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Liquid feedstock plasma spraying - An emerging process for the next generation aircraft engines

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Production Technology Centre (PTC) Trollhättan, Sweden

- A research and innovation centre founded by:
  - Saab Automobile (now NEVS)
  - Volvo Aero Corporation (now GKN Aerospace)
  - University West
- Good collaboration with industry
- State-of-the-art facilities

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Outline

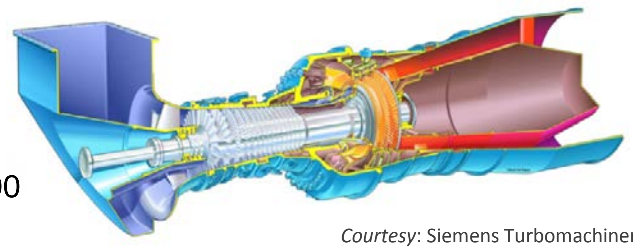
- Motivation
- Thermal Barrier Coatings (TBCs)
- Liquid Feedstock Plasma Spraying – Suspension Plasma Spraying (SPS)
  - Functional Performance of SPS TBCs
  - New materials and coating architectures
- Conclusions

TBCs in Gas Turbines

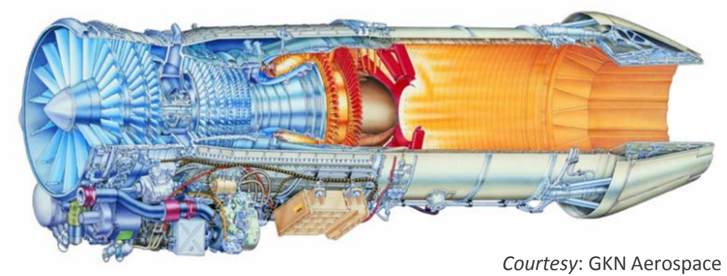
Power plants

Aeroplanes

SGT-800



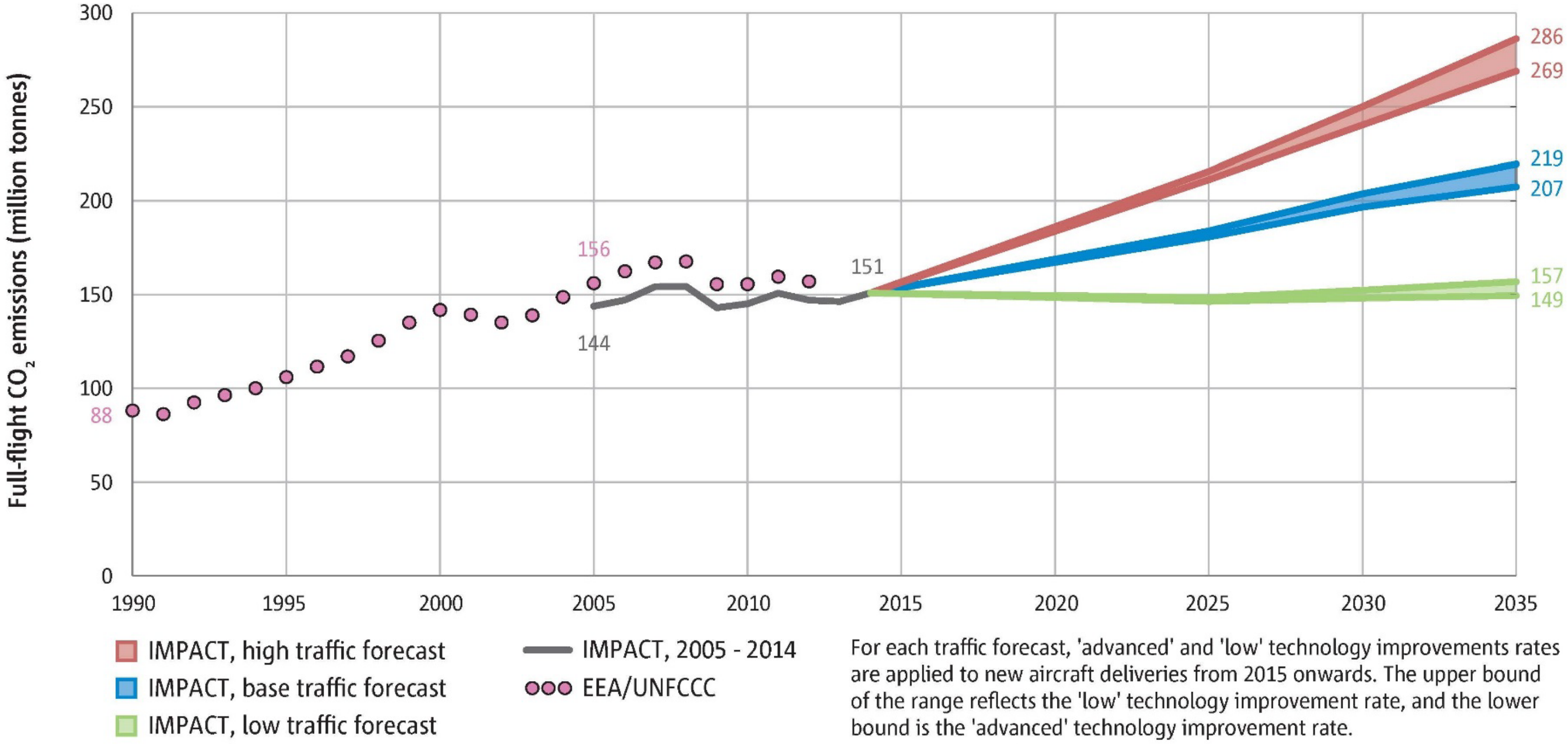
Courtesy: Siemens Turbomachinery



RM-12

Courtesy: GKN Aerospace

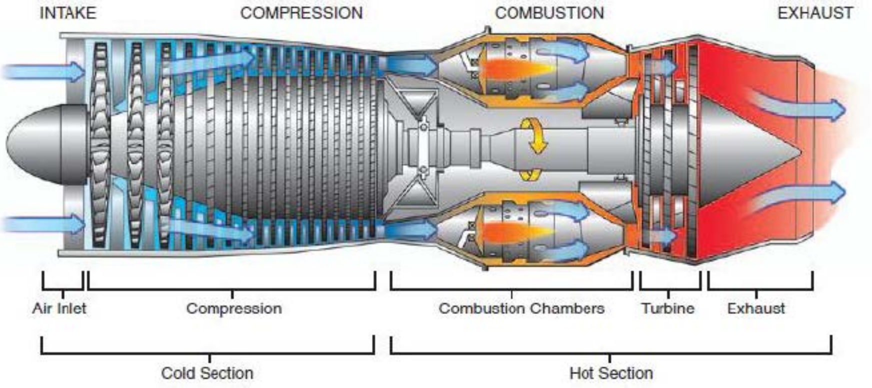
The CO_2 emissions are increasing!



