

University Contributions To The Effective Use of Thermal Barrier Coatings in ATS Engines

95-01-SR030

AGTSR Contracts: 96-01-SR046

99-01-SR073

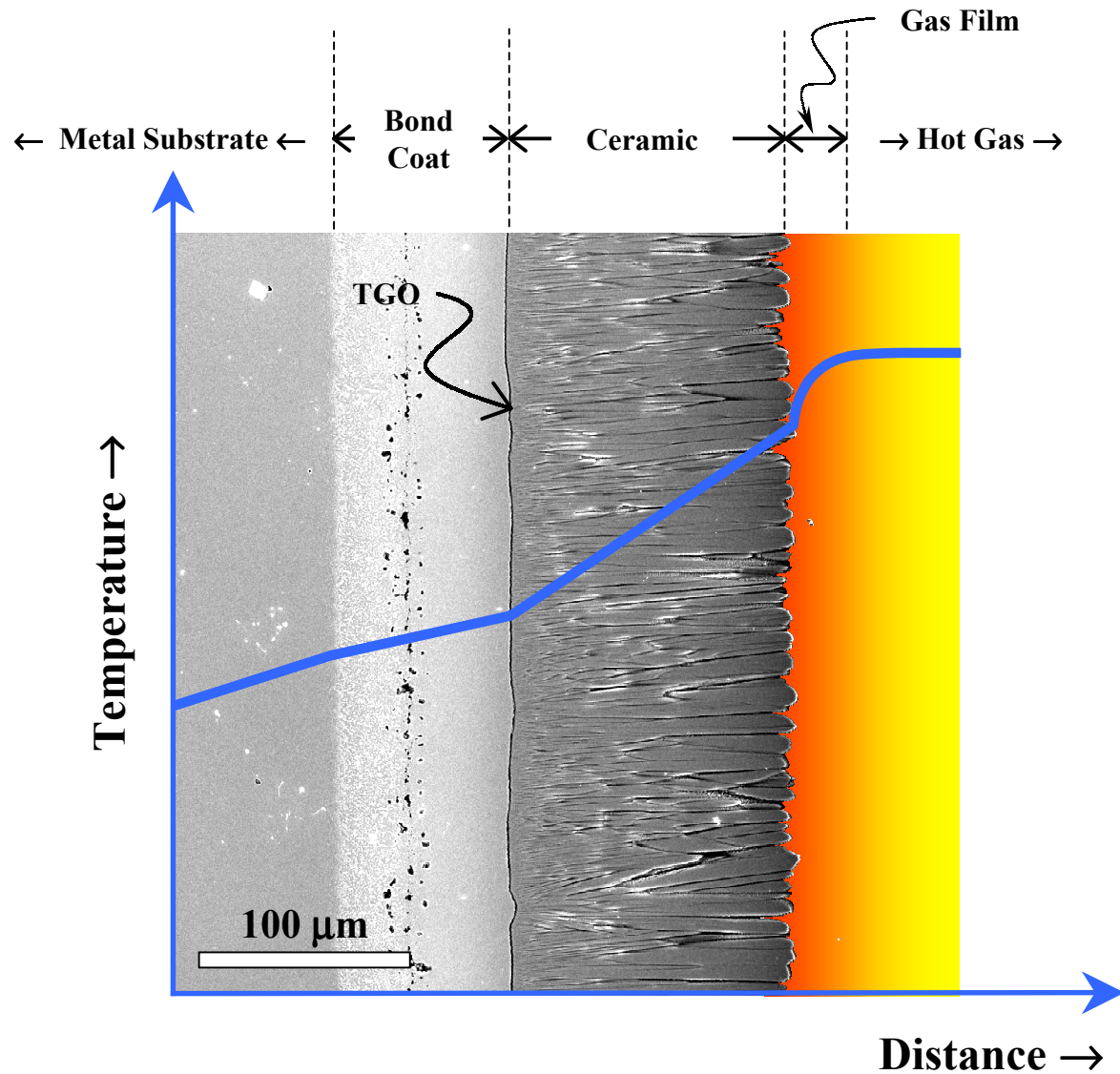


Eric Jordan and Maurice Gell
University of Connecticut

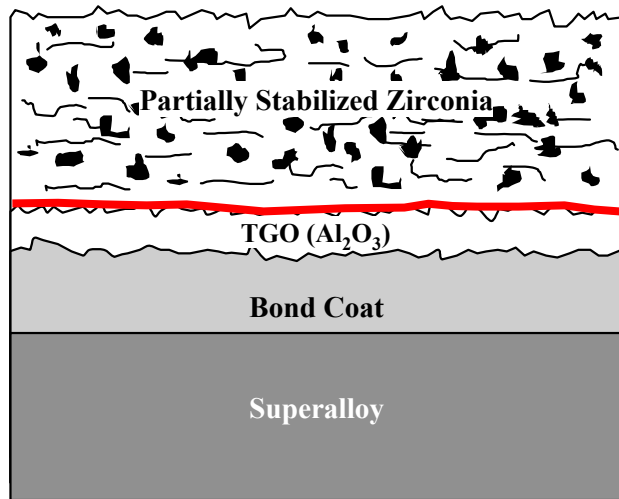


David Clarke
University of California, Santa Barbara

Temperature Profile Across TBC

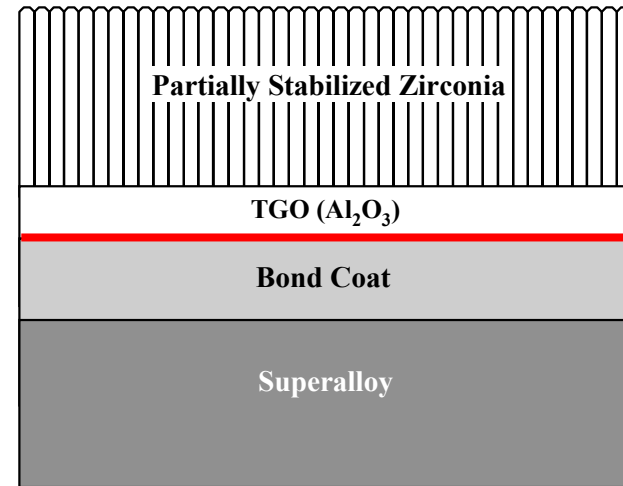


Microstructure and Spallation Failure Location of TBCs



Plasma Sprayed TBC

← **Failure** →



EB-PVD TBC

Program Organization

University of Connecticut

Eric Jordan
Maurice Gell

University of California-SB

David Clarke

ATS Engine Developers and Coating Manufacturers

ABB

Allied Signal Engines
GE Power Systems
Howmet International
Pratt & Whitney
Rolls Royce -Allison
Siemens-Westinghouse
Solar Turbines

