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High temperature oxidation and burner rig testing of different TBCs in the frame of the European Project TOPPCOAT: A summary of results

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Thermal Barrier Coatings TBC IV Irsee

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High temperature oxidation and burner rig testing of different TBCs in the frame of the European Project TOPPCOAT: a summary of results.

TOwards design and Processing of advanced, comPetitive thermal barrier COATing systems

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TOPP COAT

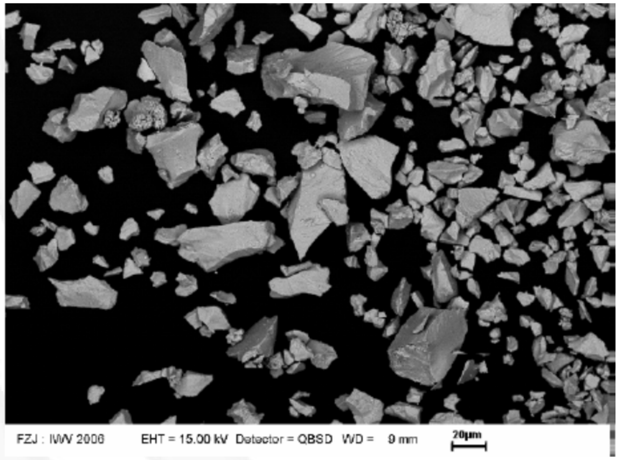
RSE Ricerca Sistema Energetico

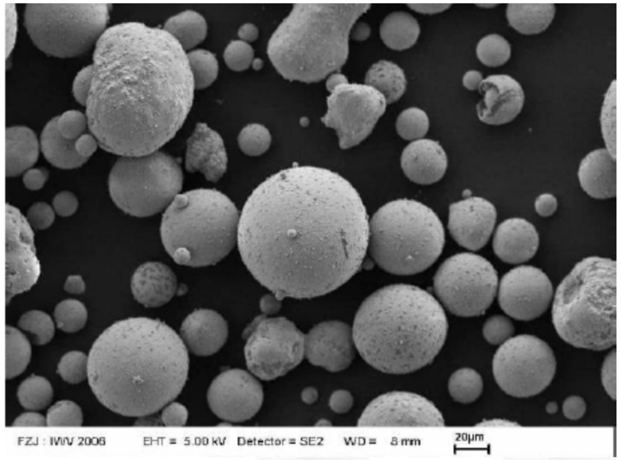
The European Community provides support to the TOPPCOAT project under contract AST4-CT-2005-516 149 (FP6), which is gratefully acknowledged.

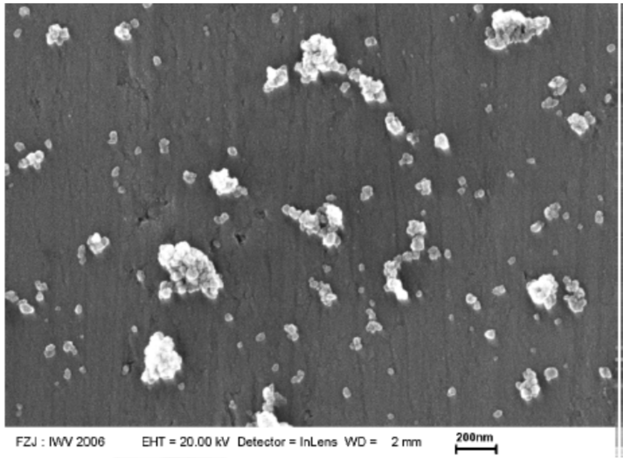
Main objective of the Project

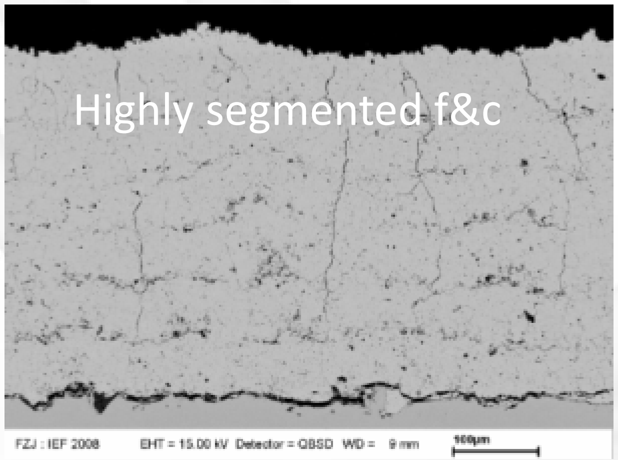
The major S&T objective of the project is the development of improved TBC systems using advanced bonding concepts in combination with additional protective functional coatings. The first specific objective will be to use these developments to provide a significant improvement to state-of-the-art APS coatings and hence provide a cost-effective alternative to EB-PVD. The second objective will be to combine these new concepts with new coating technologies to provide new, advance materials for thermal barrier systems with a capability exceeding the performance of EB-PVD coatings.

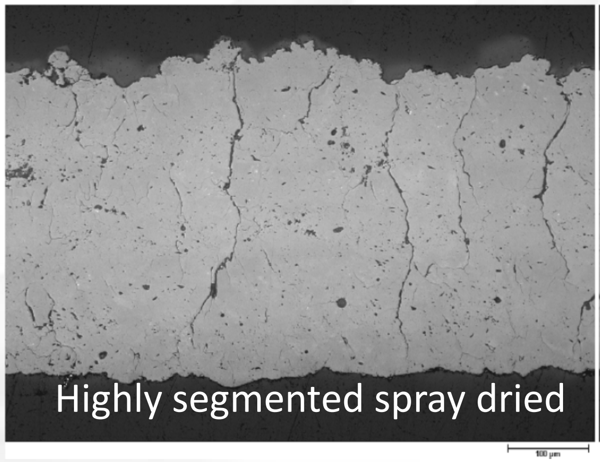
Segmented APS YPSZ TBC

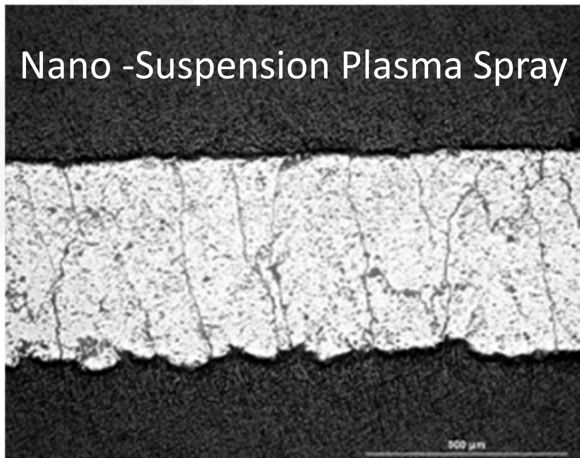




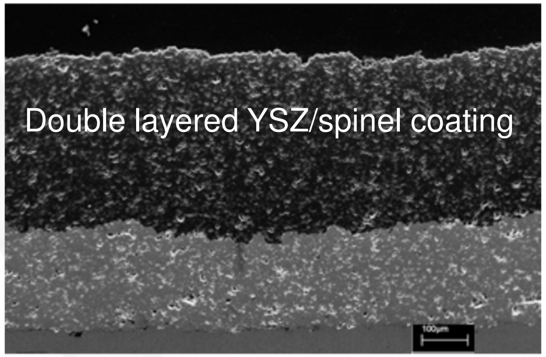


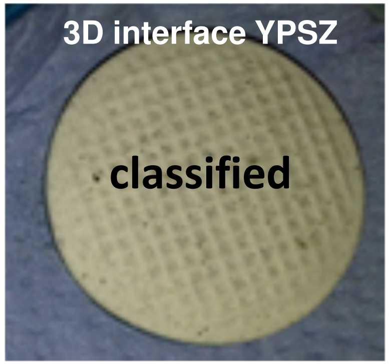


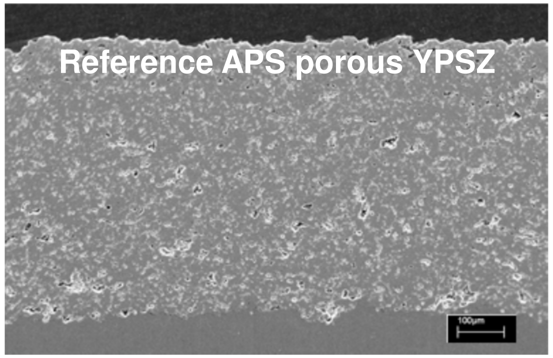


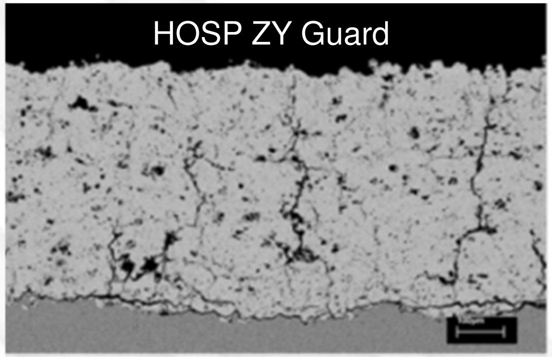


Layered or 3D interfaces segmented APS TBC

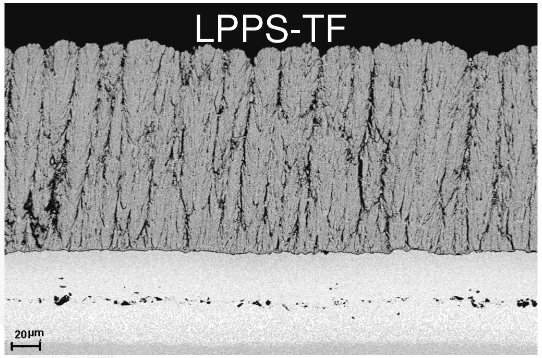


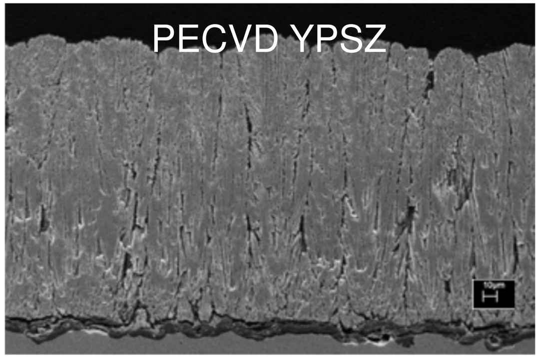


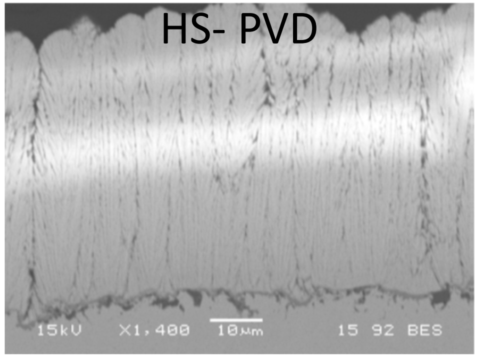


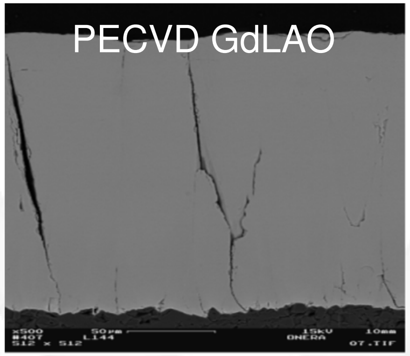


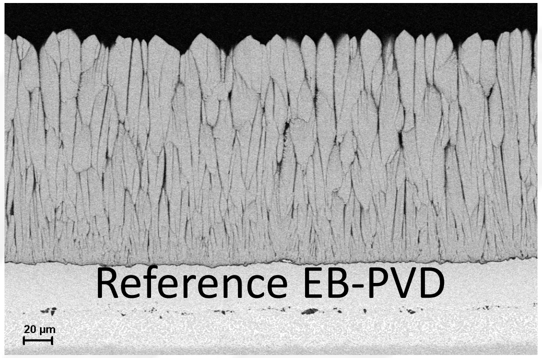
Columnar structures and new compositions











Testing approach

SCREENING TESTS: LONG CYCLE FURNACE TESTS AND BURNER RIG (DISK GEOMETRY)
AFTER THE SELECTION, LONG AND SHORT CYCLE FURNACE TESTS AND BURNER RIG (CYLINDRICAL GEOMETRY)

IN LONG CYCLE FT MORE THAN 130 SAMPLES AND 25 DIFFERENT TBCS SYSTEMS (BC, 3D, TBC POWDERS, TBC THICKNESS, DEPOSITION PARAMETERS AND SUPPLIERS) HAVE BEEN TESTED AT 3 DIFFERENT TEMPERATURES.

