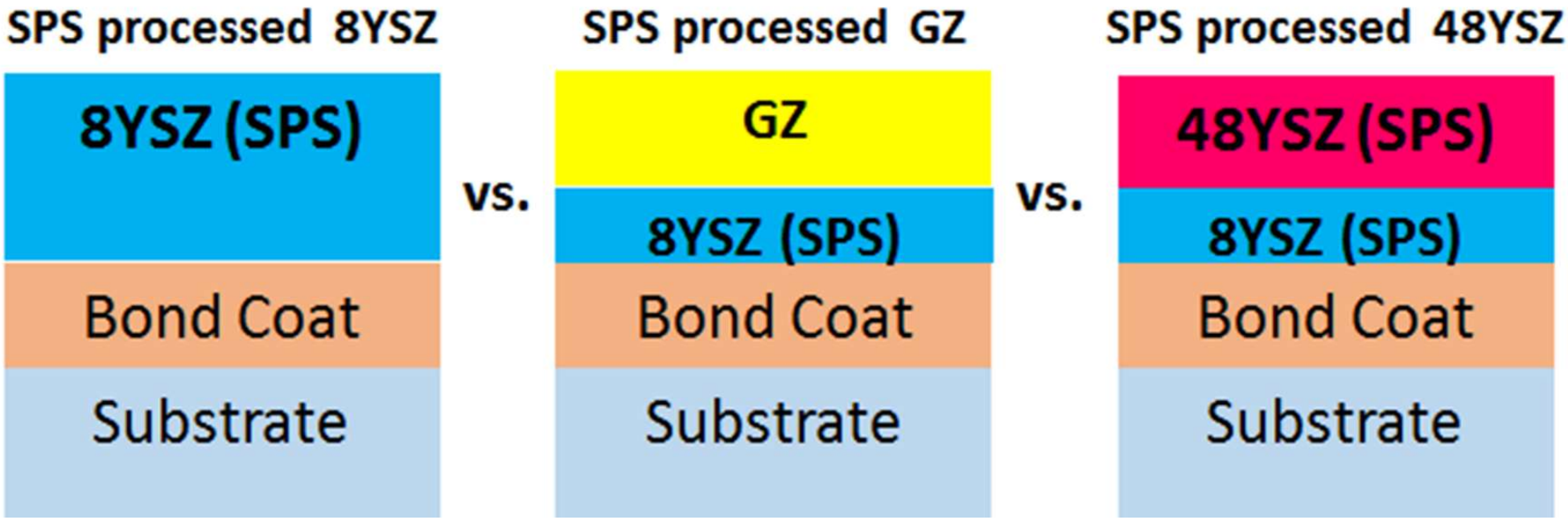

Different TBCs sprayed by suspension plasma spray process

Note:

- *8YSZ: 8 wt.% yttria in zirconia*
- *GZ: Gadolinium zirconate*
- *48YSZ: 48 wt.% yttria in zirconia*

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Characterization of TBCs

1. Microstructural analysis:

   SEM analysis of as sprayed and volcanic ash infiltrated TBCs

2. Surface topography analysis:

   Stripe projection technique

3. Porosity evaluation:

   Image Analysis at two different magnifications 300X and 5000X using Image J software

3. Phase analysis

   XRD of as sprayed TBCs and after volcanic ash infiltration

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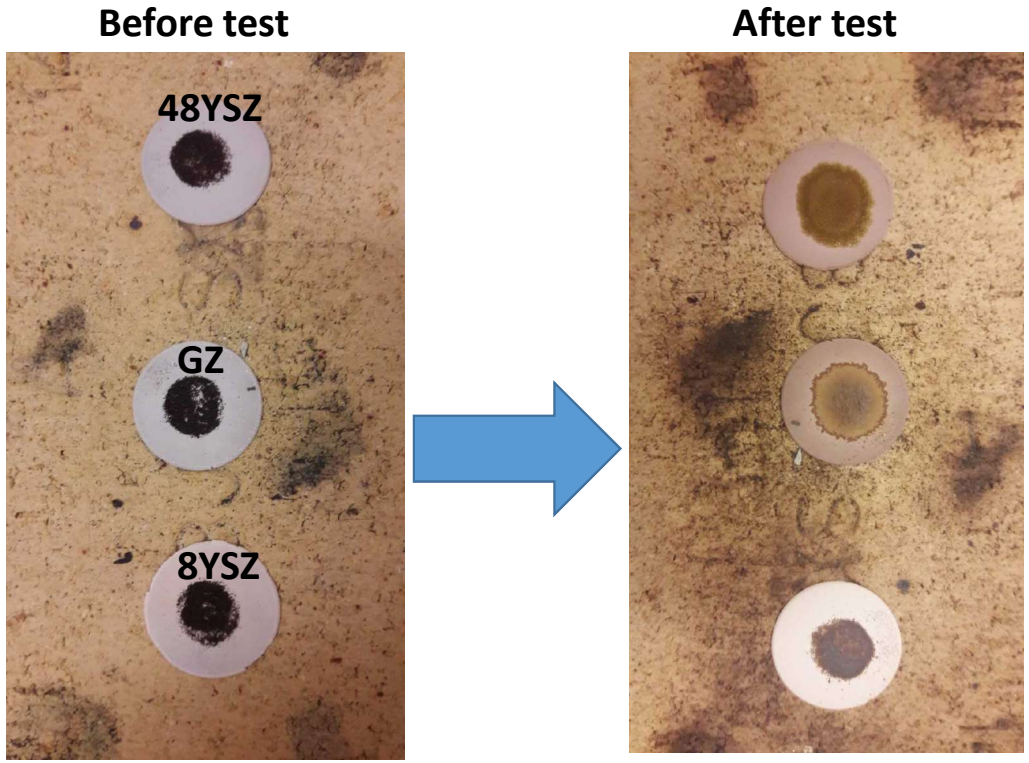
- Isothermal test conditions were used
- 20 mg of the (Laki) ash was applied over an area 1cm^2
- Temperature of exposure was 1250°C
- Time of exposure was 1 hour
- Free standing coatings were approximately 550 µm thick