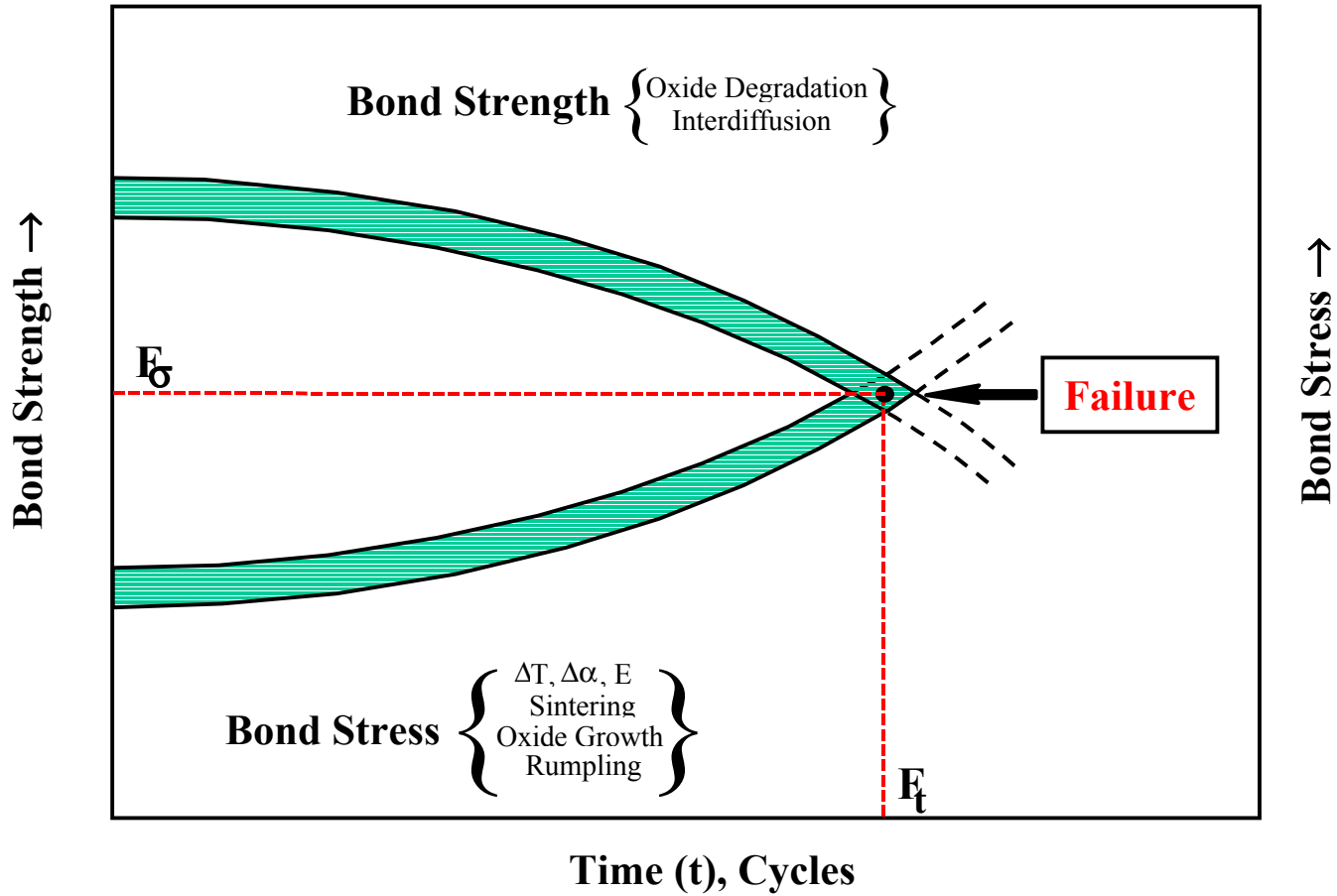
NDI Instrument Manufacturer

Renishaw Inc.

Production Thermal Barrier Coatings

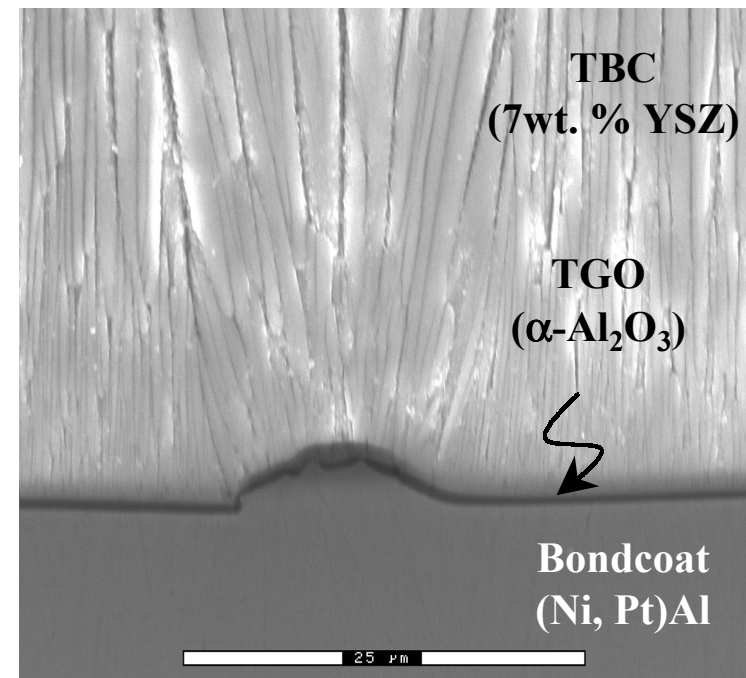
Type	Superalloy	Casting Form / Alloy Type	Bondcoat		Ceramic	
			Type	Thickness (μm)	Type	Thickness (μm)
I	N5	Single Crystal Ni	Pt - Al	65	EB-PVD	115
II	IN - 939	Polycrystal Ni	MCrAlY	70	Plasma	255
III	CMSX - 4	Single Crystal Ni	MCrAlY	120	EB-PVD	315
IV	CMSX - 4	Single Crystal Ni	MCrAlY	120	Plasma	250
V	MAR-M-509	Polycrystal Co	MCrAlY	125	Plasma	300