MORE THAN 40 SAMPLES HAVE BEEN TESTED IN GKN AEROSPACE BURNER RIG (SAMPLE SIZE, BC, 3D, TBC POWDERS, TBC THICKNESS, DEPOSITION PARAMETERS AND SUPPLIERS)

Number of samples

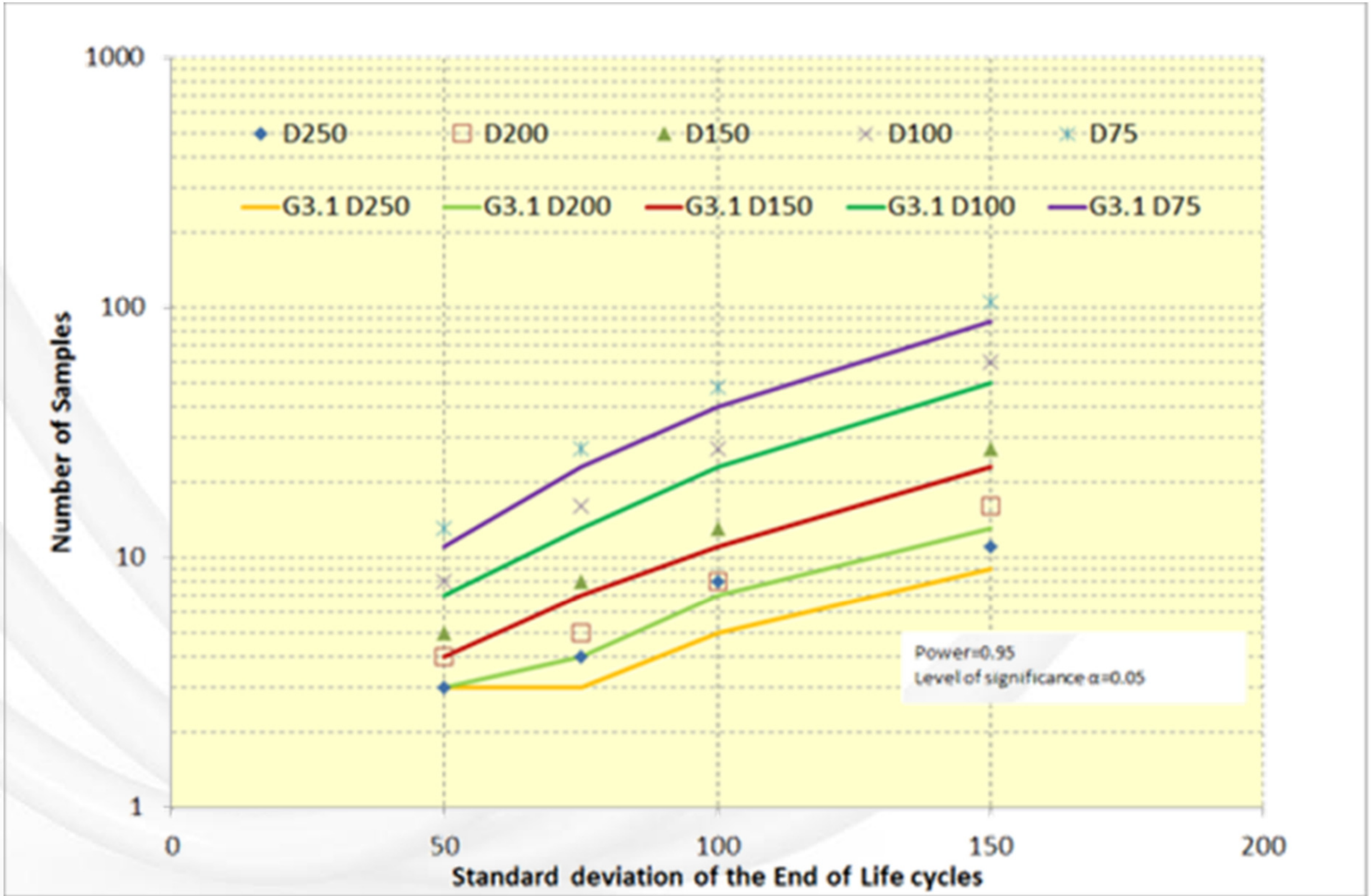
- **Define number of samples to be tested within the same experimental conditions for a statistically significant estimation of the lifetime of the different TBCs systems**

Decision	True	False
fail to reject H0	correct decision $p = 1 - \alpha$	Type II error $p = \beta$
reject H0	Type I error $p = \alpha$	correct decision $p = 1 - \beta$

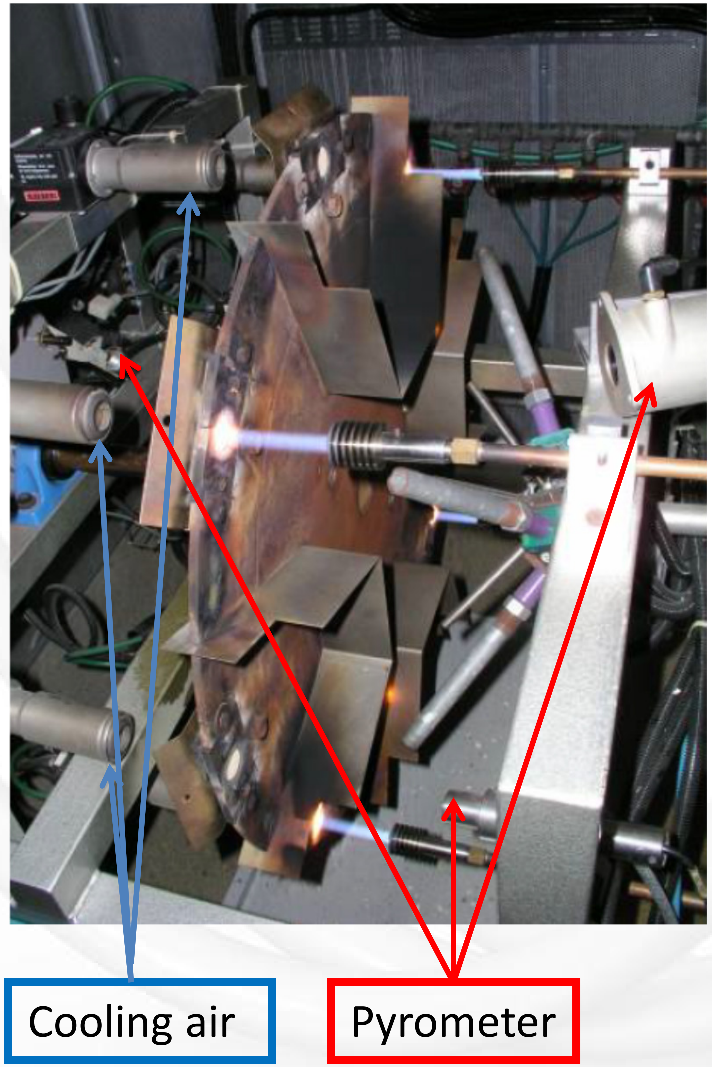
The probability (p) of making a Type I error is called **alpha** (α) and is sometimes referred to as the **level of significance** for the test.
When H0 is false and you fail to reject it, you make a type II error. The probability (p) of making a type II error is called **beta** (β).

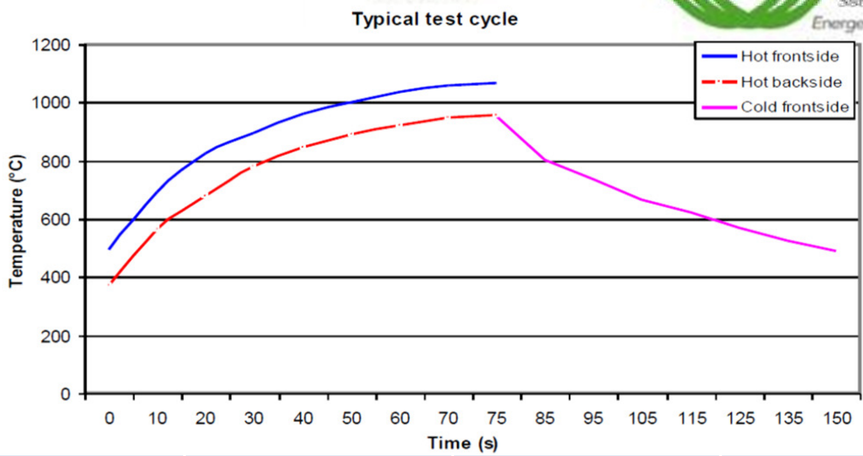
In our specific case the **H_0 hypothesis** is that the average lives of **one TBC set differ by another by X%**. We fixed a level of significance equal to 5% (the two systems differ by X% but we reject the hypothesis) and a power of at least 95%.

Number of samples

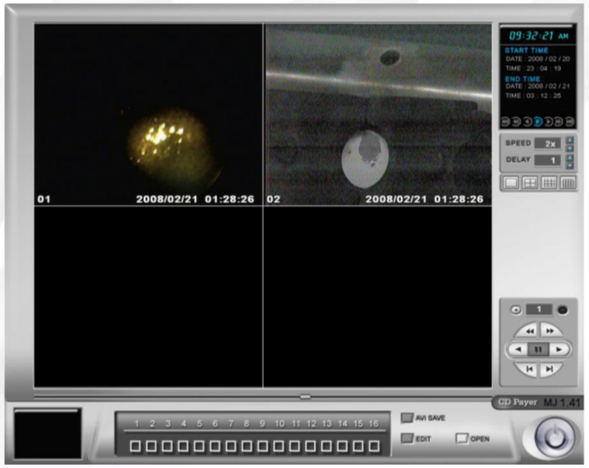


Screening tests – GKN aerospace Burner rig



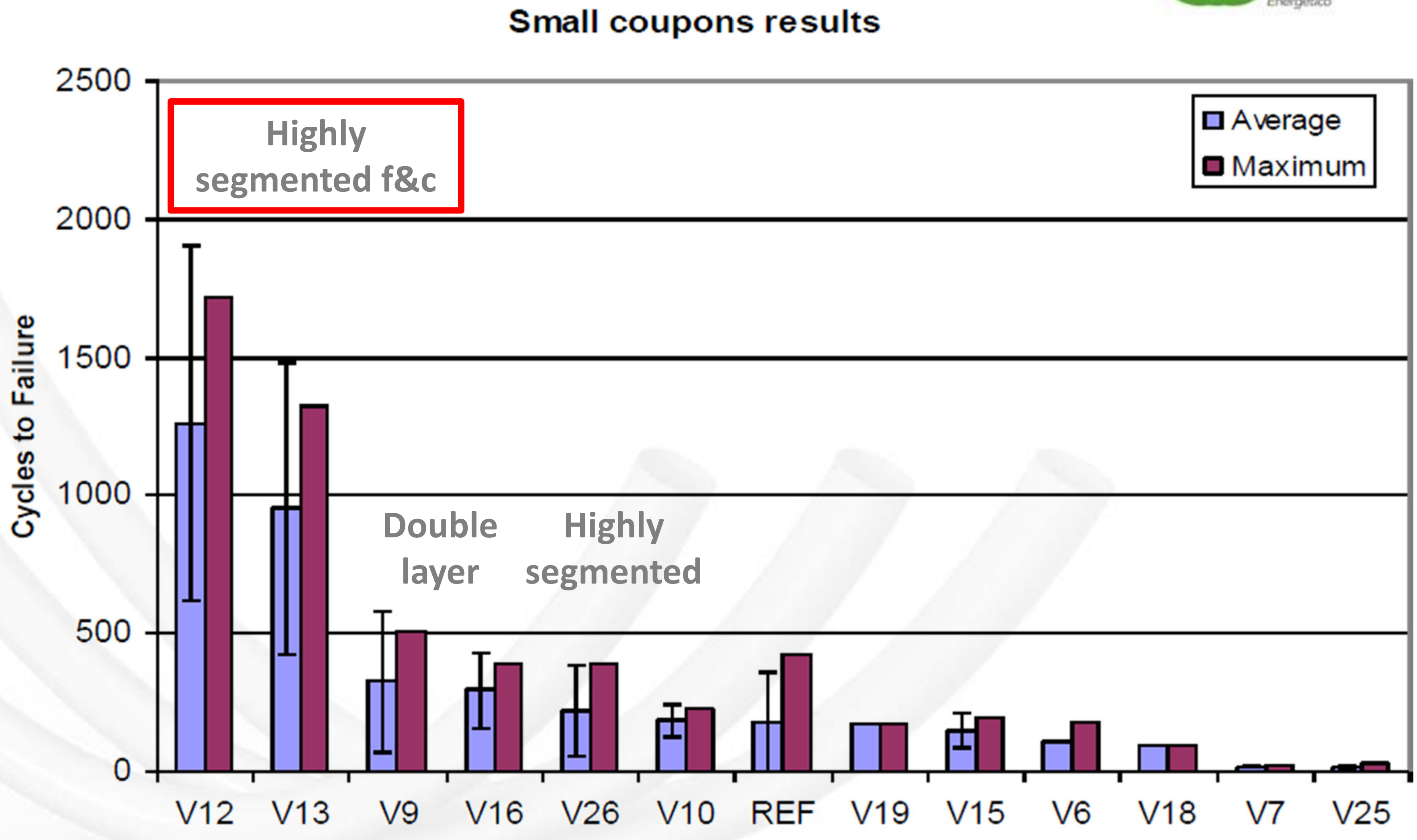


Gas flow (SLPM)	Hot max frontside T [°C]	Hot max backside T [°C]	Max BC T [°C]
27.5 - 33	1200	920	1020 - 1100