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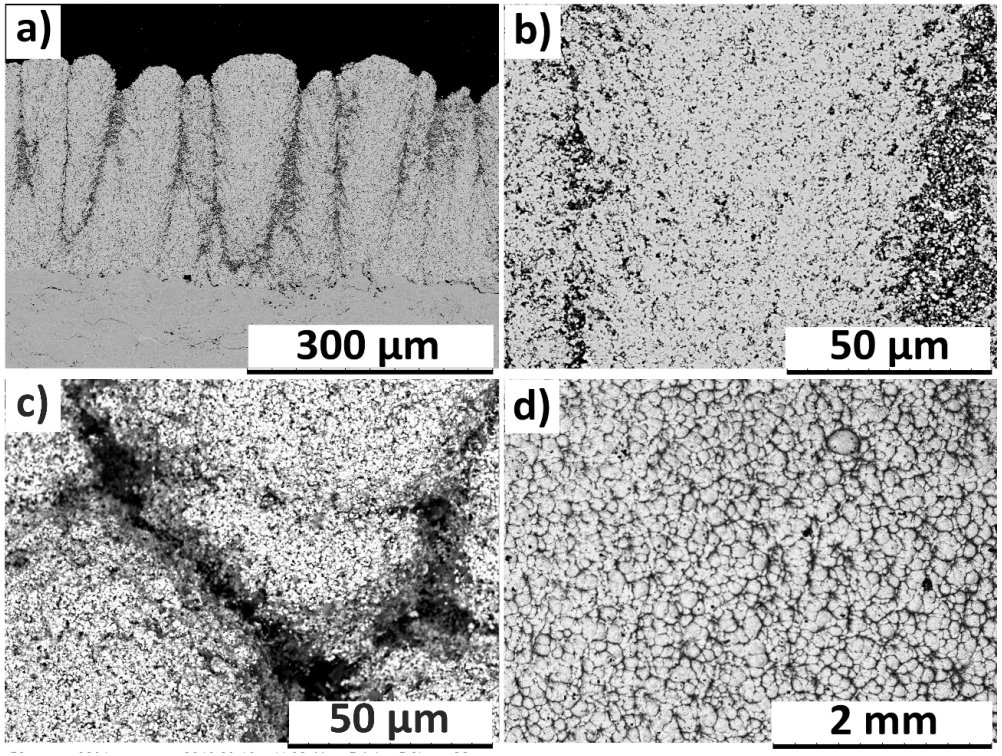
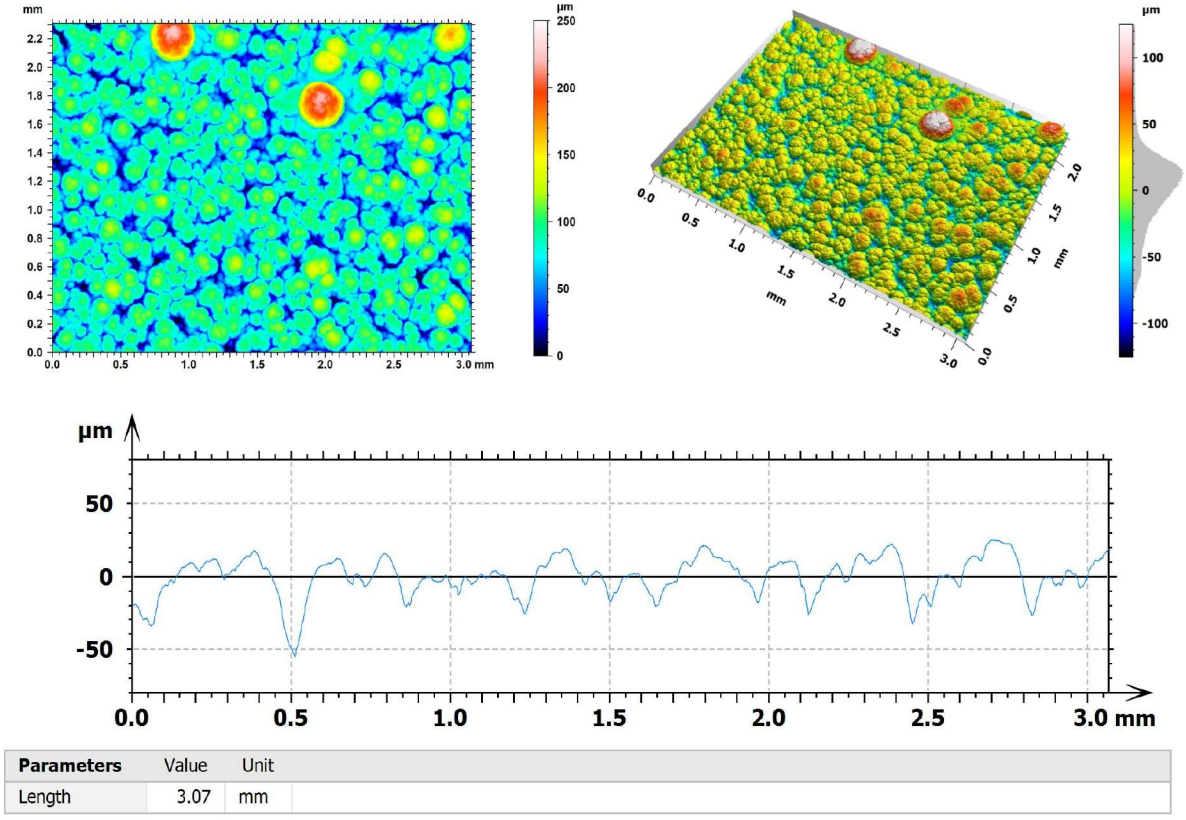
Results & Discussion

8YSZ as sprayed TBC





Parameters	Value	Unit
Length	3.07	mm

- Columnar microstructure for industry standard 8YSZ TBC was achieved
- Top surface view showed a cauliflower look-alike microstructure

