Freestanding Abradable Coating Manufacture and Tensile Test Development

Thermal Spray Coatings Technology,

Metal Improvement Company
Curtiss-Wright Surface Technologies
Derby, UK

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MATERIALS RESEARCH CENTRE
COLLEGE OF ENGINEERING
SWANSEA UNIVERSITY

Freestanding Abradable Coating and Mechanical Testing

- Background to abradable materials in aero-engines
- Abradable materials and manufacture
- Design requirements
- Lack of coating property data
- Freestanding abradable test-piece manufacture
- Tensile testing
- Al-Si hBN Abradable coating properties

Freestanding Abradable Coating and Mechanical Testing

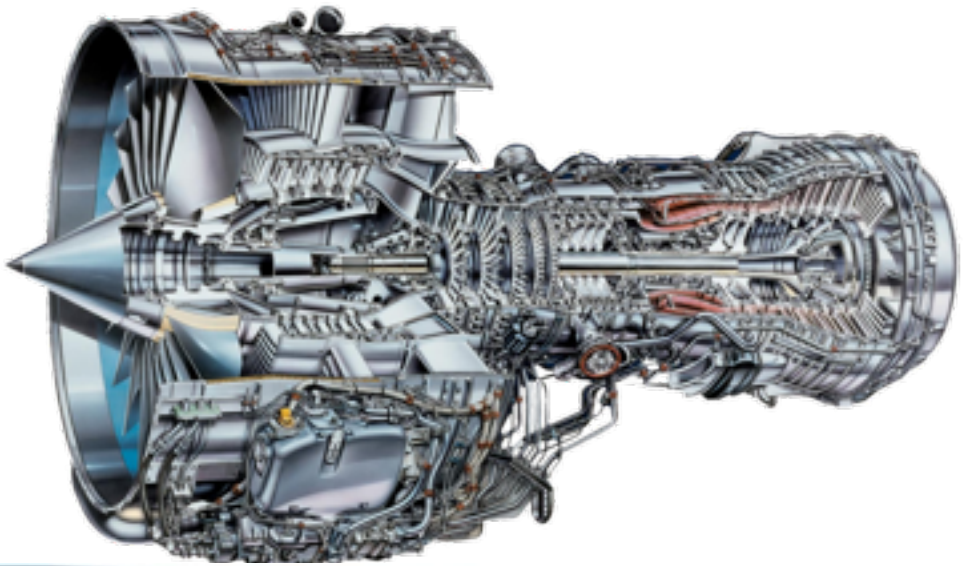
Summary of other characterisation techniques

- X-Ray Microtomography
- Abradability
- Erosion resistance
- Hardness
- Thermal shock/fatigue
- Adhesion/bond strength

Abradable Materials Background

- Aim of abradable materials is to improve engine efficiency and performance by reducing clearance gaps and minimise over-tip gas leakage.

- Abradable linings are designed to wear preferentially to other engine components.



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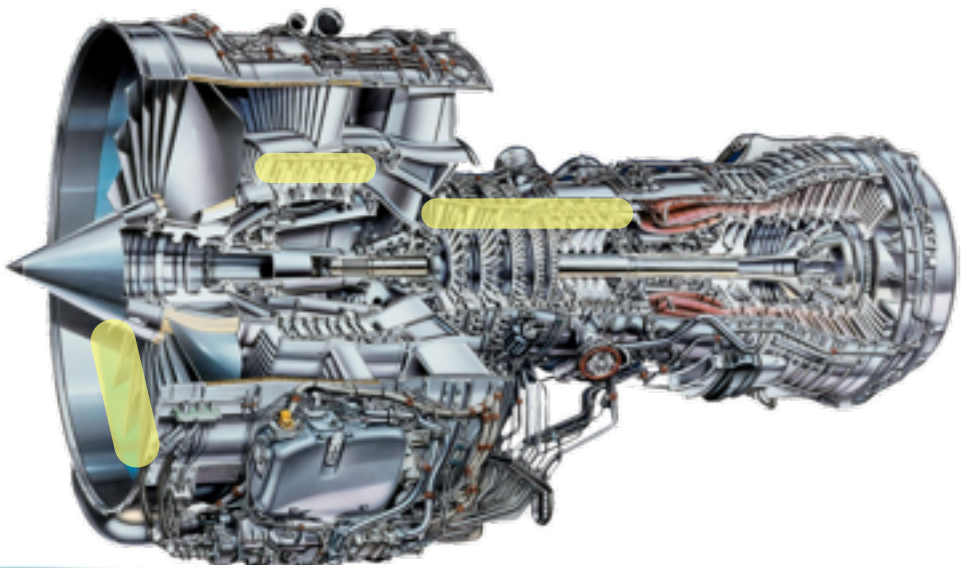

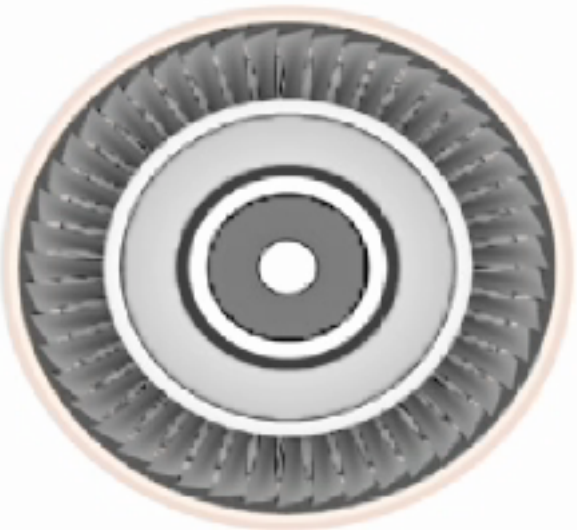

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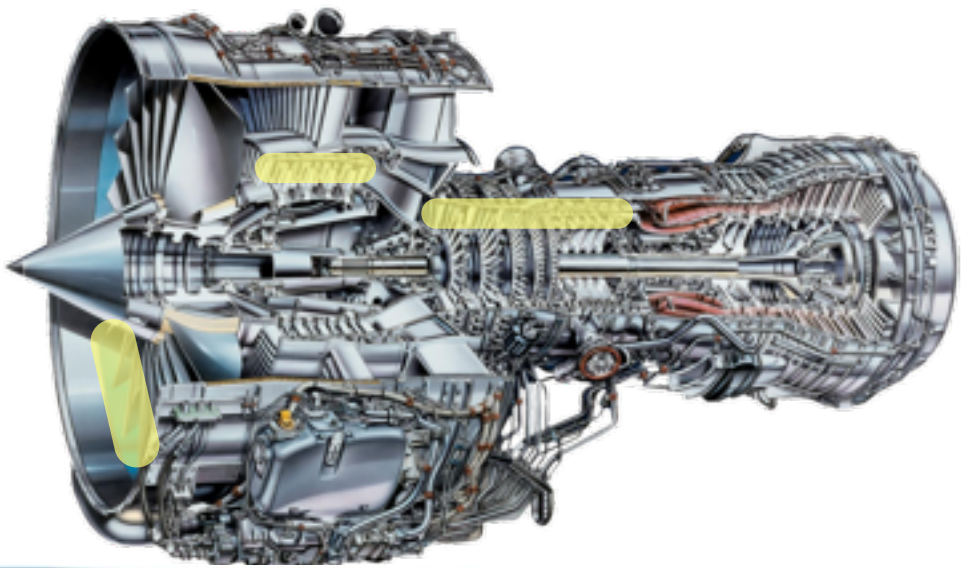
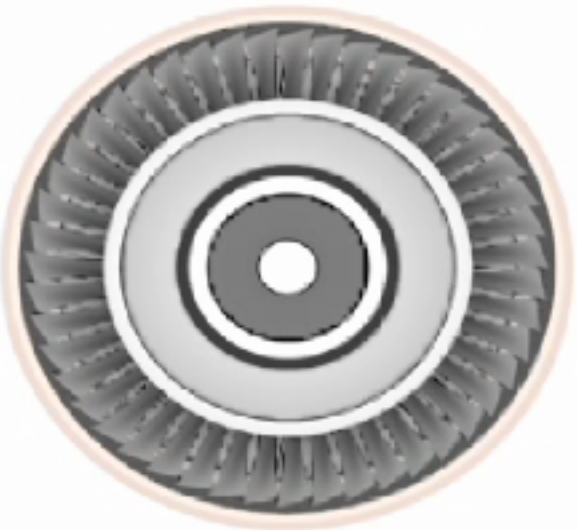
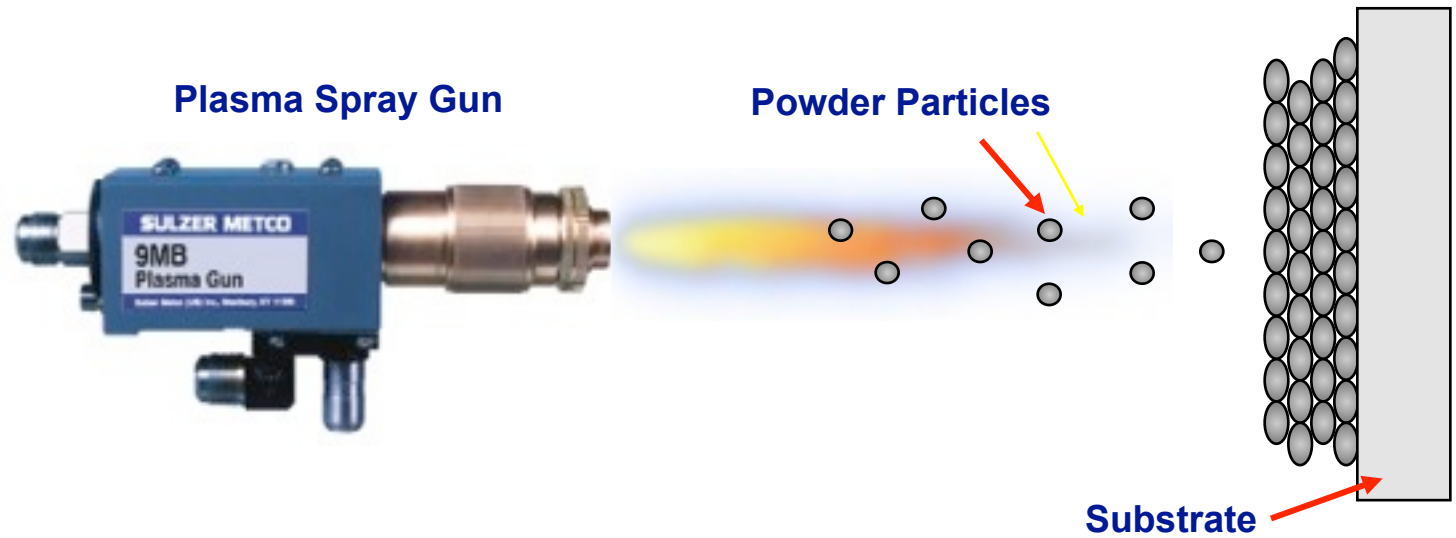




Abradable Materials and Manufacture

➢Thermally Sprayed Materials

- Powder is injected into a high-energy plasma
- Particles cool and solidify on impact