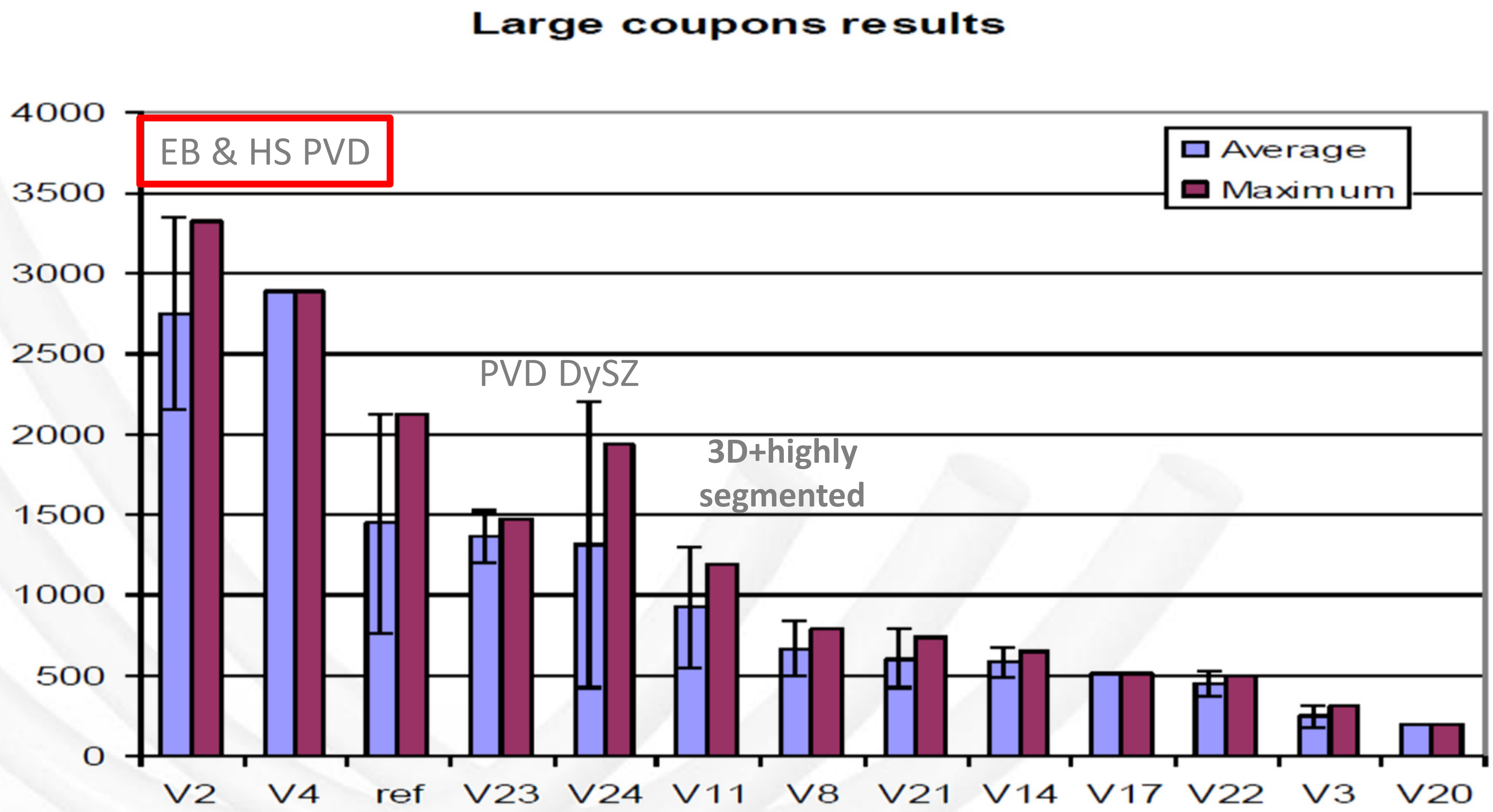


Failure criterion:
10% spallation surface area as observed by two video cameras (hot and cold positions). Hot front side temperature increase.

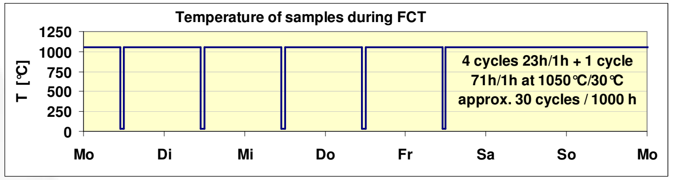
Screening tests - Volvo Burner rig

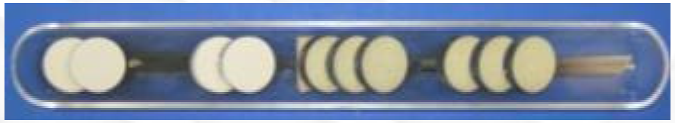


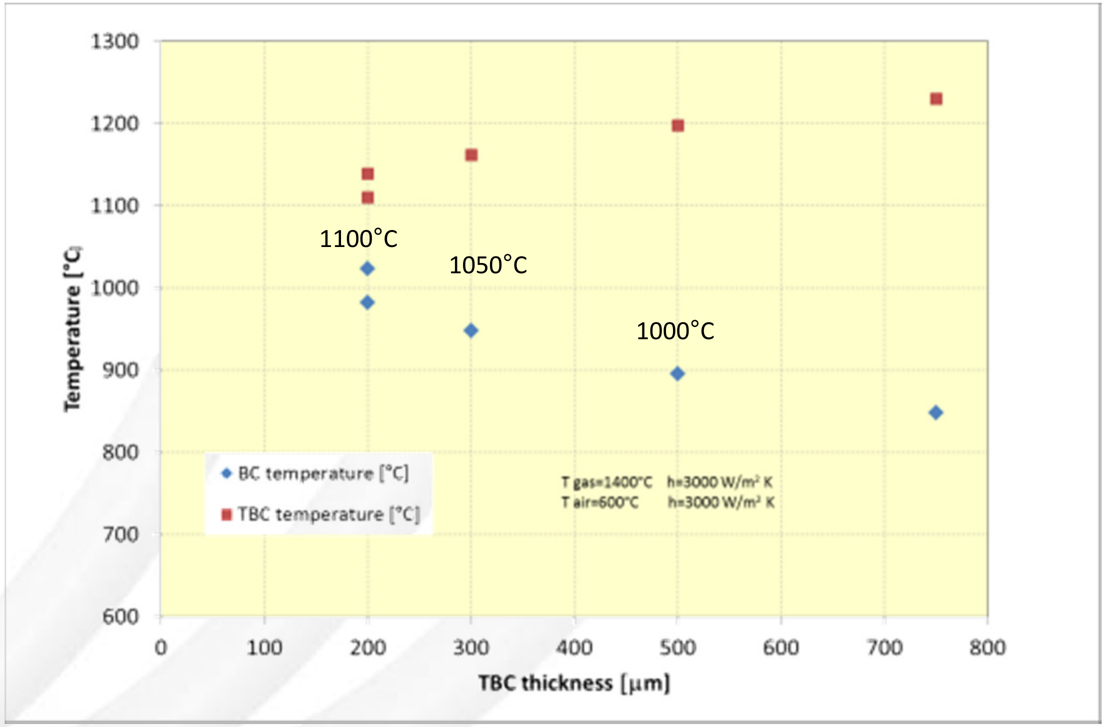
Screening tests – Volvo Burner rig



Screening tests - Alstom FCT

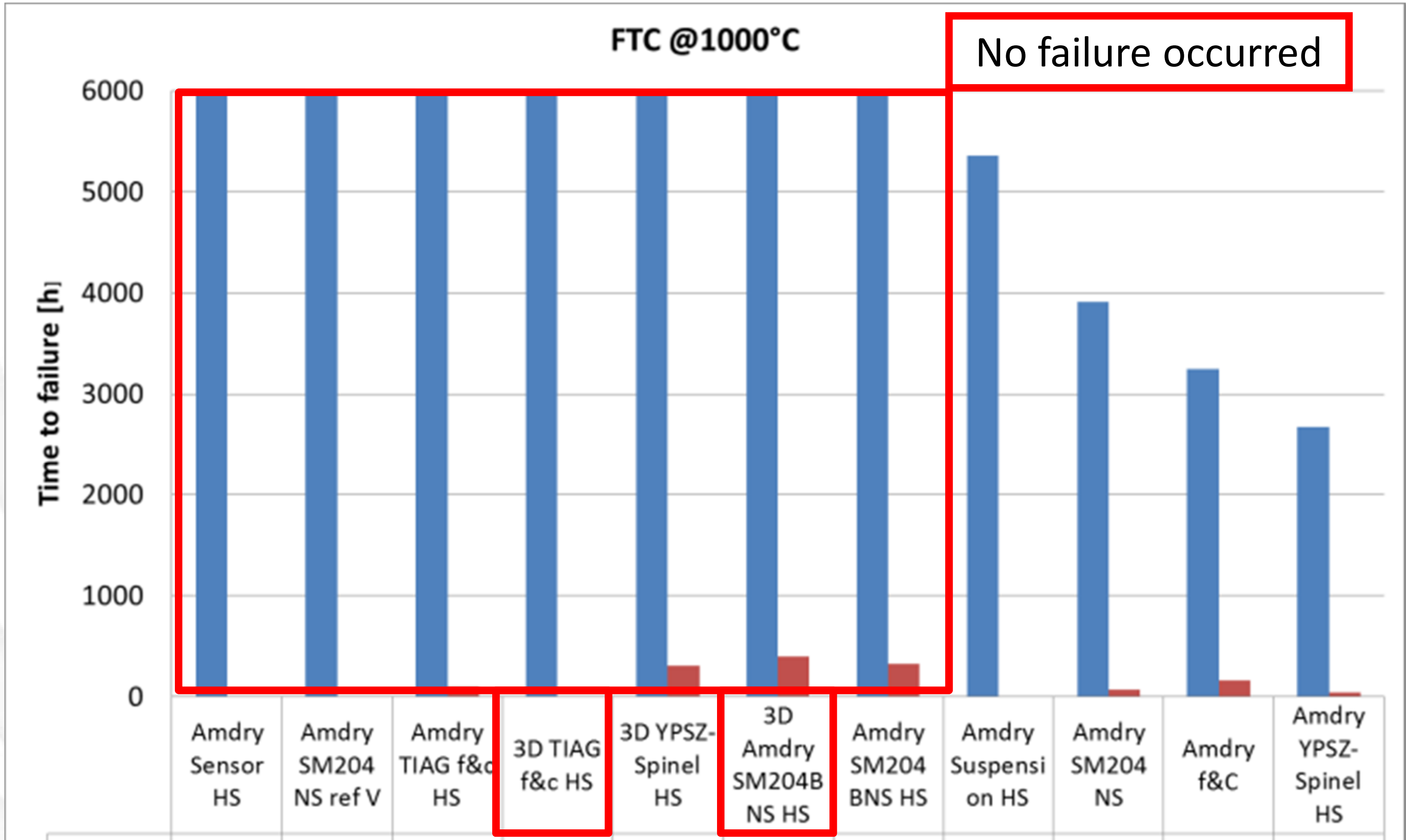






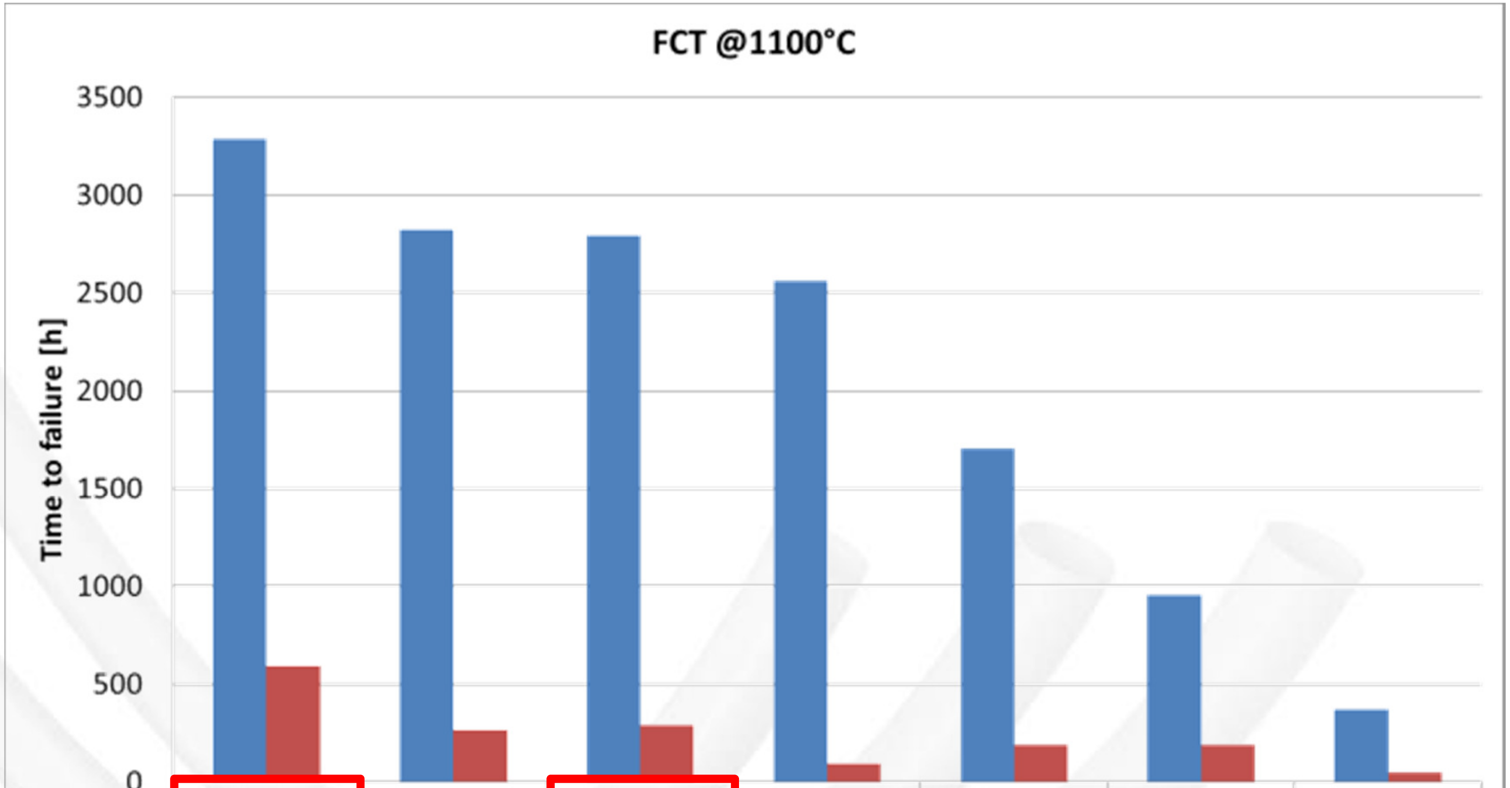
Failure criterion: spallation area wider than 10%