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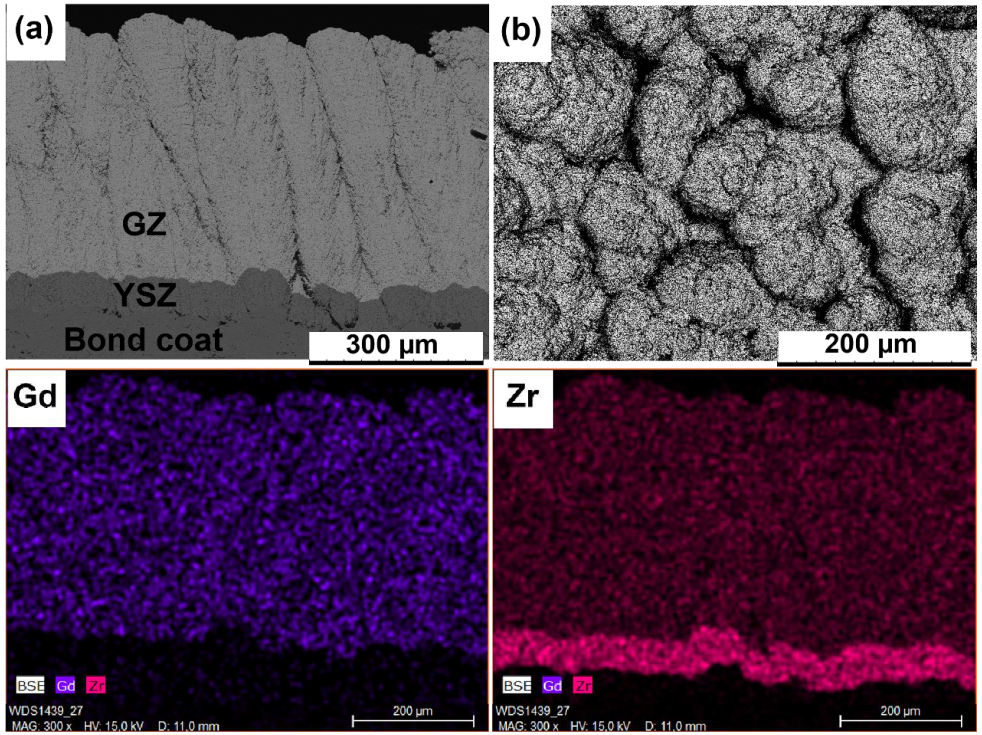
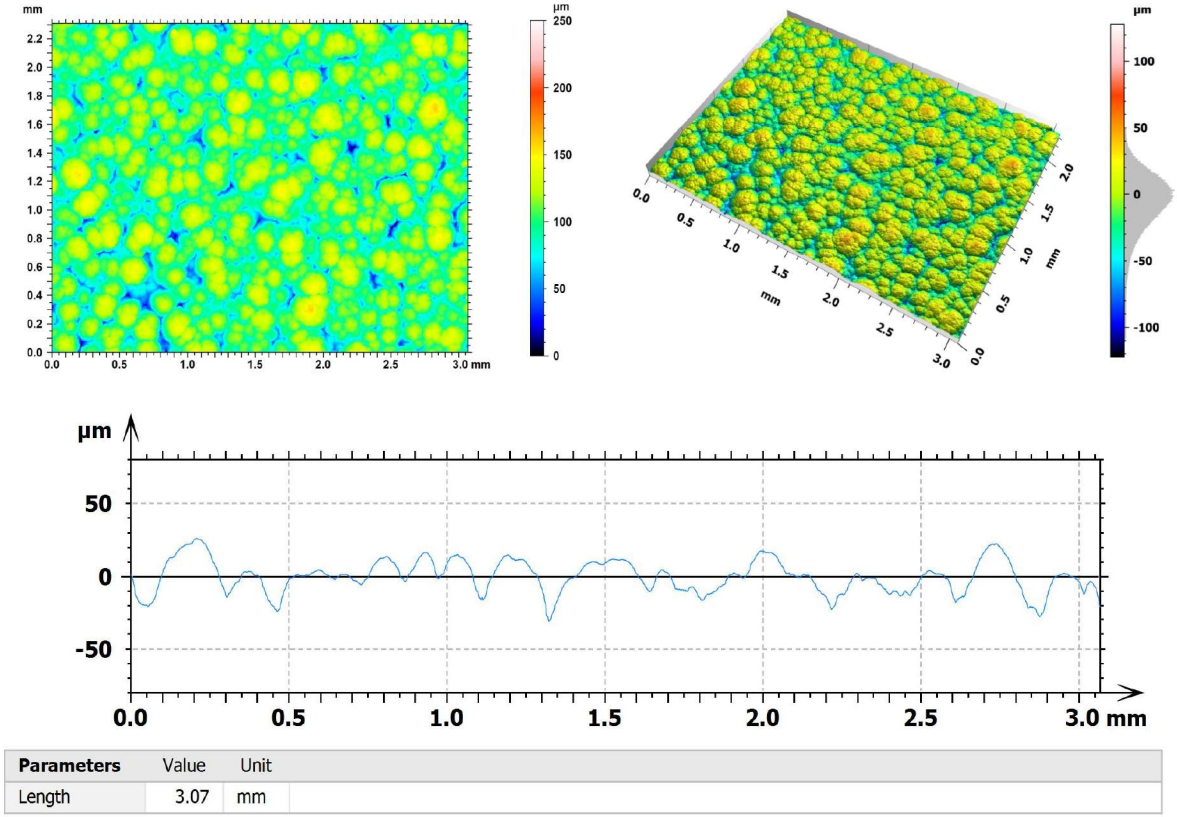
Results & Discussion

GZ as sprayed TBC





Parameters	Value	Unit
Length	3.07	mm

- Columnar microstructure for GZ/YSZ double-layered TBC was achieved
- No delamination cracks were observed at the GZ/YSZ interface