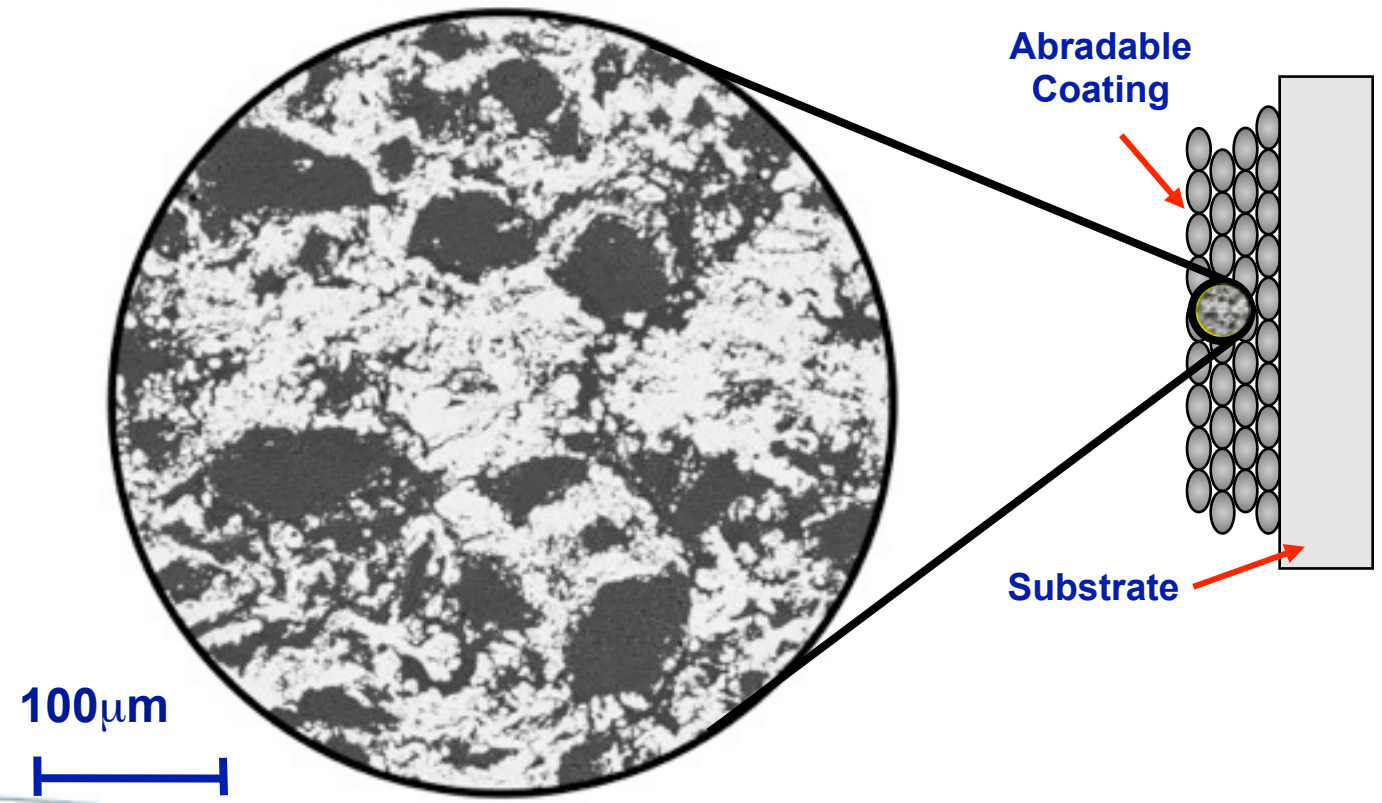


Abradable Materials and Manufacture

➢**Metallic structure**

•Metallic matrix

•Non-metallic dislocator phase



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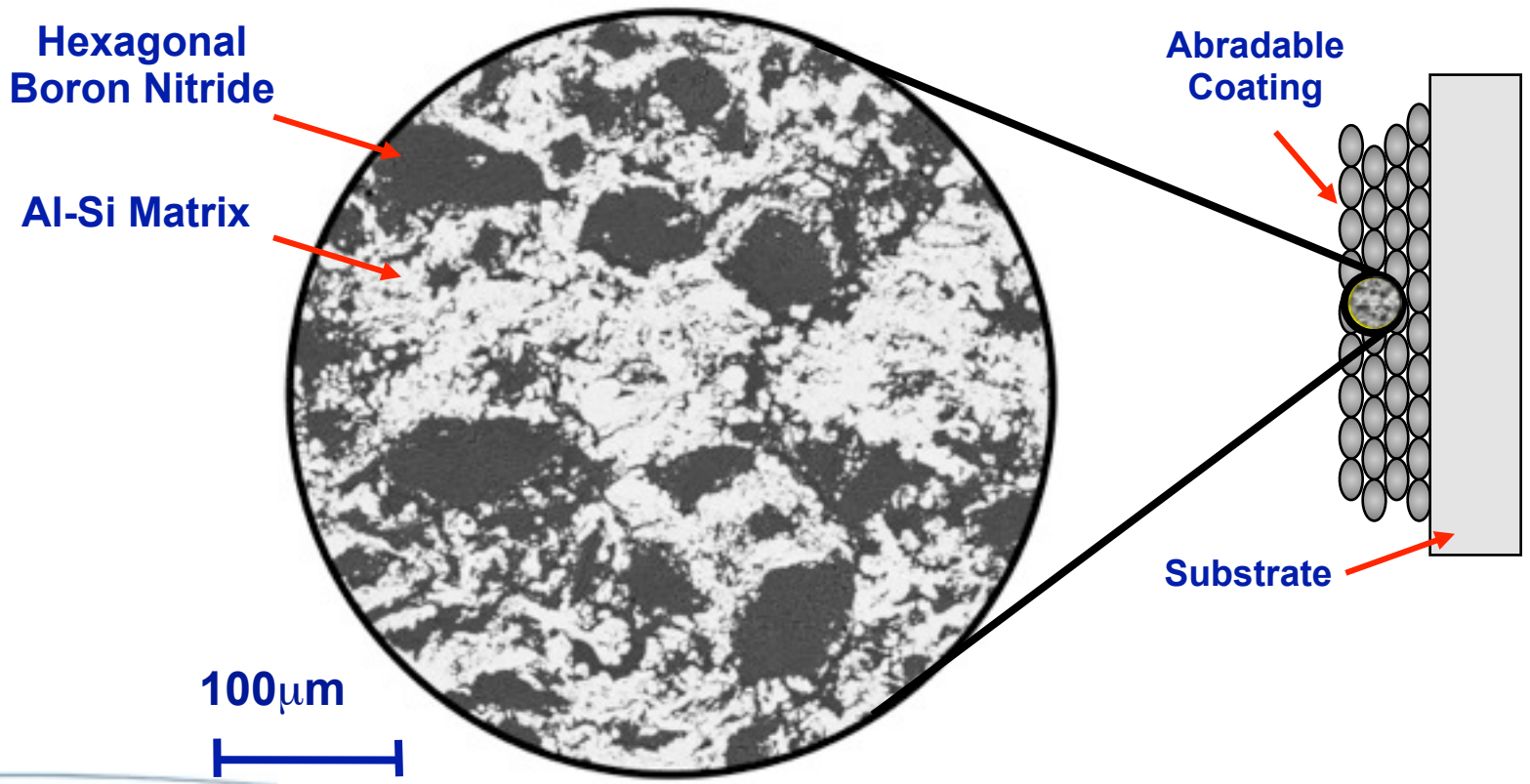
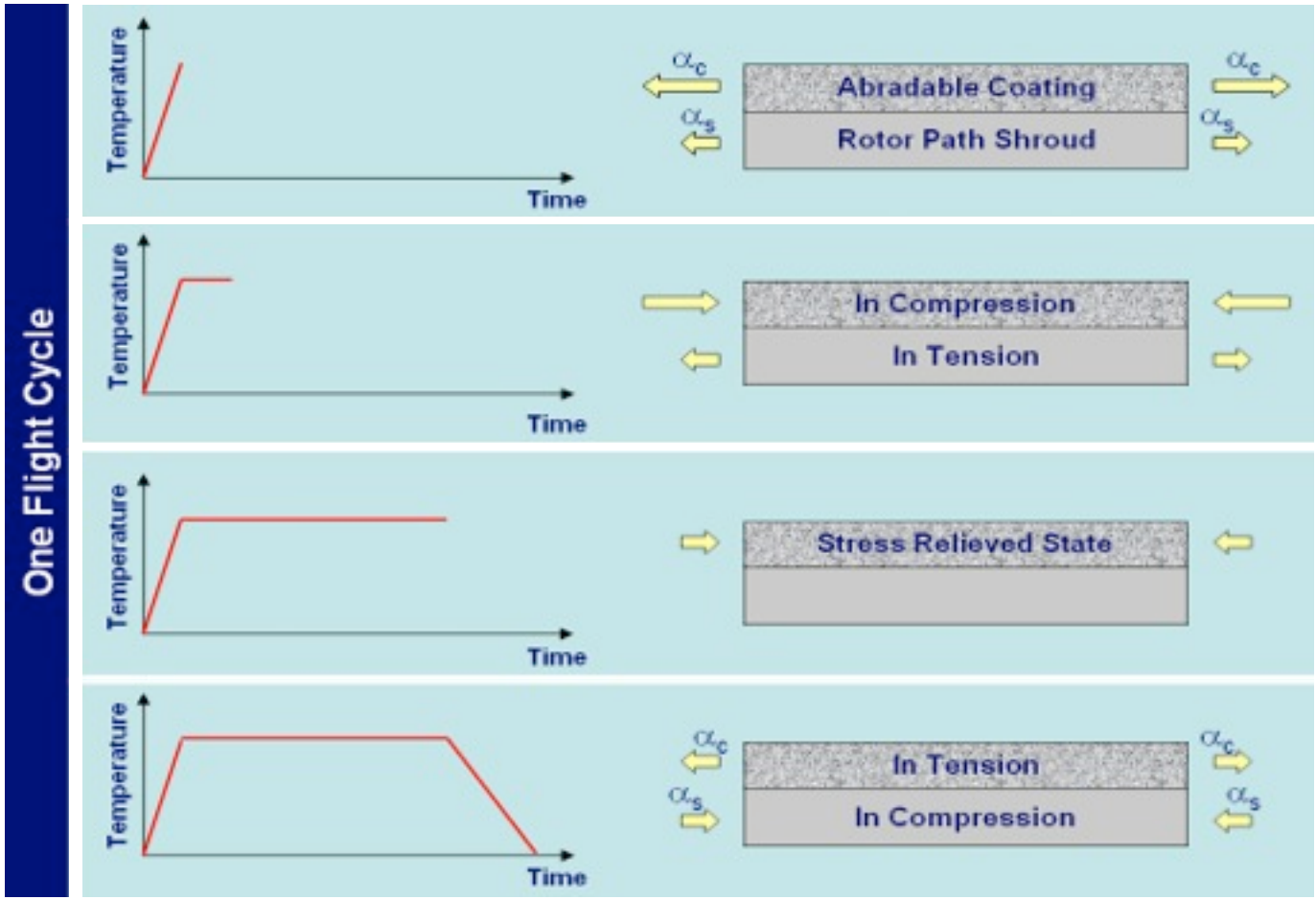


Design Requirements

- **Thermal Fatigue**



Design Requirements

- Thermal Fatigue
  - Mismatch in the Coefficients of Thermal Expansion

- Residual Manufacturing Stresses
  - Grit blasting of substrate (Mechanical)
  - Spray process (Thermal)
  - Subsequent machining (Mechanical)

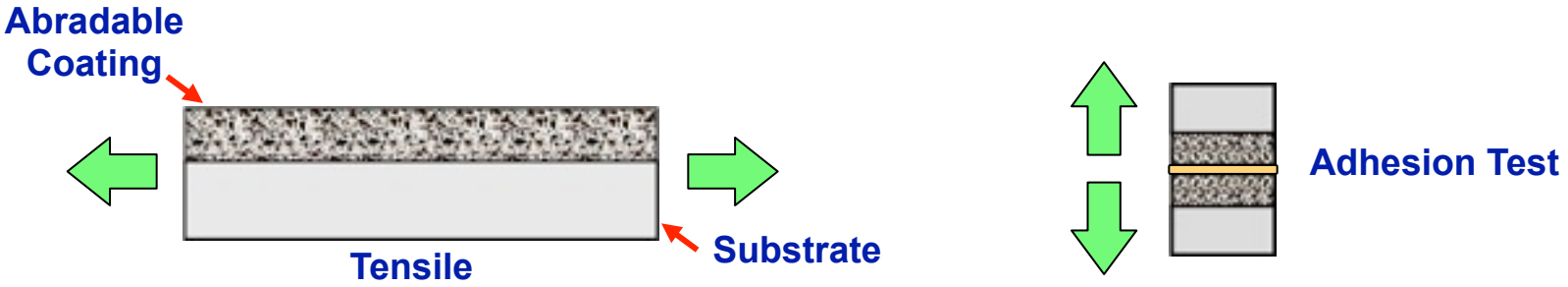
- Erosion Resistance
  - Aggressive gas stream

- High-Temperature Oxidation Resistance
  - Particularly in aggressive environments

Coating Property Data

Coating Property Data

- Difficult to generate representative stresses
- Substrate properties dominate results
- Coating structure results in anisotropic properties



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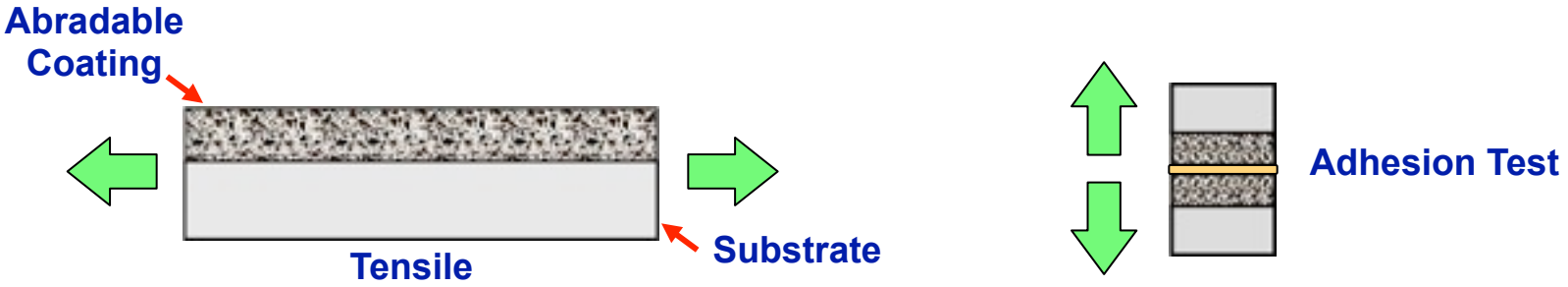
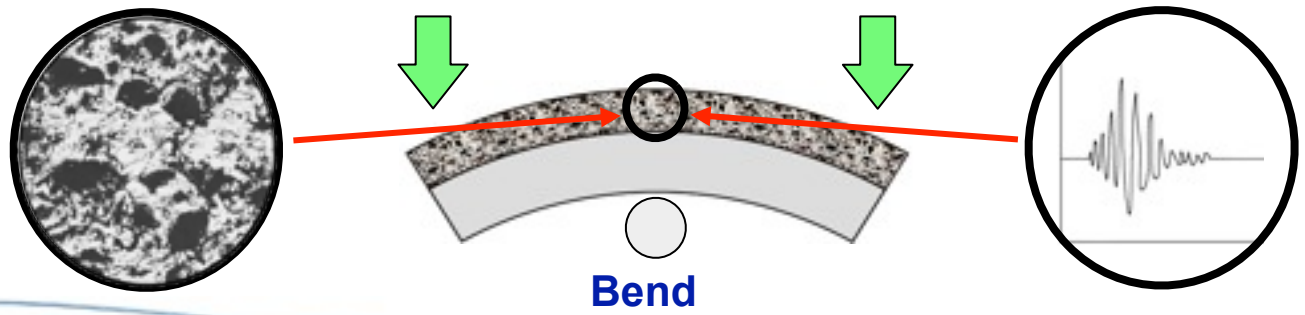


- Coating structure results in a non-brittle failure
- Difficult to detect point of failure



Freestanding Coating Manufacture

- Aquapour™ is used to produce a mould
  - Non-toxic polymer composite material
  - Guaranteed to withstand >200°C
  - Dissolvable in water

Johnston and Evans, *Surf Coat Tech*, Vol 202(4-7), 2007.

