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Liquid Feedstock Plasma Spraying - an Emerging Process for Advanced Thermal Barrier Coatings

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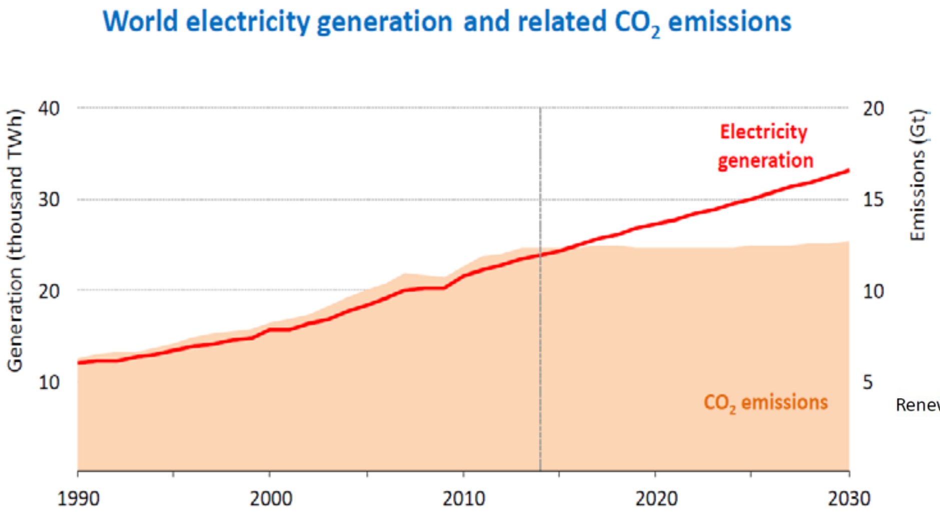
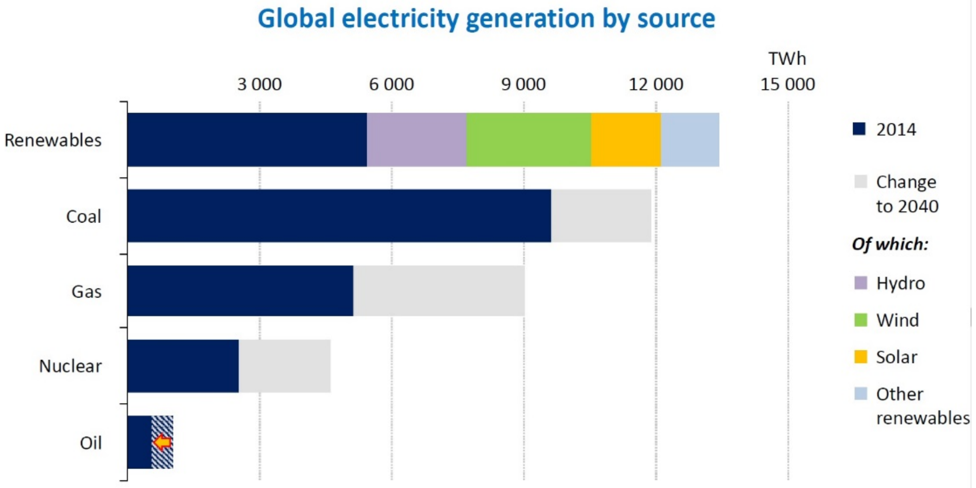
Outline

- Introduction
- Thermal Barrier Coatings (TBCs)
- Liquid Feedstock Plasma Spraying – Suspension Plasma Spraying (SPS)
- Functional Performances of SPS TBCs
- Conclusions

We live in a world with continuously increasing energy demands



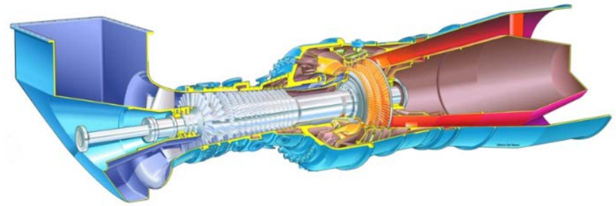
Source: IEA WEO 2015



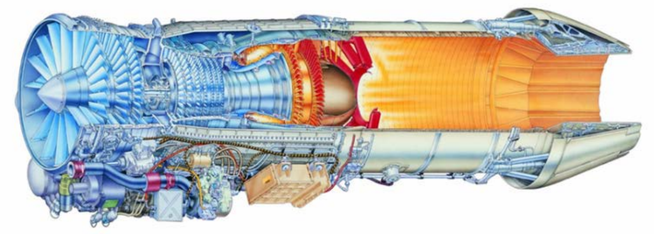
Further improvements and optimisation of the current power sources is still needed

Gas Turbines

- a $ 42 billion industry worldwide (2010)



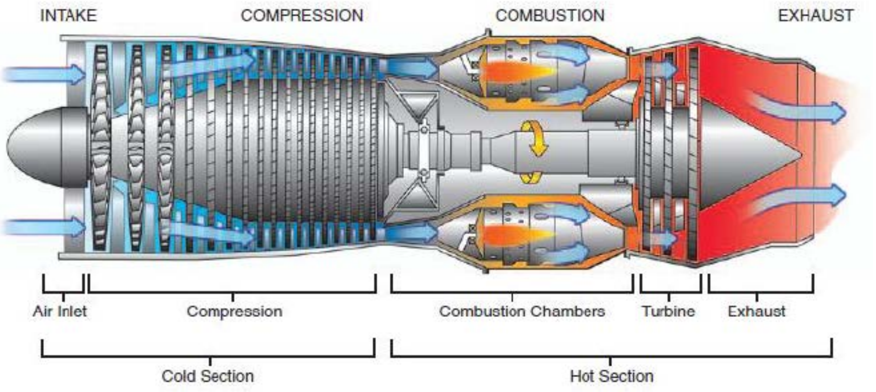
SGT-800, Courtesy Siemens Industrial Turbomachinery, Finspång Sweden



RM-12 engine, Courtesy: GKN Trollhättan, Sweden

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



6,5€/GJ fuel cost, 8000 h/a

Ref: M. Oechsner, Siemens, TBC Systems for Gas Turbine Applications – Status and Future Challenges, Turbine Forum, Nice, April 25, 2012

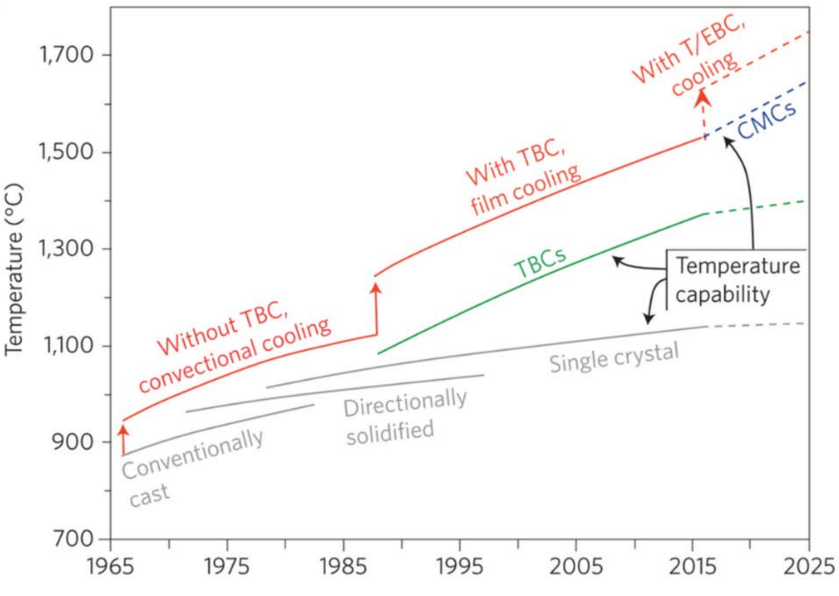
Objective: Improve engine efficiency

- Increase the operating temperature
  A. Lower thermal conductivity TBCs => Design of coating microstructure
  B. Multilayered systems with new materials