Source: European Aviation Environmental Report 2016

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

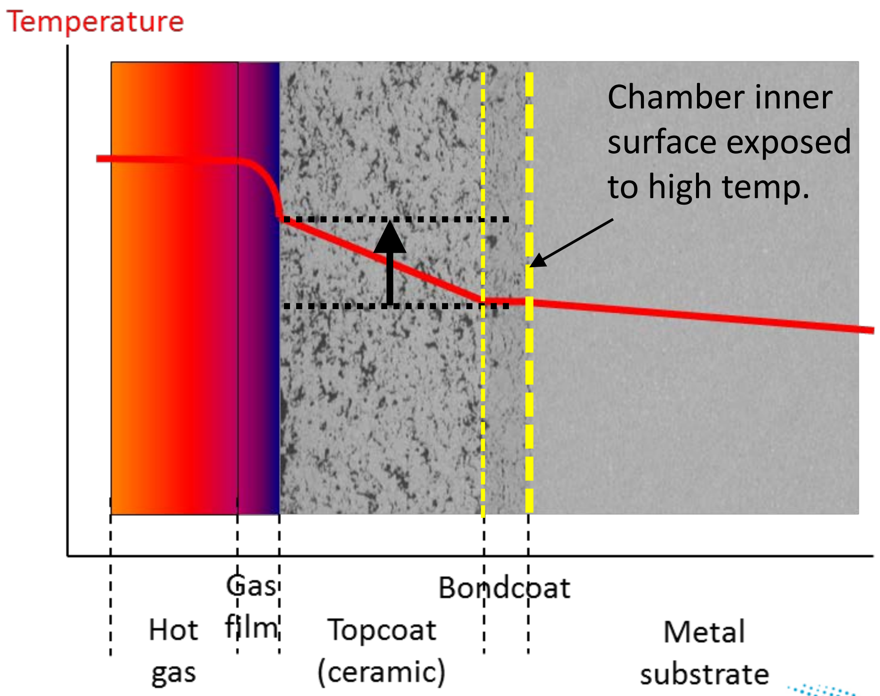
Ref: M. Oechsner, Siemens, TBC Systems for Gas Turbine Applications – Status and Future Challenges, Turbine Forum, Nice, April 25, 2012

Objective: Improve engine efficiency

- Increase the operating temperature
  - ⇒ Lower thermal conductivity TBCs => Design of coating microstructure
  - ⇒ Multilayered systems with new materials
- Better durability of TBCs
  - ⇒ Protection against harsh environment => New materials

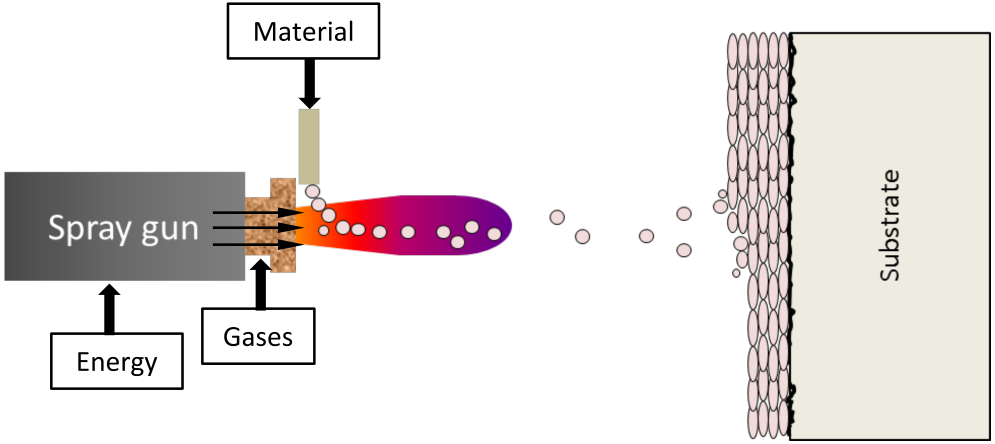
Thermal Barrier Coatings (TBCs)

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



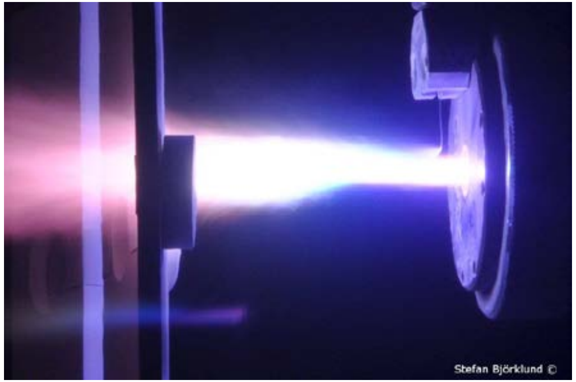
Thermal Spraying

- Branch of surface engineering
- Heat generated by combustible gases/electric arc
- Coating built up particle by particle