Spallation Model

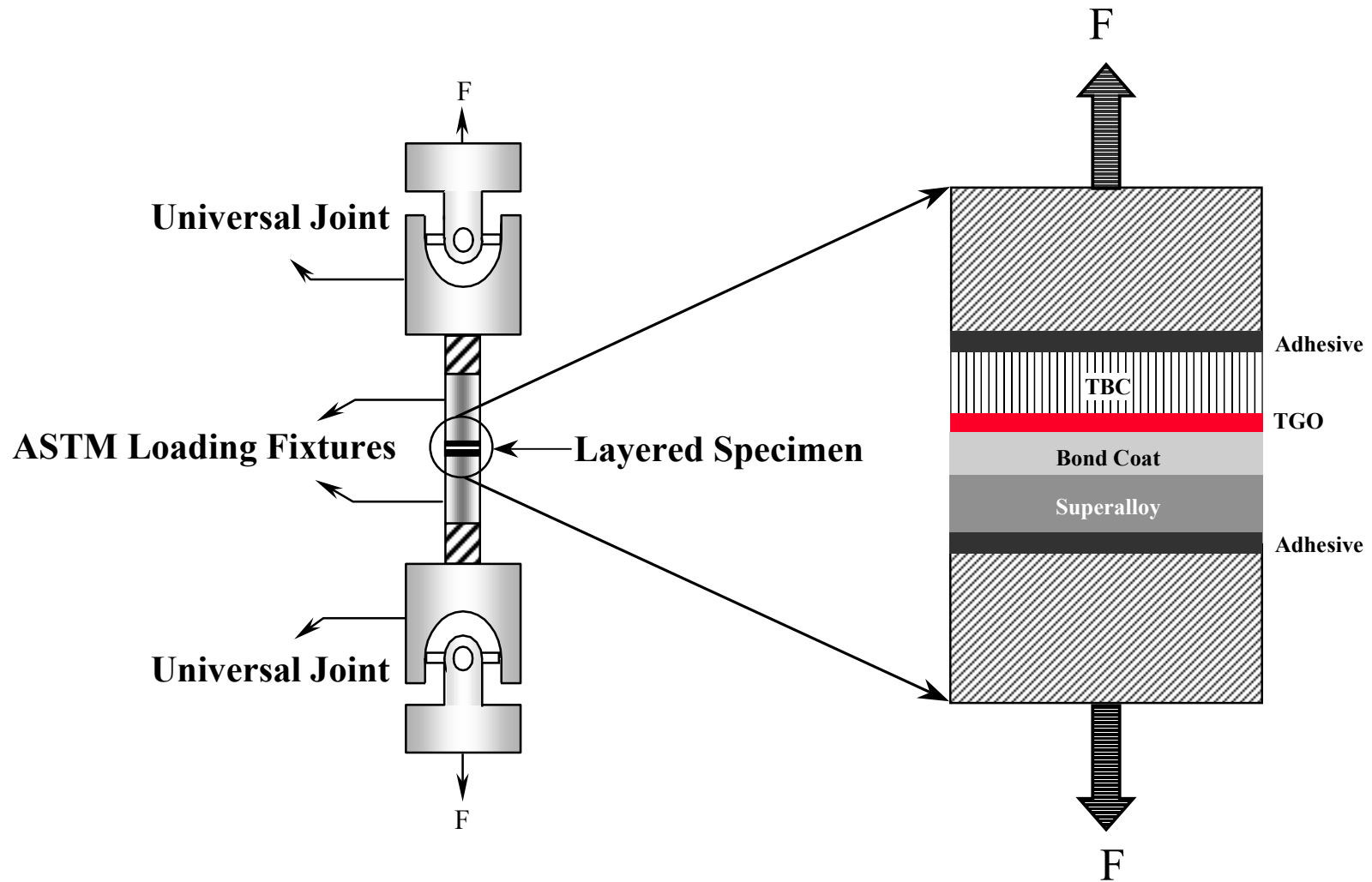


Five Bill of Materials Systems Studied Supplied by Commercial Vendors

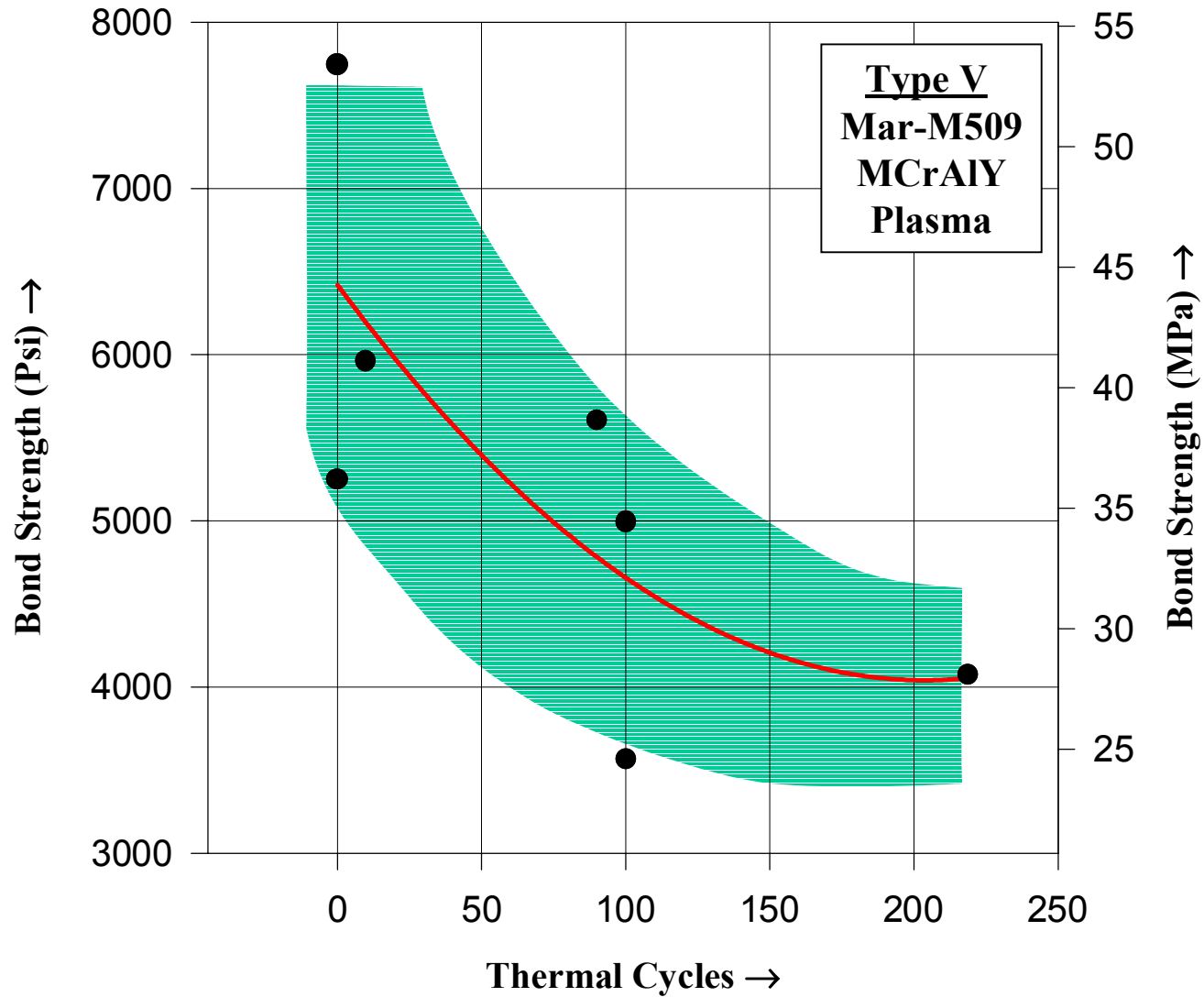
- **Failure - System Specific**
- **Defects Play a Key Roll**