- Better durability of TBCs
  ⇒ Protection against harsh environment

TBCs effect on combustion temperature

Thermal barrier coatings (TBCs) are applied to metallic surfaces used in gas turbine to insulate them from heat loads



- Improvement of GT efficiency by increase of combustion temperature

$$\eta_{real} < \eta_{Carnot} \leq 1 - \frac{T_{inlet}}{T_{outlet}}$$

- Protection of metallic base materials of internally cooled parts with TBC

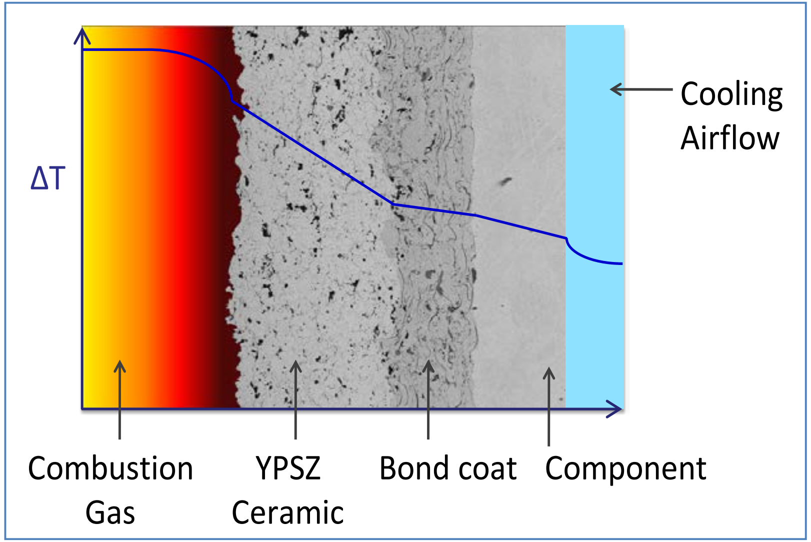
$$j_Q = -\lambda \frac{\Delta T}{\Delta x}$$

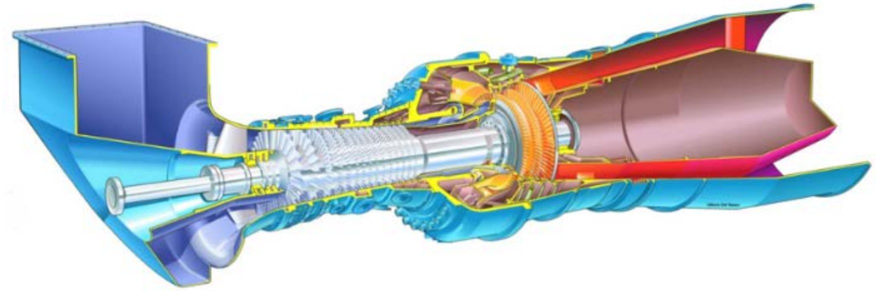
ΔT: temperature drop
Δx: TBC thickn
λ : thermal co

Nitin P. Padture, Nature Materials 15, 804–809 (2016) doi:10.1038/nmat4687, courtesy: Macmillan Publishers Ltd

What is a TBC?

Components which need thermal insulation include: combustor, turbine blades & vanes, afterburner etc.



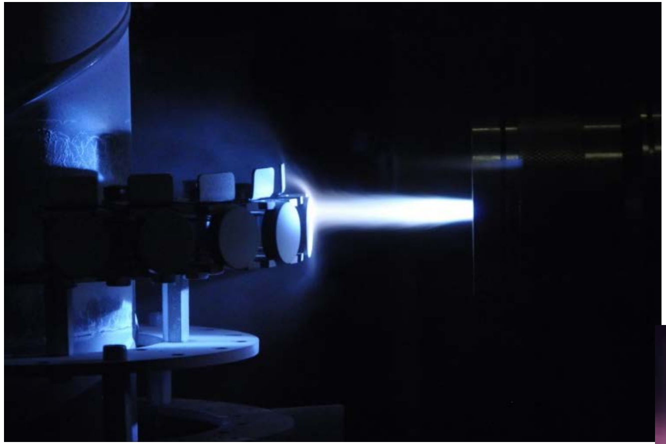


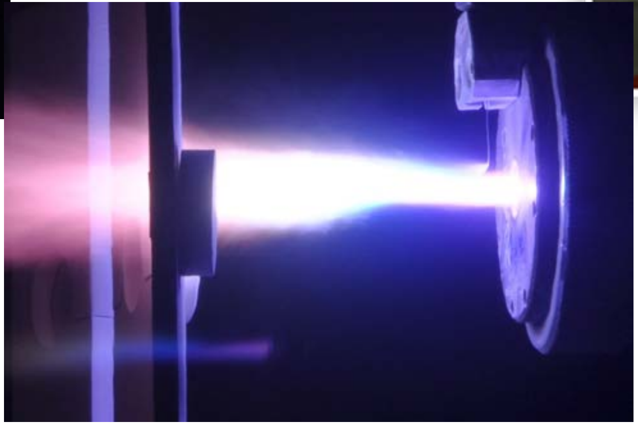
SGT-800, Courtesy Siemens Industrial Turbomachinery, Finspång Sweden

The temperature drop depends on several factors such as microstructure, porosity content, top coat composition etc.

Liquid feedstock processes

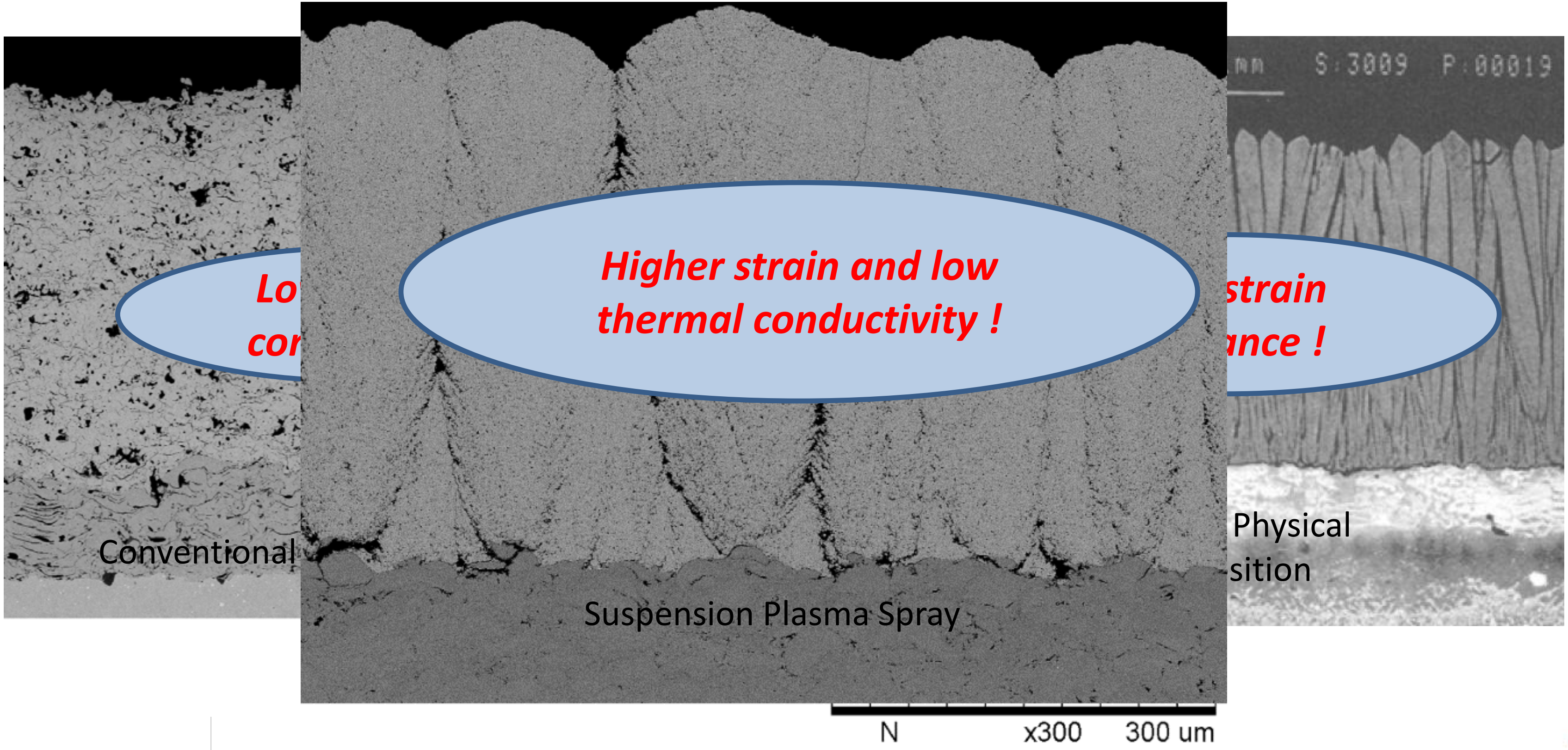
Solution Precursor Plasma Spraying (SPPS)





