Evaluation Methodology for Mechanical Property of Complex-Shaped Ceramic Components

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Outlines of Presentation

- Background

  Motivation of present research effort

- Evaluation approaches employed for complex-shaped ceramic components

As-processed properties at room- and high-temperature:

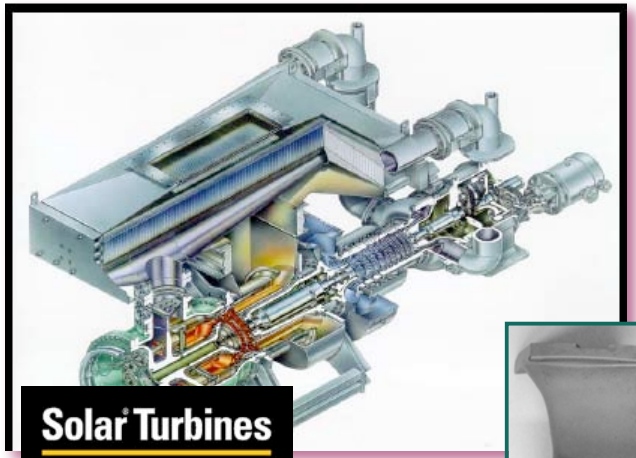
- Ingersoll-Rand *SN237* rotor and
- UTRC air-cooled *SN282 vanes*
- Solar Turbine NT154 blades

Environmental effect:

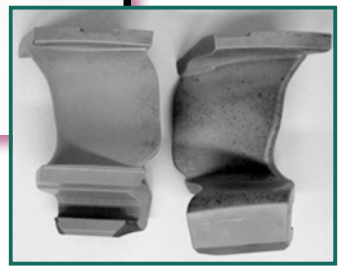
- Royce Allison *AS800* vanes after exposure to industrial gas turbines

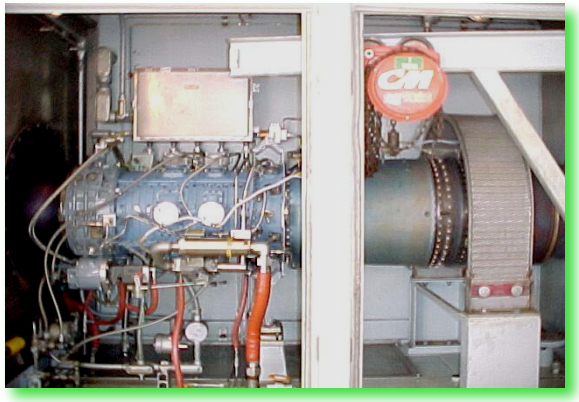
- Summary & Discussions

Silicon Nitride Ceramic Components Have Been Designed and Implemented for Distributed Energy Systems