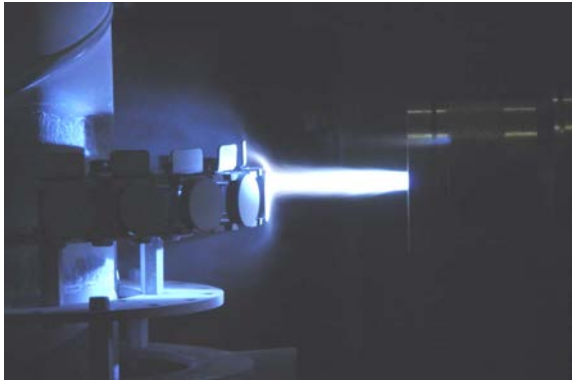


A. TBCs with new microstructures

- Liquid feedstock – Suspension plasma spraying
- Smaller particle sizes – sub-micron to nanometric



- Progressive Surface 100HE
- Radial injection
- Injection parameters require tuning and are sensitive to suspension parameters



- Mettech Axial III
- Axial injection
- Less sensitive to suspension properties and injection parameters

Higher enthalpy required to melt the particles in liquid than in powder spraying

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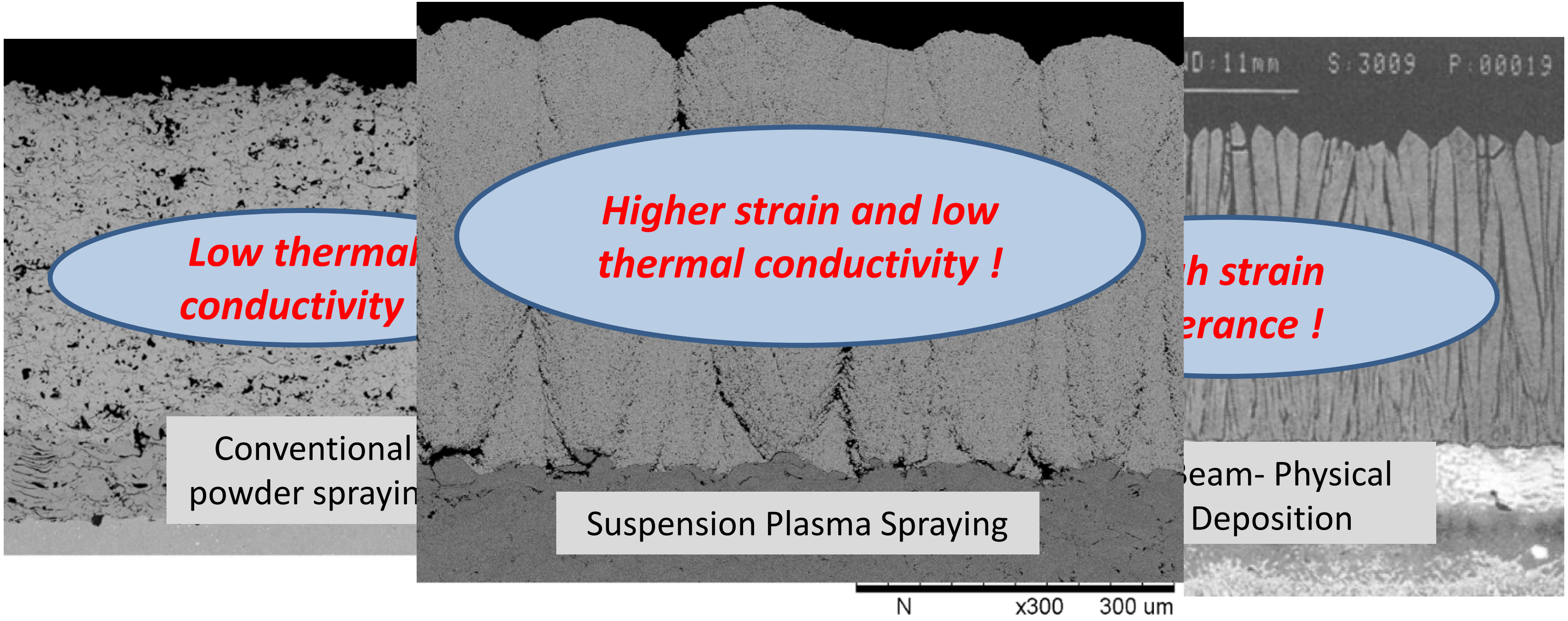
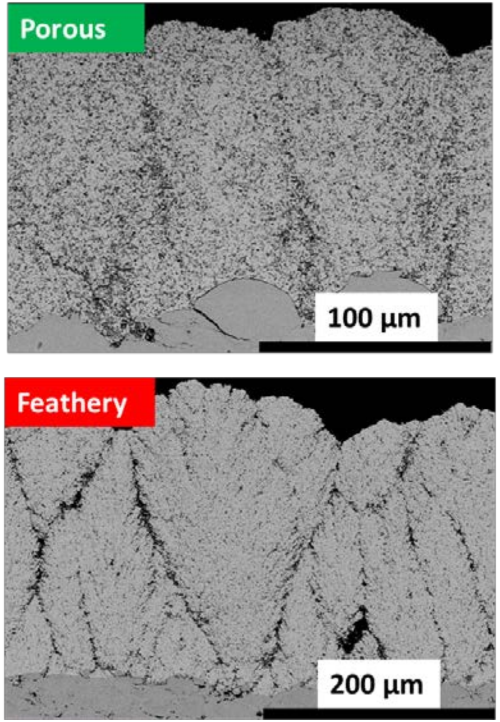
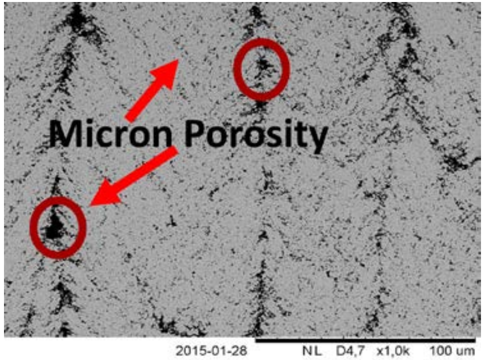
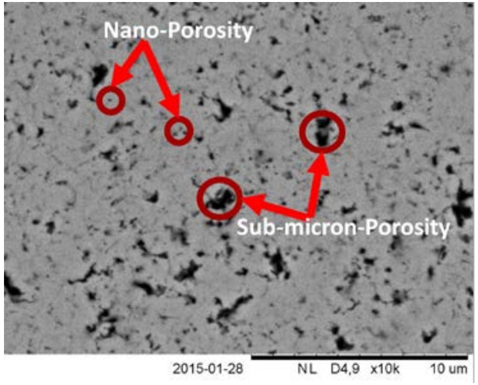
Why Suspension Plasma Spraying?