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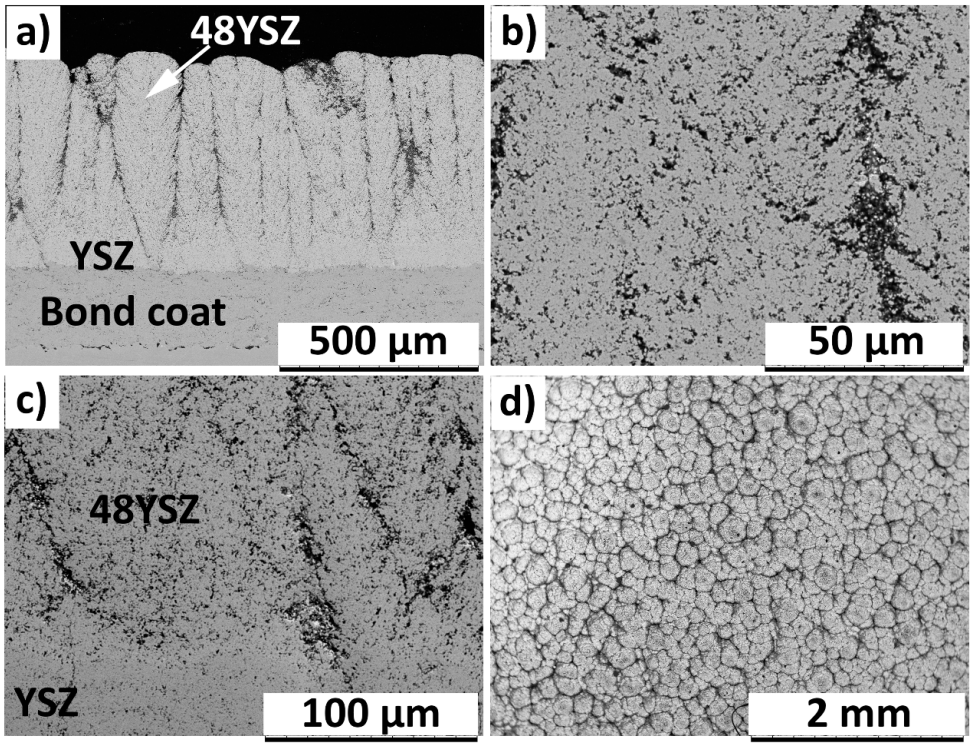
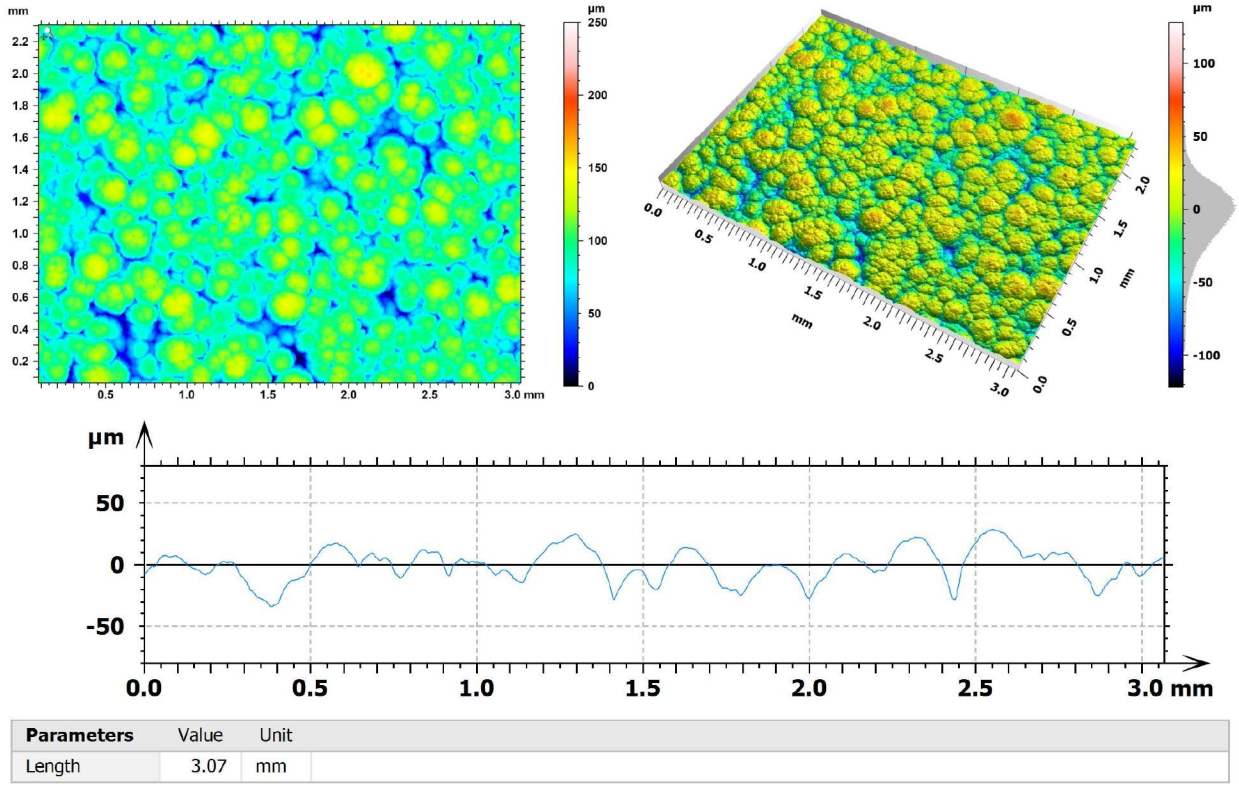
48YSZ/8YSZ as sprayed TBC





Parameters	Value	Unit
Length	3.07	mm

- Columnar microstructure for 48YSZ TBC was achieved
- 48YSZ/8YSZ double layered TBC did not show delamination cracks