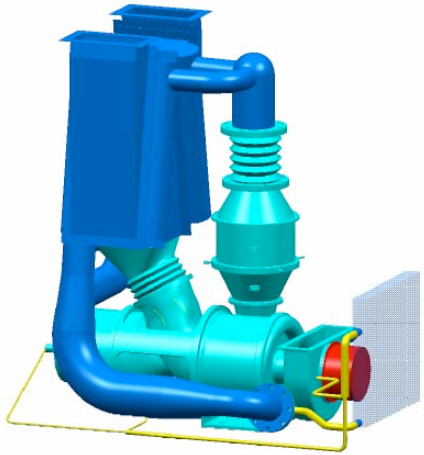
Solar Turbines
A Caterpillar Company





Rolls-Royce

PowerWorks



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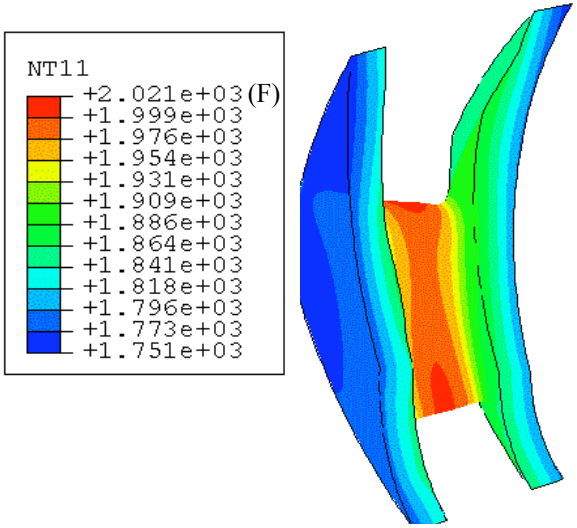
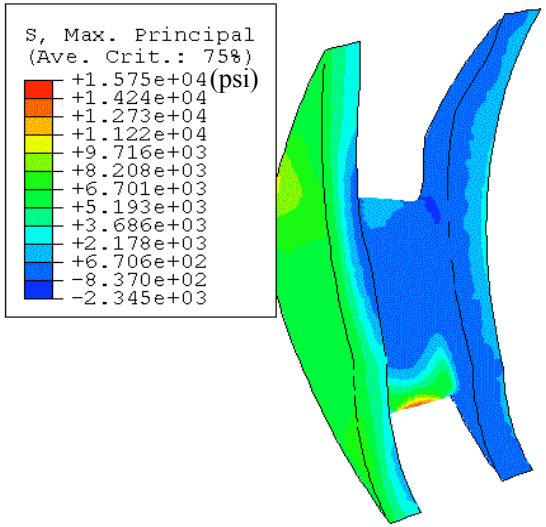
DER
Distributed Energy Resources

FEA Life Prediction of SN282 Integrated Vane Ring





Steady State Analysis of SN282 Vane Ring

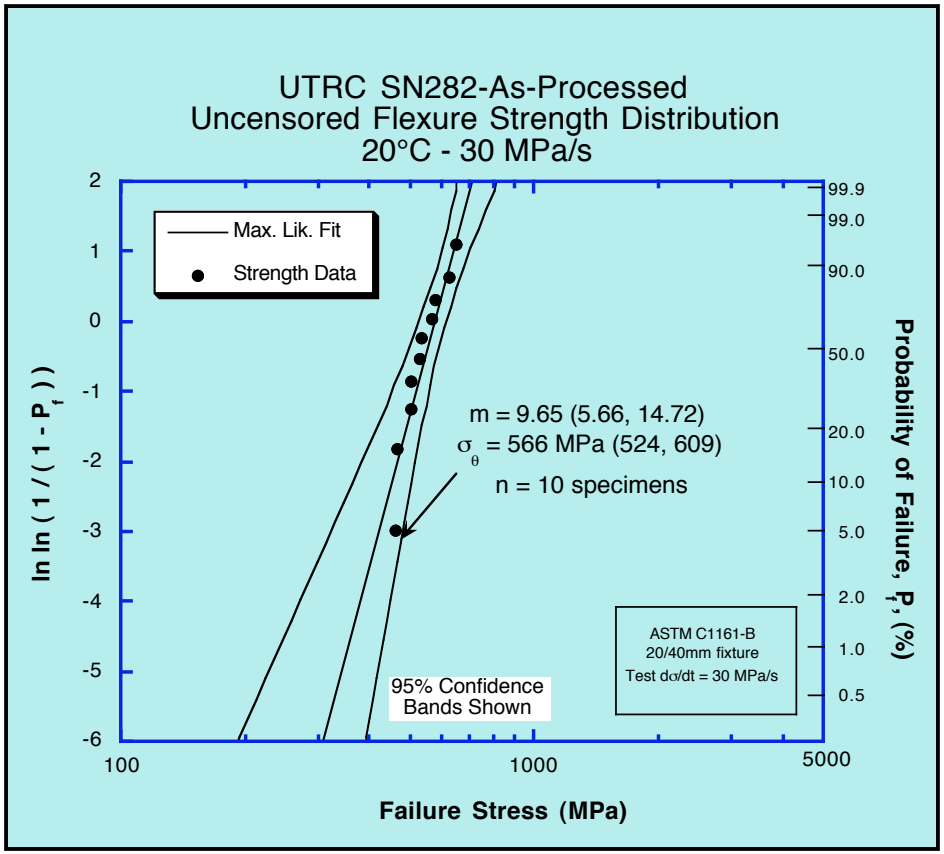
Value	Location	Silicon Nitride (SN282)	
		Average Inlet	Hot Streak
Temperature	Max. in Airfoil	2025	2200
	Min. in Airfoil	1900	1930
	Casing (approx.)	1770	1780
Stresses (ksi)	Trailing Edge	15.5	27.5
	Casing (approx.)	5 - 7	9 - 11
Failure Probability (CARES)	w/ RT Strength data	4.60E-08	3.50E-06
	w/ 1371 C Strength data	1.10E-06	8.40E-05