Screening tests - Alstom FCT



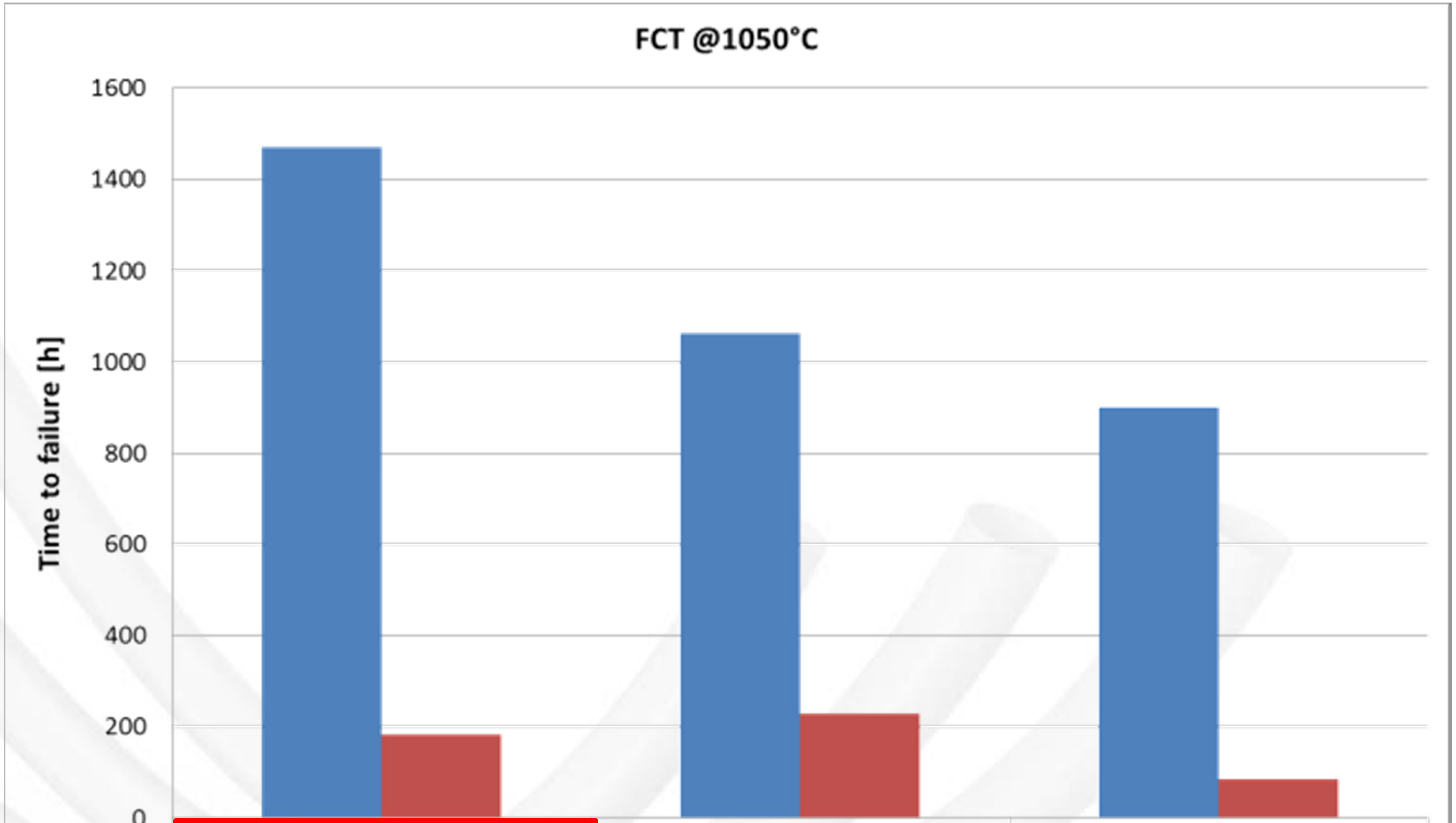
	Amdry Sensor HS	Amdry SM204 NS ref V	Amdry TIAG f&c HS	3D TIAG f&c HS	3D YPSZ-Spinel HS	3D Amdry SM204B NS HS	Amdry SM204 BNS HS	Amdry Suspension HS	Amdry SM204 NS	Amdry f&C	Amdry YPSZ-Spinel HS
Average	8895	8823	8470	7053	6875	6658	6240	5353	3912	3242	2677
std dev			99		308	395	326		66	165	46

Screening tests - Alstom FCT



	TF-LPPS SM204 NS mod	HS-PVD	EBPVD	TF-LPPS DSZ	PE CVD n°1	PE CVD YSZ	PE CVD GLAO
Average	3286	2820	2793	2560	1704	955	369
std dev	591	266	291	94	188	186	47

Screening tests - Alstom FCT



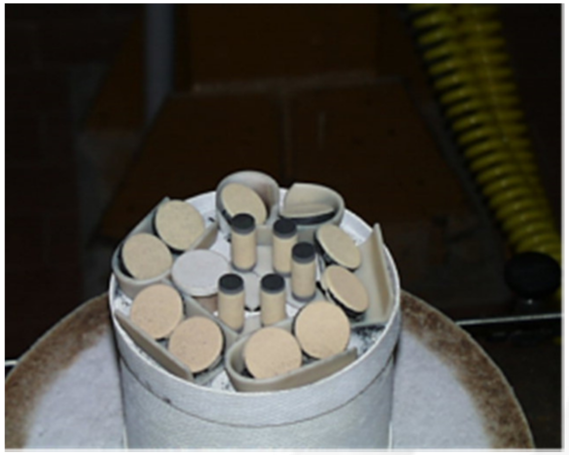
	System 6 HCST 827.7	System 4 SM ZYGuard	System 4 TIAG f&c
Average	1470	1063	900
std dev	182	229	85

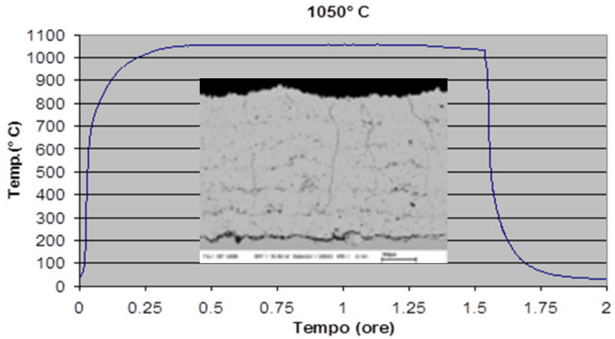
The Magnificent Seven

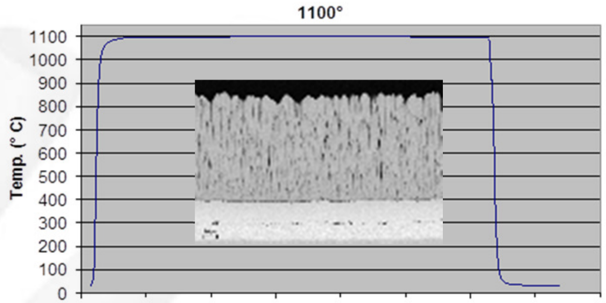
4

✓ Hot Corrosion

FCT tests - RSE Short cycle (2h)



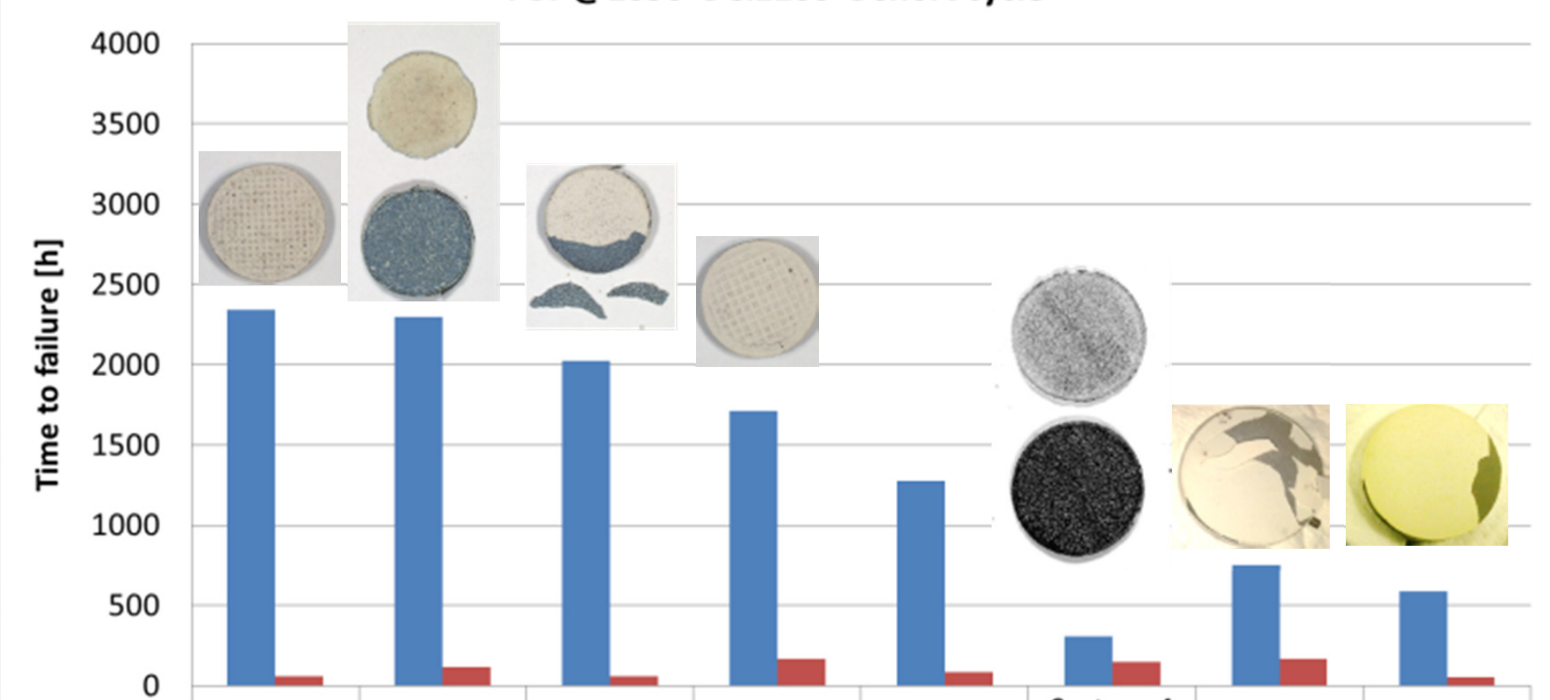




Some samples have been tested up to the End of Life while the others have been stopped at shorter times for characterisation of the kinetics of TGO and Dext growth

Failure criterion: spallation area wider than 10%

FCT tests - RSE Short cycle (2h)



	System 2 3D TIAG f&c HS	System 6 (19 - 23% por[illegible])	System 5 TIAG f&c HS	System 1 3D SM204 BNS HS	System 6 (14 -15% po[illegible]ty)	System 4 SM 204BNS HS	System 7 EBPVD	System 3 TF LPPS
Average	2344	2[illegible]	2022	1714	[illegible]	305	751	586
std dev	58	[illegible]	59	167	[illegible]	148	169	50