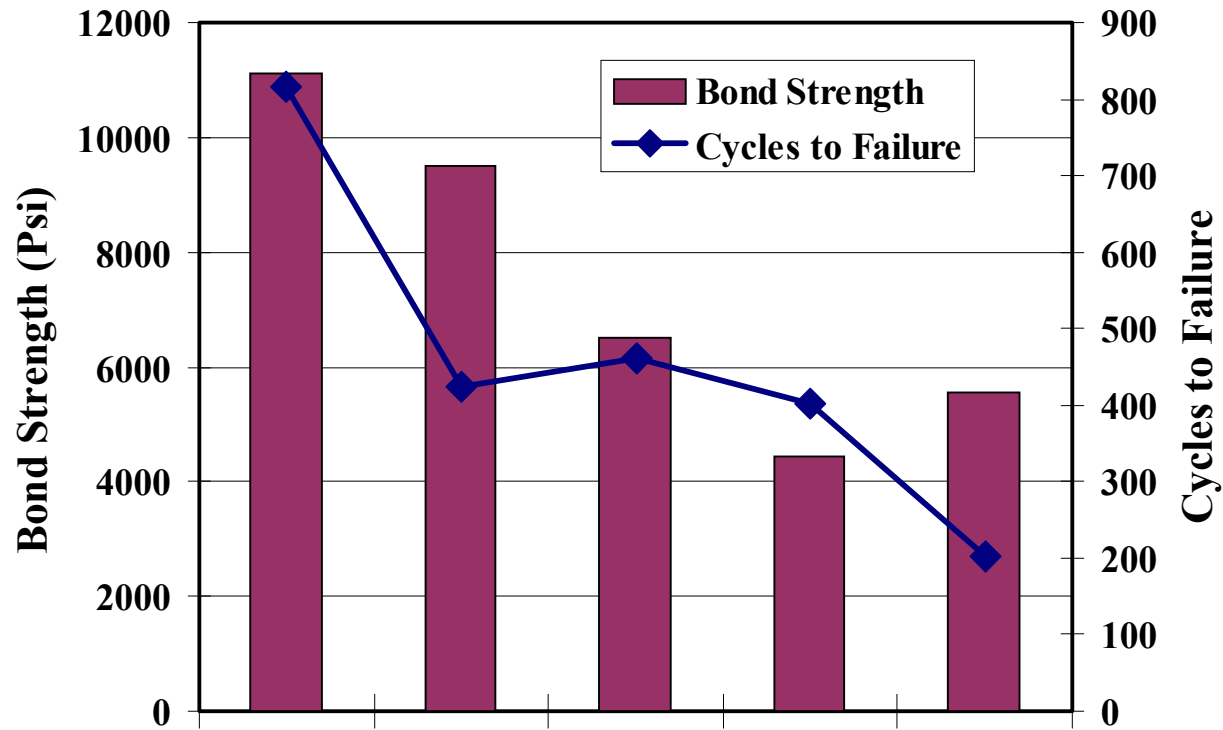
Modified ASTM Direct Pull Test



Bond Strength of Type V Coating



Initial Bond Strength Vs. Cycles to Failure



Coating Type

I

III

V

IV

II

Bond Coat

Pt-Al

MCrAlY

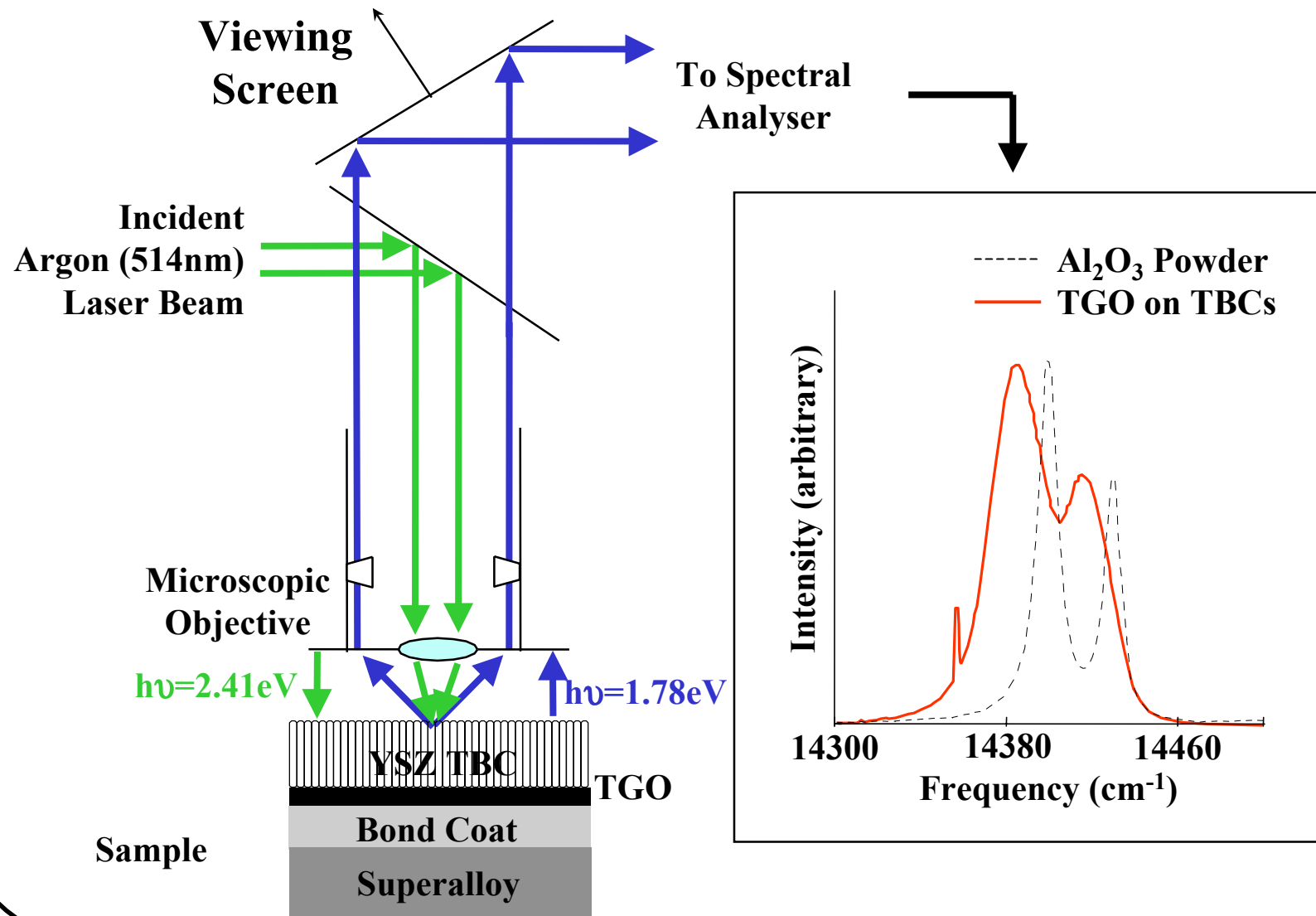
MCrAlY

Ceramic Process

EB-PVD

Plasma-Sprayed

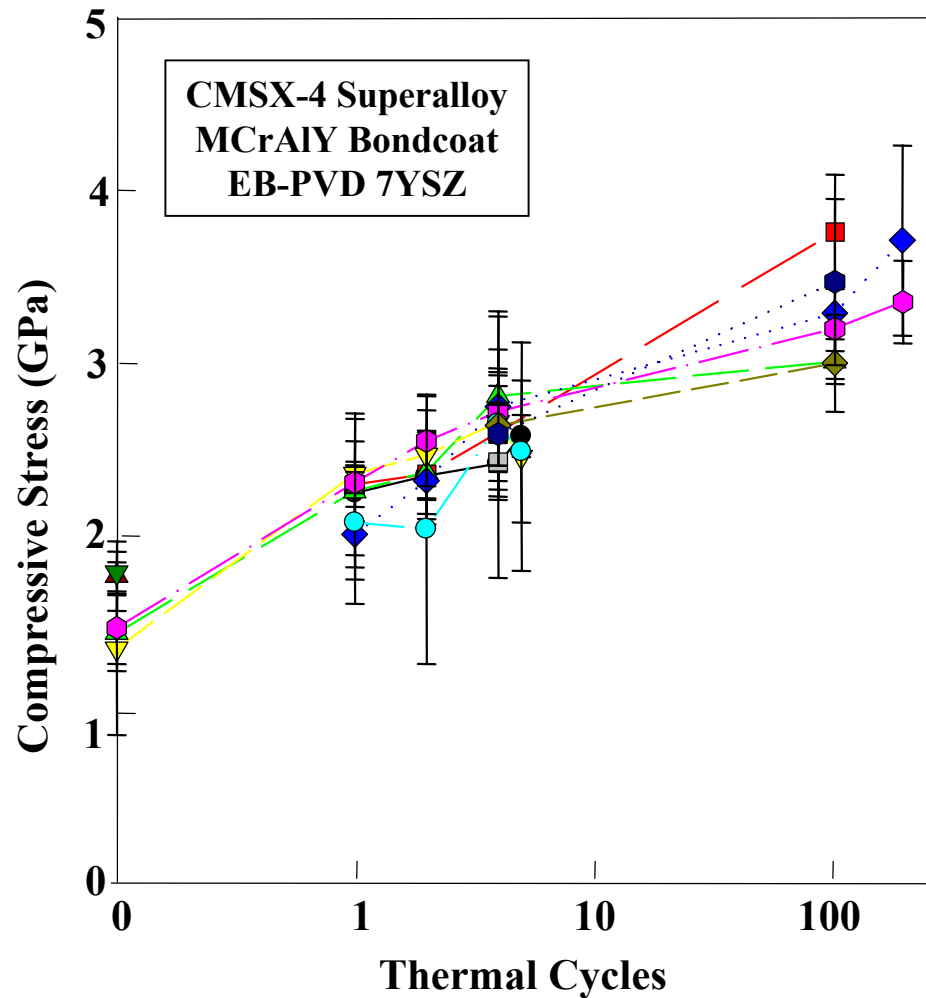