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➢Coating is sprayed into moulds

•Rotational configuration representative of engine component

•Abradable material fills mould cavity and bonds to Aquapour™

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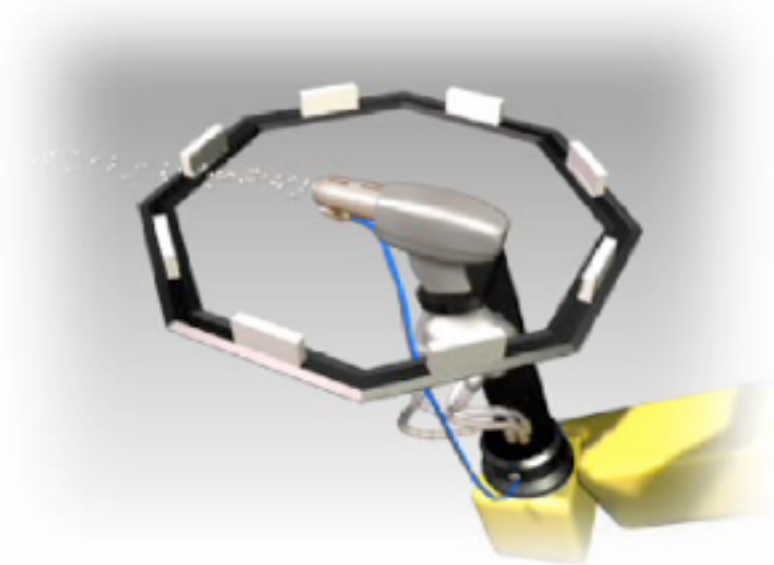

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Freestanding Coating Manufacture

➢Mould material is removed

•Mould structure dissolves in water

•Producing a freestanding abradable coating

•Final test piece machining ensures surface finish

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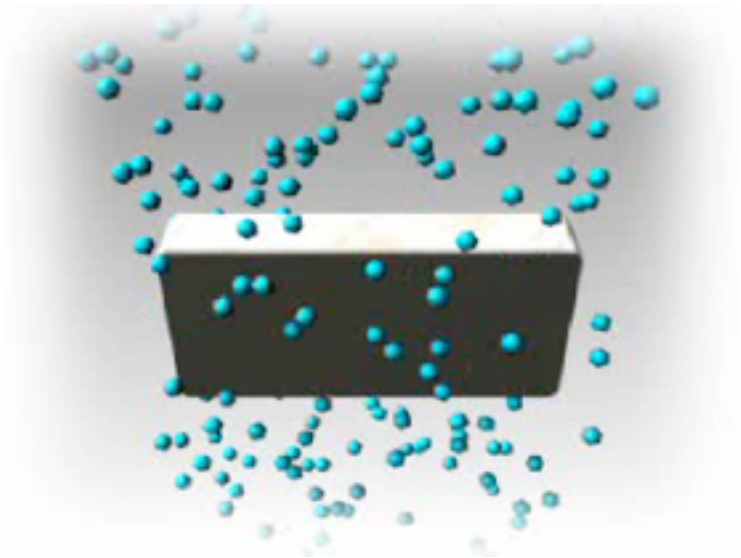

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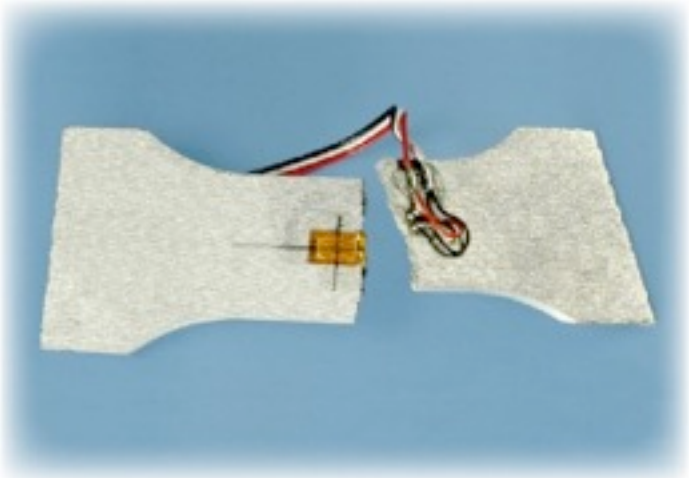
➢Freestanding coating specimen tensile test

•Machined specimen was tested to failure under a tensile load

•Iterative improvement of specimen dimensions



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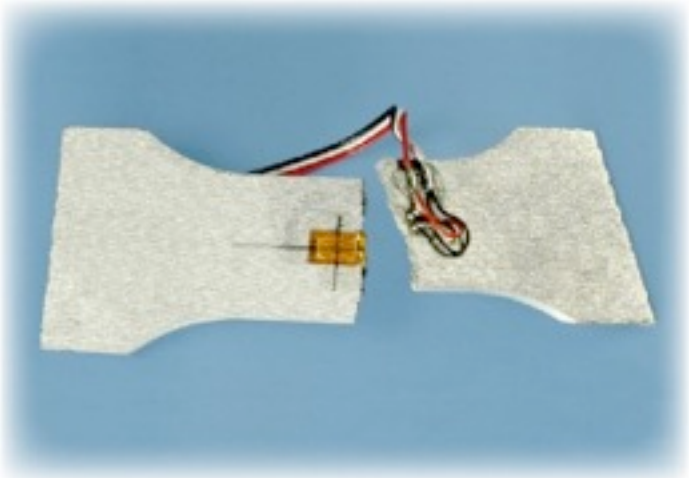

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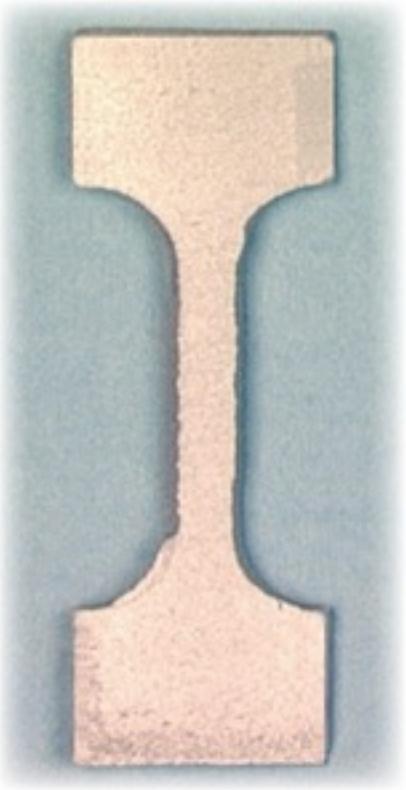
Freestanding Test Piece Development

➢Geometry Considerations

•Small gauge width designed to cause failure within gauge length
•Edge cracking during machining



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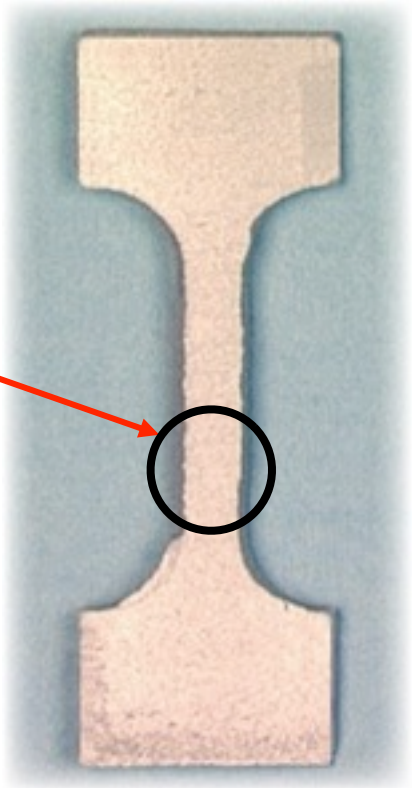

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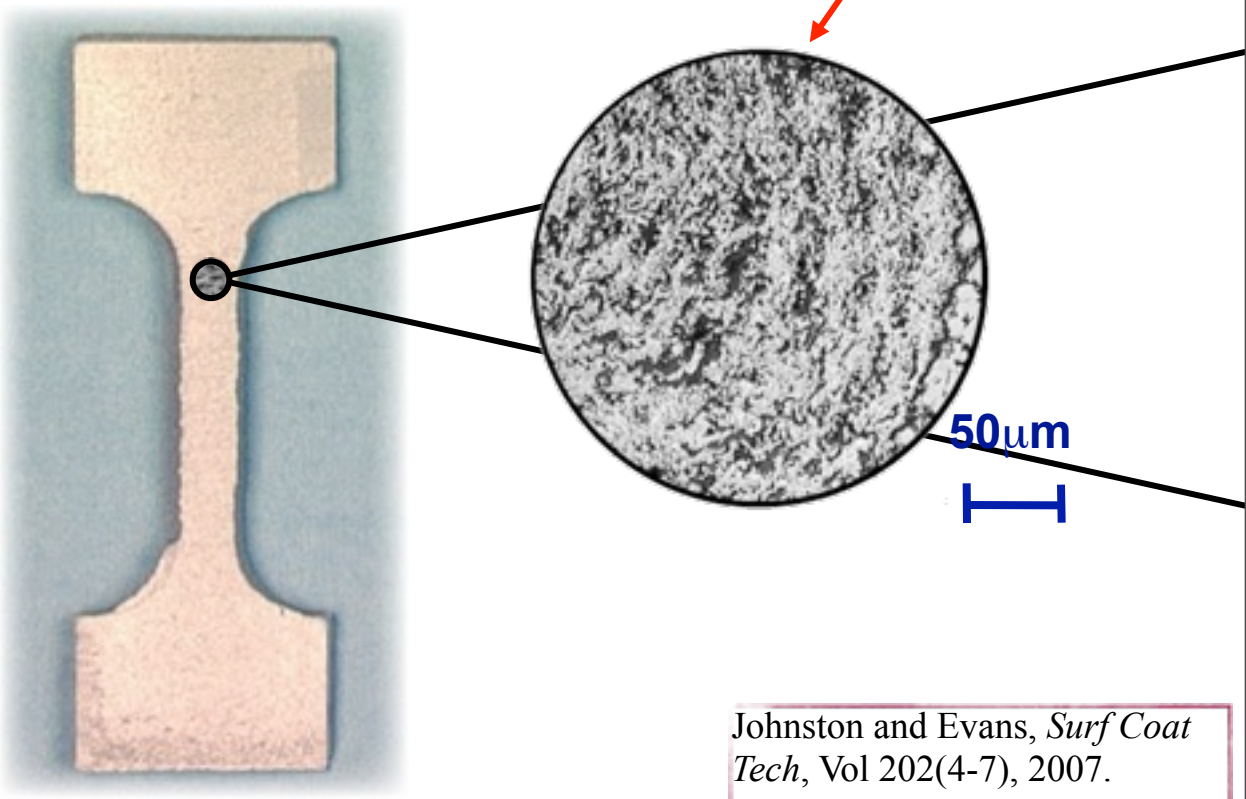