Comments

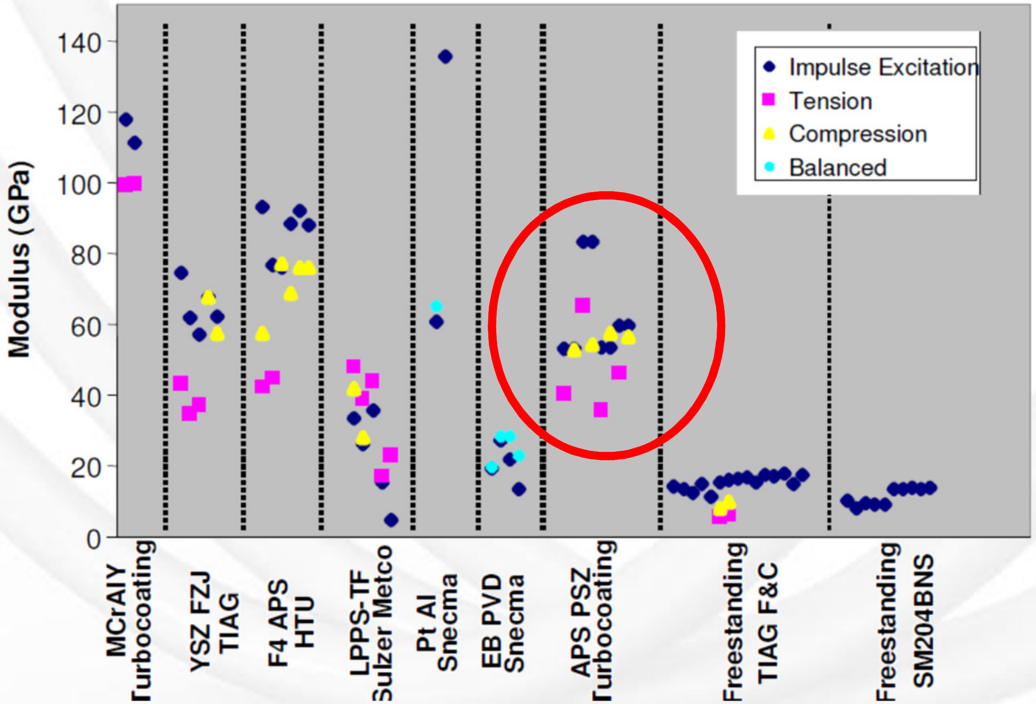
- **Although more samples would be needed for statistically sound conclusions**:
  - ✓ by increasing the temperature and reducing the cycle length a discrimination among different TBC systems is allowed
  - ✓ failure mode of 3D samples differ from that of the other APS coatings
  - ✓ 3D and porous reference APS samples seem to be the best performers*
  - ✓ The PVD coatings perform similarly within the scatter of data, as pointed out also by long cycle FCT

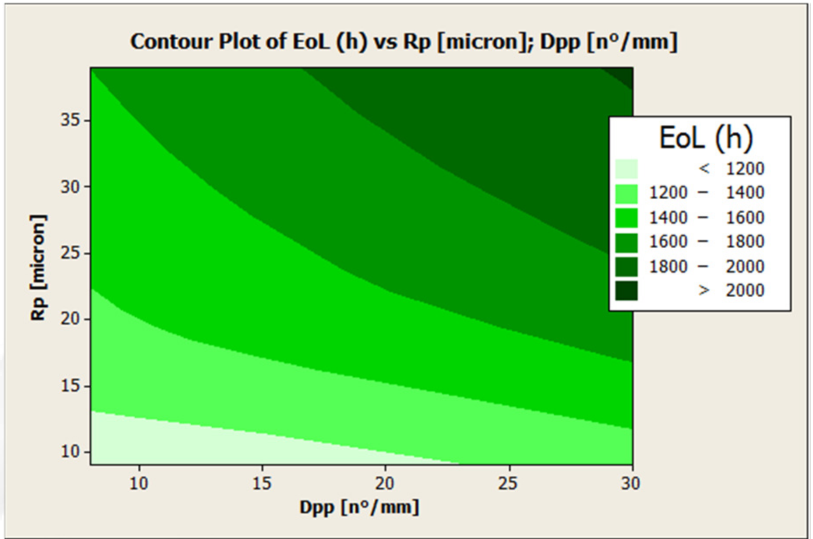
FCT tests – follow up: modelling

$$\frac{da}{dt} = A * \left(G_{el} + \frac{1}{b} * G_{TGO}\right)^m \qquad G_{TGO} = \frac{E_{TGO} * (1 - \upsilon_{TGO}^2)}{(1 - \upsilon_{TGO})^2} * (\beta * (1 + fox))^2 * d_{TGO} * Y^2 * f(r)$$

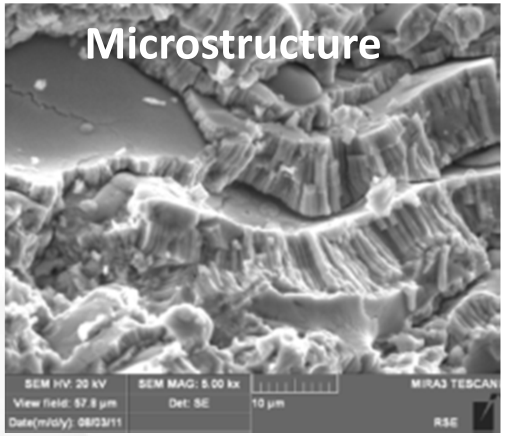
$$G_{el} = \frac{E_{TBC} * (1 - \upsilon_{TBC}^2)}{2 * (1 - \upsilon_{TBC})^2} * \left(\left(\alpha_{th}^{TBC} - \alpha_{th}^{Sub}\right) * (DBTT - T_{min})\right)^2 * d_{TBC} * Y^2 * f(r)$$

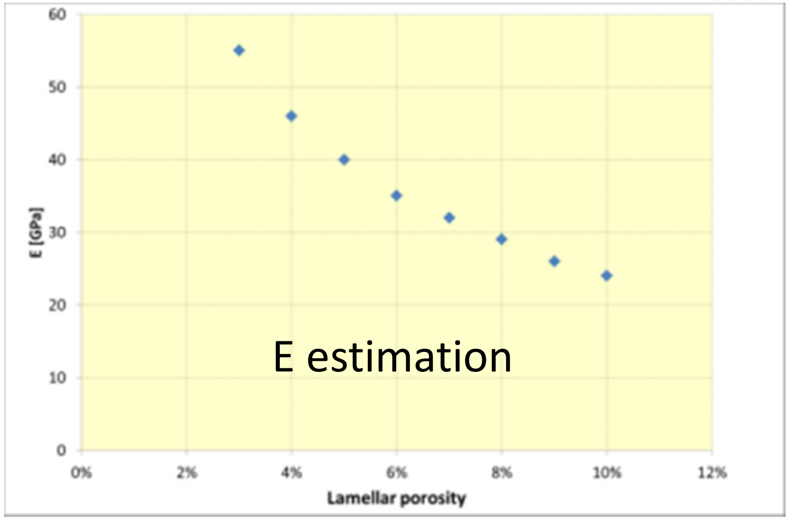
T. Beck, R. Herzog, O. Trunova, M. Offermann¸ Surface Coatings and technology 202 (2008) 5901 – 5908.



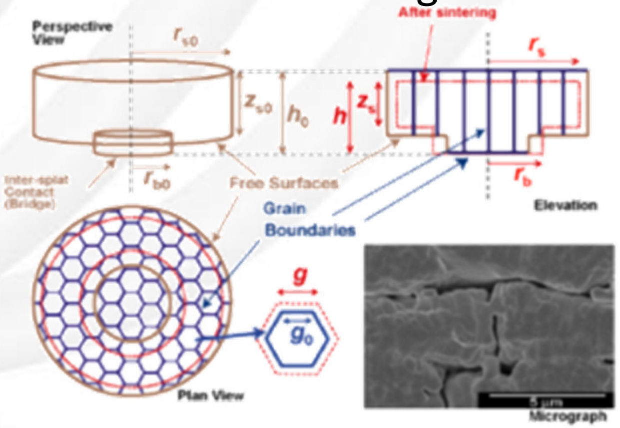


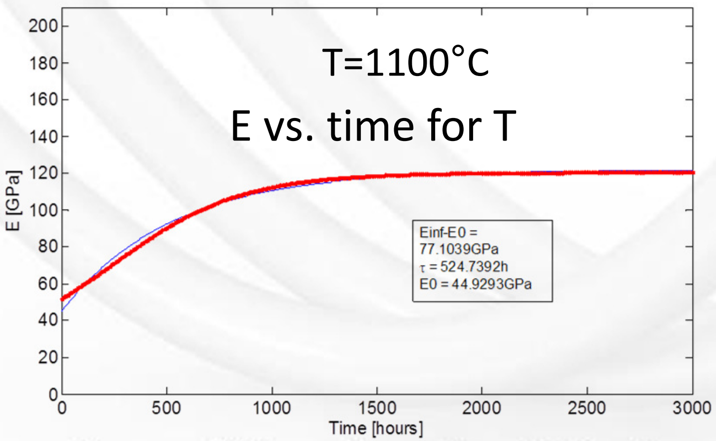
FCT tests – follow up: modelling





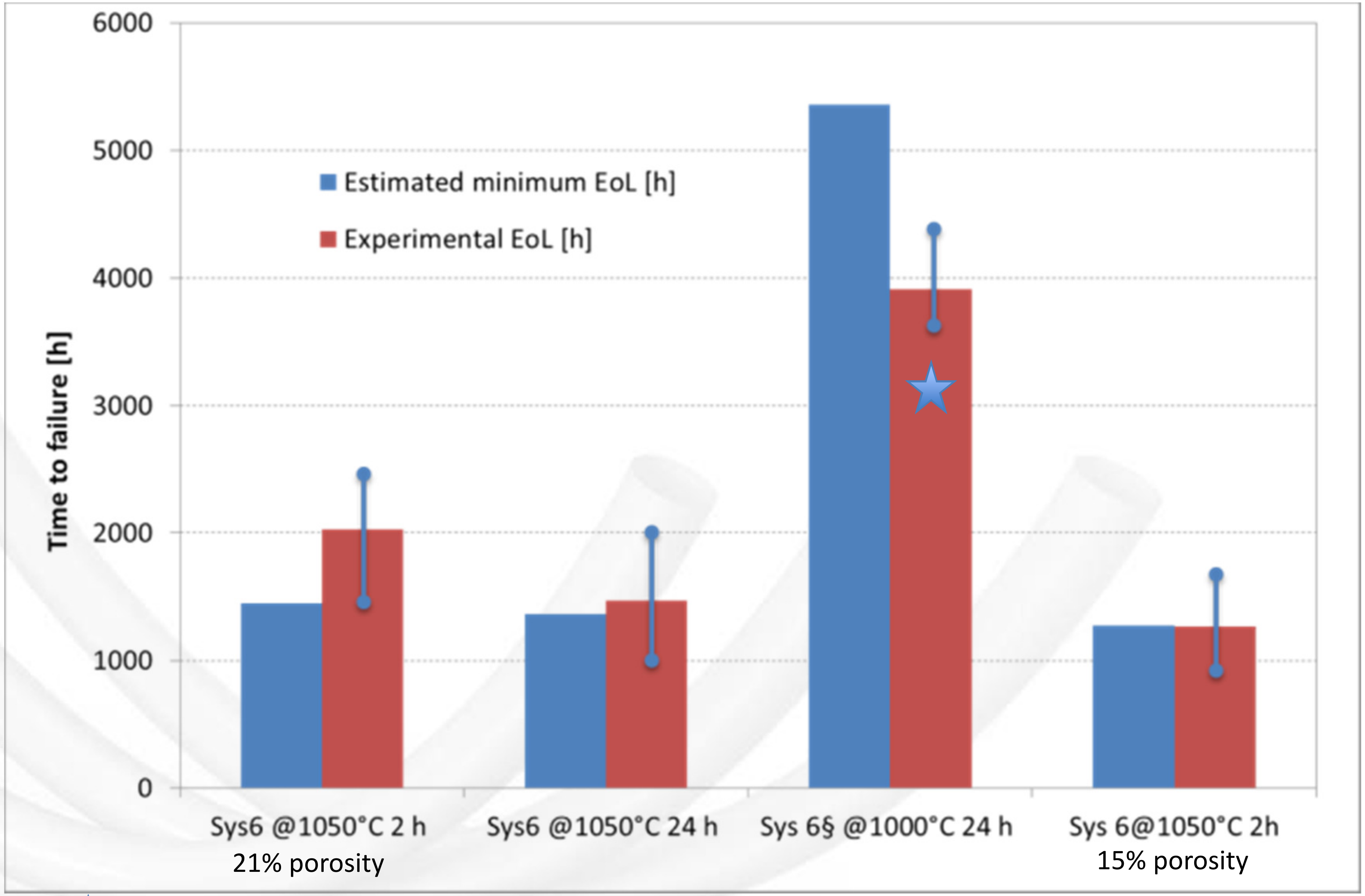
Pore Sintering





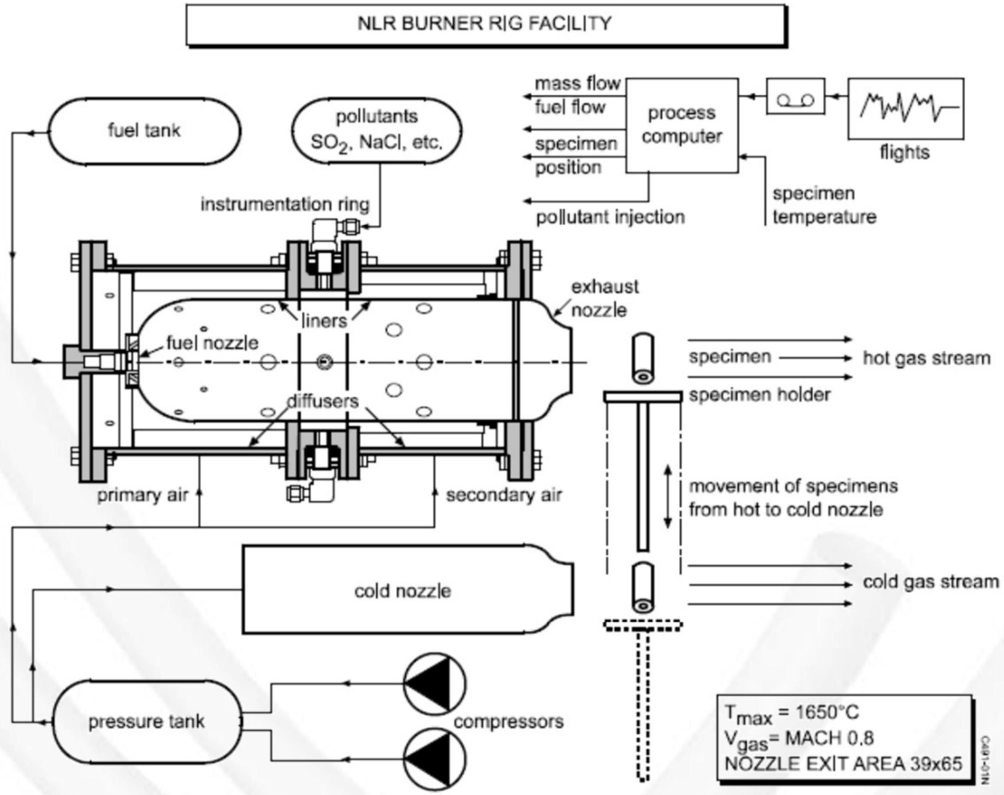
A. Cipitria, I.O. Golosnoy, TW Clyne, Acta Mat. 57 (2009) 980-992