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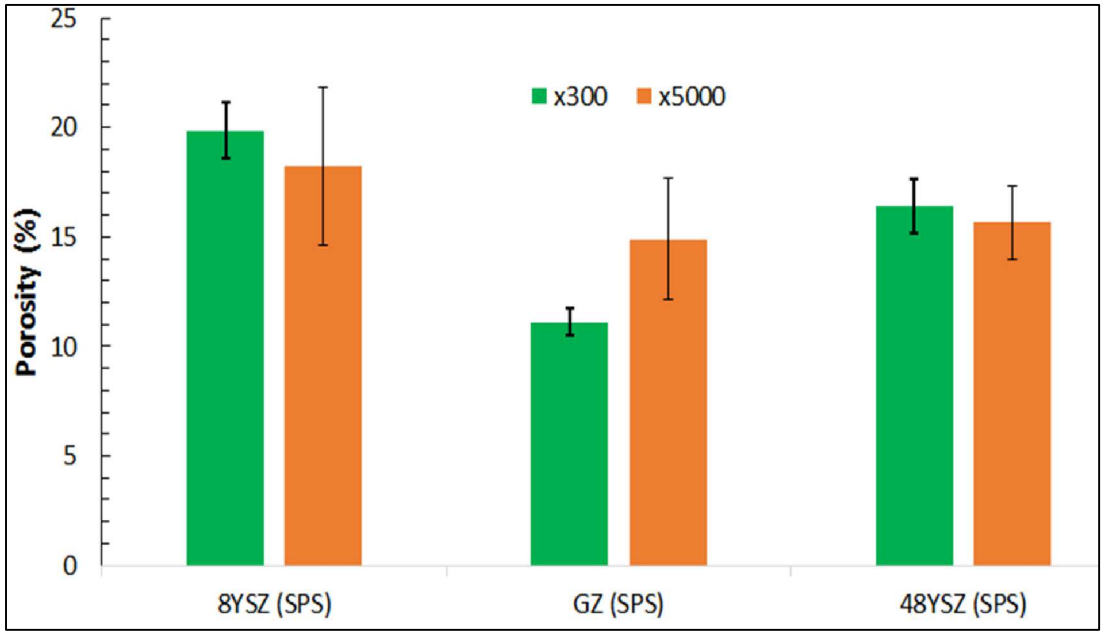
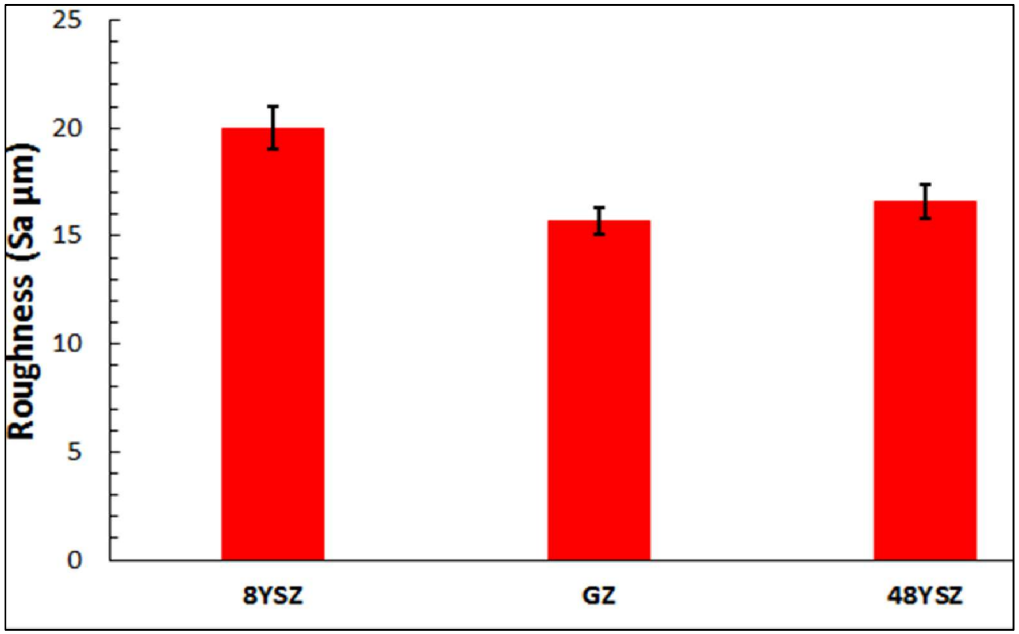
Porosity content of as sprayed TBCs at low and high magnification



Surface roughness of the as sprayed TBCs



- Higher porosity content for 8YSZ TBC than GZ and 48YSZ TBCs
- Higher surface roughness for 8YSZ TBC than GZ and 48YSZ TBCs

❖ ***Higher porosity and higher surface roughness would favor higher CMAS infiltration***