Suspension Plasma Spraying (SPS)

Why Suspension Plasma Spraying?



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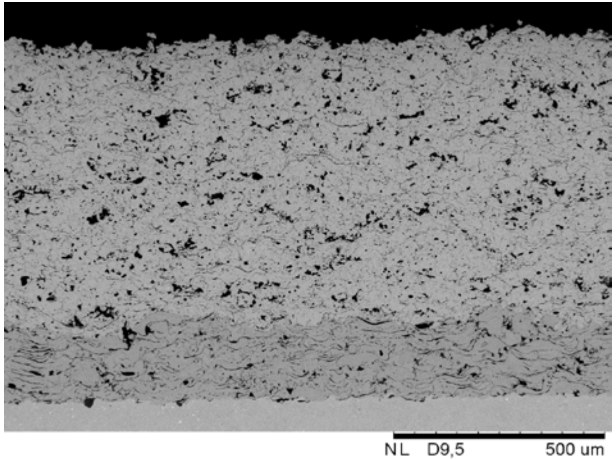
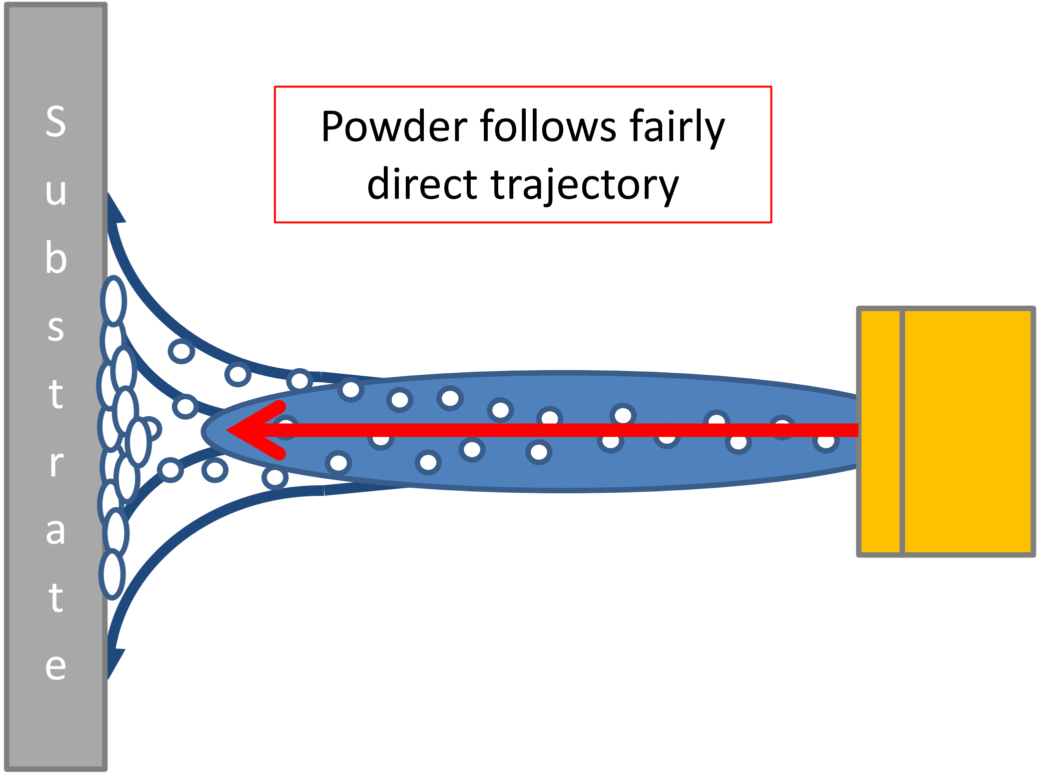
Coating Build up: Solid Powder