Laser Fluorescence Technique



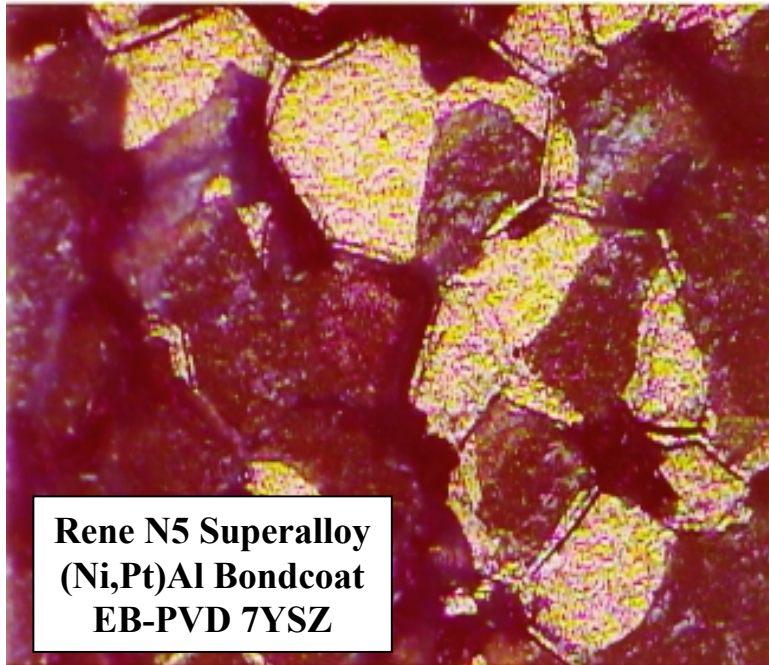
Applications of Laser Fluorescence for Thermal Barrier Coatings

- **Assessment of Life Remaining**
- **Input for Lifetime Prediction Methods**
- **Quality Control**
- **Coating Development**

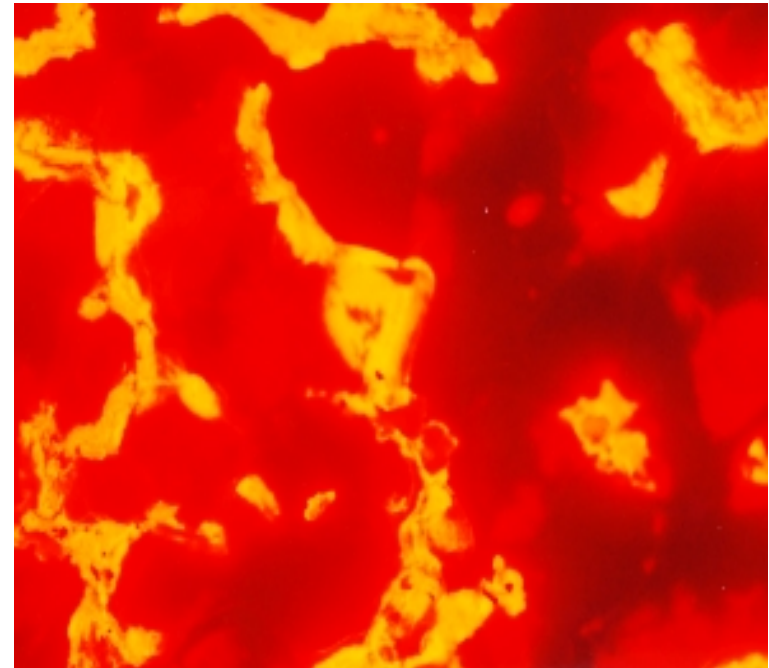
Evolution of Compressive Stress in TGO with Thermal Cycling for TBCs