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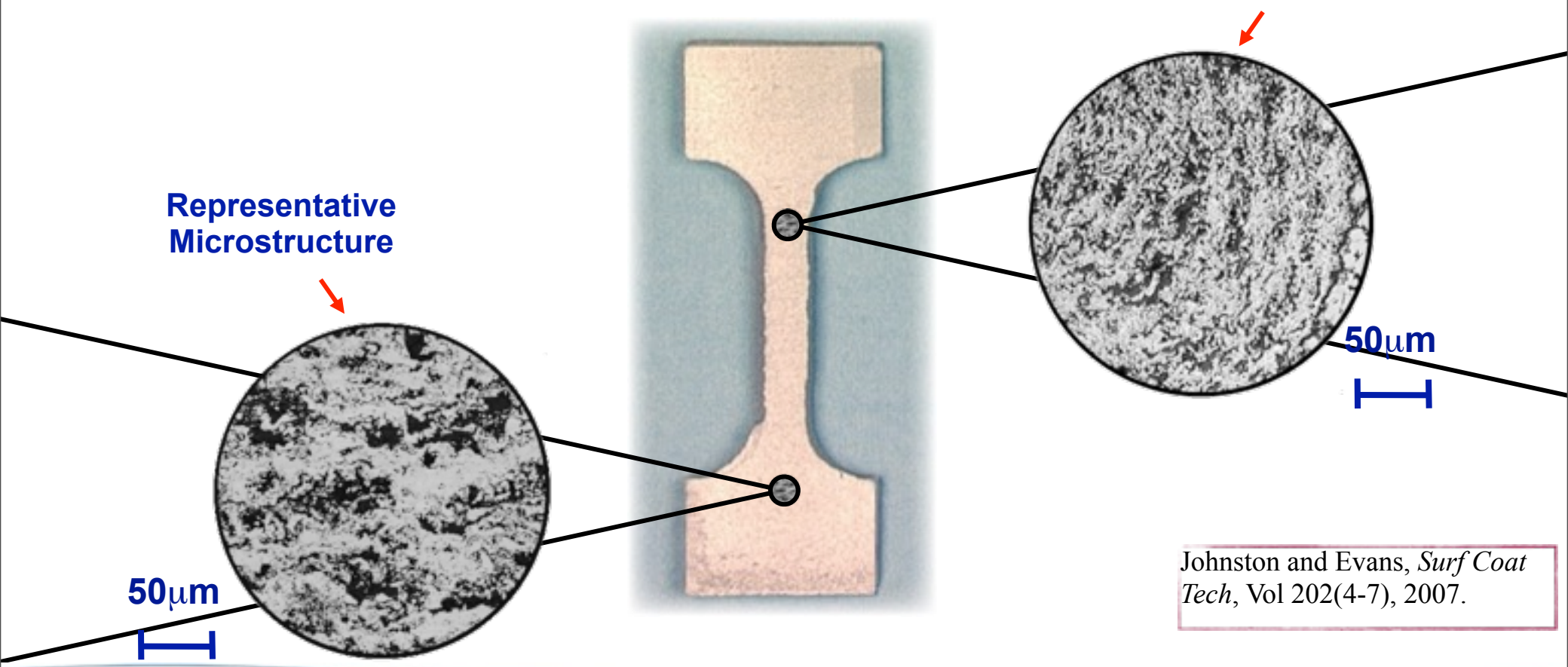

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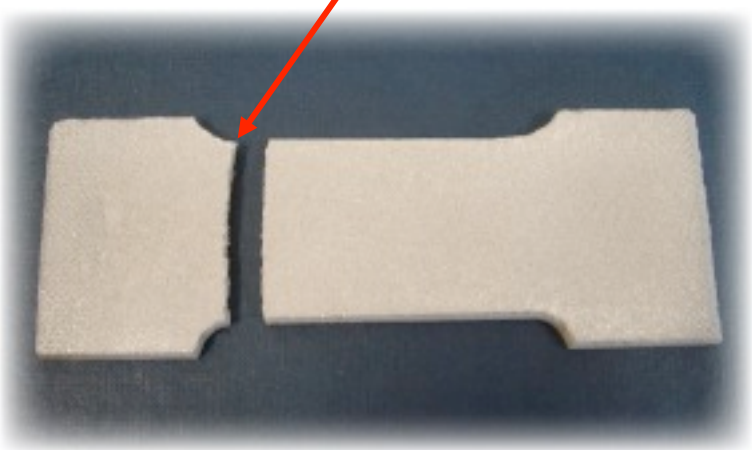
- Test piece geometry optimisation study



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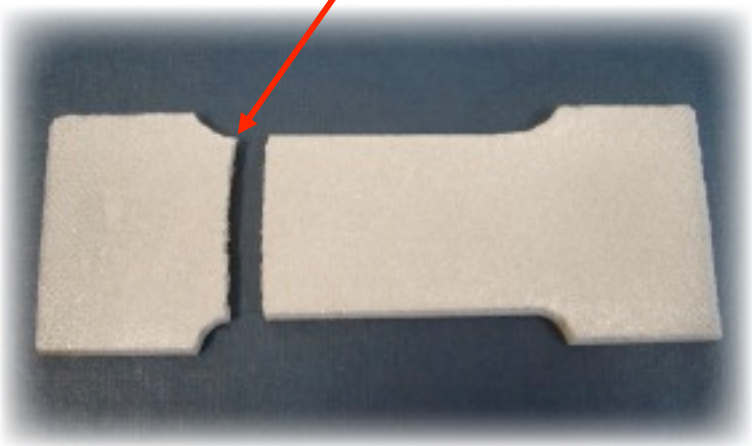
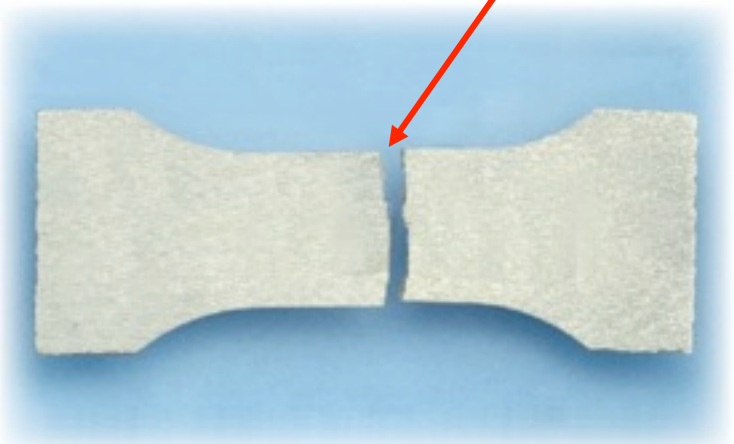
Crack Initiation at Blend Radius
(10mm)



Failure Initiated Within Gauge Length



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Strain Measurement

➢Tensile Testing

•Accurate measurement of load vs extension
•Low stress (< 20 MPa)
•Delicate specimens

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Extension Measurement	Sensitive to Small Loads	Abradable 'Friendly'	Low Extension Accuracy
Cross-Head Movement	✗	✓	✗
Laser Extensometer	✓	✓	✗
Clip Gauge	✓	✗	✓
Strain Gauge	✓	✓	✓

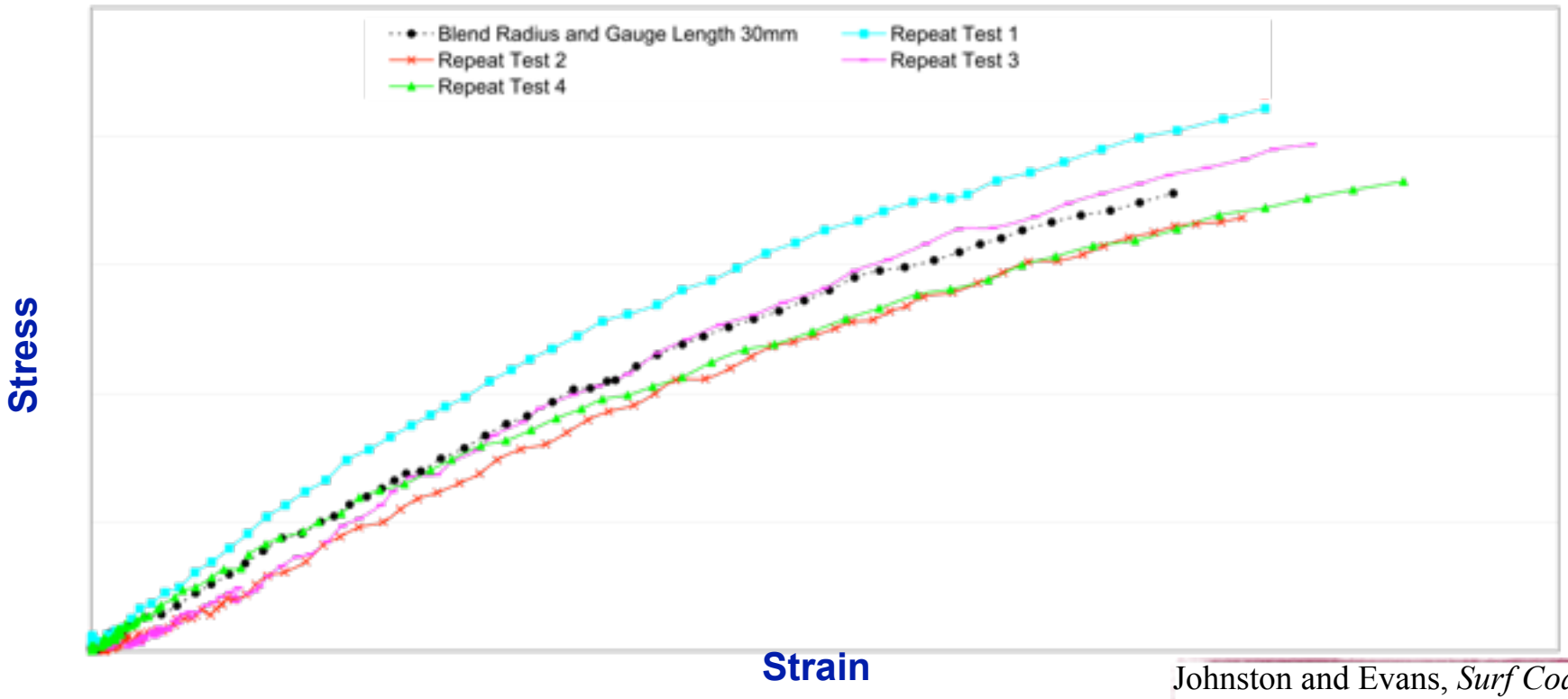
Johnston and Evans, *Surf Coat Tech*, Vol 202(4-7), 2007.

Measured Abradable Coating Properties

➢Stress – Strain plot for Al-Si + hBN abradable coating

•No pure elastic response

•Low strain to failure



Johnston and Evans, *Surf Coat Tech*, Vol 202(4-7), 2007.

Freestanding Coating Development

➢Iterative Development

•Variation of gauge length

•Variation of gauge width

•Variation of blend radius

•Methods of strain measurement

•Assessed failure location, measured properties, statistical repeatability.

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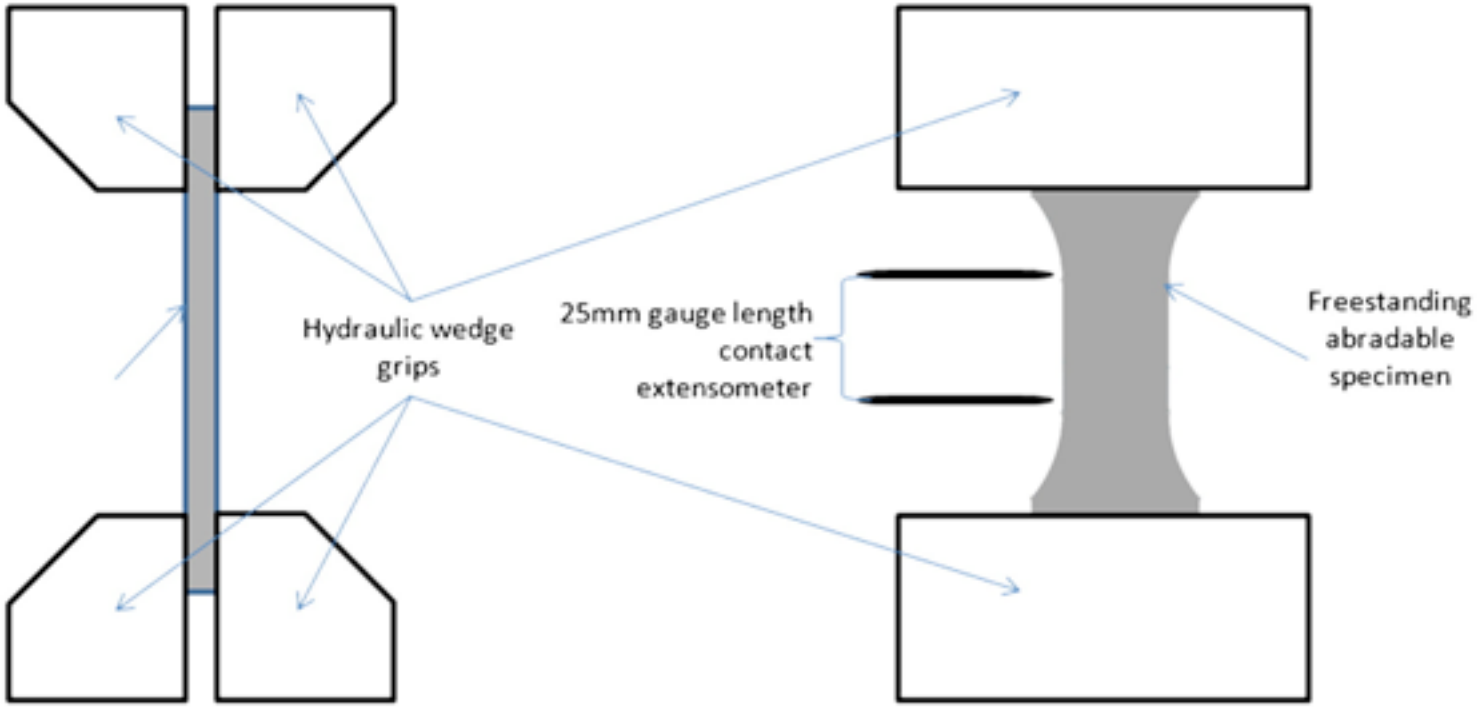

Johnston, *Surf Coat Tech*, Vol 205(4-7), 2011.