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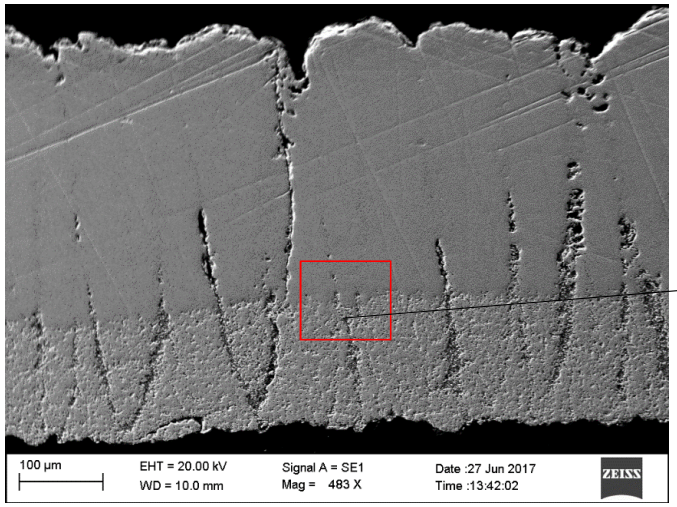
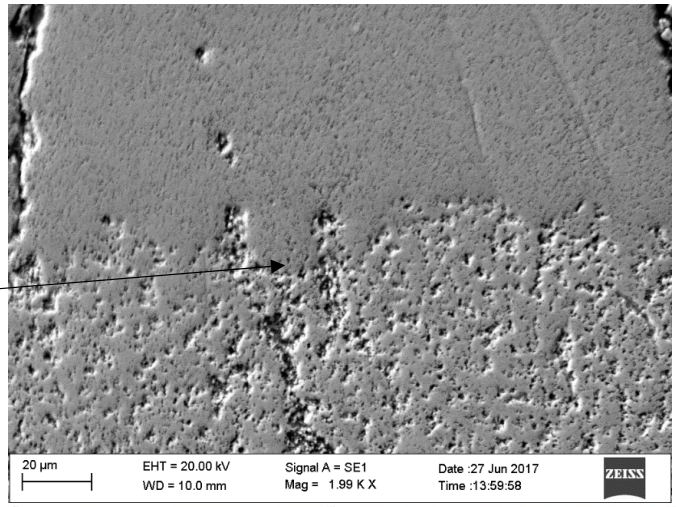
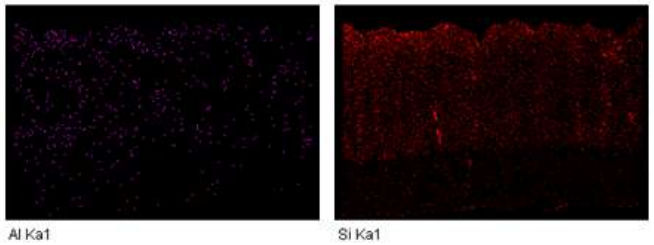
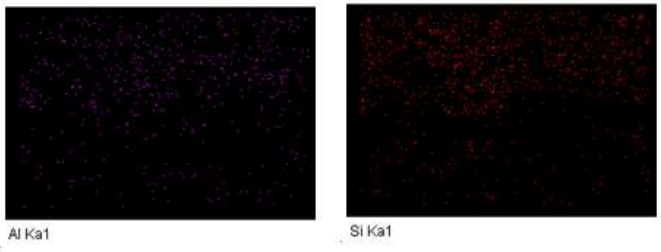
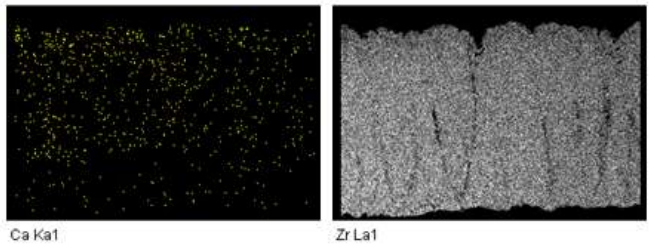
8YSZ after Volcanic Ash (VA) infiltration

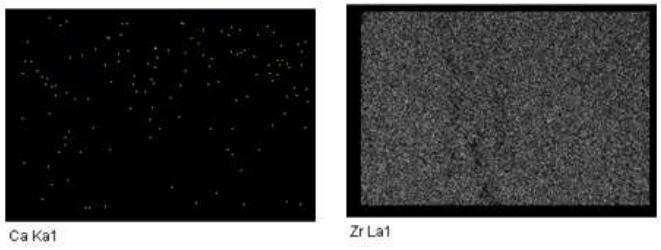






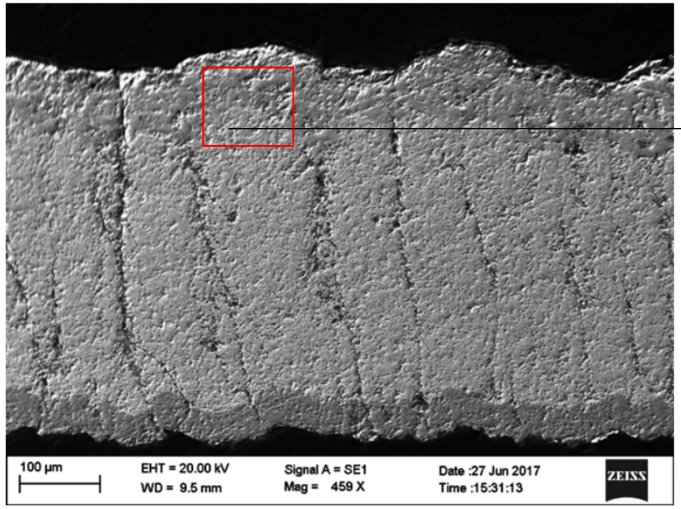


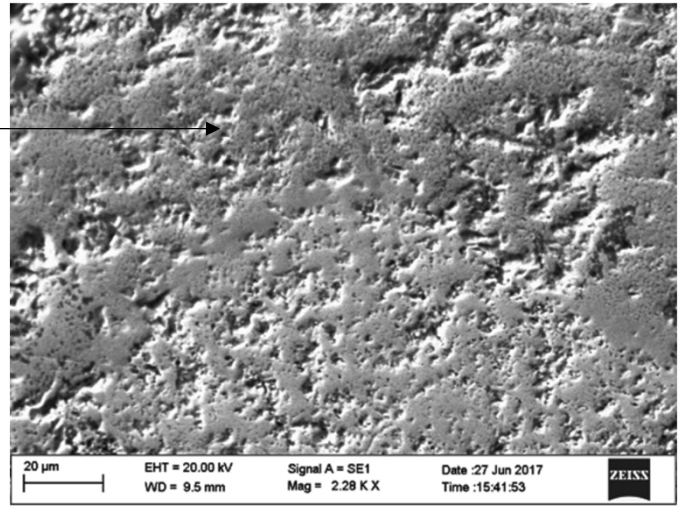


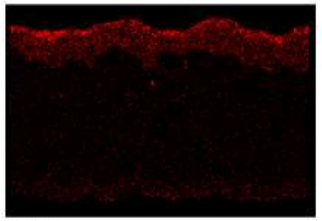


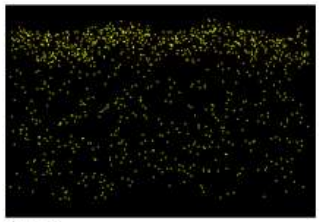
- VA infiltration depth for 8YSZ TBC was ~260 µm
- The elemental maps (EDS) detected Si, Al and Ca
- The infiltrated (smooth) and non infiltrated (porous) zones can be identified in the SEM micrographs
- Infiltration in the columns and column gaps was similar