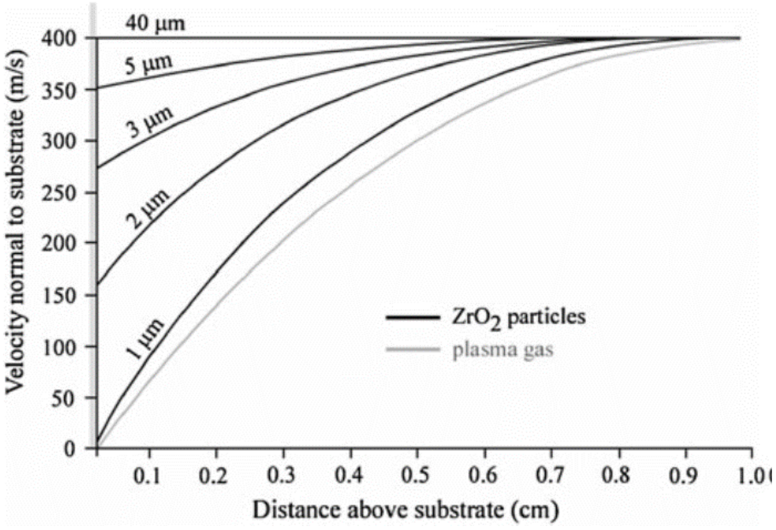


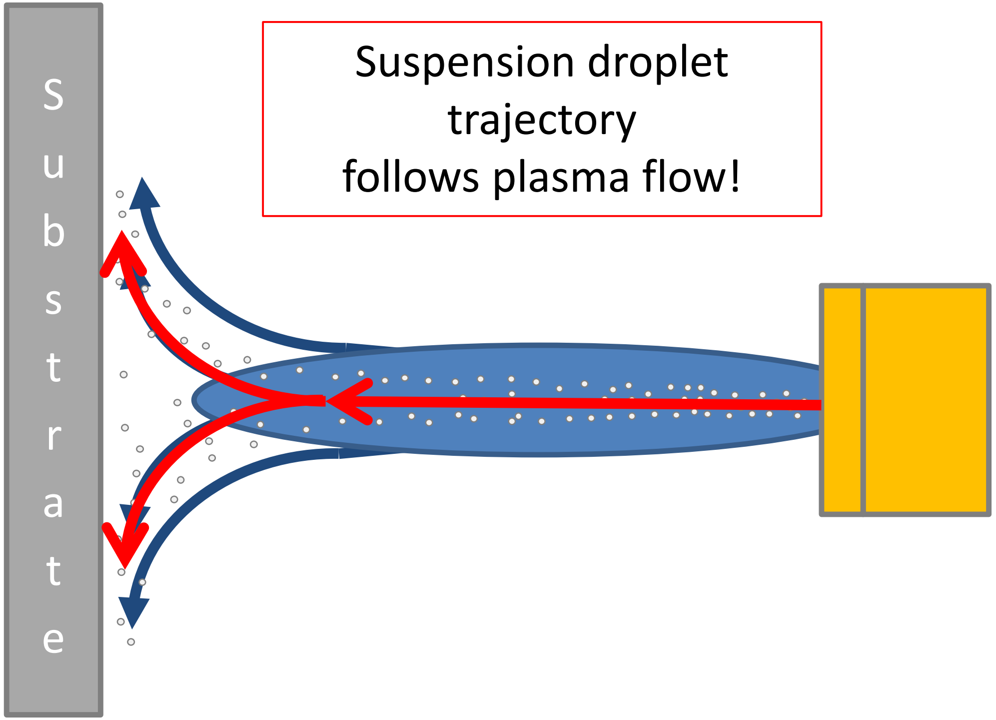
Conventional Thermal Spray



Coating Build-up: Liquid feedstock

Smaller particles tend to follow plasma gas stream





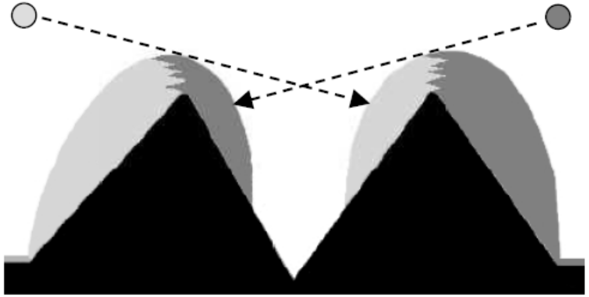
Ref: VanEvery et al., JTST, 20(4), 2011,
Sokolowski, JTST, 25(1-2), 2016

Coating Build up

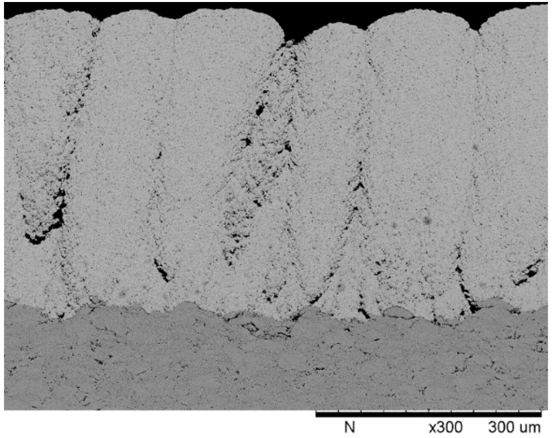
Particle trajectory results in column-like structures

Microstructure influenced by surface topography?

Columnar coatings – cheaper alternative to EB-PVD!!



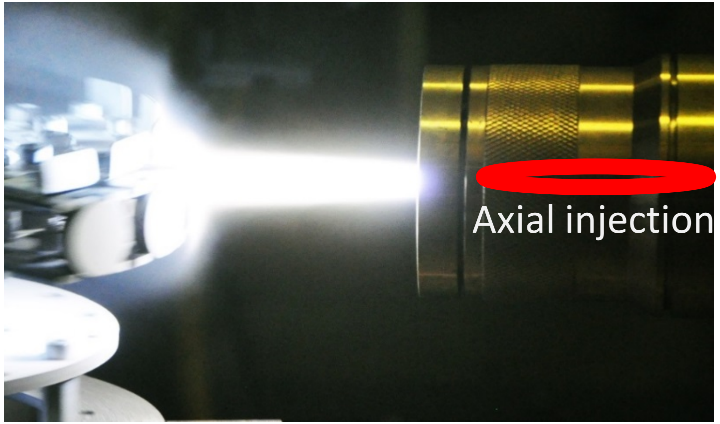
K. VanEvery *et al*, *J.Thermal Spray Tech*, 20(4), p. 817-28, (2011)

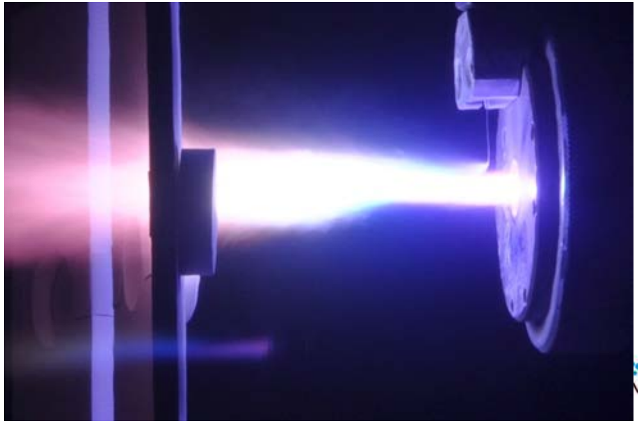


A. TBCs with new microstructure

Axial - Suspension Plasma Spraying (SPS)

- Robust process with large process window
- No overspray
- High deposition efficiency





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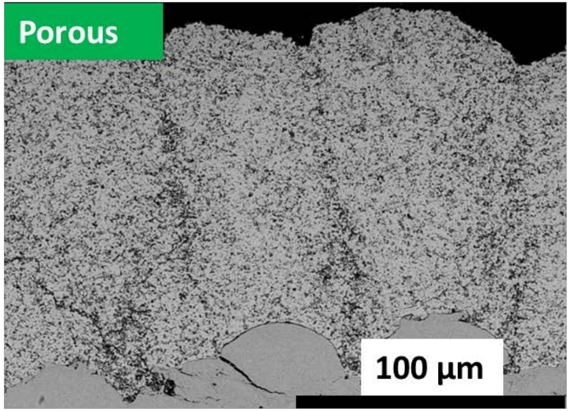
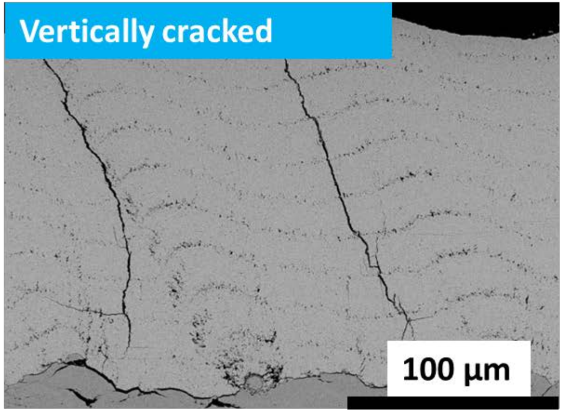
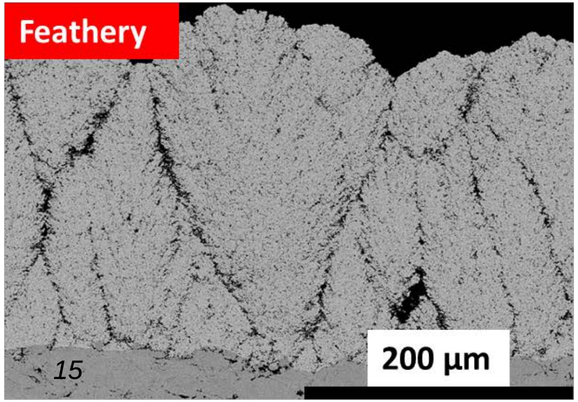
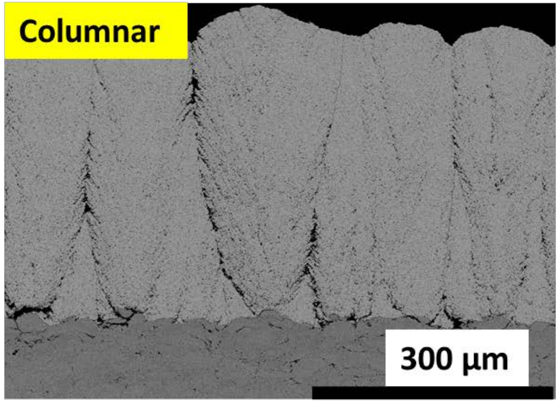
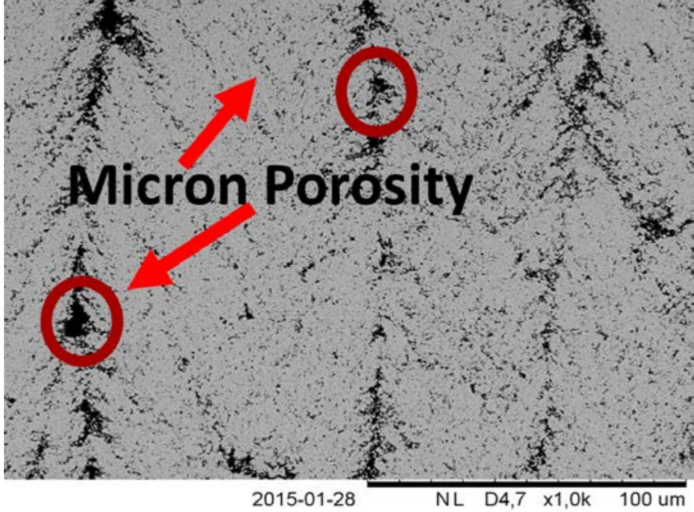
Great potential for better TBCs