Hopkins and Shipman, Patent Nos. EP2361998 A2,A3,B1, US20110203251 A1, 2011-12.

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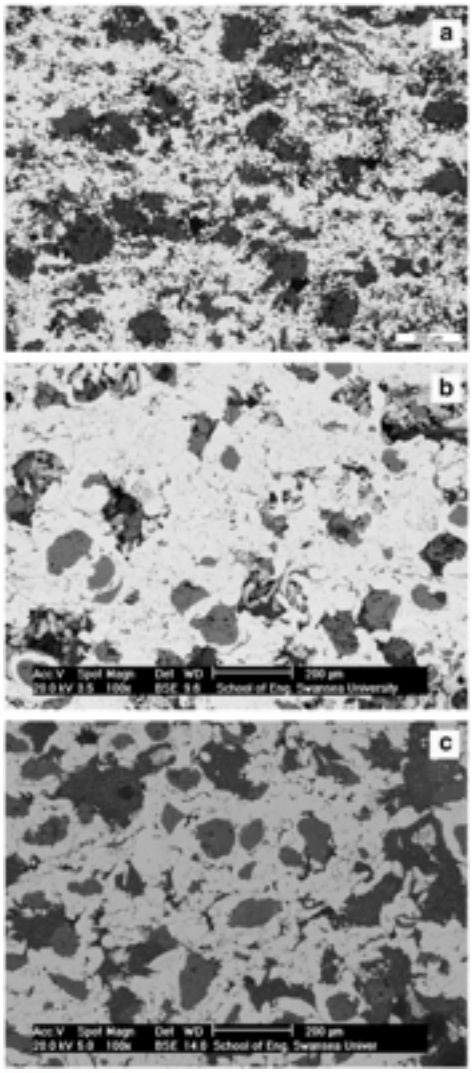

AlSi-hBN

NiCrAl-Bentonite

NiCrAl-Bentonite-BN

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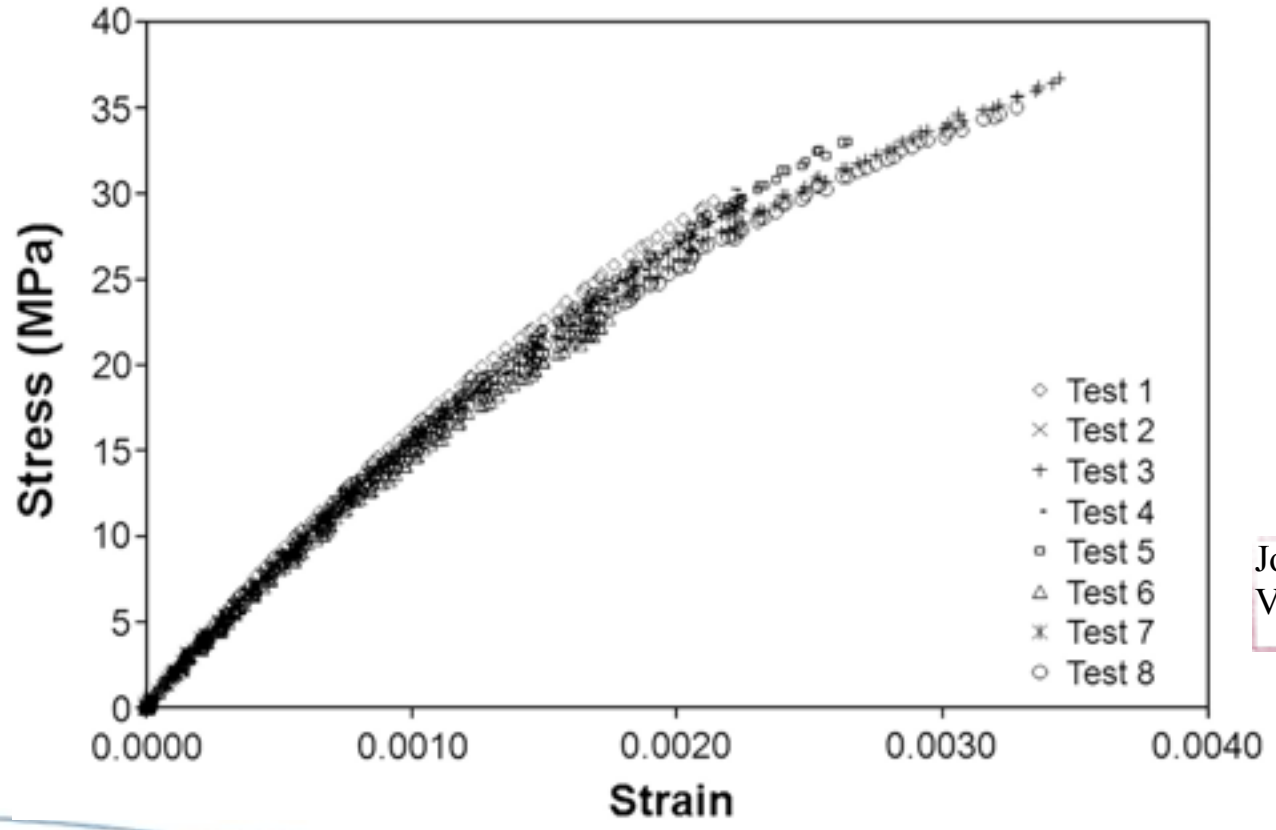
Measured Abradable Coating Properties

➢ Established the methodology → Apply to abradable systems

•AlSi-hBN



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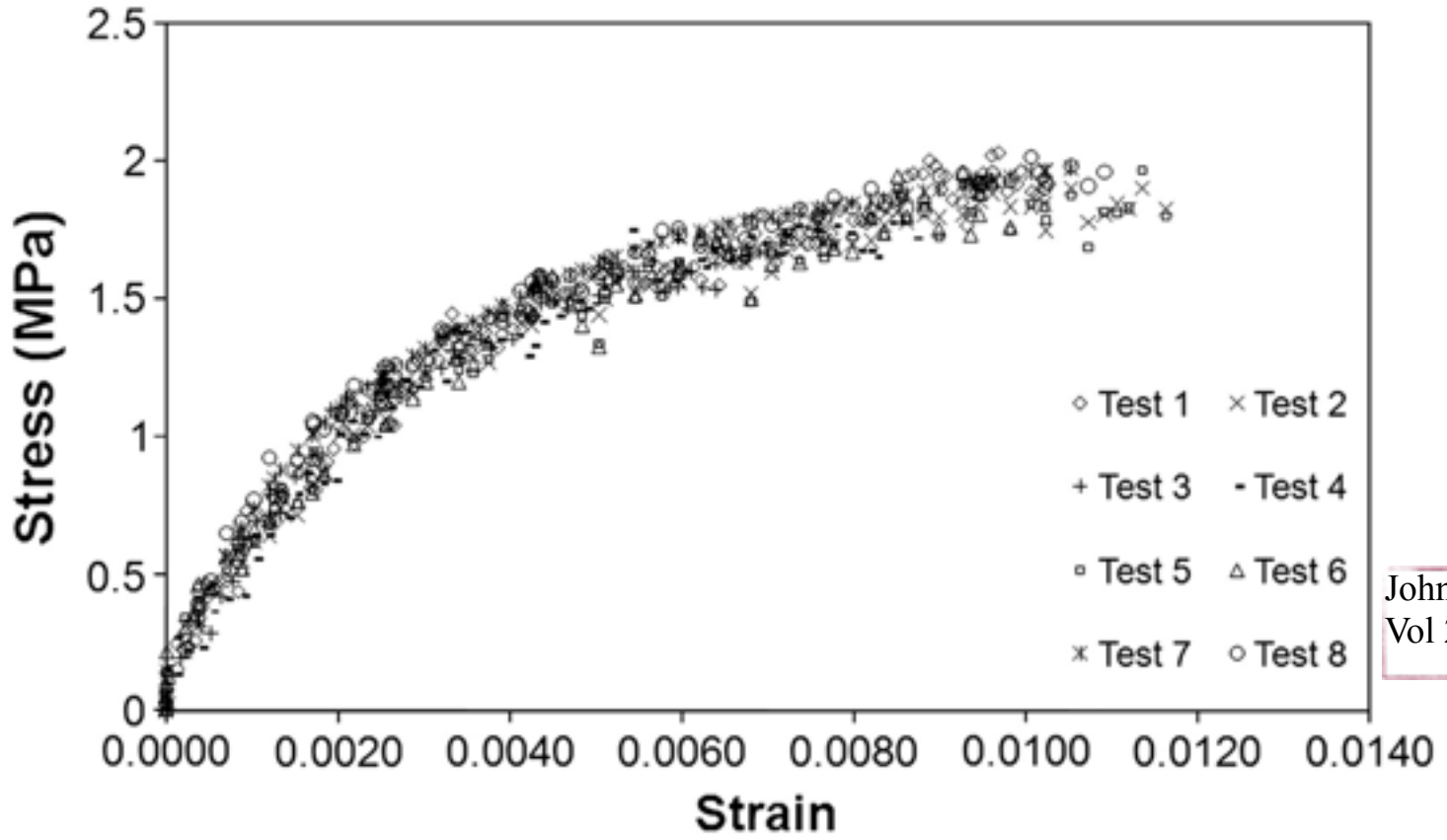
Measured Abradable Coating Properties

- NiCrAl-Bentonite-BN



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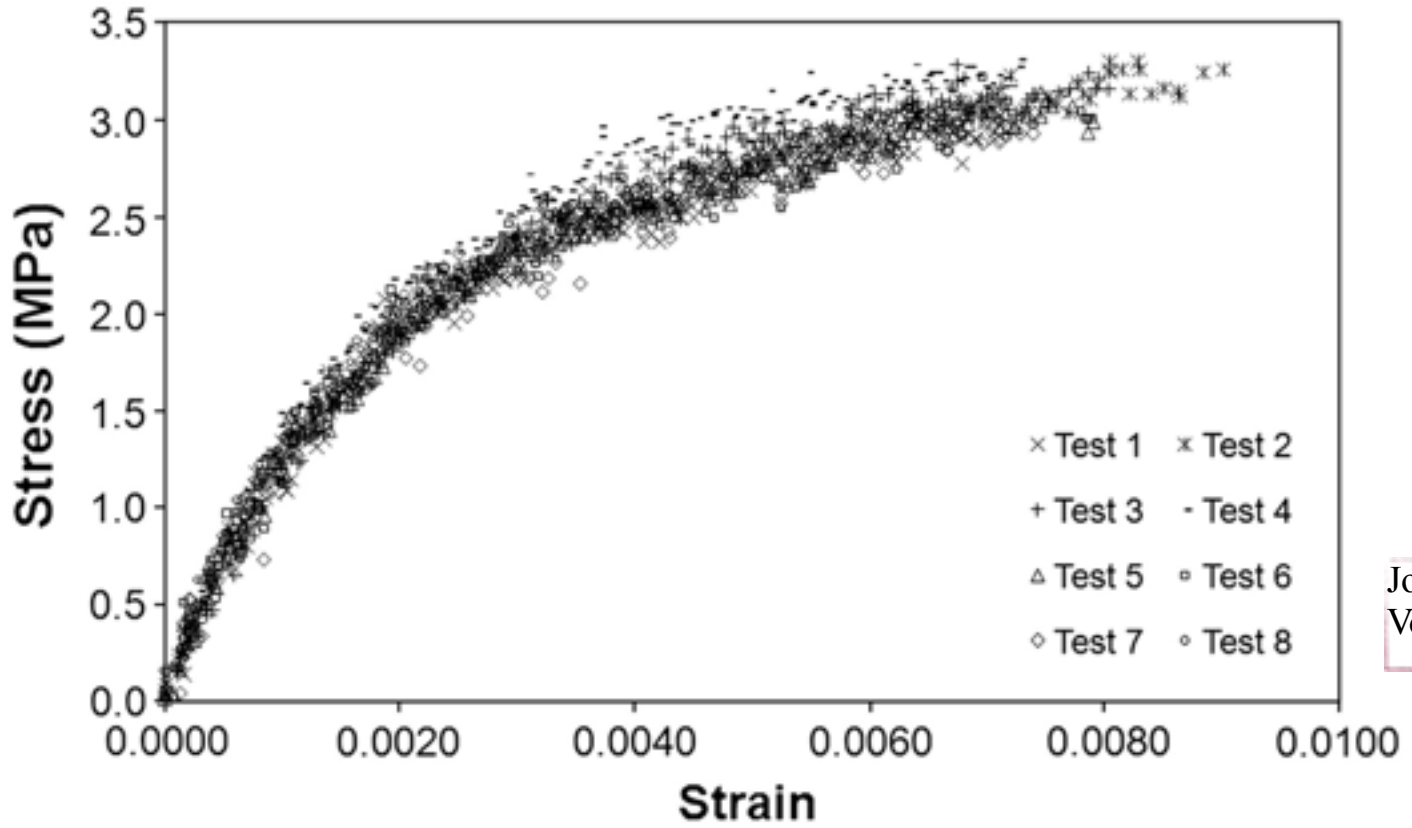