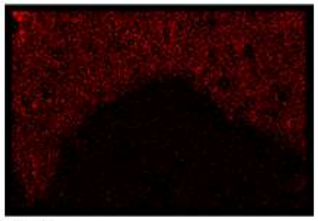
GZ after VA infiltration

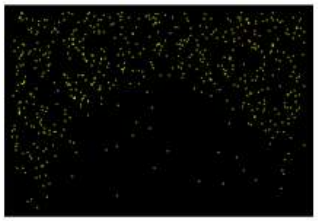


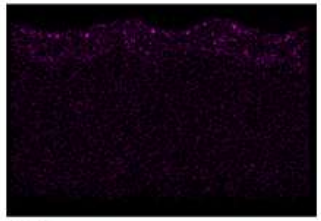


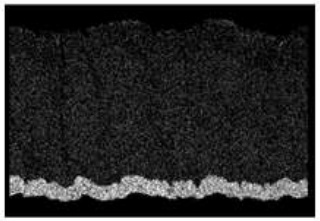

Si Ka1

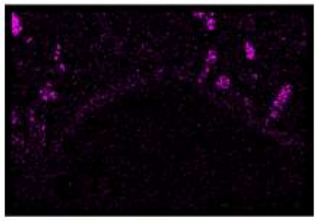

Ca Ka1


Si Ka1


Ca Ka1


Fe Ka1

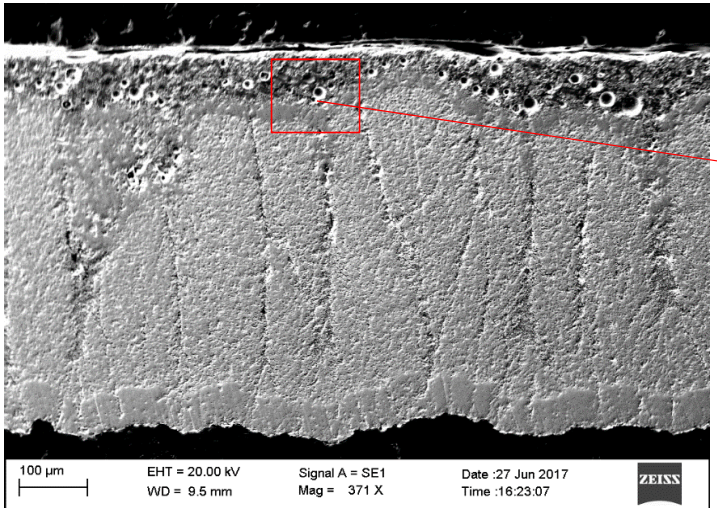

Zr La1

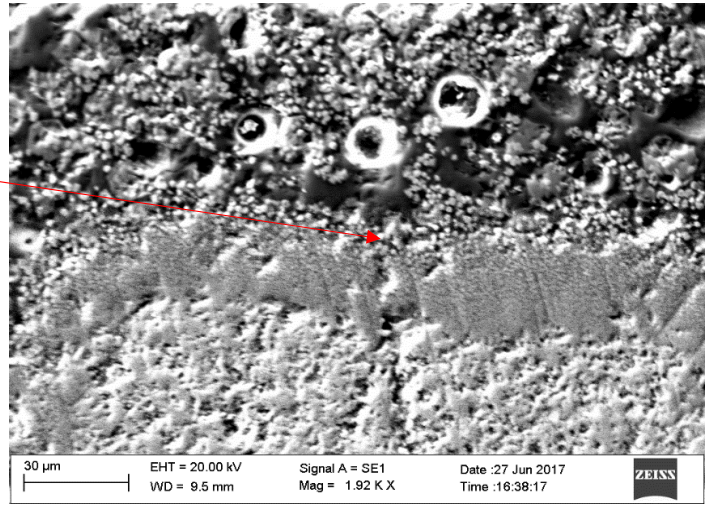

Fe Ka1

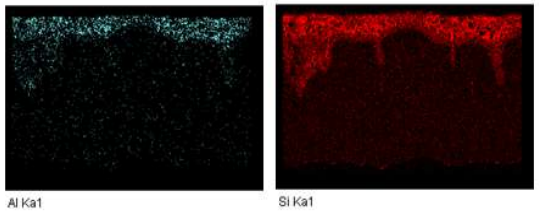

Zr La1

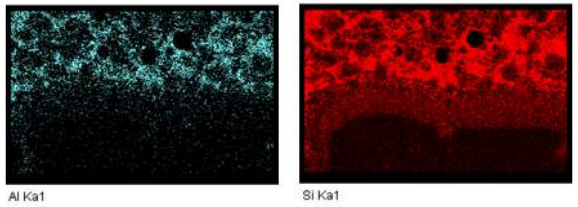
- VA infiltration depth for GZ based TBC was ~80 µm
- The VA was arrested near the surface of GZ TBC
- The elemental maps (EDS) detected Si, Fe and Ca
- The infiltrated (smooth) and non infiltrated (porous) zones can be identified in the SEM micrographs