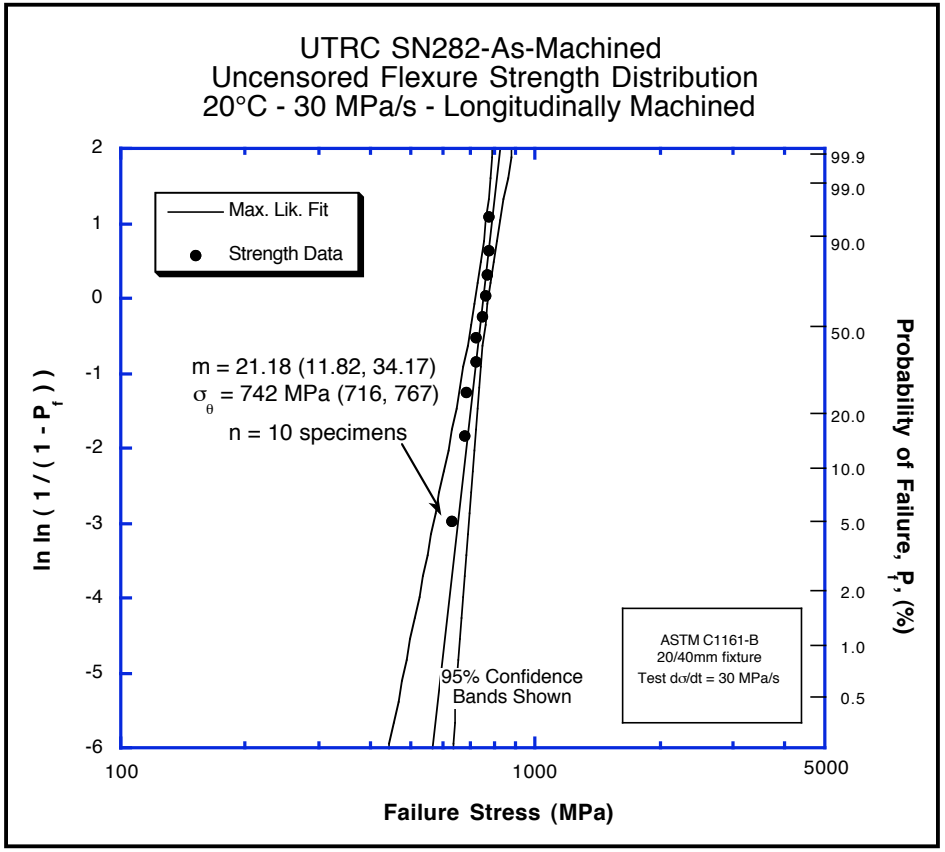
SN282: Silicon Nitride from Kyocera Industrial Ceramics Corp.

(Provided by S. Jun, UTRC)

Mechanical database generated from machined simple type testing specimens is used for probabilistic component design and life prediction

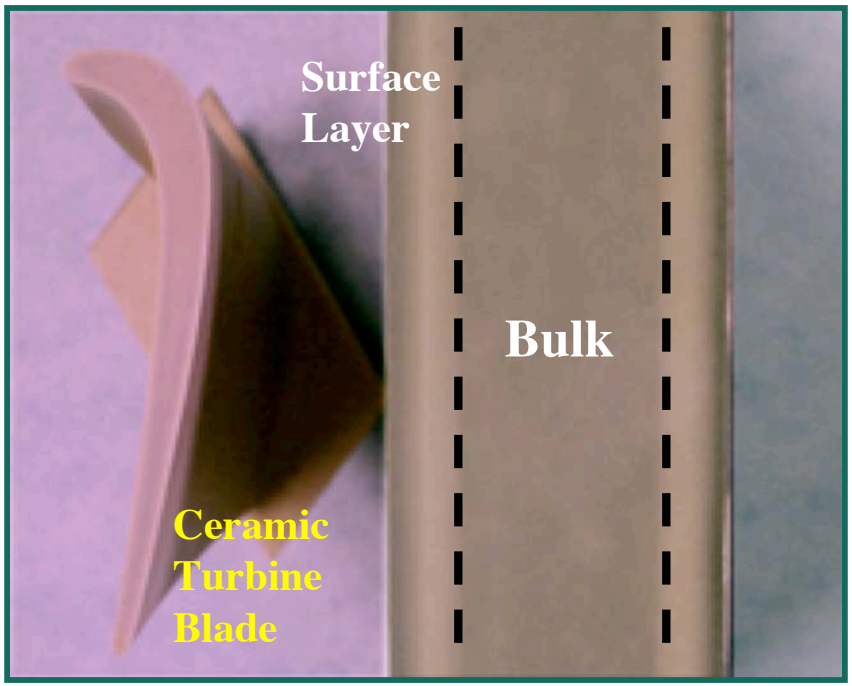
Mechanical Characteristics are Quite Different Between Samples with As-Processed and As-Machined Surface