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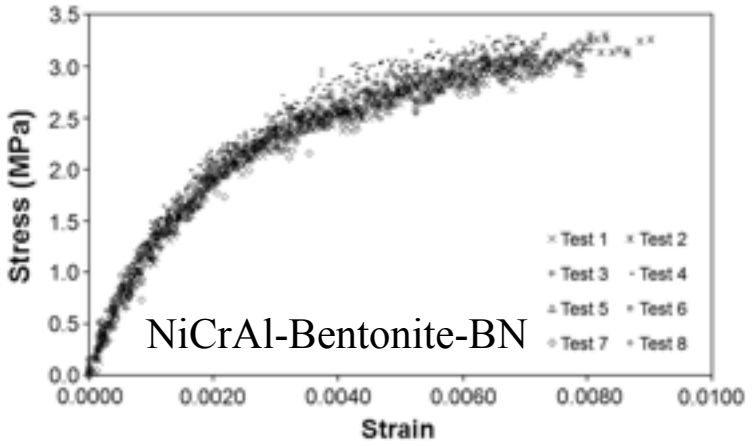

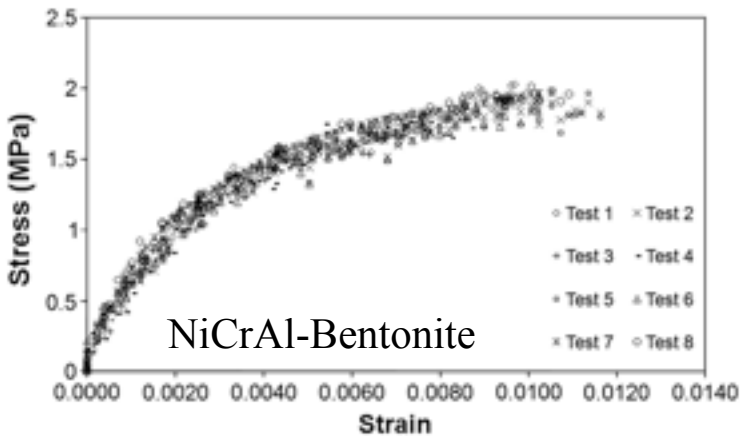

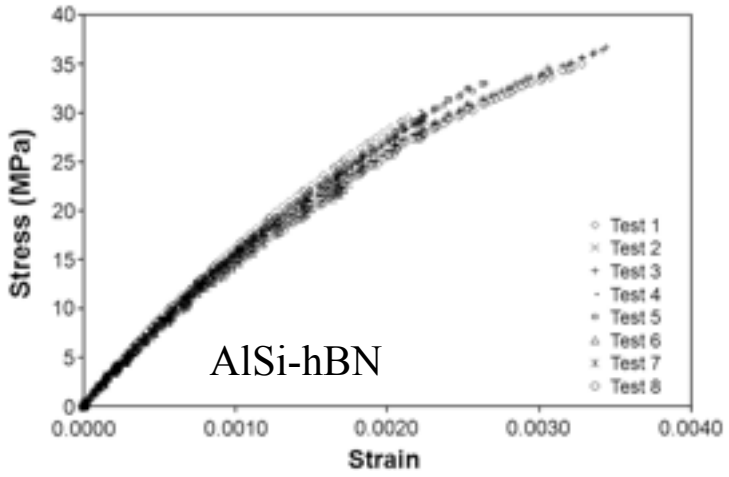

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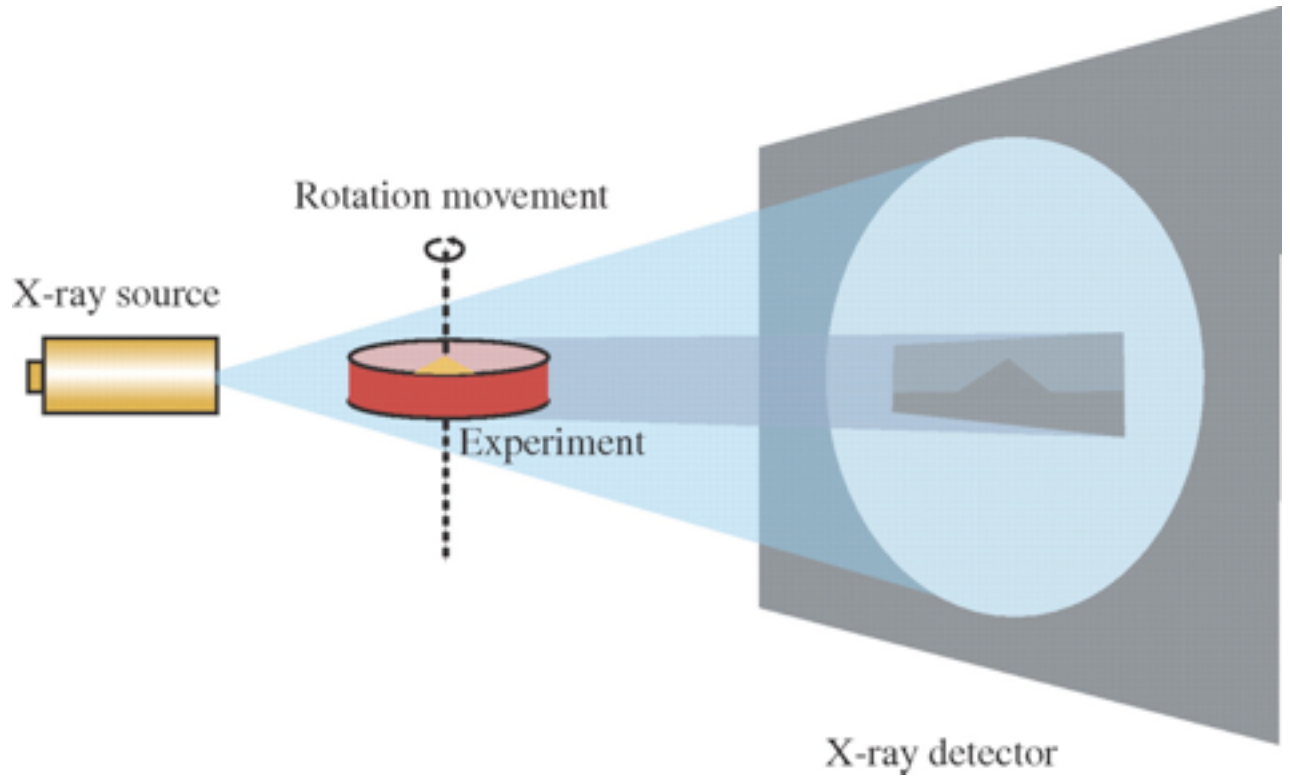
Measured Abradable Coating Properties

Coating	Mean modulus, E (GPa)	Confidence interval for E (GPa)	Mean UTS (MPa)	Confidence interval for UTS (MPa)	Mean strain to failure, εf	Confidence interval for εf
AlSi-hBN	17.22	0.84	29.51	5.31	0.00236	0.00062
NiCrAl-Bentonite-BN	0.75	0.08	1.93	0.07	0.0101	0.00124
NiCrAl-Bentonite	1.39	0.17	3.18	0.11	0.0077	0.00054

Johnston, *Surf Coat Tech*, Vol 205(4-7), 2011.

X-Ray Computed MicroTomography



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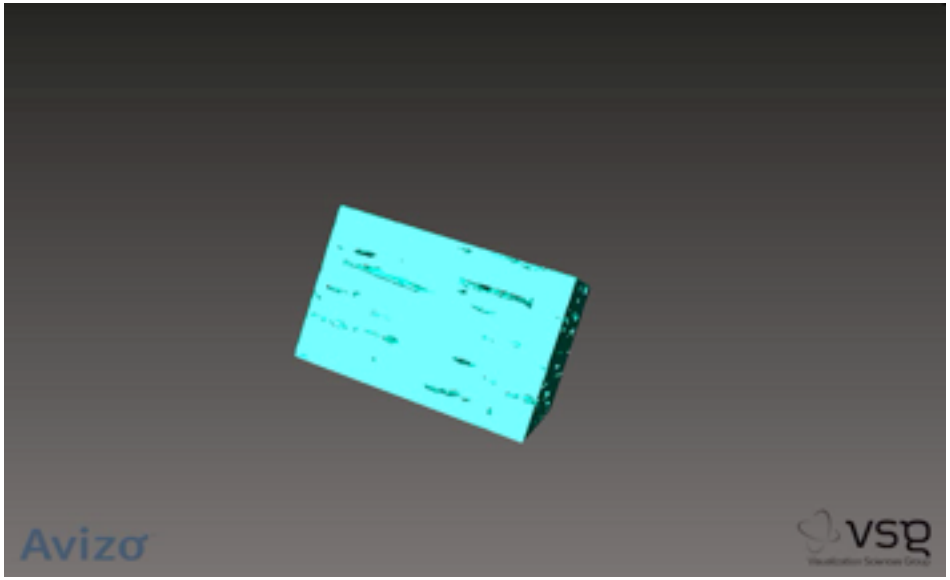

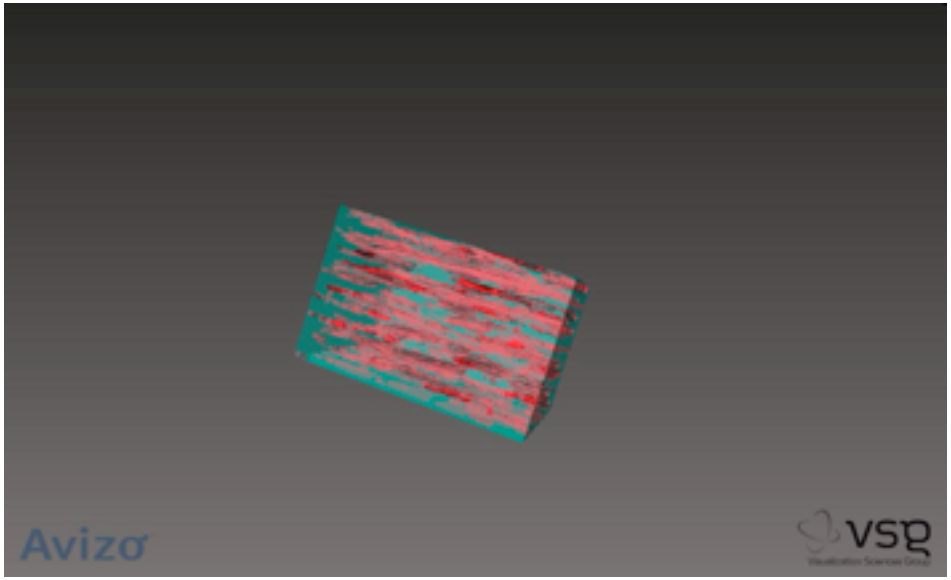

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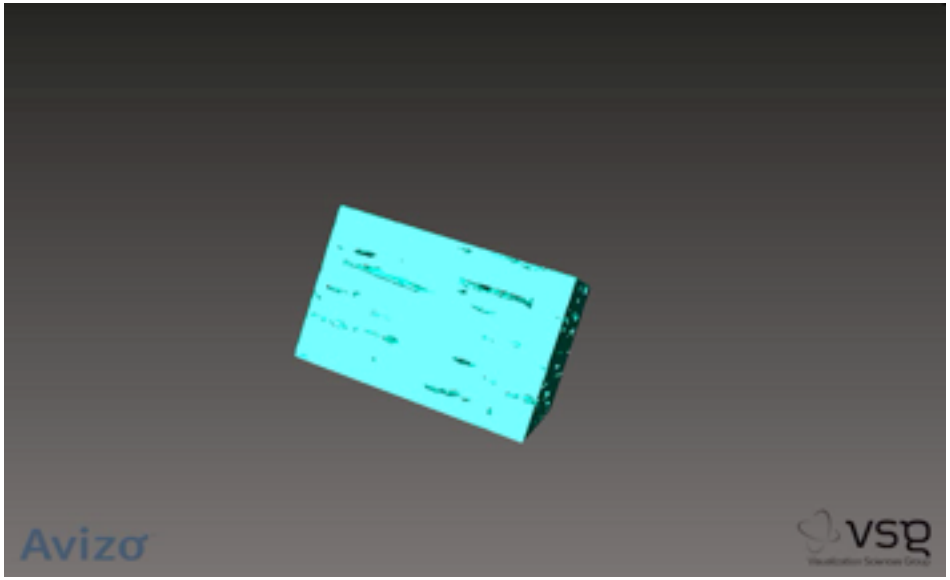