Fracture Surface of TBC After 400 Cycles



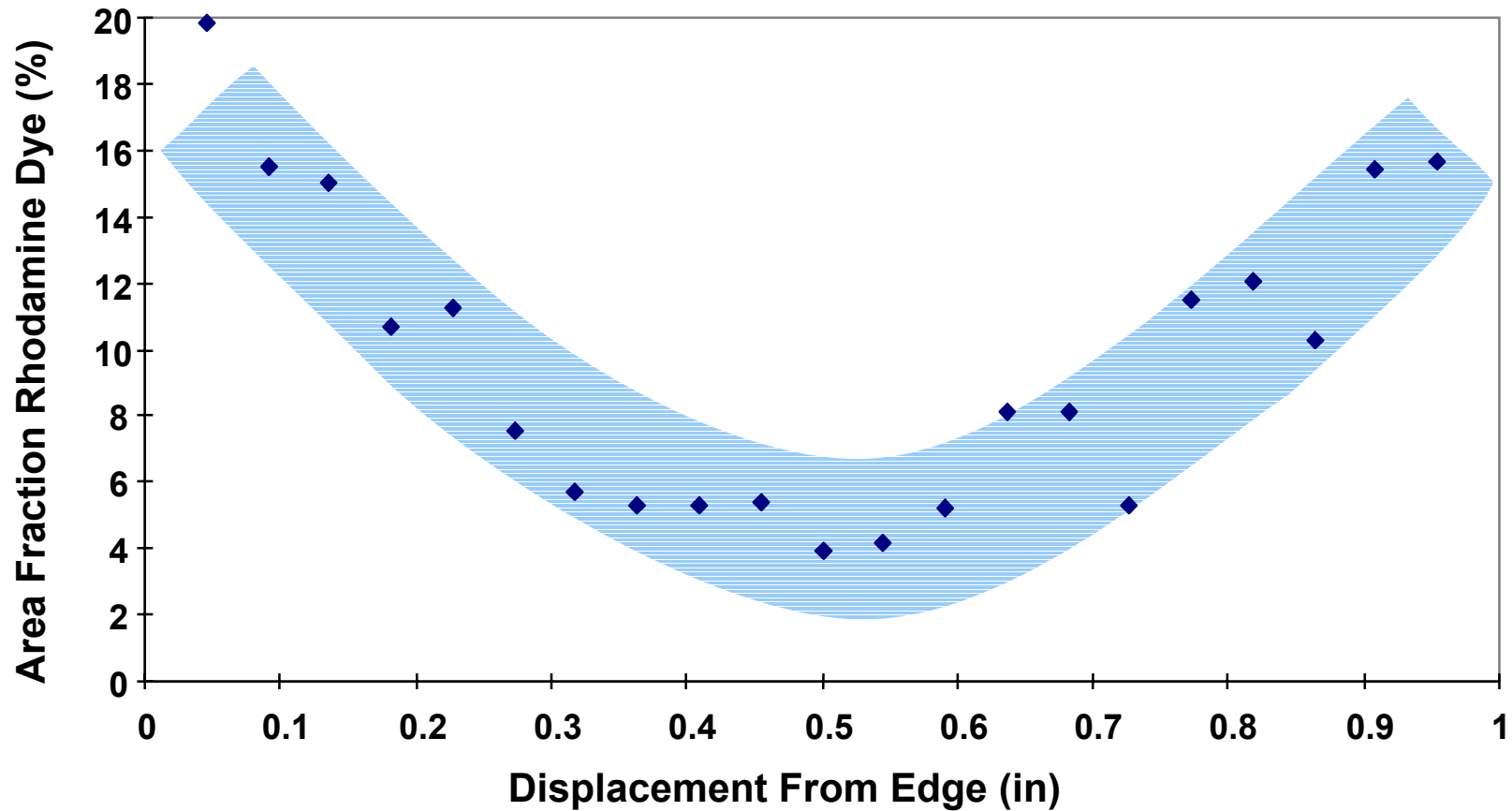
Optical Micrograph



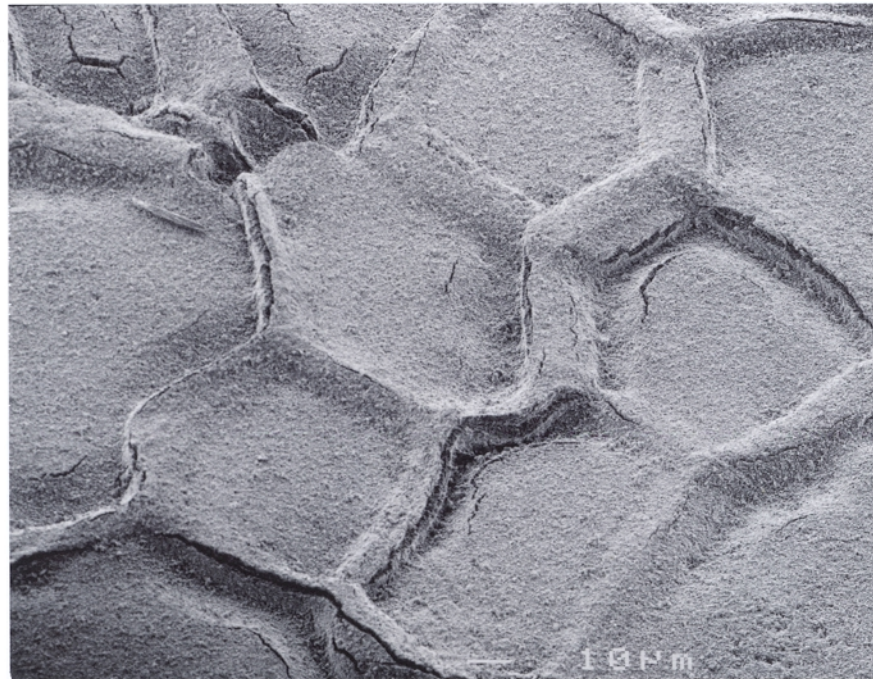
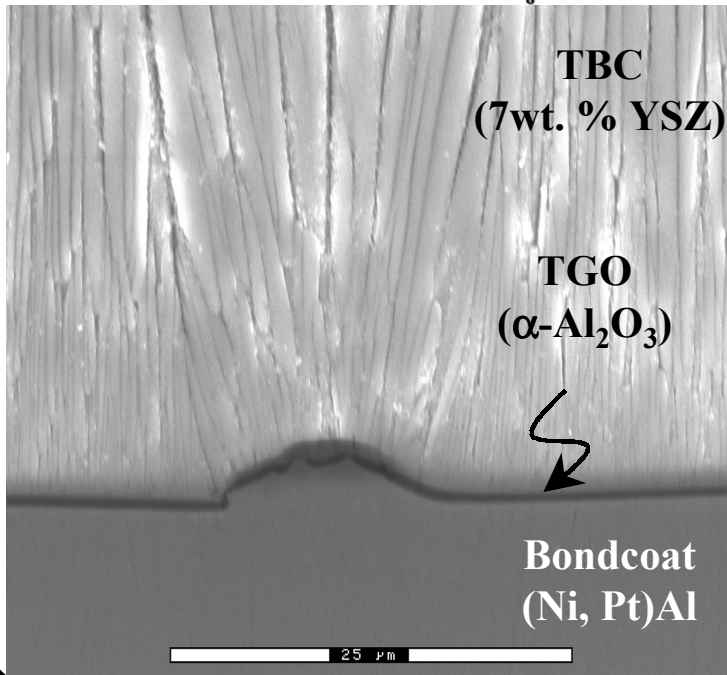
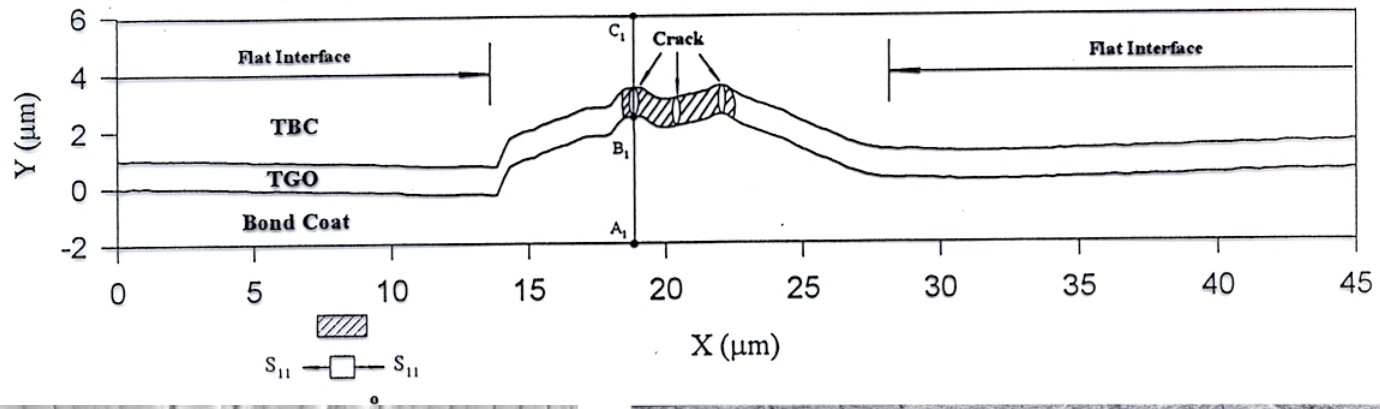
Fluorescence Micrograph

**Fracture Surface Exposed by Modified Direct-Pull Test (ASTM)
After Vacuum Infiltration of Fluorescence Dye.**

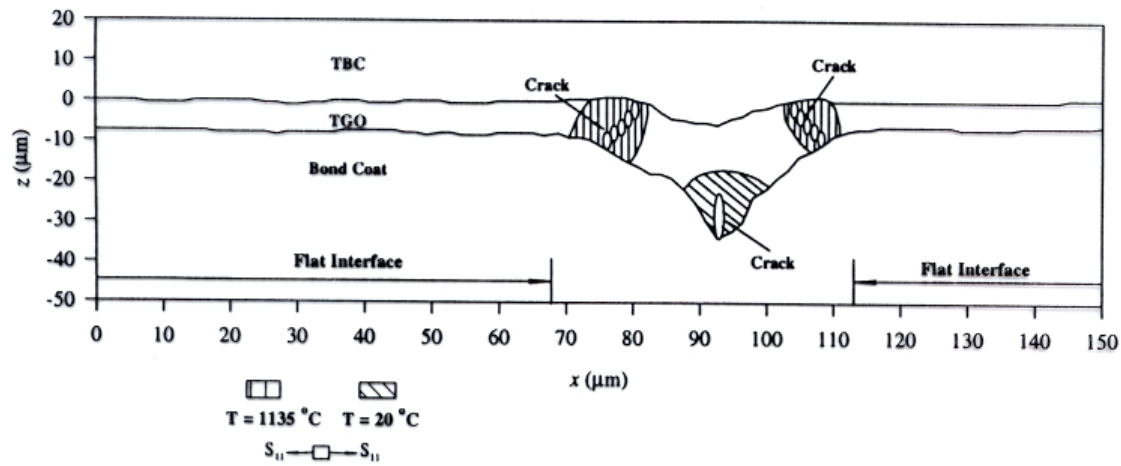
Damage Accumulation Across Disk Specimen