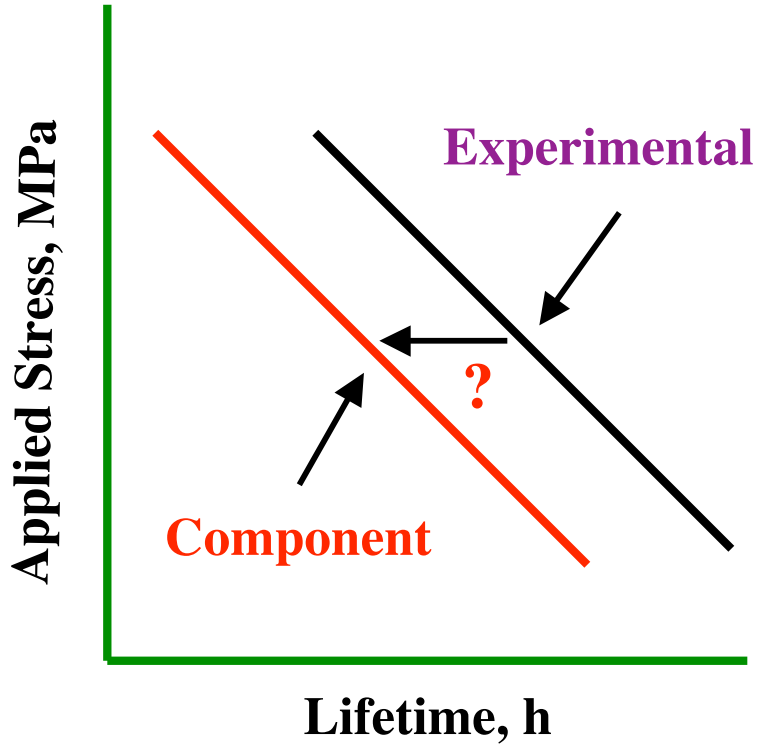


Probabilistic life prediction of components using machined MOR samples may not be accurate due to difference in strength limiting flaws population

Database Generated from Machined Bulk Materials Used for Lifetime Prediction of Ceramic Components

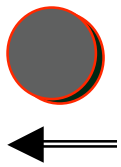


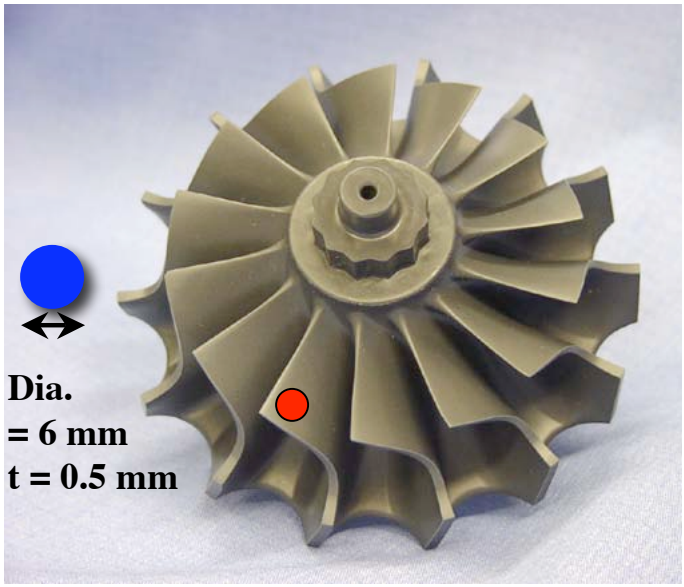
Surface reaction layer thickness is similar to the component airfoil