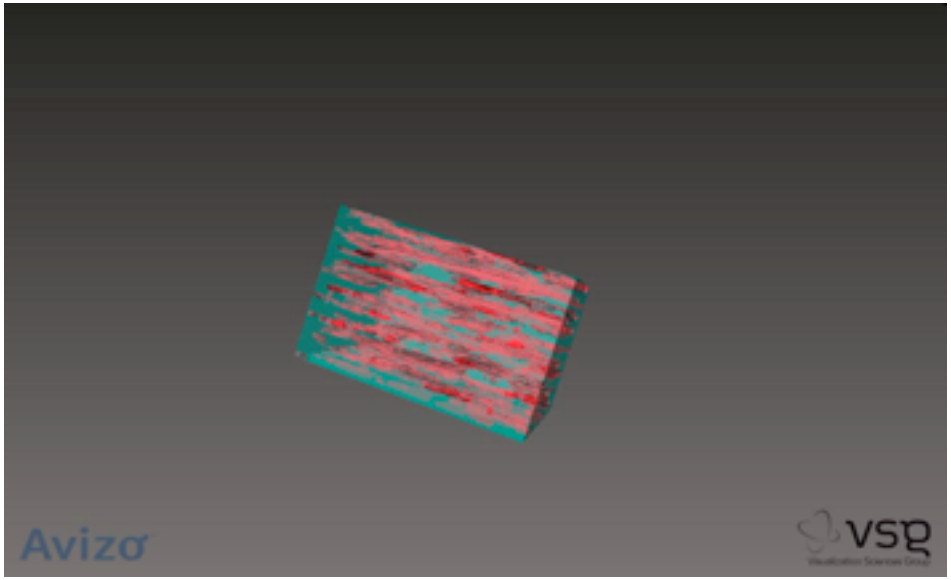

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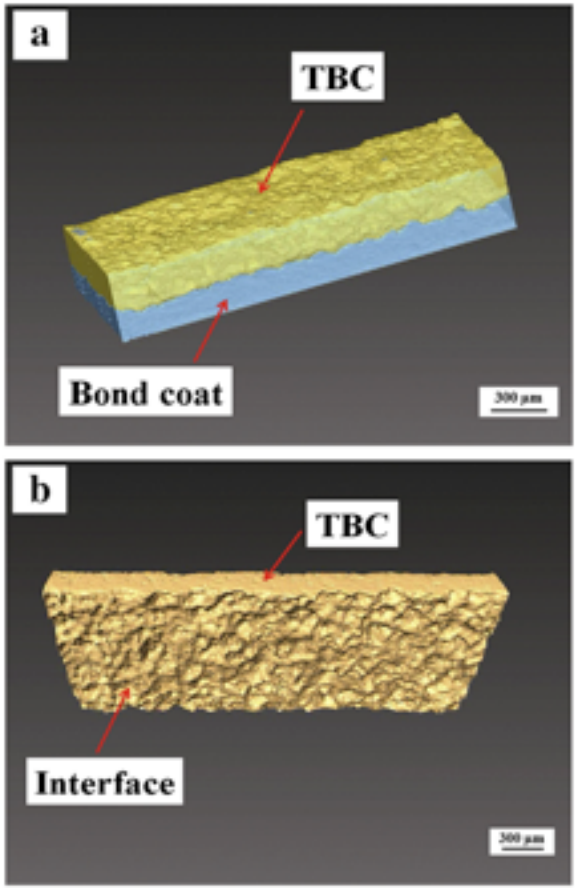

Zhao et al, *Surf Coat Tech*, Vol 205(23), 2012.

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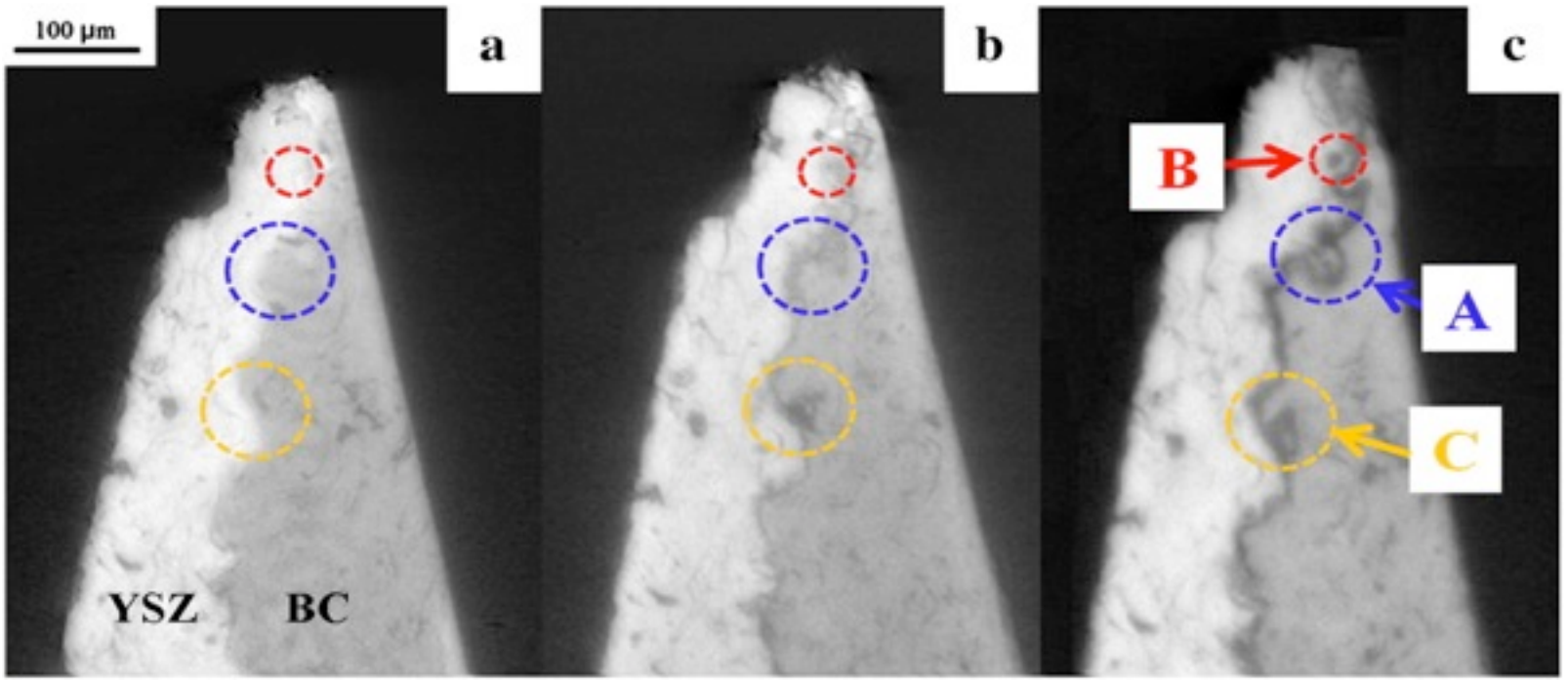


Micro-tomography slices taken from 3D images of the microstructure of a sample exposed at 1150C for 0 (a), 20 (b), 120h (c).

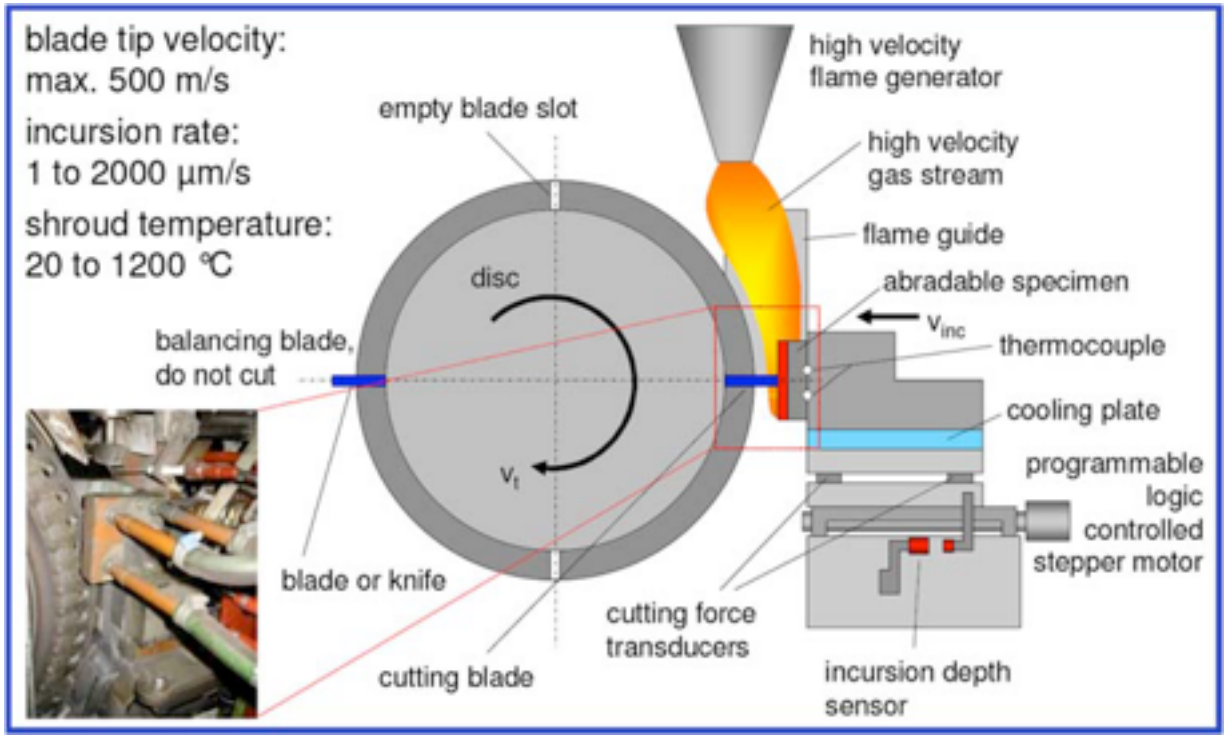
Zhao et al, *Surf Coat Tech*, Vol 205(23), 2012.

Abradability Testing

- Difficult to reconstruct extreme conditions within gas turbine

- Temperature at the rear of segment
- Blade tip velocity
- Wear track length
- Incursion rate and depth
- Blade height discrepancy
- Surface temperature of abradable
- Wear track roughness
- Vibration data
- Wear mechanism

Sulzer-Innotec Rig

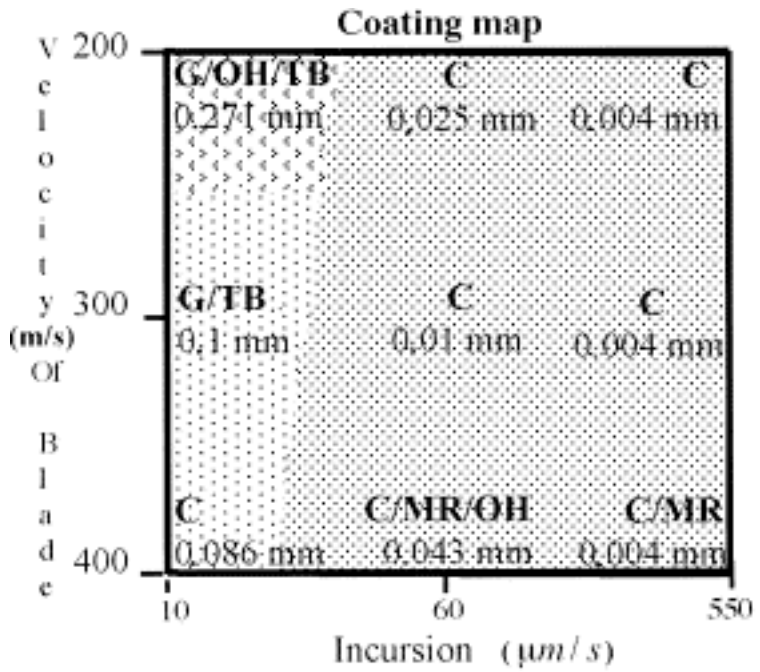


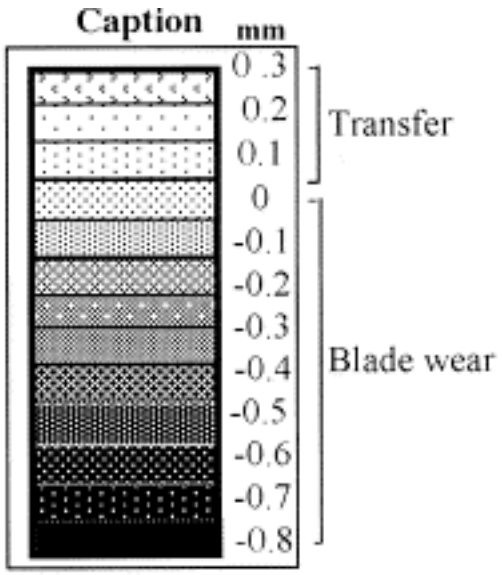
Bardi et al, *J Therm Spray Tech*, Vol 17(5-6), 2008.

Abradability Testing - Wear Tracks

Sporer and Wilson, *Thermal Spray 2012: Proceedings from the International Thermal Spray Conference and Exposition*, Houston, TX, May 2012.