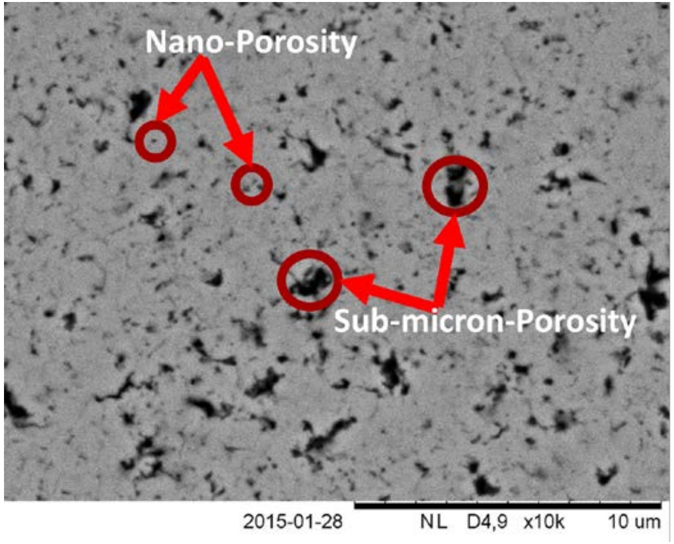




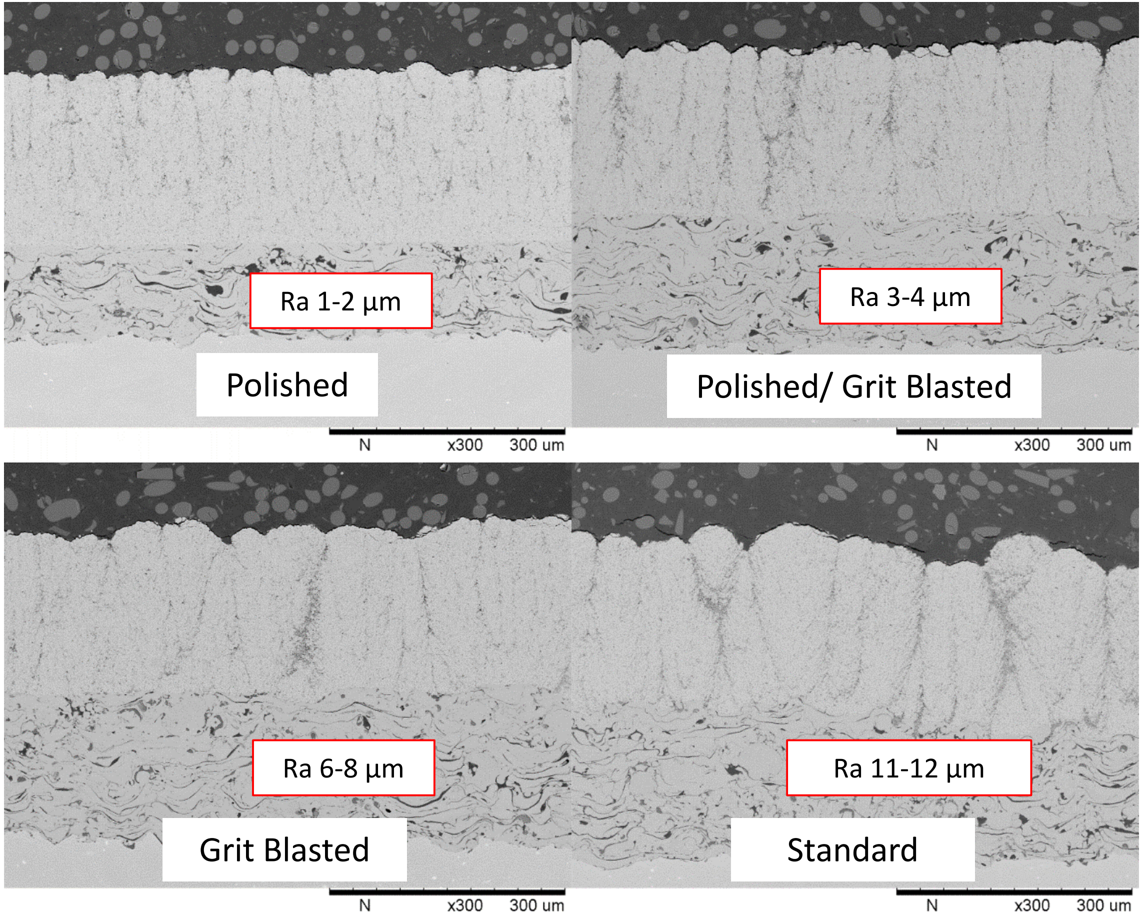








Influence of bond coat roughness on column density



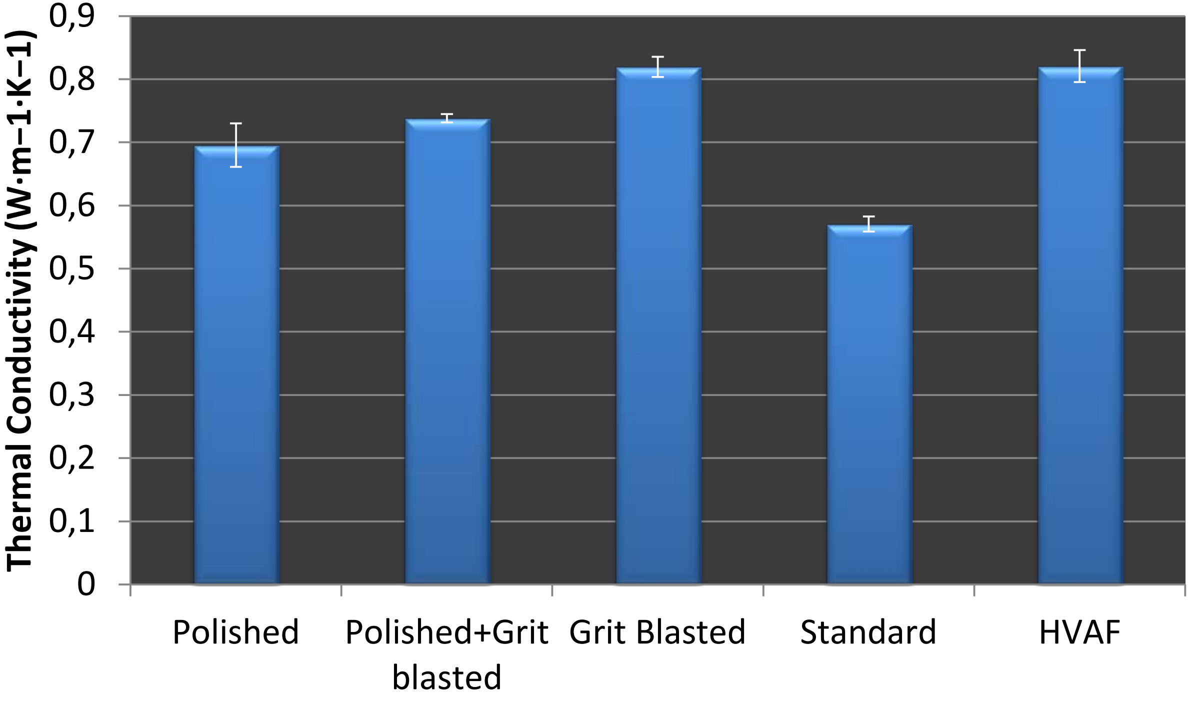
Substrate specimen: Hastalloy X,

Bond coat: AMDRY 386, sprayed by APS, F4 gun,

Topcoat: 8YSZ suspension, 10wt.% solid load, sprayed with Mettech Axial III gun

N. Curry, Z. Tang, N. Markocsan, P. Nylen, Surf. Coat. Technol., 268, 2015, p. 15-23

Thermal Conductivity