OBJECTIVE: **Database establishment of ceramic components for component probabilistic design life prediction and verification**

Test Methodology Developed Supports the Development and Implementation of Complex-Shaped Ceramic Components in Distributed Energy Systems





Evaluation of As-processed Surface Properties

Phase identification by X-Ray
Residual Stress
Microstructure Characterization

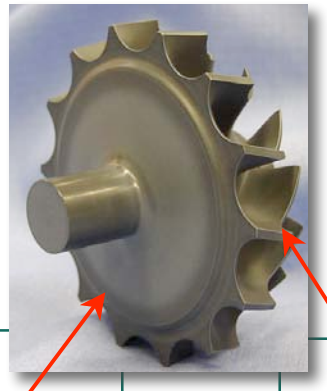
Evaluation of Bulk Properties

Extraction Procedures of Biaxial Disk Samples from Kyocera SN237 Silicon Nitride Rotor

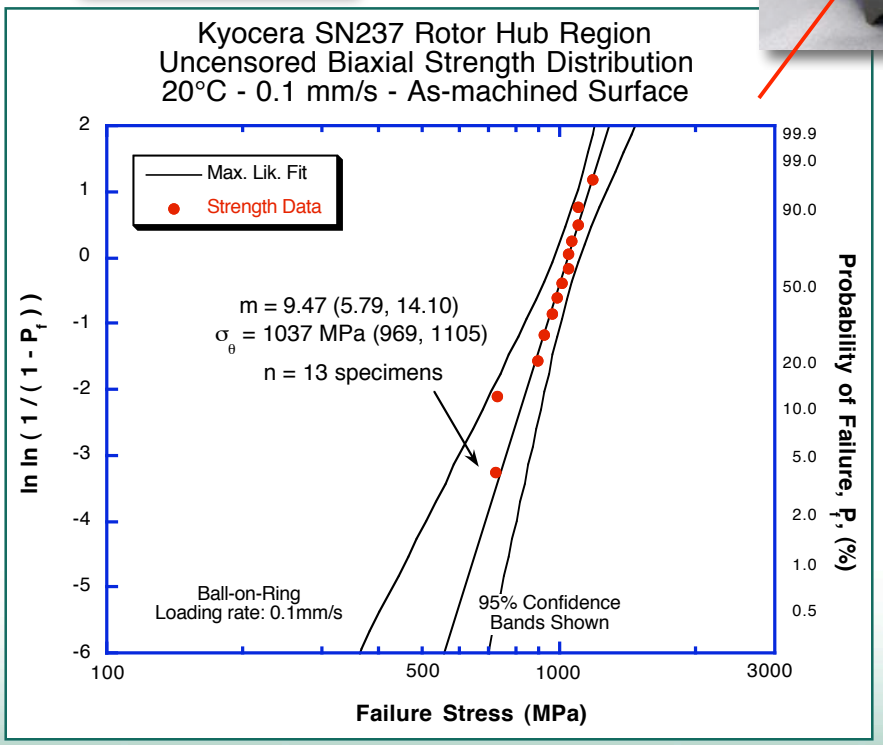
Samples with As-Processed Surfaces Exhibited Lower Biaxial Strength than Those with Machined Surface