Abradability Testing - Wear Maps



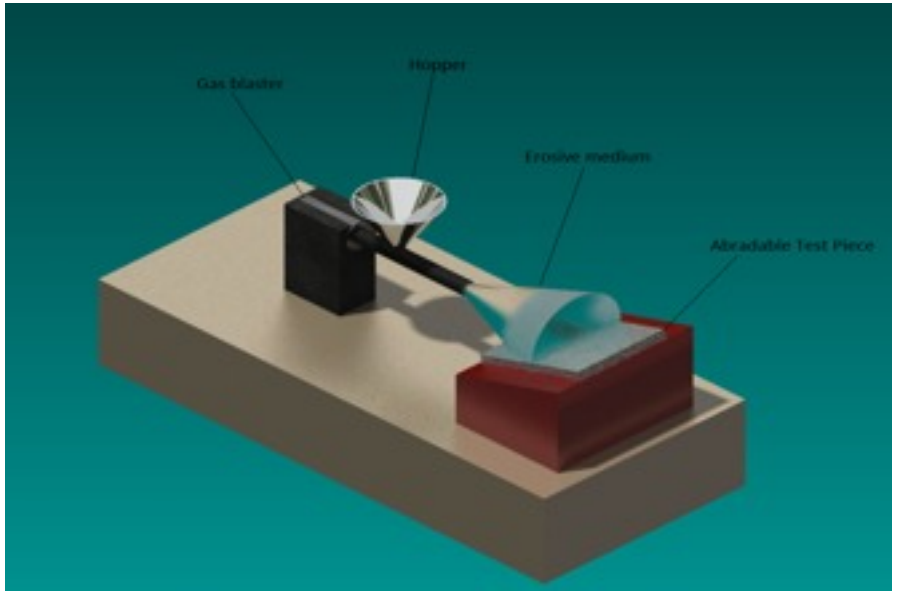


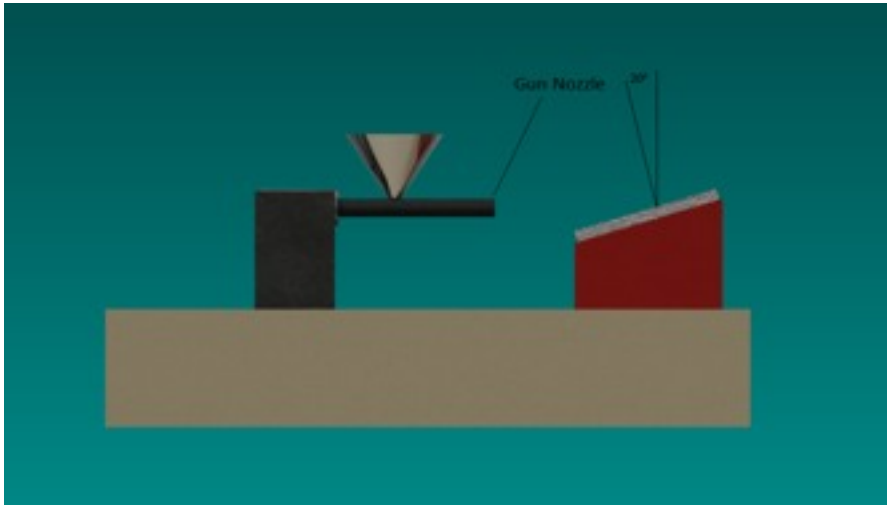
Key:

- **C** : Cutting
- **G** : Grooving
- **TB** : Transfer on blade
- **OH** : Over heating
- **MR** : Microrupture

Bounazef et al, *Materials Letters*, Vol 58(27-28), 2004.

Erosion Behaviour

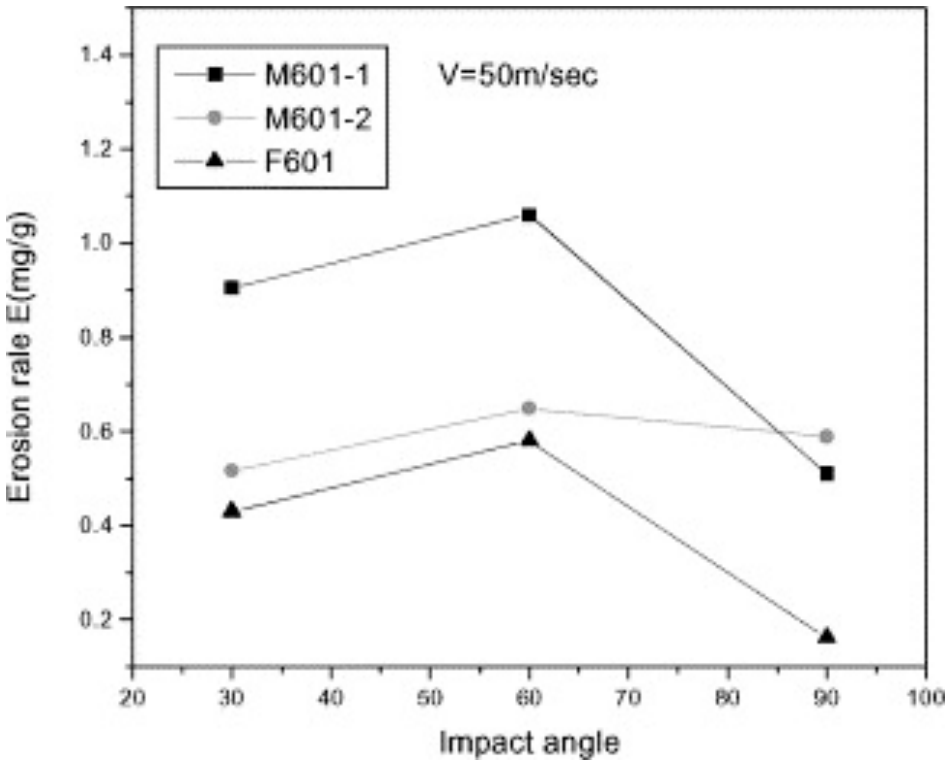


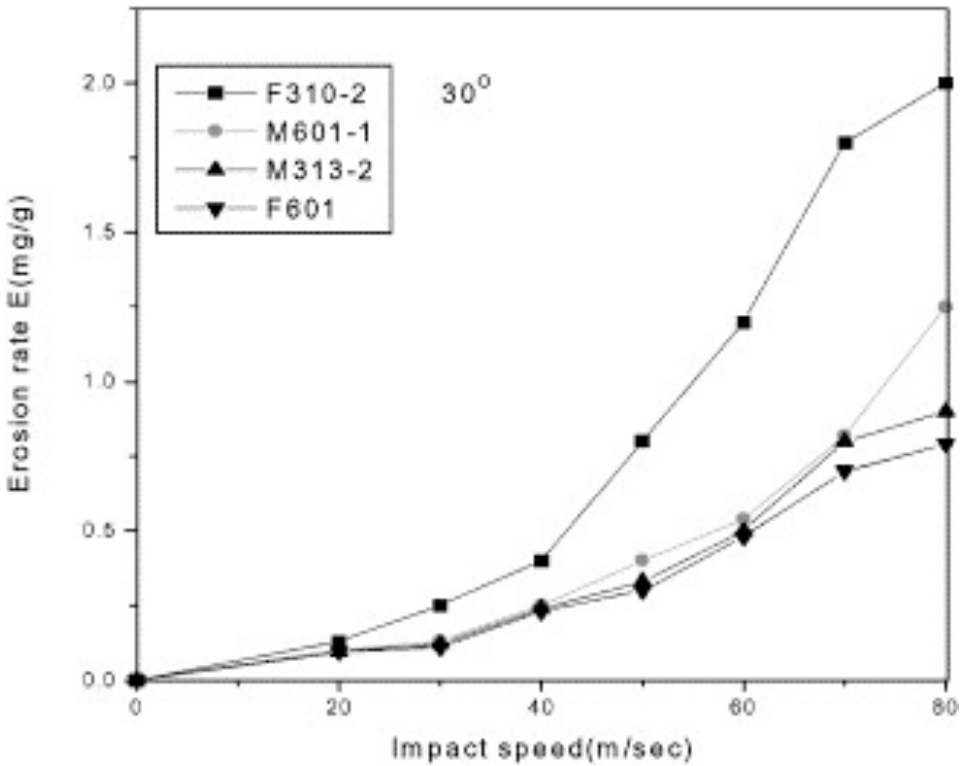


The ratio of the mass loss of the specimen to the mass of the grit is called erosion rate, E in mg/g.

ASTM G76 - 07 Standard Test Method for Conducting Erosion Tests by Solid Particle Impingement Using Gas Jets

Erosion Behaviour





Maozhong et al, *Wear*, Vol 252(1-2), 2002.

Abradable Coating Hardness Testing

- Hardness is a quick measure of mechanical integrity

- Used in manufacturing

- Relatively simple test compared to other characterisation methods for abradable coatings

- Normally using Rockwell superficial hardness HR15Y

- Can use Vickers microhardness for characterisation of abradable microstructure components

Thermal Shock/Fatigue Testing

- Thermal shock or thermal fatigue in abradable coatings is driven by the thermal expansion coefficient mismatch between coating and substrate

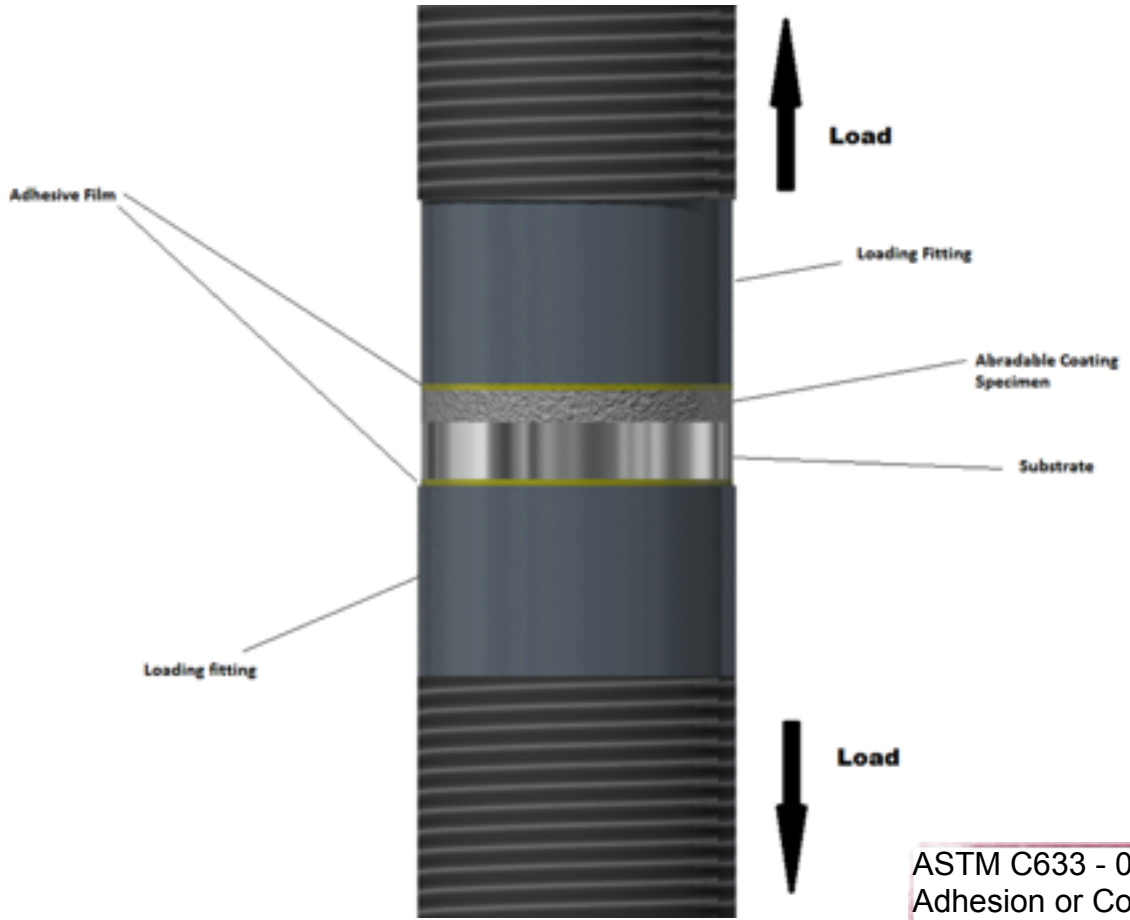
- Relatively basic methods of characterising

- Can measure number of cycles until spallation/delamination, residual stress, phase changes

- Scrivani et al. showed that increased porosity in YPSZ TBCs, enhances the thermal fatigue resistance, and reduces the in-phase compressive stress

Scrivani et al, *J Therm Sp Tech*, Vol 15(5-6), 2007.

Adhesion/Bond/Cohesive Strength



ASTM C633 - 01(2008) Standard Test Method for Adhesion or Cohesion Strength of Thermal Spray Coatings

Summary

- Development of a novel manufacturing route and testing methodology for freestanding thermal spray coatings

- Looked at non-destructive ways of visualising constituent phases and porosity

- Number of additional methods for evaluating mechanical behaviour

- A suite of significant and applicable characterisation techniques will be suitable, depending on the application.

Freestanding Abradable Coating Manufacture and Tensile Test Development

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