Thermal conductivity measurement were done using the Laser Flash Method

N. Curry, Z. Tang, N. Markocsan, P. Nylen, Surf. Coat. Technol., 268, 2015, p. 15-23

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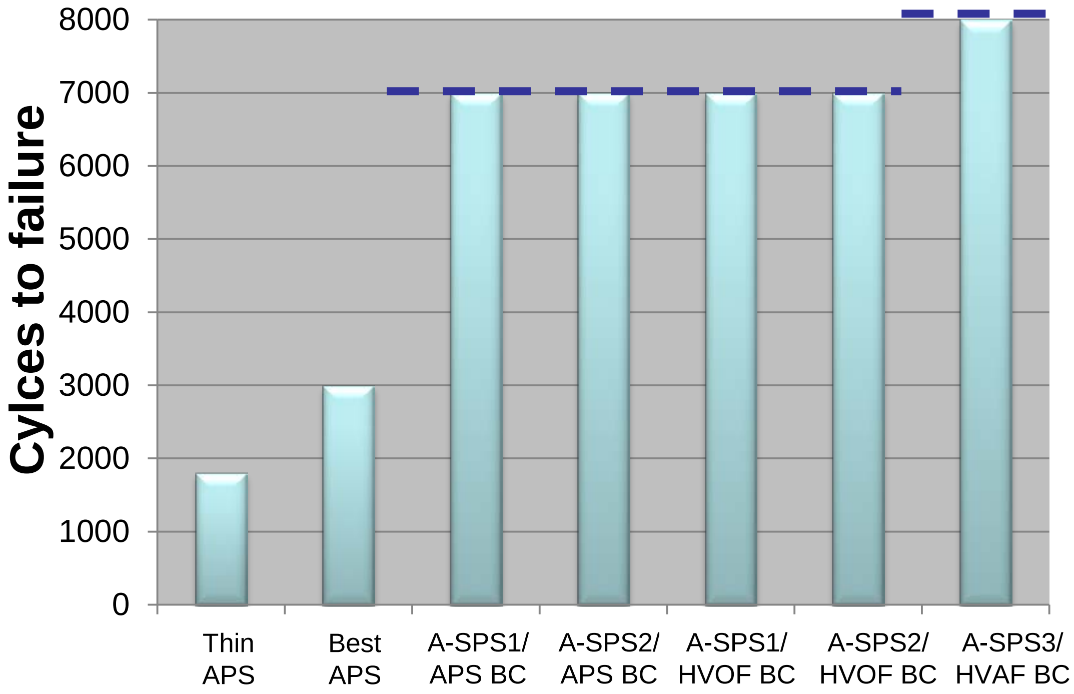
Thermal Shock Results

Burner Rig Test

Heating: Oxy-fuel flame
Temperature (front): 1200 – 1300°C
Temperature (back): ~1000 °C
Heating time: 75s

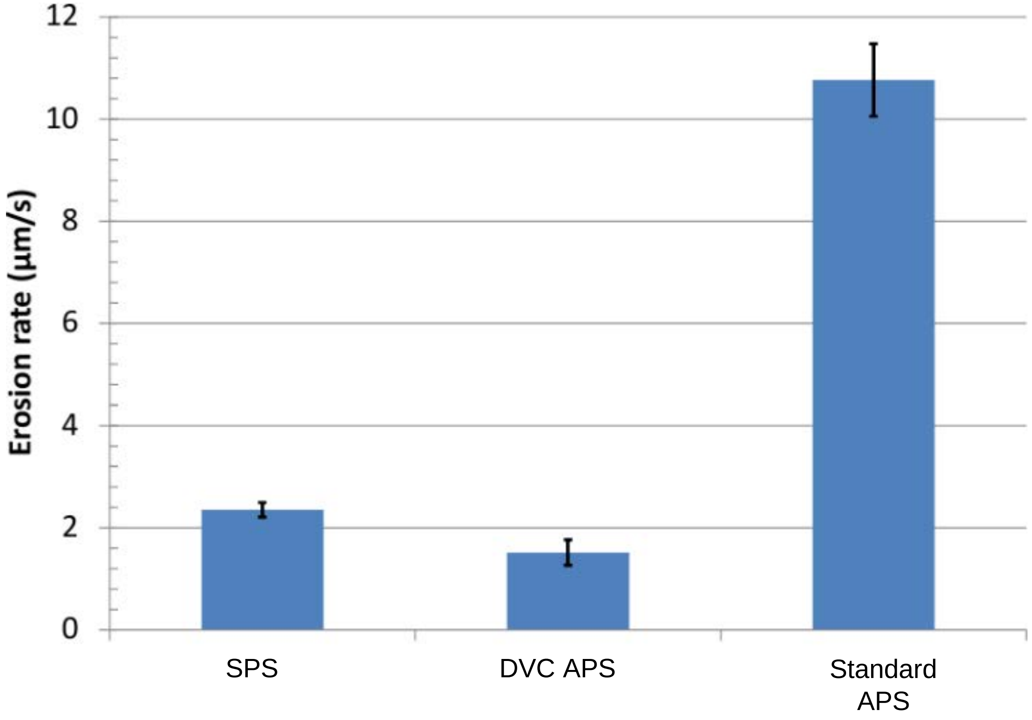
Cooling: Heated Pressurised Air
Cooling temperature: ~ 450 °C
Cooling time: 75s