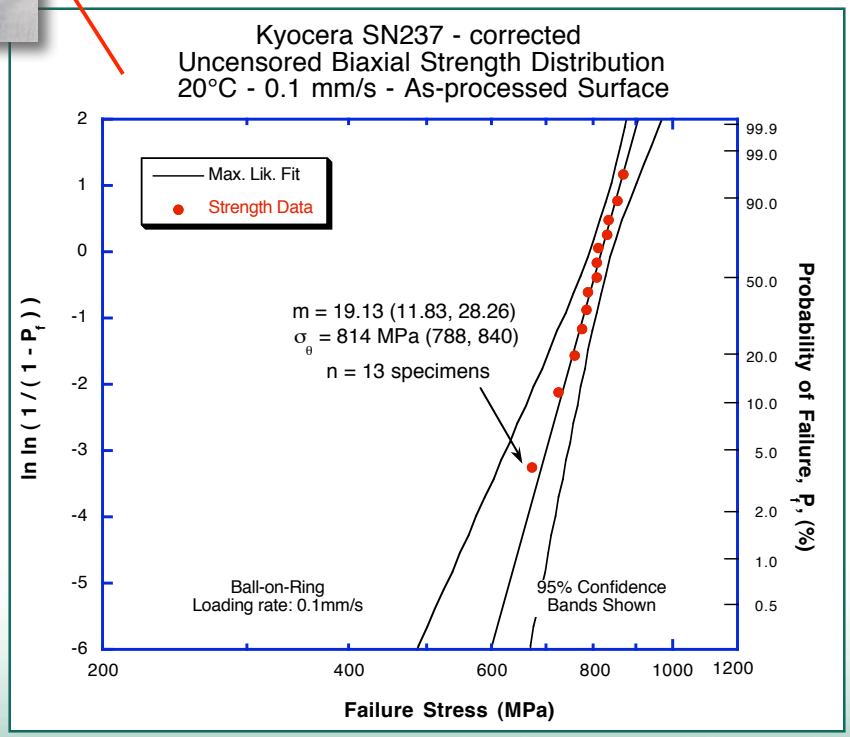
KYOCERA

IR PowerWorks

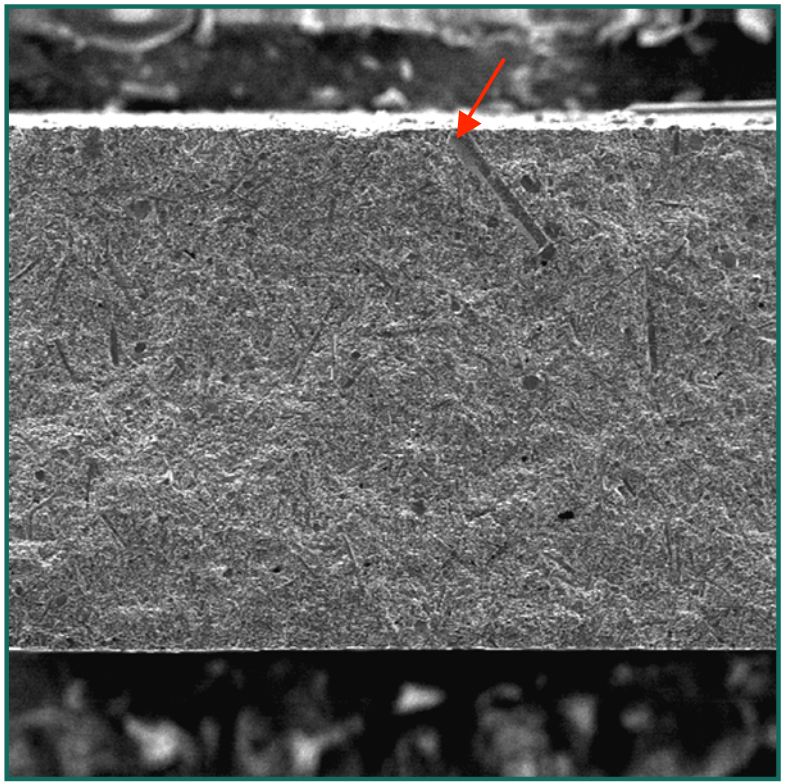


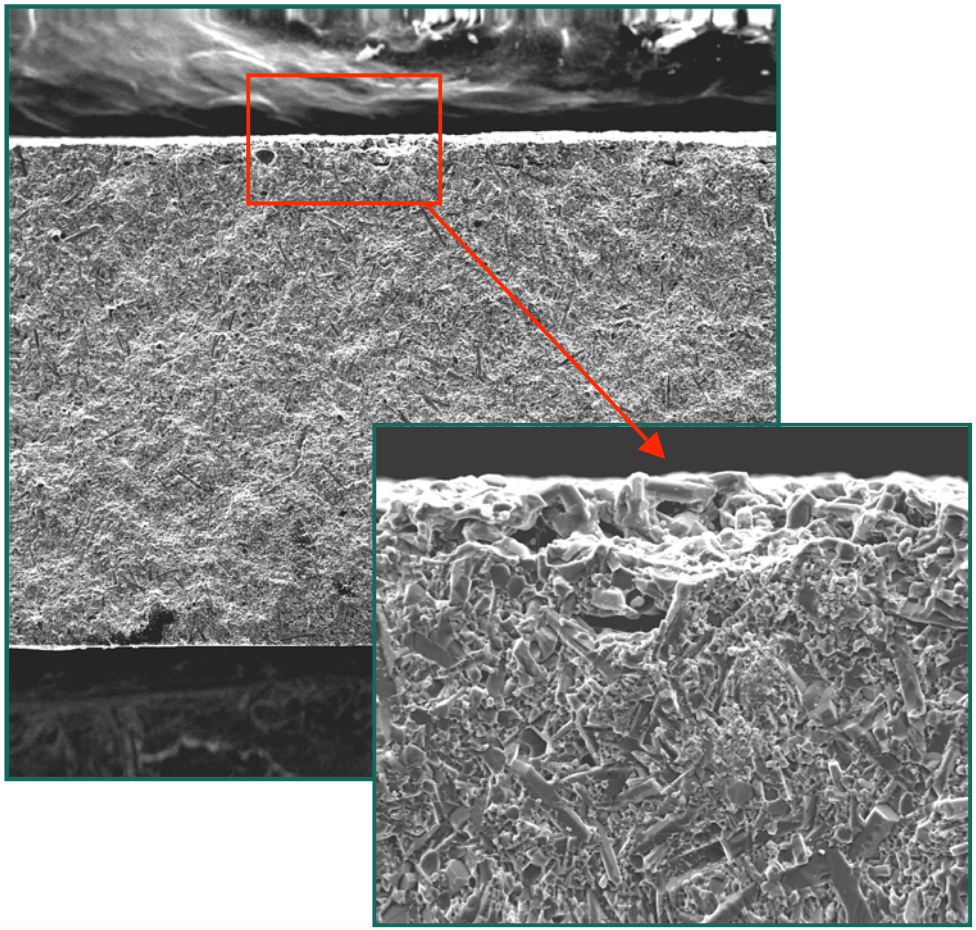
Application of data from machined MOR bars could over-estimated component lifetimes





Strength Limiting Flaws Observed in As-processed Airfoils are Large Si_3N_4 Grains or Processing Flaws