Great potential for better TBCs – Unique microstructures

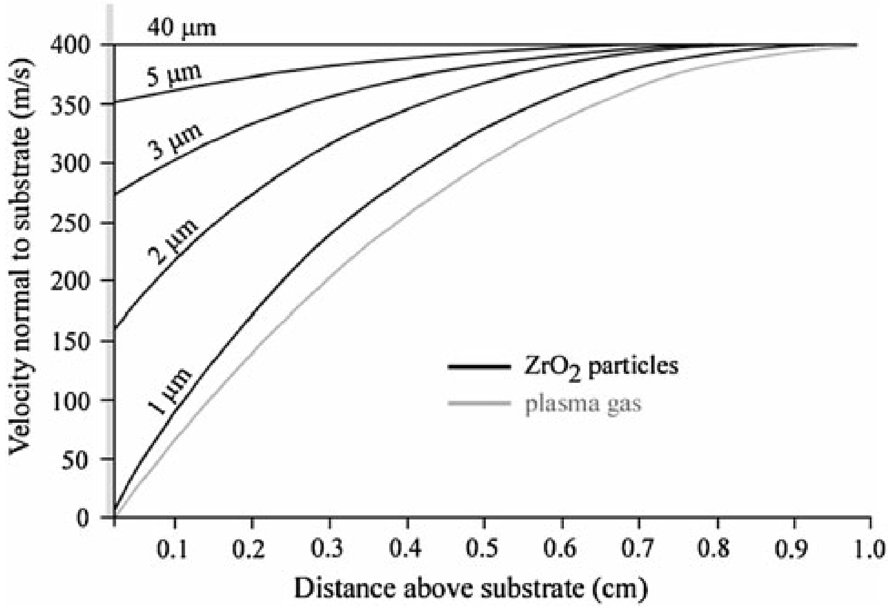


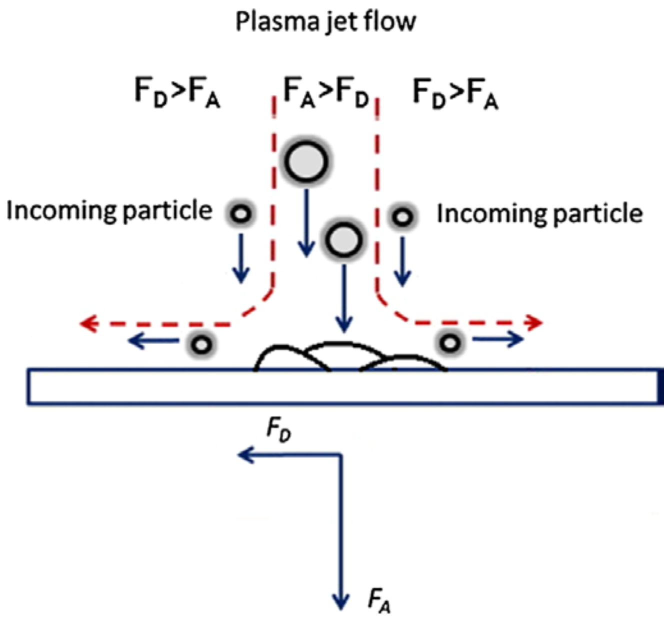




Powder vs liquid feedstock spraying

- Smaller particles tend to follow plasma gas stream

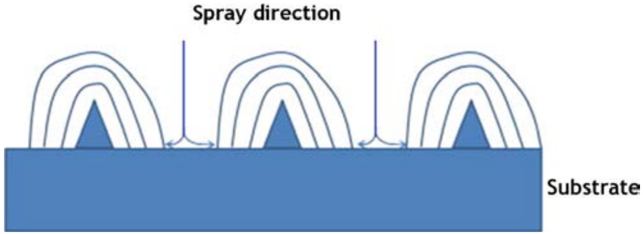




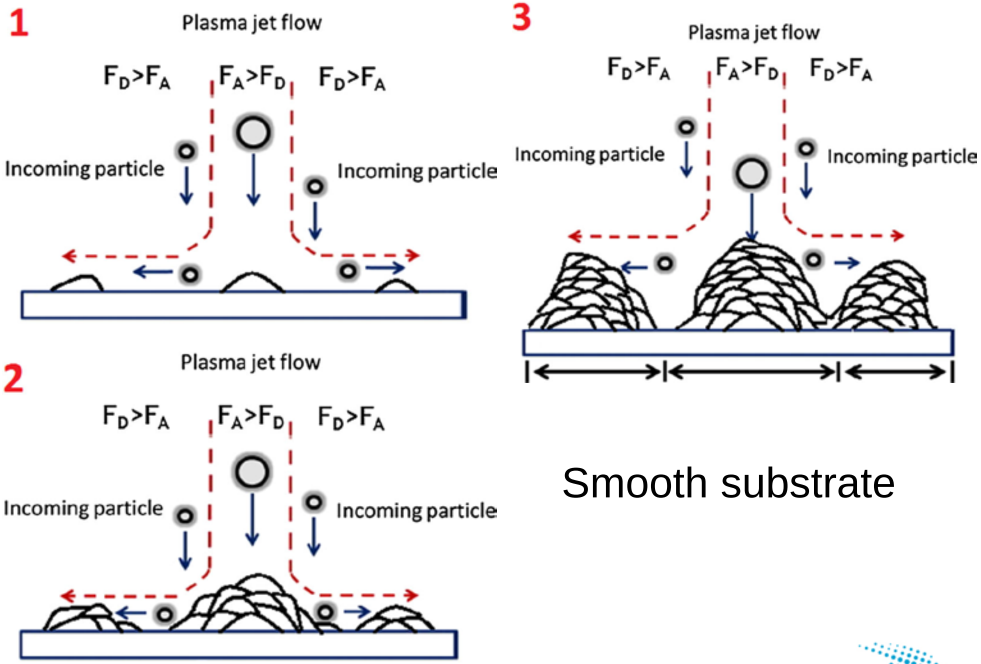
Source: VanEvery et al., JTST, 20(4), 2011,
Sokolowski et al., JTST, 25(1-2), 2016

Column formation – liquid feedstock

Columnar coatings – cheaper alternative to EB-PVD!!