Failure Criteria: >10% surface spallation



N. Curry, K. VanEvery, T. Snyder N. Markocsan, *Coatings* **2014**, *4*, 630-650; doi:10.3390/coatings4030630

Erosion resistance of 8YSZ sprayed by different methods



Erosion test was conducted at room temperature according to GE standard E50TF121

N. Curry, K. VanEvery, T. Snyder N. Markocsan, *Coatings* **2014**, *4*, 630-650; doi:10.3390/coatings4030630

B. Multilayered systems with new materials

- Higher operating temperature (>1200°C) poses several challenges
  - State of the art topcoat TBC material YSZ has limitations above 1200°C such as
  - Poor phase stability
  - Poor sintering resistance
  - Susceptibility to CMAS attack
- Need for new ceramic materials which can overcome these drawbacks


Saudi Arabian Sand


Iceland Volcano

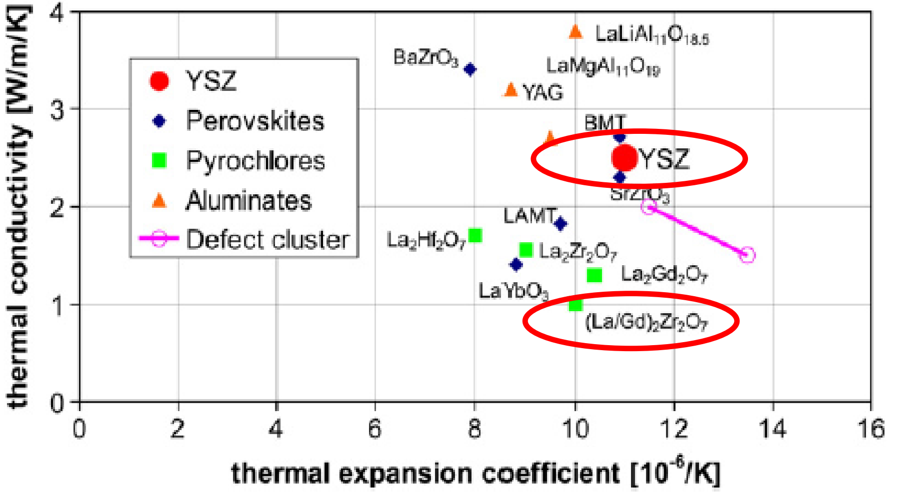
New TBC material – Gadolinium Zirconate

Why Gadolinium Zirconate?

- Lower thermal conductivity
- Excellent phase stability
- CMAS attack resistance

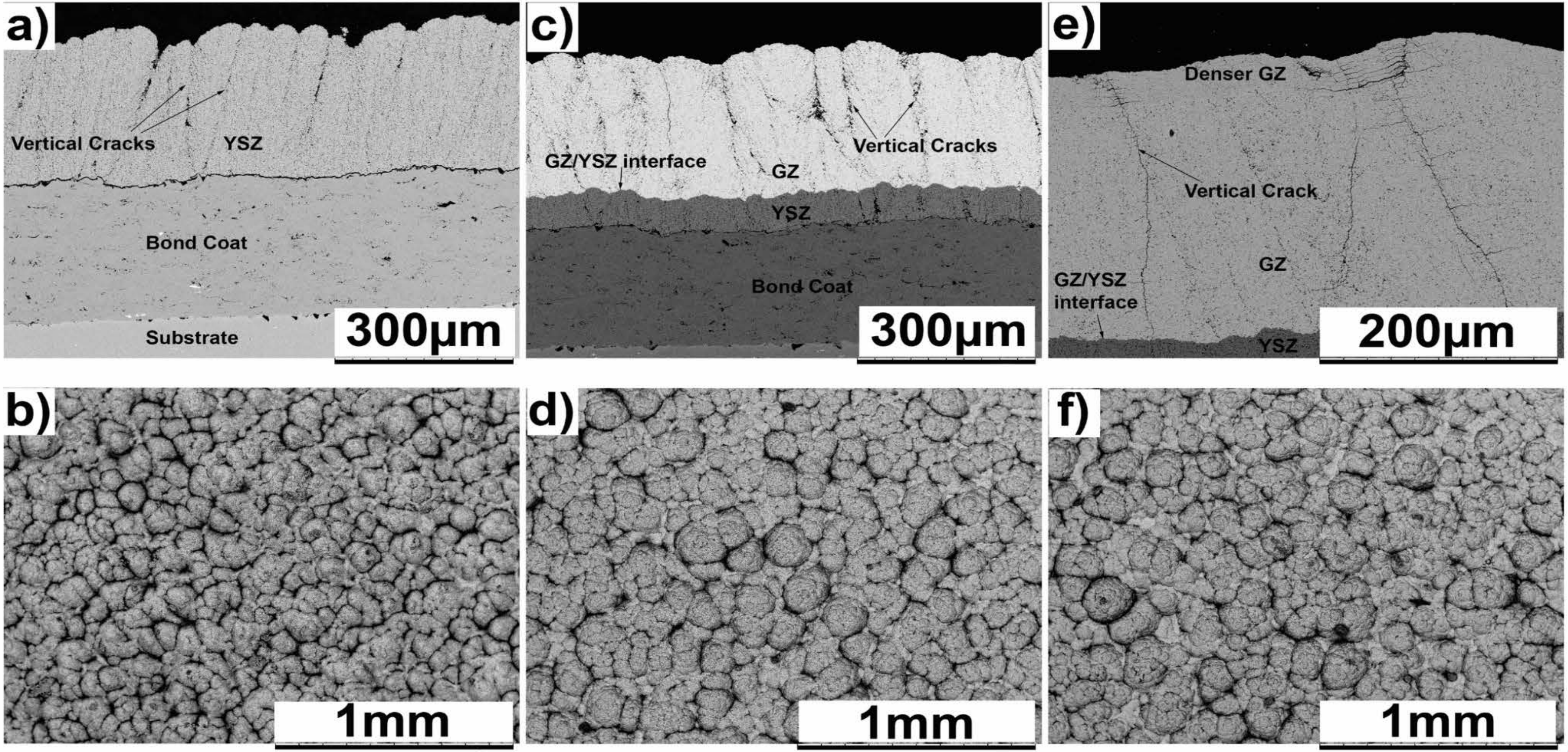
Why Double layer GZ/YSZ?

- GZ has a lower fracture toughness than standard 8YSZ
- GZ reacts with alumina (TGO), leading to formation of GdAlO3
- Therefore, GZ/YSZ double layered TBCs are widely investigated



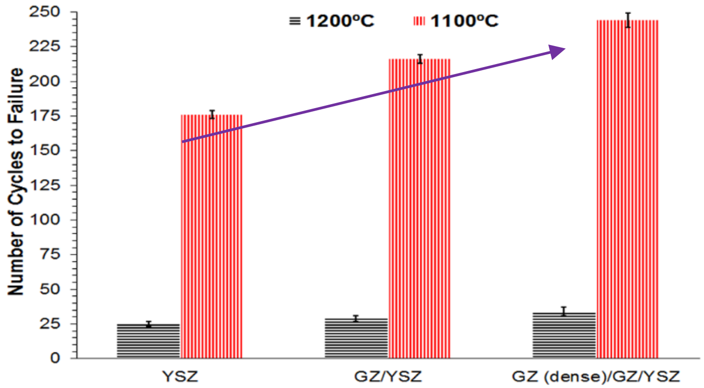
Vassen et al. 'Overview on advanced thermal barrier coatings' Surf. Coat technol, Vol. 205, 2010