More Detailed Approaches of Biaxial Data Analysis Will be Presented by M. K. Ferber and A. A. Wereszczak

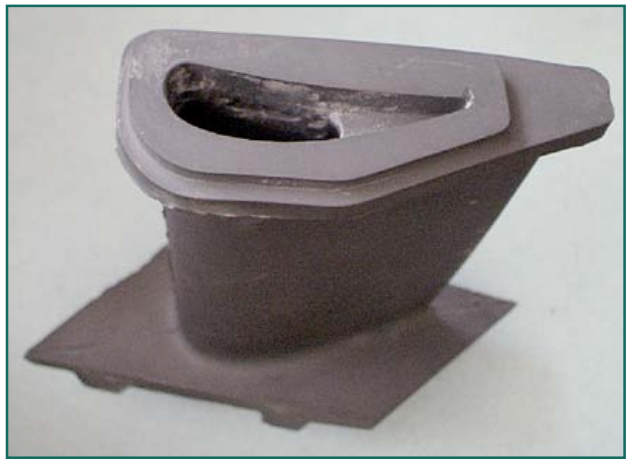
- ***CB-S2-61-2004: 2:20 PM (Room Columbia)***

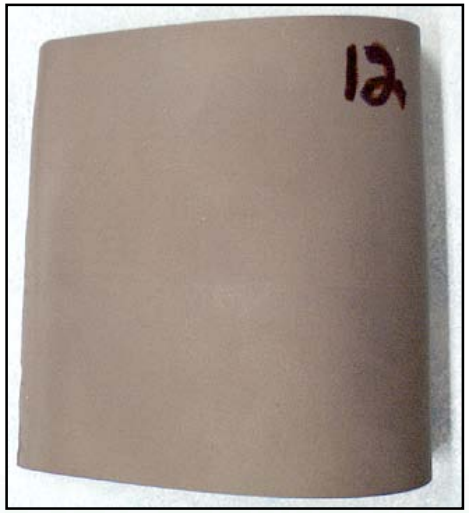
A. A. Wereszczak *et al*. "Strength-Size-Scaling in Zirconia Laminates"