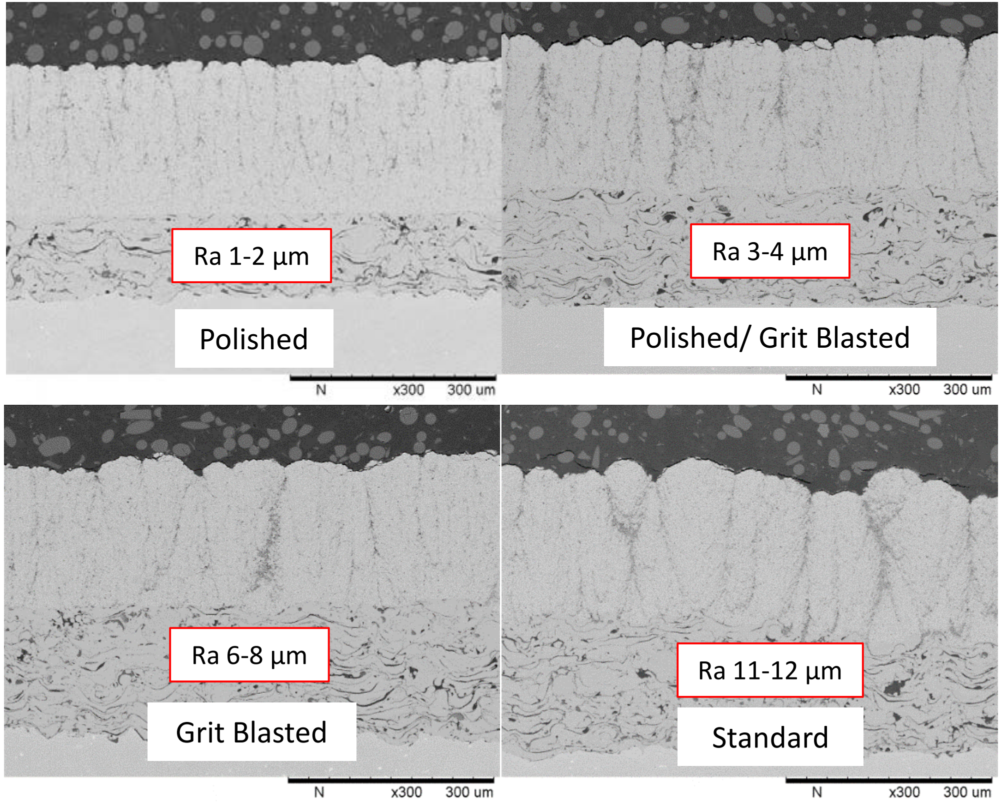
Rough substrate



Smooth substrate

Source: Sokolowski et al., JTST, 25(1-2), 2016

Influence of roughness on column density



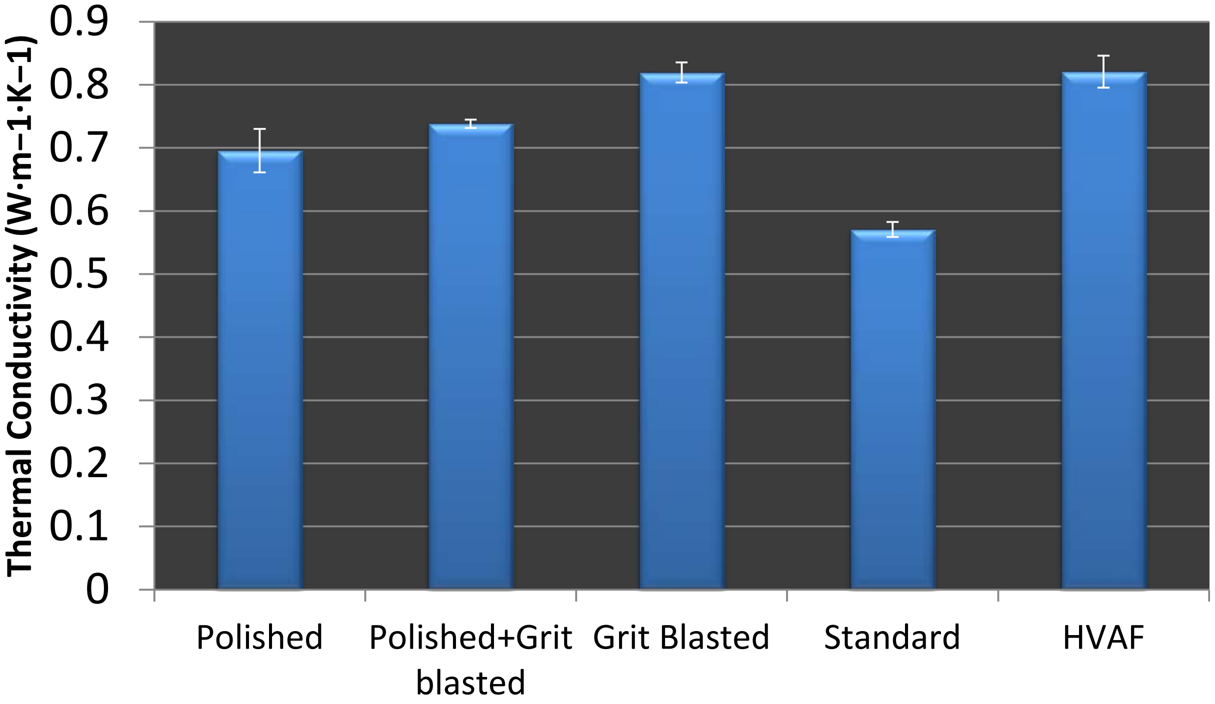
Substrate specimen: Hastelloy X

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

Low Thermal Conductivity