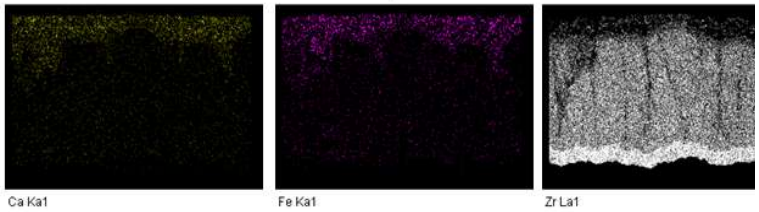
48YSZ after VA infiltration

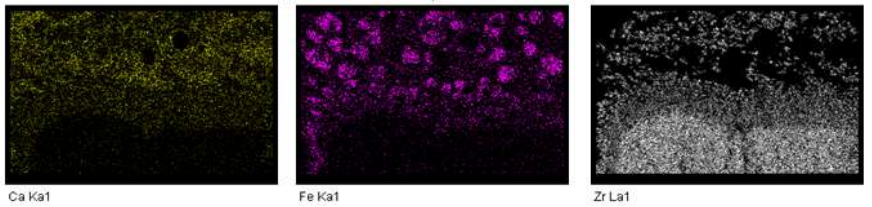










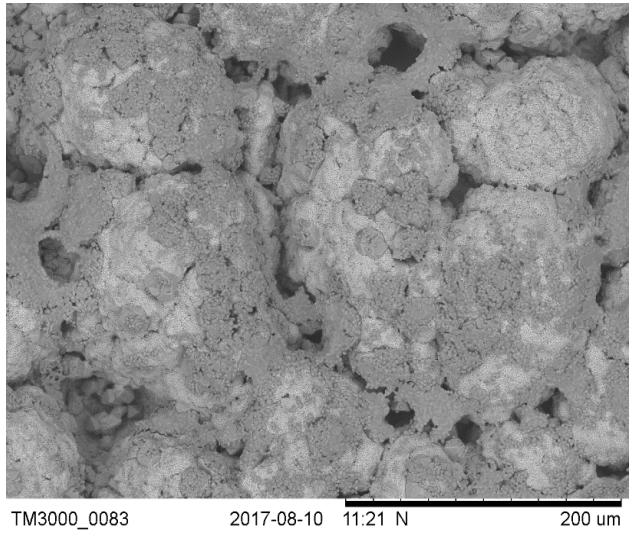


- VA infiltration depth for 48YSZ based TBC was ~25 µm
- The VA was arrested near the surface
- The elemental maps (EDS) detected Si, Fe, Al and Ca
- The infiltrated/reacted zone (smooth) and non infiltrated (porous) zones can be identified in the SEM micrographs

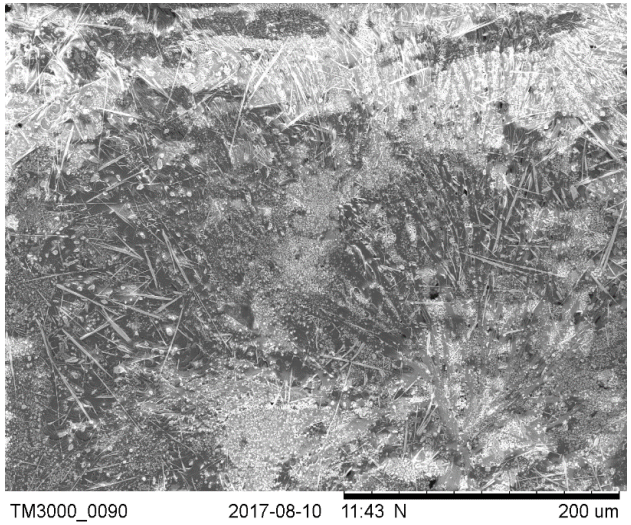
VA Infiltration depth of the TBCs

	Penetration depth (µm)
YSZ	330±10
GZ	80±10
48YSZ	25±10

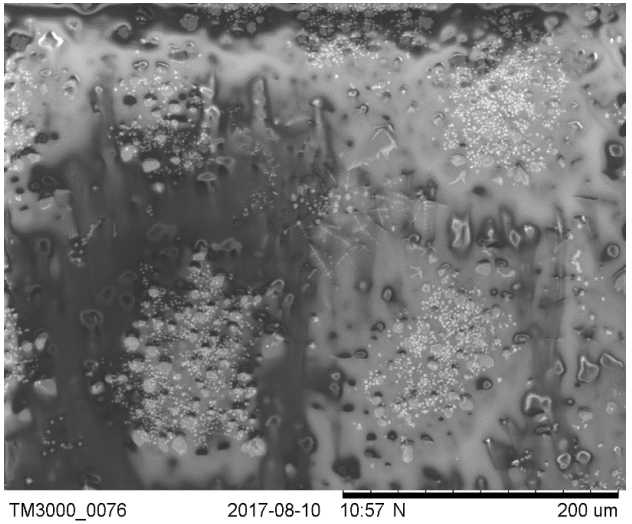
Top view SEM micrographs after volcanic ash (VA) infiltration



8YSZ



GZ



48YSZ

- 8YSZ top view SEM micrograph shows cauliflower like microstructure, indicating the complete infiltration of VA
- GZ and 48YSZ TBCs top view does not show cauliflower like microstructure, indicating the arrest of VA on the surface
- Top view SEM results confirm poor volcanic ash (VA) infiltration resistance of industry standard 8YSZ TBC

Conclusions

- Columnar microstructured TBCs of different composition (8YSZ, GZ, 48YSZ) could be produced by suspension plasma spray (SPS)
- 8YSZ TBC showed higher porosity content and higher surface roughness compared to GZ and 48 YSZ TBCs when deposited with identical spray parameters
- GZ and 48YSZ based TBCs were more resistant to volcanic ash infiltration than the industry standard 8YSZ TBC
- Among GZ and 48YSZ based TBCs, 48YSZ showed better volcanic ash infiltration resistance than GZ

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Acknowledgements

- **Prof. Bill Clyne** and **Dr Catalina Taltavull** from **University of Cambridge**, U.K, for providing Icelandic Volcanic Ash

- **Mr. Stefan Björklund from University West**, Sweden for spraying the TBCs

- **Dr. Nicholas Curry**, **Treibacher Industrie AG**, Austria for providing the suspension

- **KK foundation (Dnr: 20140130)**, Sweden, for funding this work

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Thank you for your attention

Most welcome to Trollhättan!