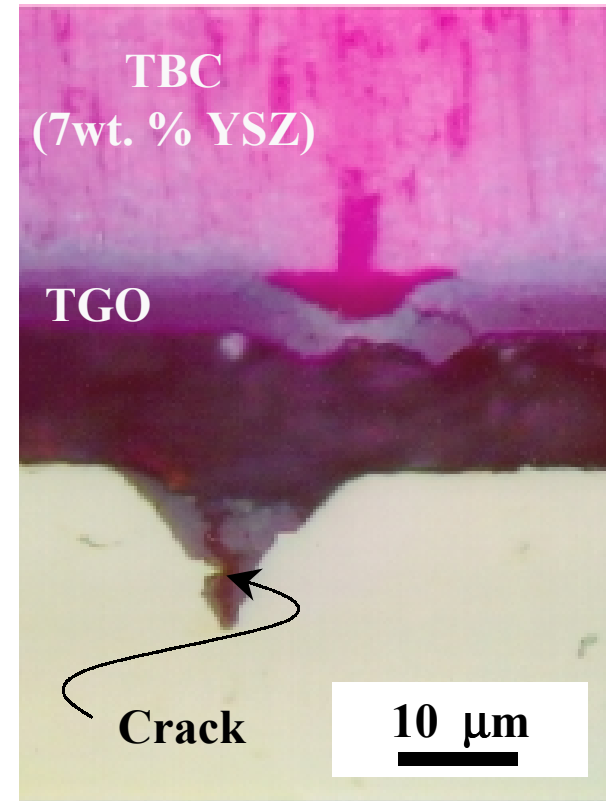
Cross-Section of a Bondcoat Ridge



Calculation vs. Observation

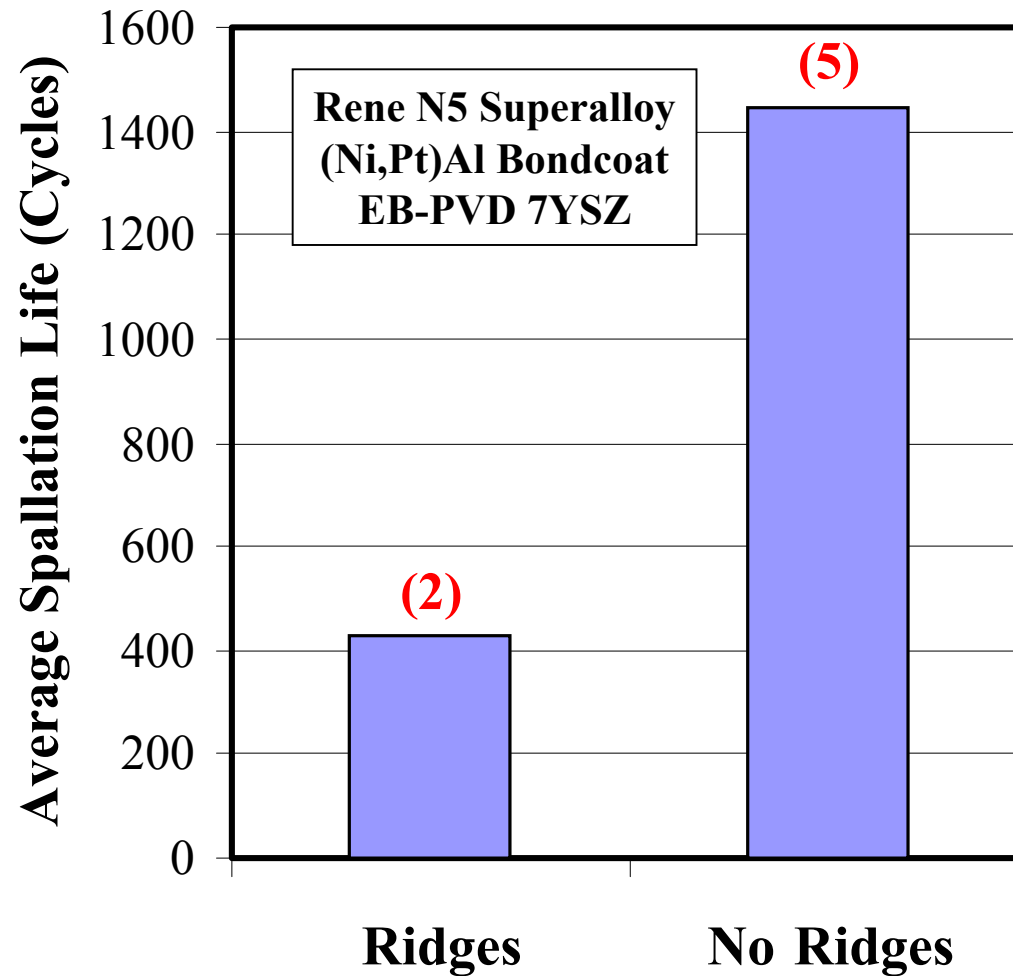


Predicted tensile stress zone (shadowed region)
at the cavity tip and transition shoulder