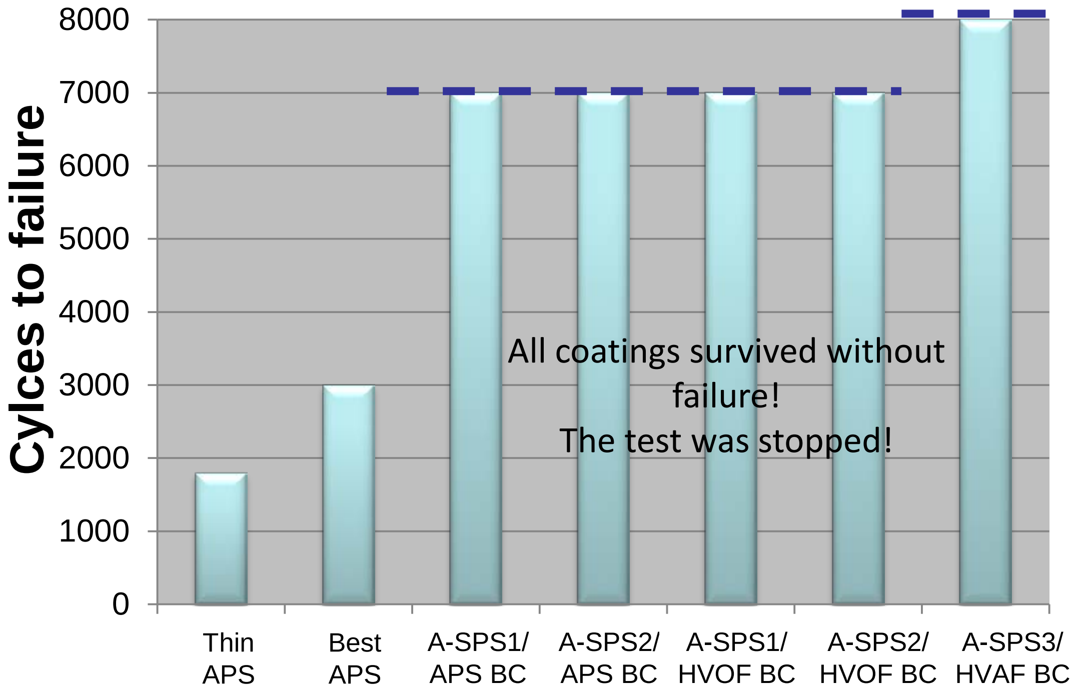


Thermal conductivity measurements were done using the Laser Flash Method

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

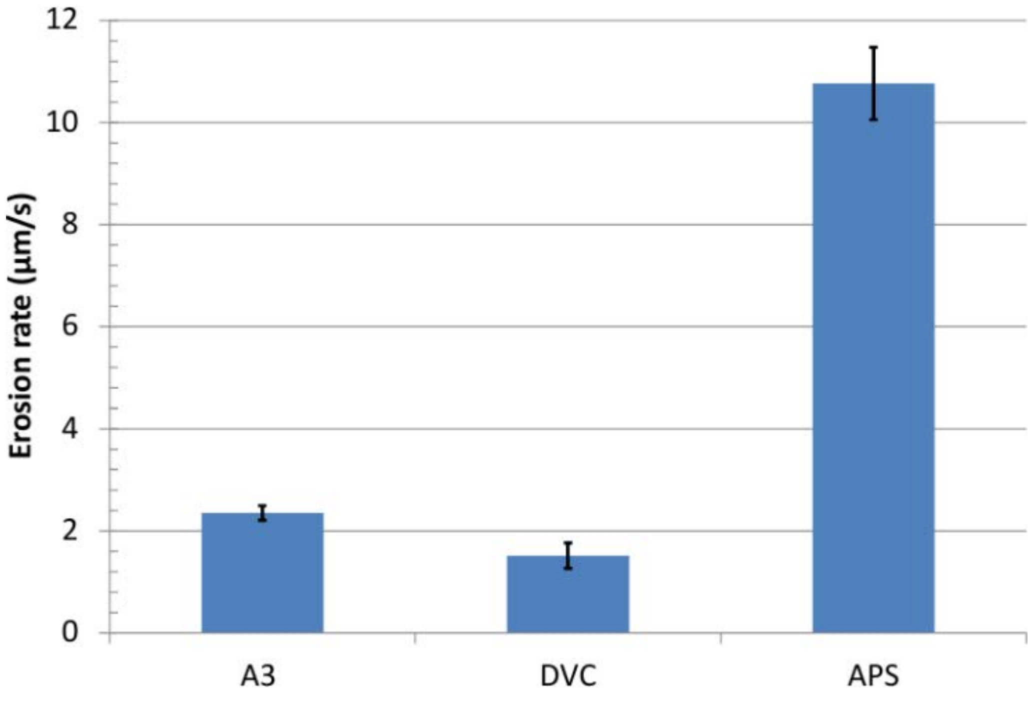
High Lifetime

- Standard lifetime test developed by GKN Aerospace
- Burner rig testing (Thermal shock testing)