Multilayered TBCs

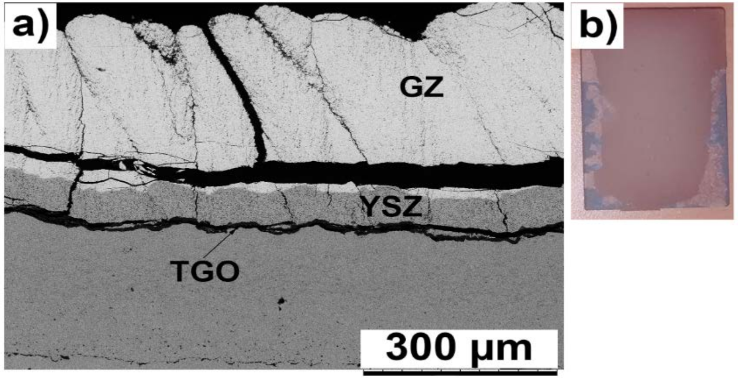


S. Mahade, N. Curry, S. Björklund, N. Markocsan, P. Nylén, Surface and Coatings Technology, *Vol. 283, 2015, pp. 329-336*

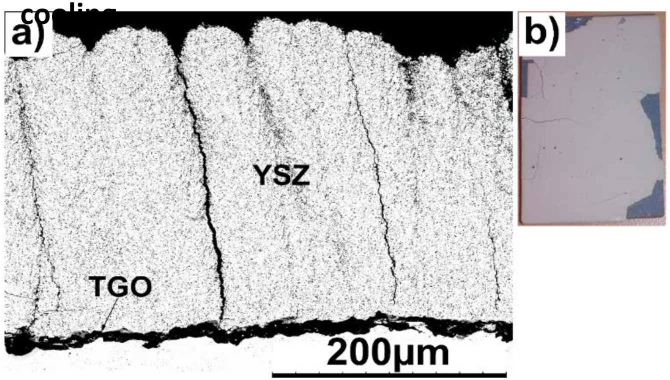
Lifetime & failure modes



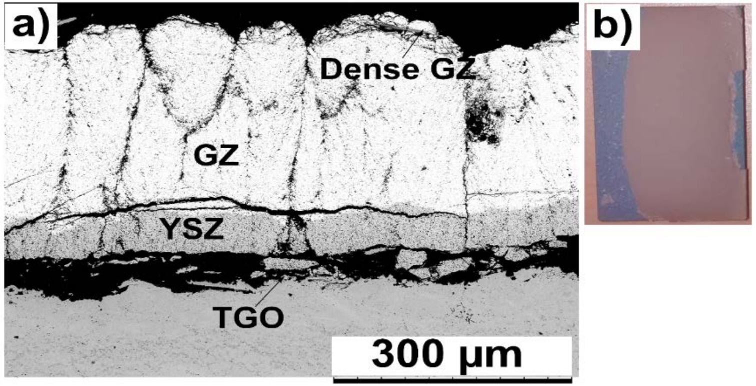
TCF test with 1hr heating and 10 min cooling



TCF failed double layer GZ/YSZ a) SEM micrograph b) Photograph



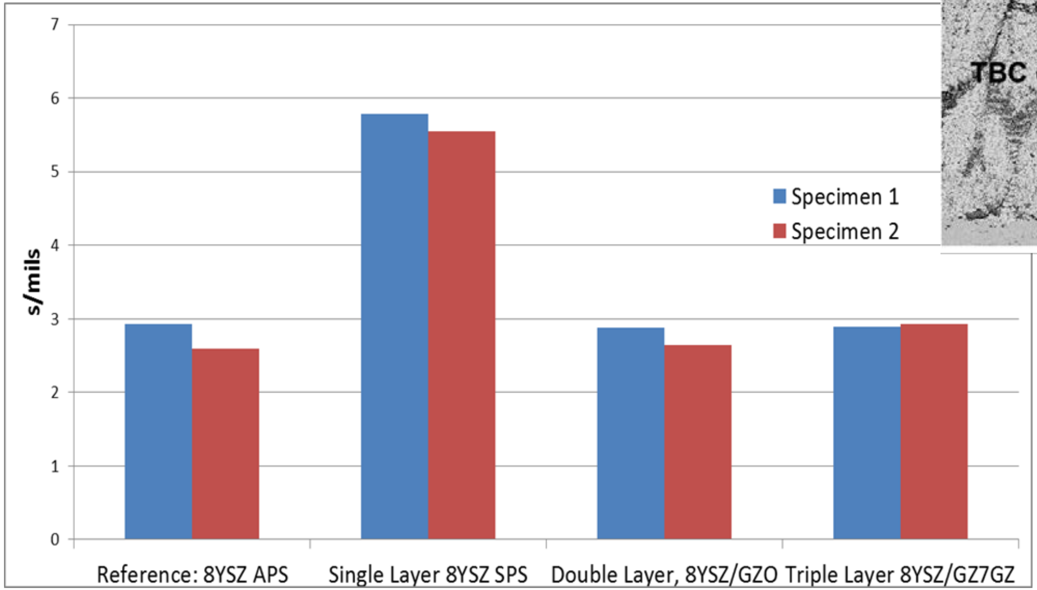
TCF failed single layer YSZ a) SEM micrograph b) Photograph

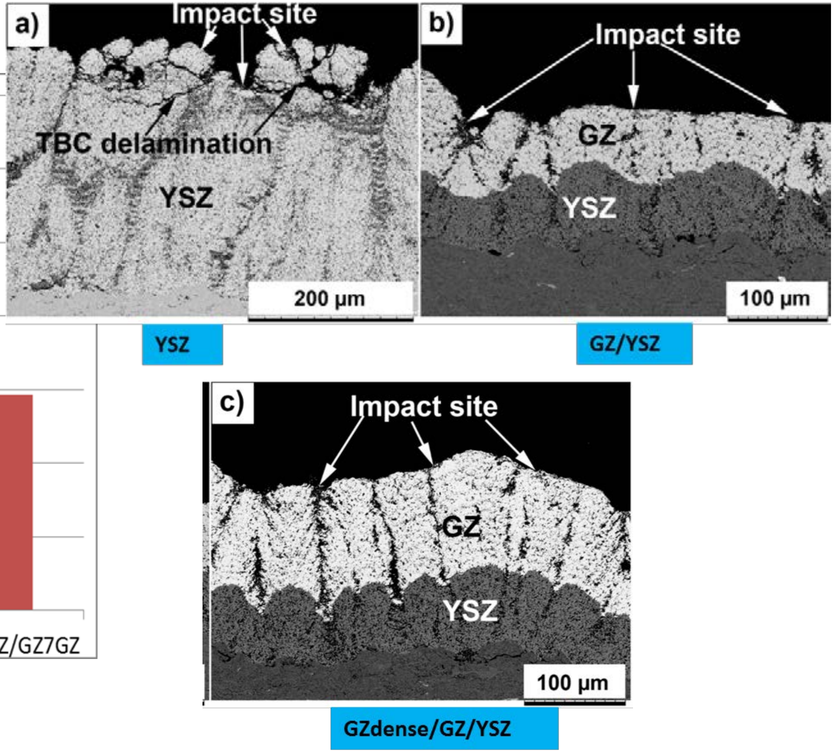


TCF failed triple layer GZdense/GZ/YSZ a) SEM micrograph b) Photograph

S. Mahade, N. Curry, S. Björklund, N. Markocsan, P. Nylén: Surface and Coatings Technology, Vol. 283, 15 December 2015, pp. 329-336

Erosion resistance of multilayered TBCs





S. Mahade, N. Curry, S. Björklund, N. Markocsan, P. Nylén, R. vassen: Proceeding of the ITSC Conf. Shanghai 2016, DVS324, pp. 343-347

Conclusions

- Thermal Barrier Coatings can still bring improvements engine efficiency of GT
  - New materials
  - New deposition processes
  - Multi-layered TBCs
- Liquid feedstock plasma spraying – a promising method for next generation TBCs
  - Cheap, easy to scale-up method
  - Coatings with improved functional performances

Acknowledgements

- Funding
  - KK-foundation
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Thank you for your attention!

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