Observed cracking
at the cavity tip and shoulder

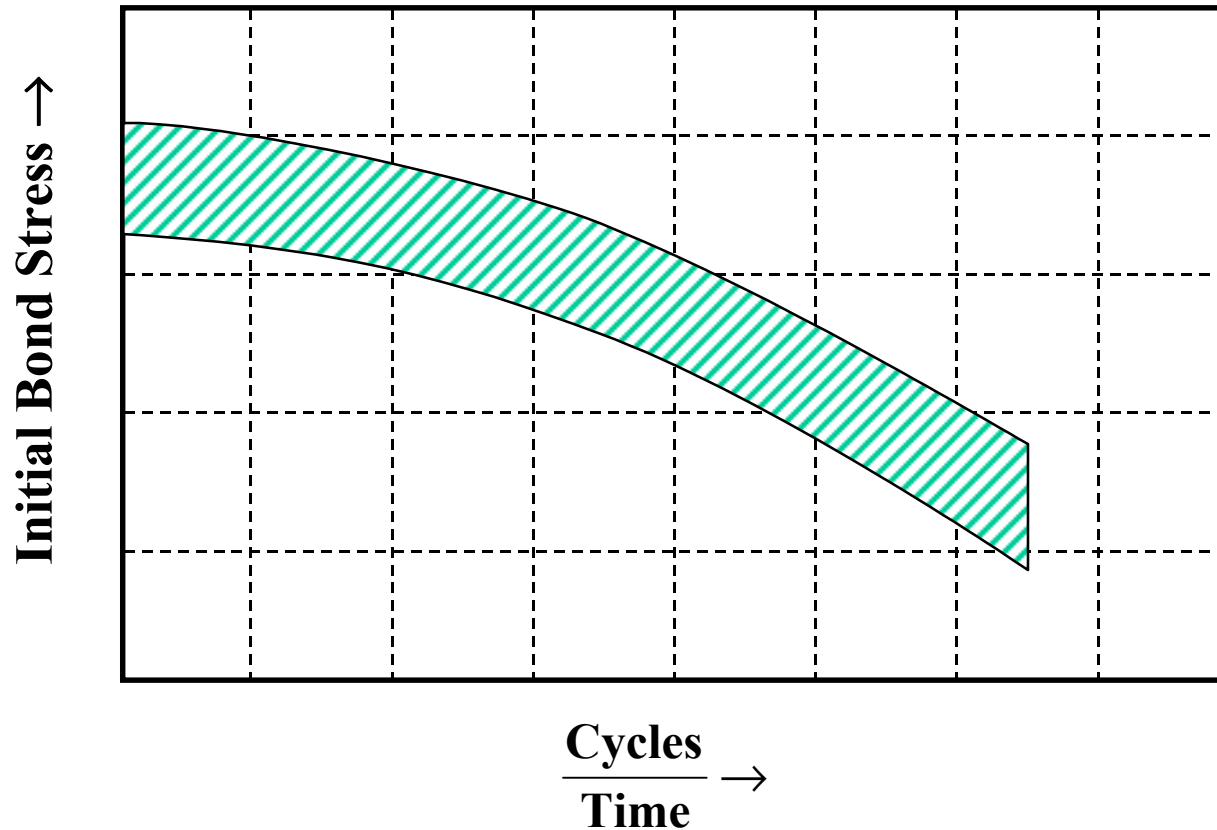
Effect of Ridges on Spallation Life



Strong Potential for Mechanism Based Life Prediction is Emerging

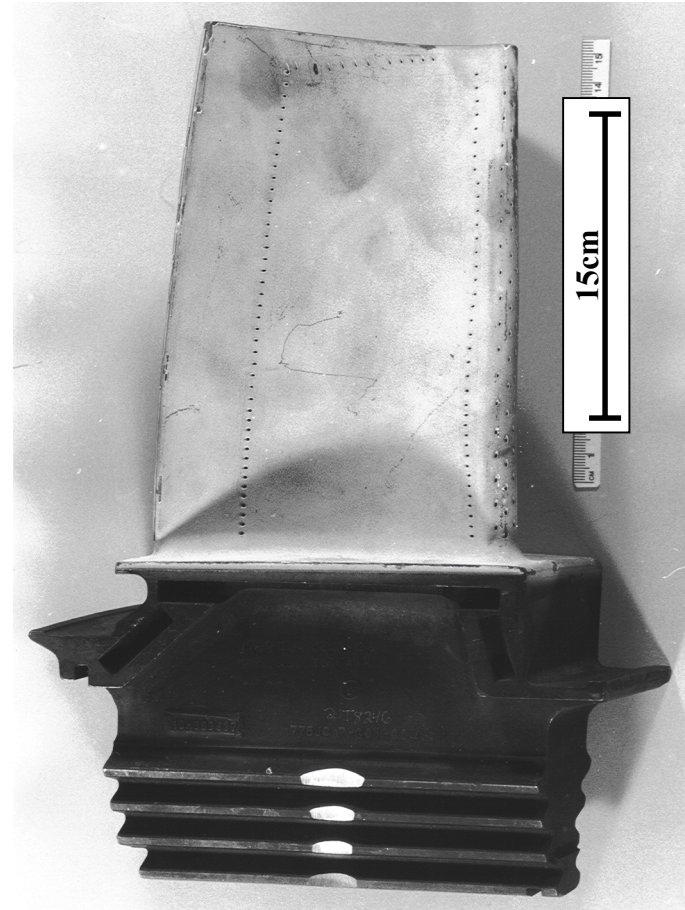
- **Stress Measurement**
- **Toughness Measurement**
- **Determination of Fractional Debonding**
- **Increasingly Realistic Mechanical Modeling**

Laser Fluorescence as NDI Technique



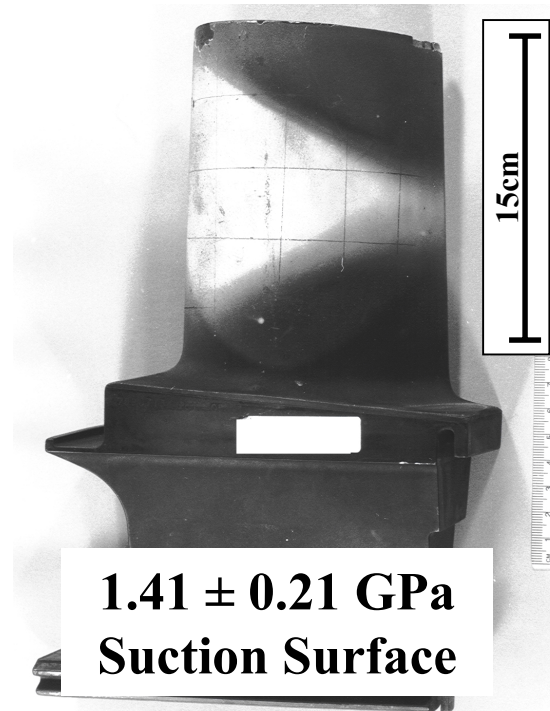
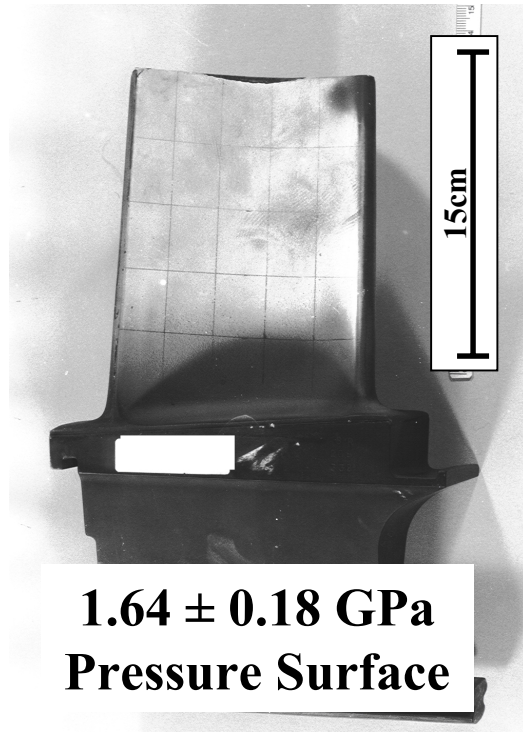
- Measure initial bond stress in critical regions of component
- Measure same area after service
- Use calibration curve to assess life remaining

Portable Laser Fluorescence NDI Technique for TBCs Demonstrated



Application of Laser Fluorescence on Thermal Barrier Coated Turbine Blades

27000 Service Hours



University of Connecticut AGTSR TBC Programs

--- Highlights ---

- **Five Production Coatings Tested and Showed Characteristic As-Coated TGO Stress and Bond Strength.**
- **Quality of Coating and Spallation Life Related to TGO Stress and Bond Strength.**
- **Laser Fluorescence Measurement of TGO Stress Demonstrated on As-Coated and Engine Run Turbine Blades.**
- **Laser Fluorescence Has Potential for Being Used as Technique for (1) NDI, (2) Life Remaining Assessment, (3) Quality Control and (4) Coating Development.**

University of Connecticut AGTSR TBC Programs

--- Highlights ---

- **Mechanisms of Spallation Determined.**
- **For EB-PVD TBC, Damage Initiation Occurs at Bond Coat Defects.**
- **When Defects are Removed, 3X Improvement in Life is Obtained.**
- **Good Correlation Between Finite Element Analysis and Observed Cracking.**
- **Quantitative Assessment of Damage Developed Using Fluorescence Dye Technique.**
- **Mechanism-Based Models Should be Defined for Each TBC.**
- **Development of Accurate Lifetime Prediction Systems Now Possible.**