N. Curry, K. VanEvery, T. Snyder N. Markocsan, *Coatings* 2014, *4*, 630-650

Low erosion resistance



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

B. New materials and architectures

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

Iceland Volcano

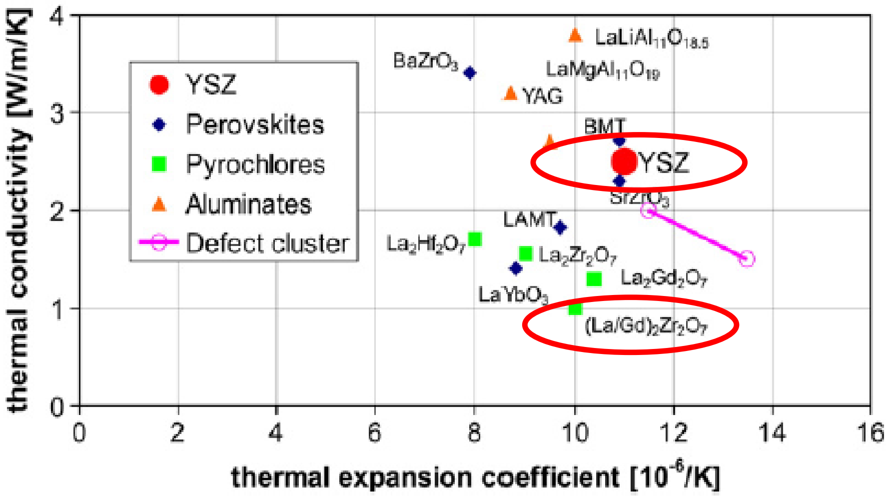
New TBC material – Gadolinium Zirconate

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 $GdAlO_3$
- Therefore, GZ/YSZ double layered TBCs are widely investigated



Source: Vassen et al., Surf. Coat technol, 205, 2010.

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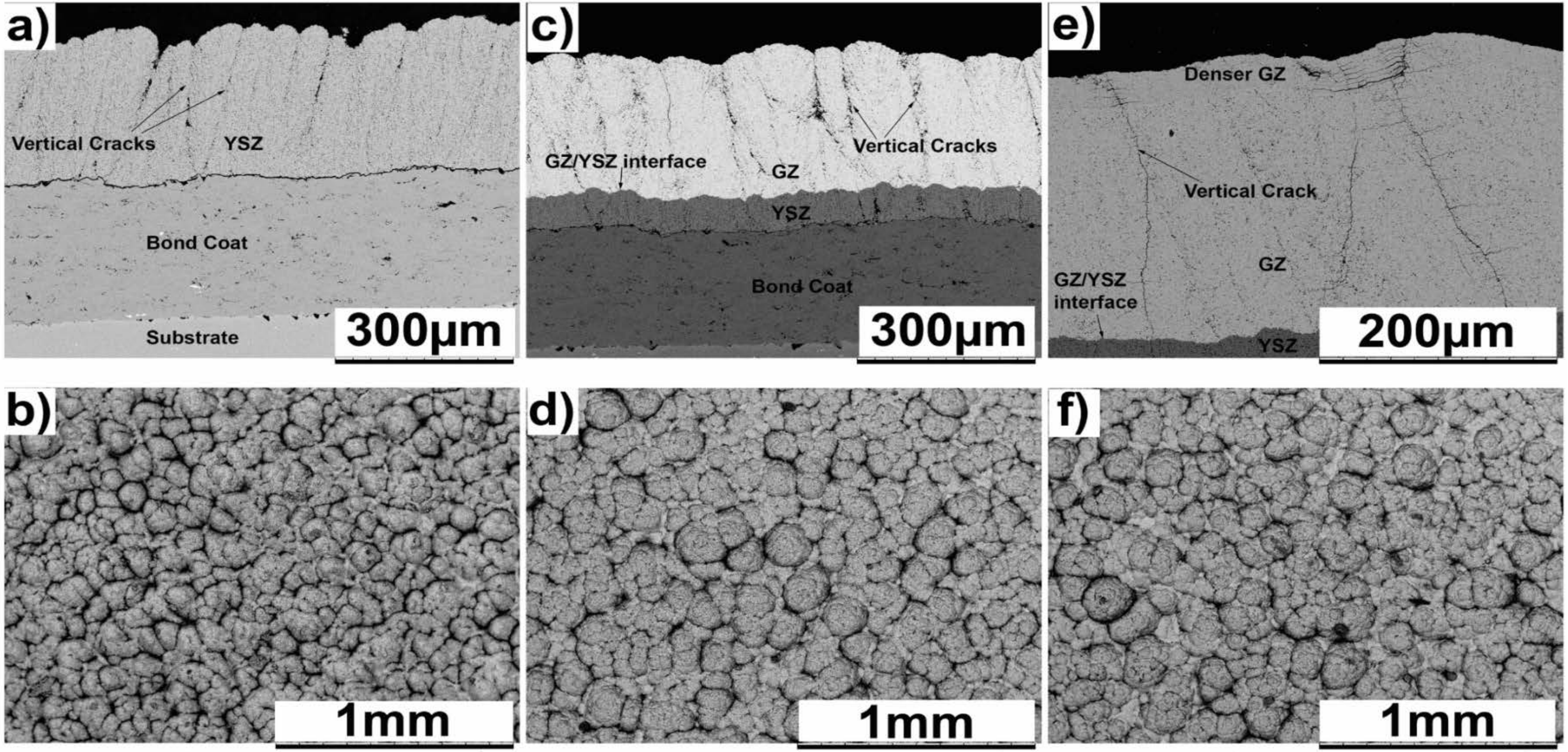
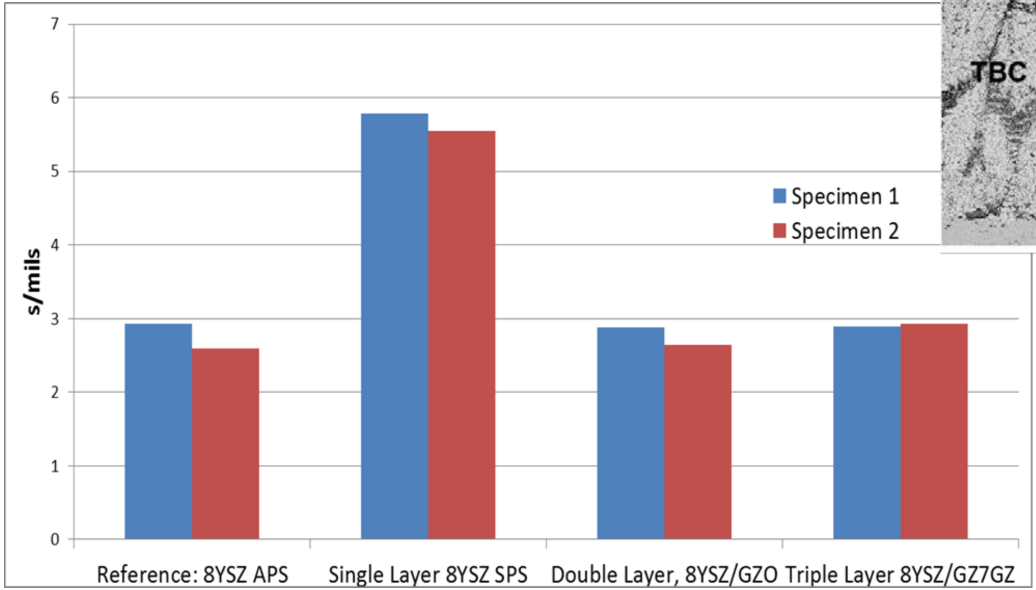
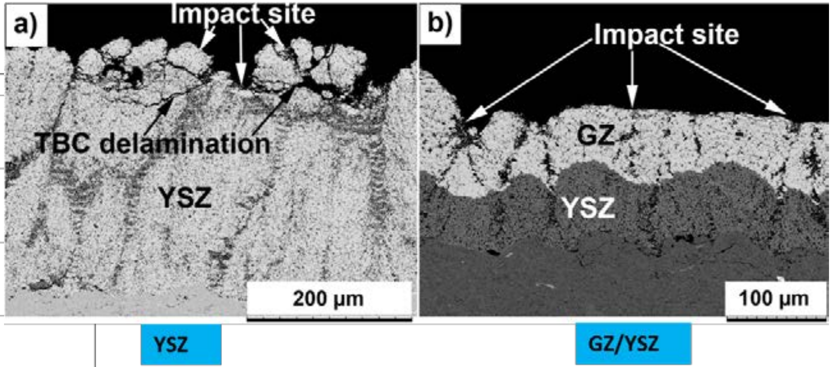
Multilayered TBCs