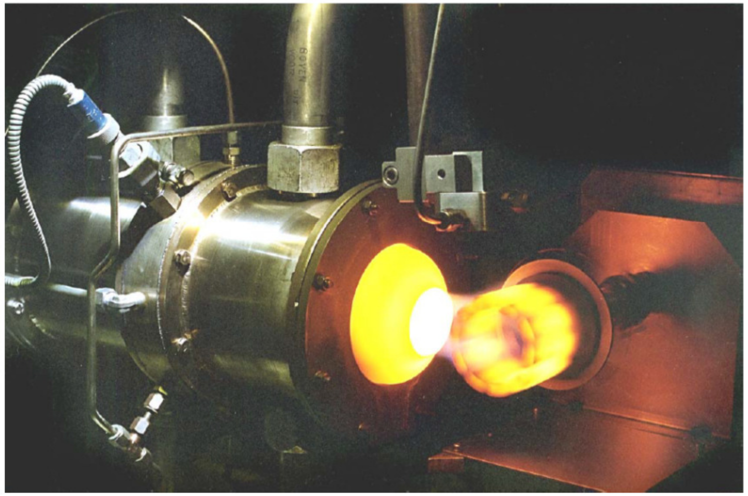
FCT tests – follow up: modelling



★ Different TBC powder

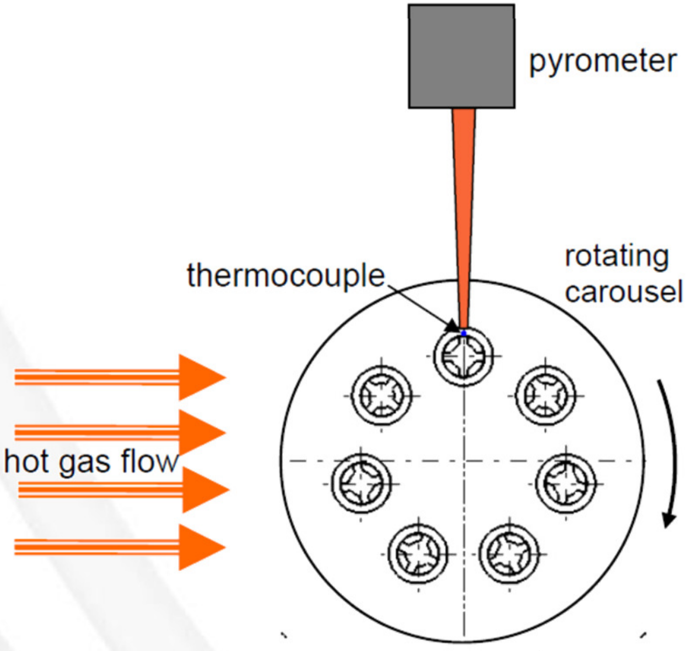
NLR Burner rig

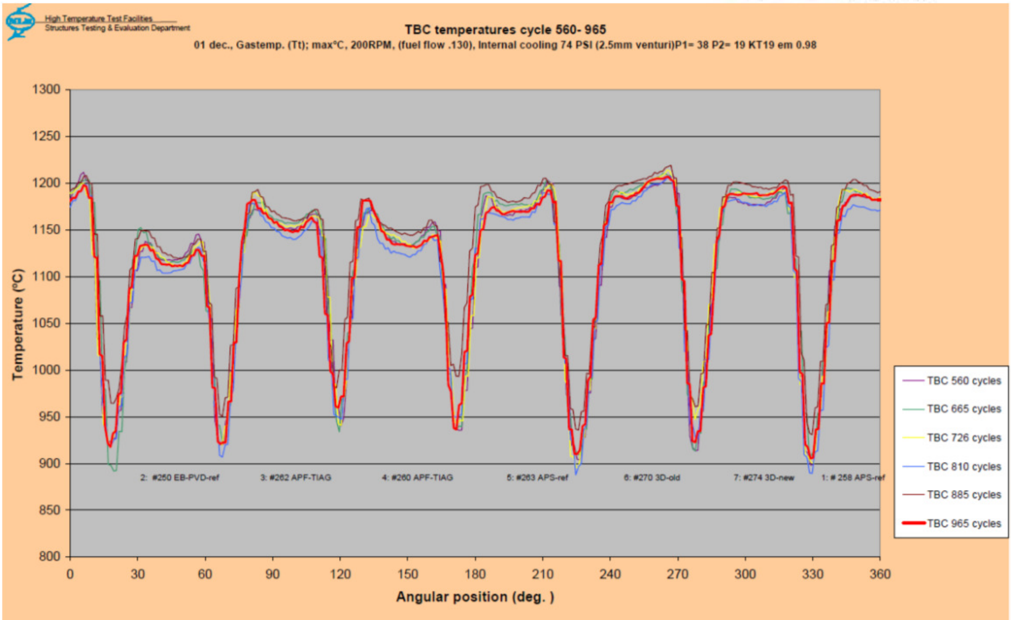


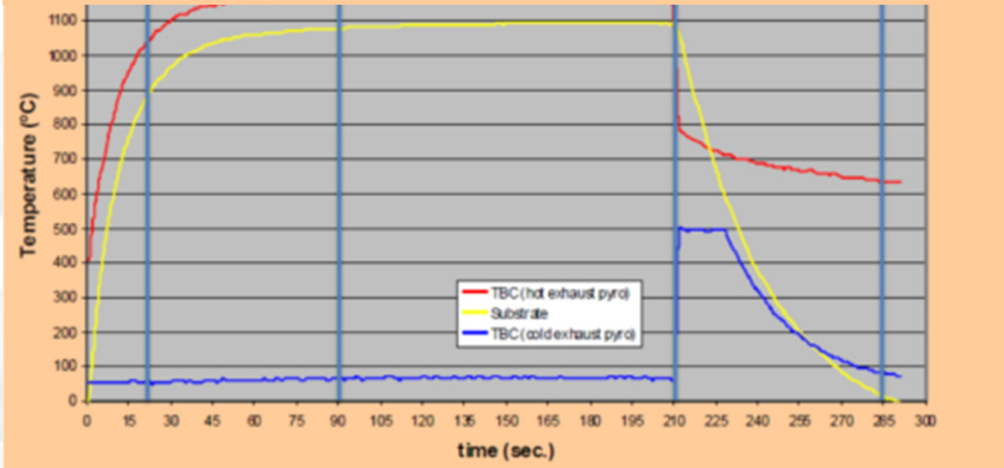


Failure criterion: spallation length >8 mm

NLR Burner rig

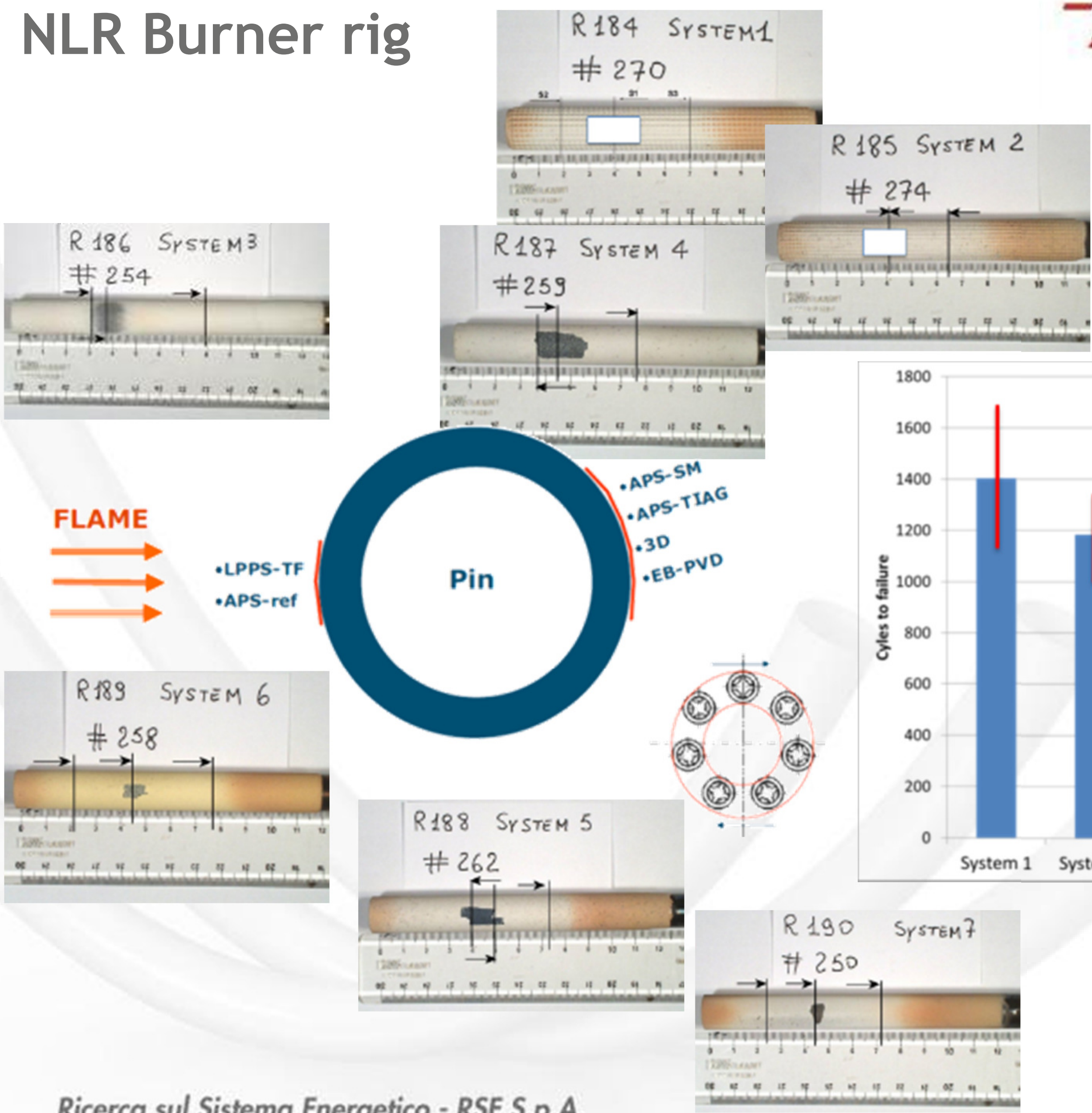


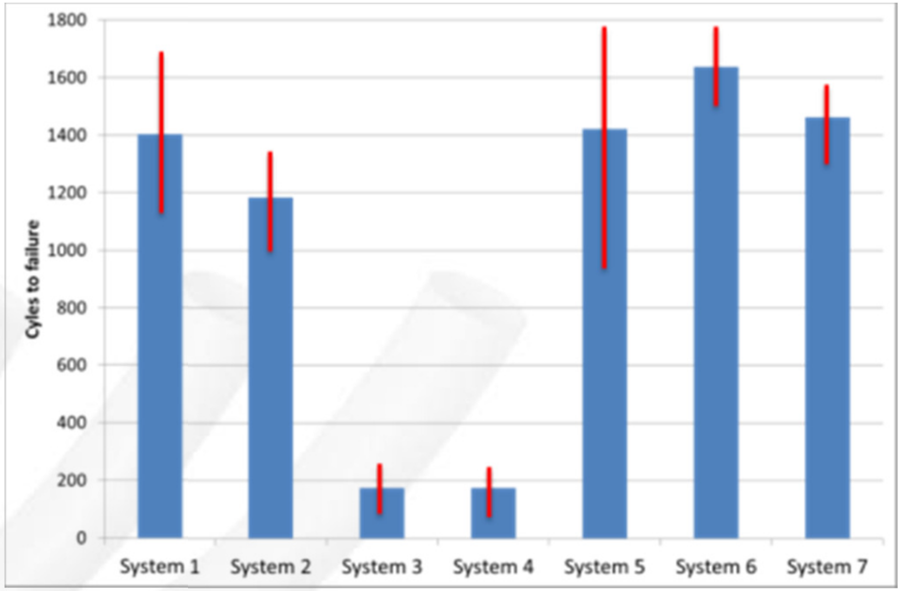




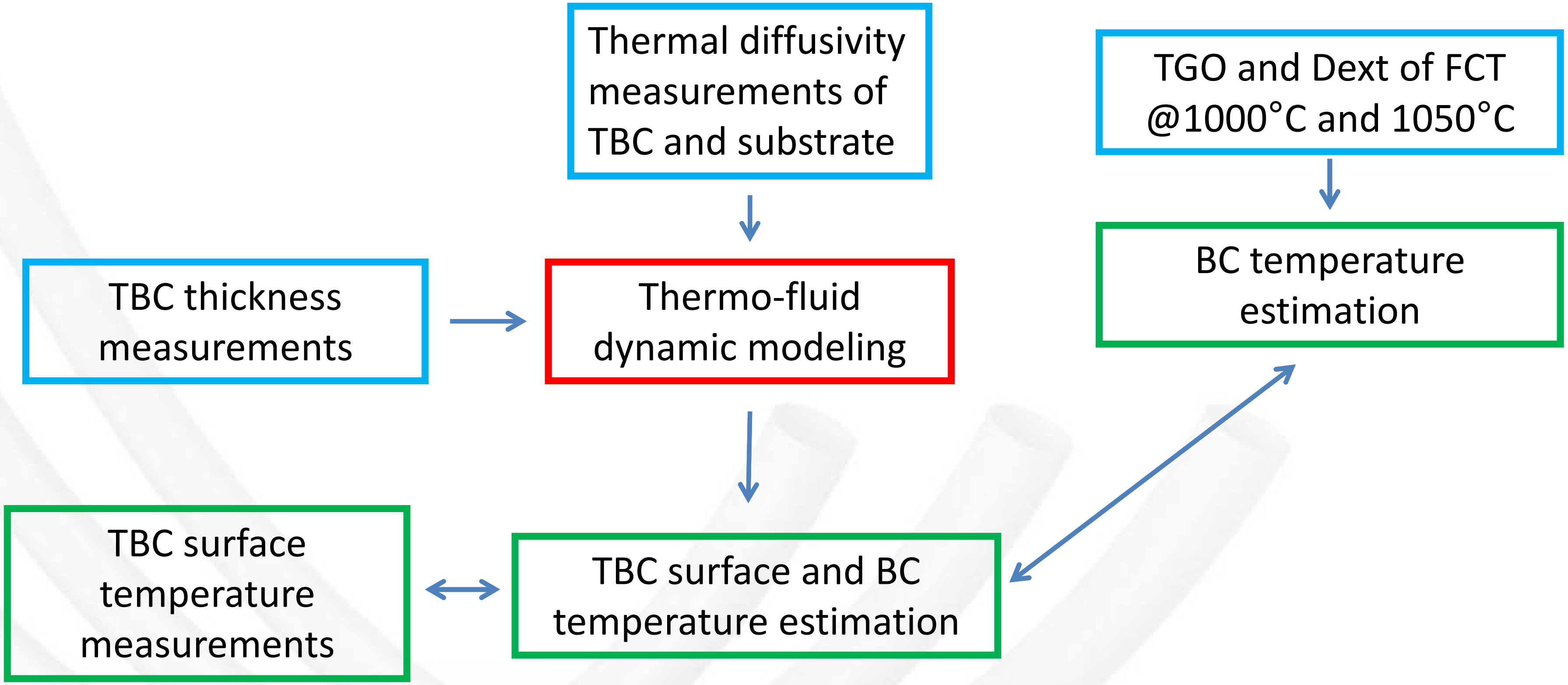
- TBC SURFACE TEMPERATURE 1200°C
- 3 SAMPLES EACH SYSTEM
- 200 RPM COMPATIBLE WITH PYROMETER MINIMUM ACQUISITION TIME
- STOP EVERY 30 CYCLES FOR CHECK INTEGRITY OF TBC

NLR Burner rig

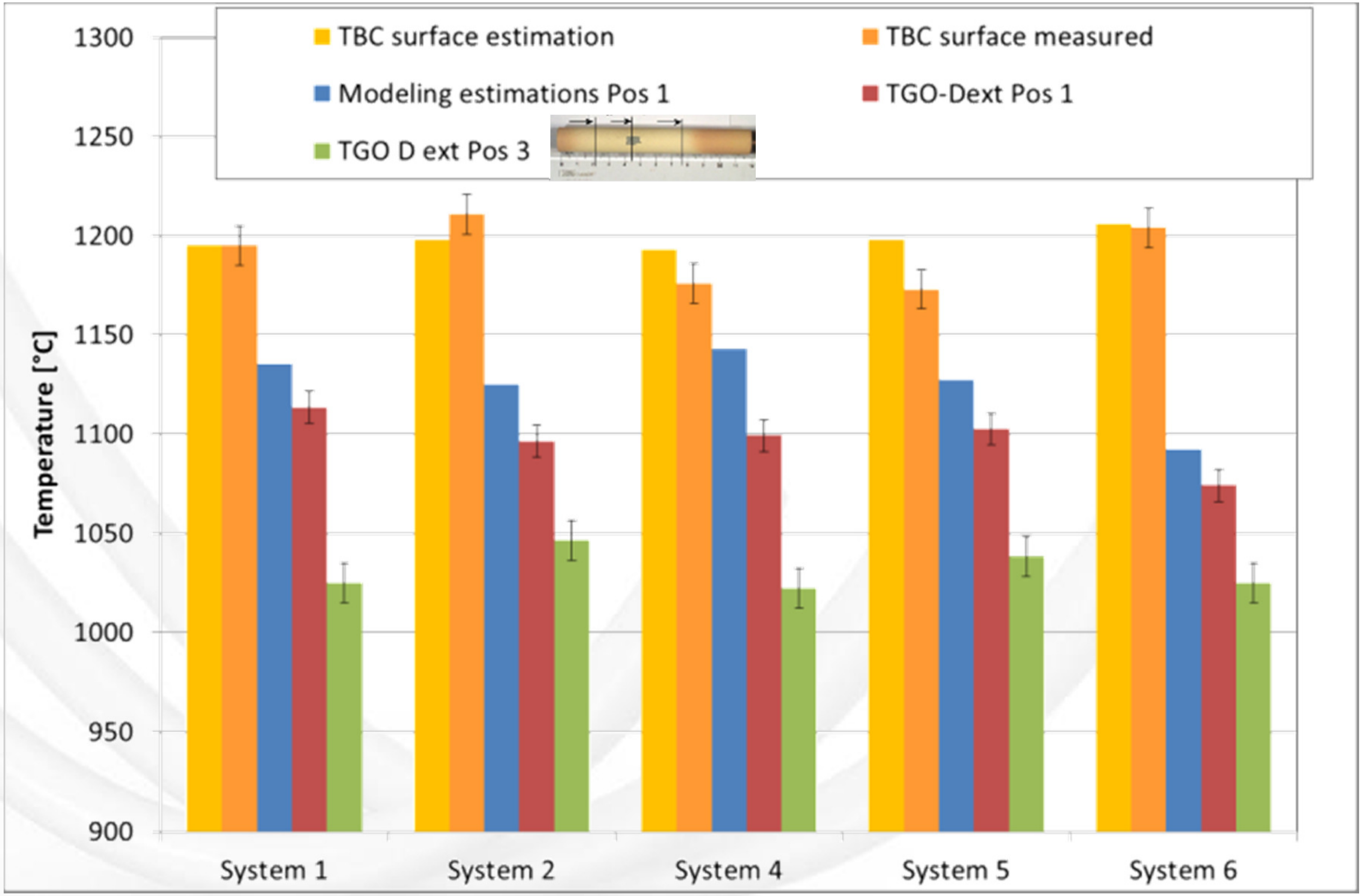




NLR Burner rig - modelling



NLR Burner rig – modelling



NLR Burner rig

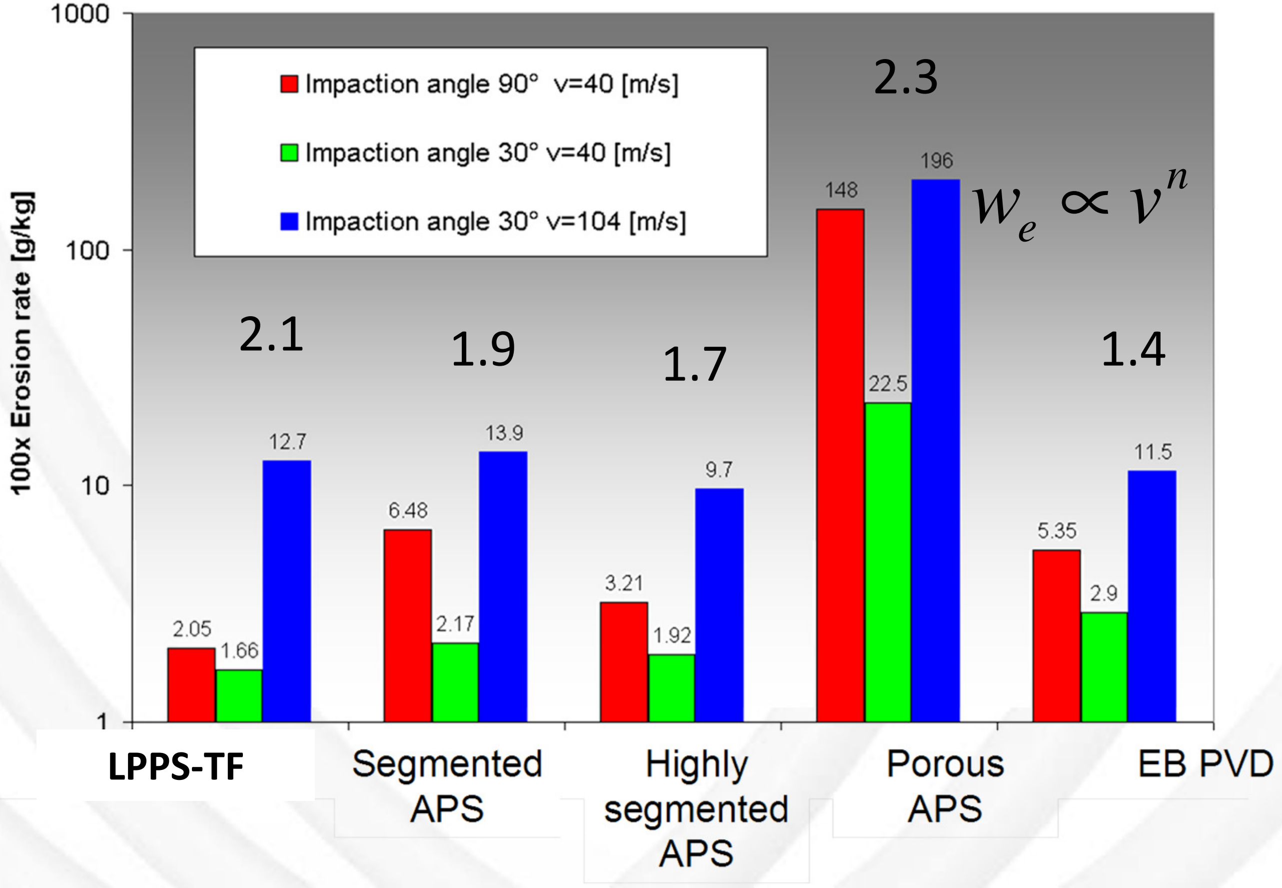
Although TBC and BC temperatures as estimated by the model of the samples show large variations (20 – 40°C) compared to the pyrometer and TGO&Dext estimations, respectively, the outcomes of the model are in line with the experimental data.

Possible causes for quantitative misfit could be:

- differences in **heat transfer coefficient** per coating system owing to **different roughness**.
- differences in **surface emissivity** of both the TBC and the metallic substrate
- **local differences in coating thickness**. For the calculations an average coating thickness was used. The thickness of the coating at the measurement spot of the pyrometer might differ more than ±10% as indicated by the measurements
- differences in **thermal conductivity** between coated test **pins and coated buttons**. This could be especially true for 3D interface samples. In fact thermal diffusivity estimation for such a complex sample could be affected by a higher uncertainty: TGO and Dext has been measured between 3D structure while thermal diffusivity and TBC thickness have been considered on the whole section.