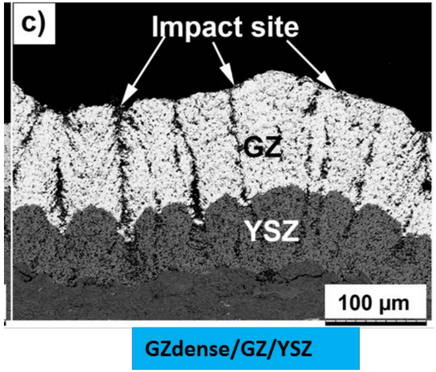


S. Mahade, N. Curry, S. Björklund, N. Markocsan, P. Nylén, Surface and Coatings Technology, *Vol. 283, 2015, pp. 329-336*

Erosion resistance of multilayered TBCs

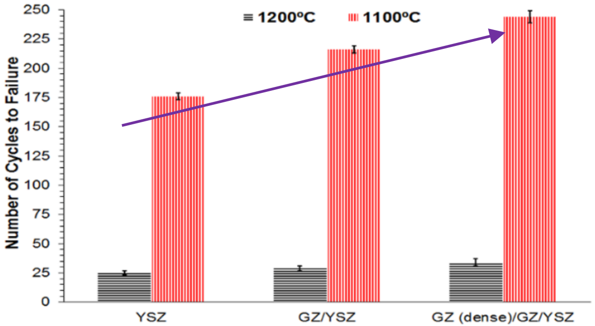




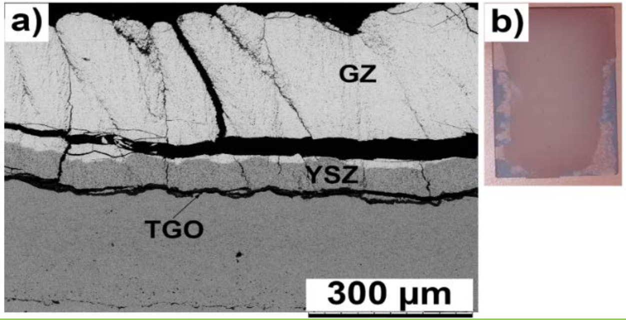


S. Mahade, N. Curry, S. Björklund, N. Markocsan, P. Nylén, R. Vassen, Proceedings of the ITSC 2016, pp. 343-347

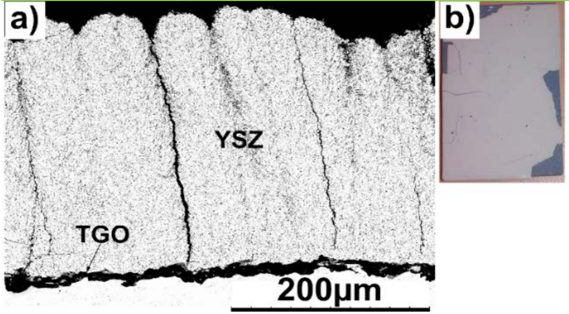
Lifetime & failure analysis



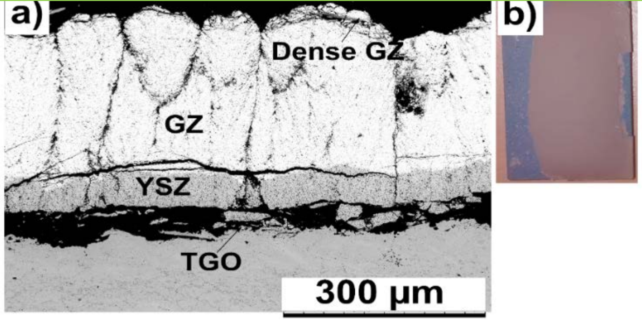
TCF test with 1hr heating and 10 min cooling



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

Conclusions

- Improvement in TBCs can improve engine efficiency significantly
  - 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
- SPS coatings with improved functional performance

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  - KK-foundation
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Thank you for your attention

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