Temperatures 3.5 cm far from the failure zones resulted 50 – 75°C lower (as estimated by TGO&Dext thickness)

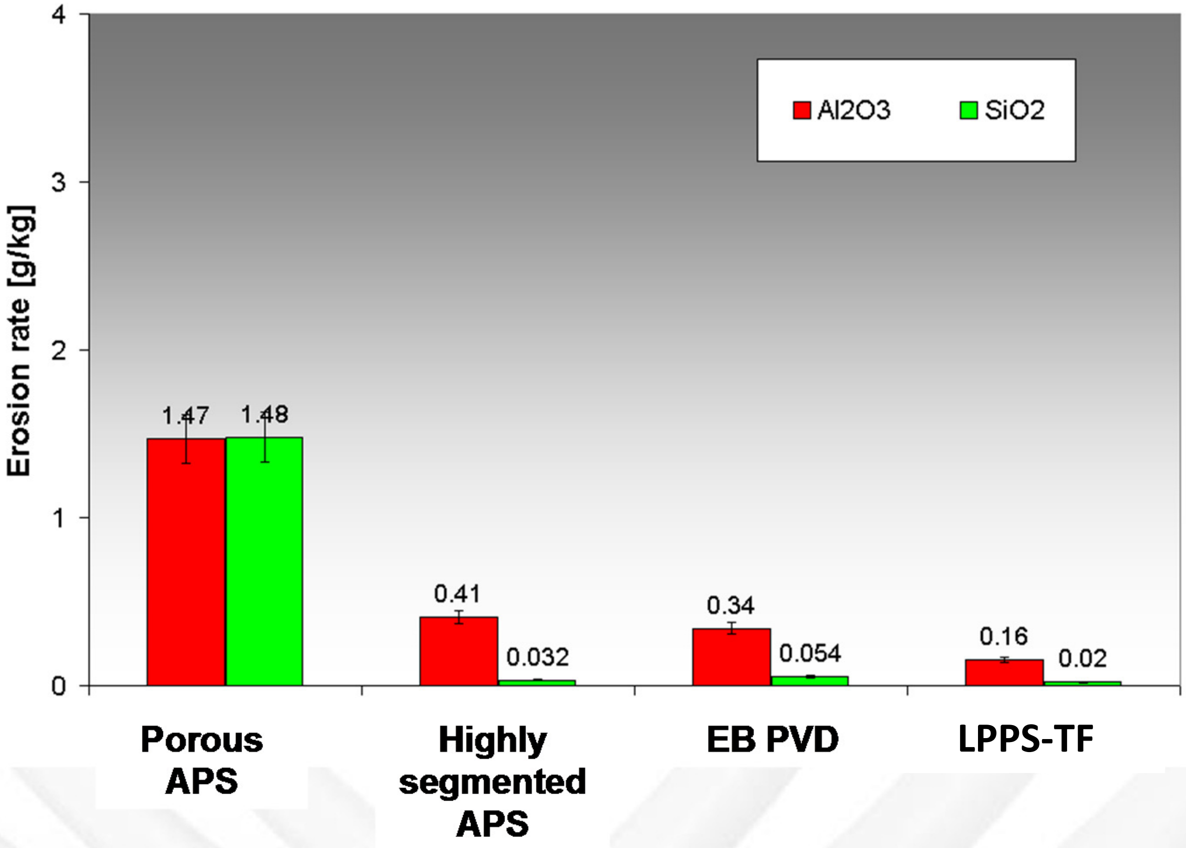
SPE: the erosion rates



F. Cernuschi, C. Guardamagna, L. Lorenzoni, S, Capelli, M. Karger, R. Vassen, K. Von Niessen, N. Markoscan, J. Menuey, C. Giolli, Wear 271 (2011) 2909– 2918

- ✓ LPPS-TF™ performs better than the other TBC systems at low speed
- ✓ HS APS performs similar to EBPVD TBC
- ✓ Erosion rate decreases with impingement angle. The increase from 30° to 90° is in the range 20% - 85%
- ✓ Erosion rate increases from 4 to 9 times increasing the speed
- ✓ The index *n* estimated by comparing erosion rates @ two speeds is close to 2 (3 for bulk ceramics)

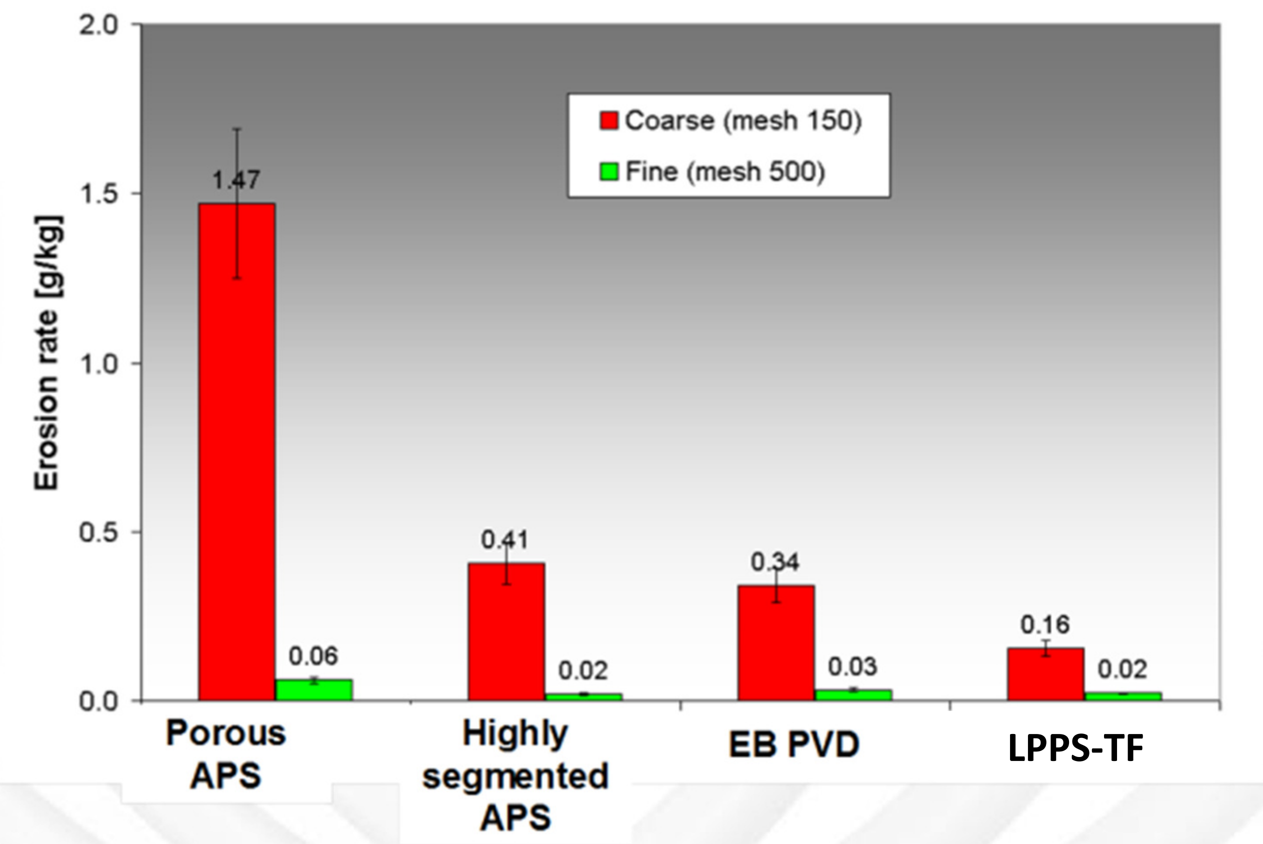
The results: 90° v=40 m/s 104 µm



- ✓ LPPS-TF performs better than EB-PVD and HS-APS (low speed)
- ✓ Erosion rate increases one order of magnitude from SiO_2 to Al_2O_3 for PVD and Segmented APS systems (the particle size distribution coarser for SiO_2)
- ✓ Porous APS is so poorly resistant that erosion rate is less sensitive to particle hardness (Samples supplied by another Lab!! Porosity 16% vs 23%)

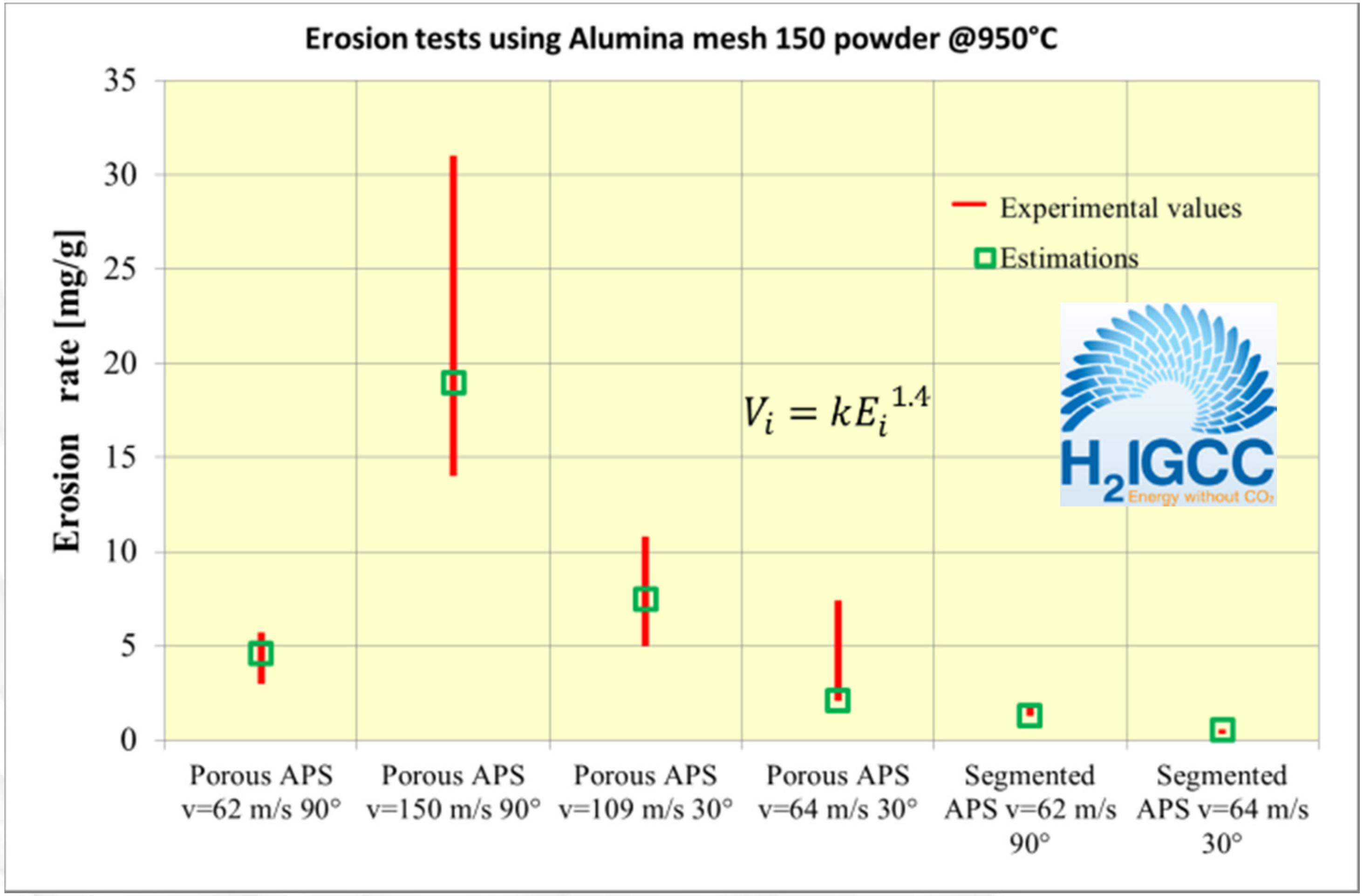
In Advanced Ceramic Coatings and Materials for Extreme Enviroments II, Ceramic Engineering and Science Proceedings Vol. 33, Issue 3, 2012, Wiley.

The results: 90° v=40 m/s



- ✓ Erosion rates decrease from coarse to fine particle size.
- ✓ LPPS-TF performs better than EB-PVD and HS-APS
- ✓ HS APS performs similar to EBPVD TBC

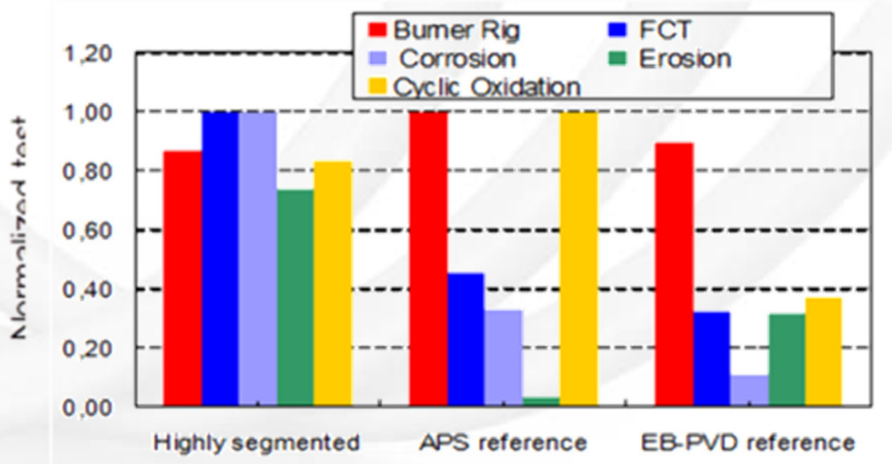
SPE Modelling



Conclusive remarks

Although the outcomes from the testing activity give some indications on the performances of the different TBCs systems, the number of samples tested in each experimental condition is not high enough be statistically significative, but a complete characterisation of all the tested samples was well beyond the efforts and the time scheduling of the project.

Some TBC systems have been tested during the development phase when not all the deposition parameters were completely optimized. This means that poor results cannot be considered as the final finding.



Thank you very much for your attention!