- ***CB-S2-60-2004: 2:00 PM (Room Columbia)***

M. K. Ferber *et al*. "Influence of Specimens Size and test Geometry Upon the Biaxial Strength of Y-ZrO_2"

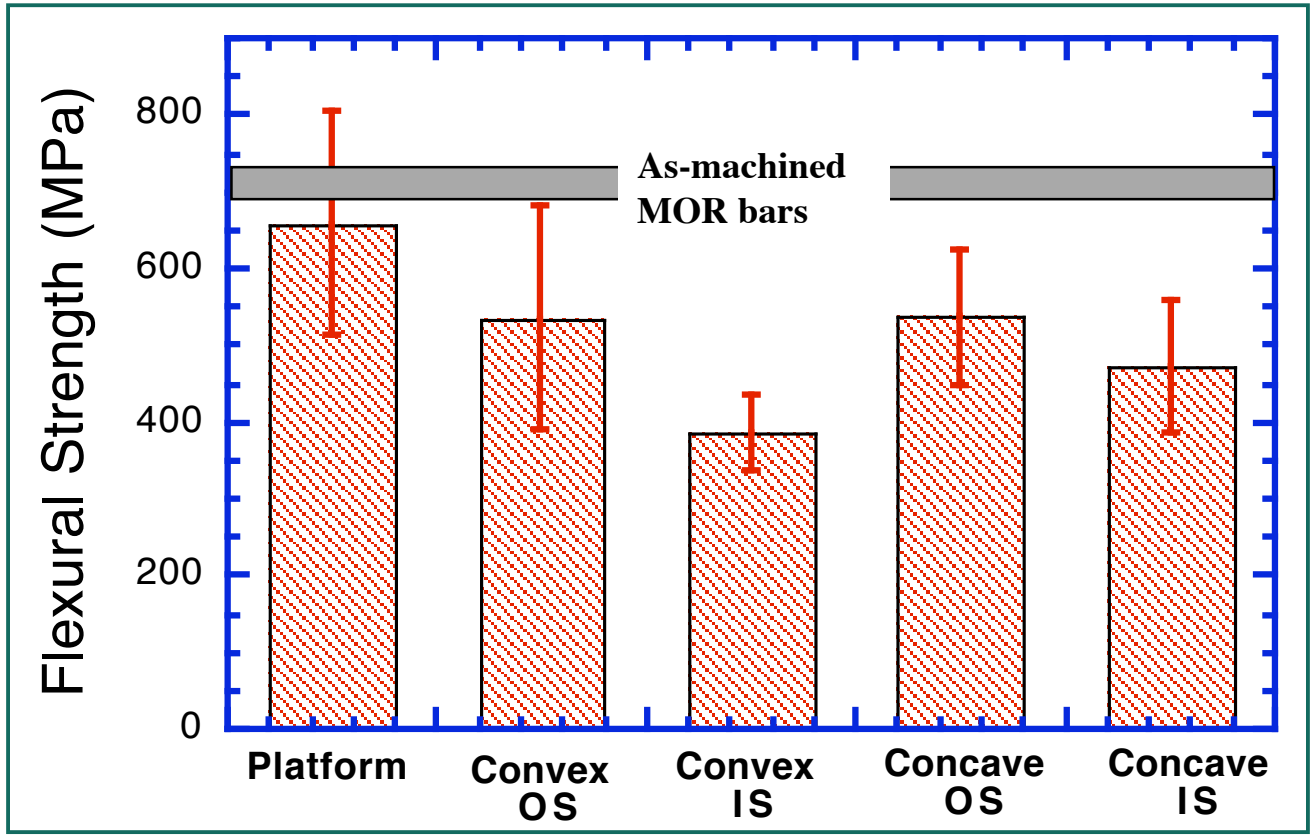
Air-Cooled SN282 Silicon Nitride First Stage Vane for Pratt & Whitney FT8 Turbine Engine





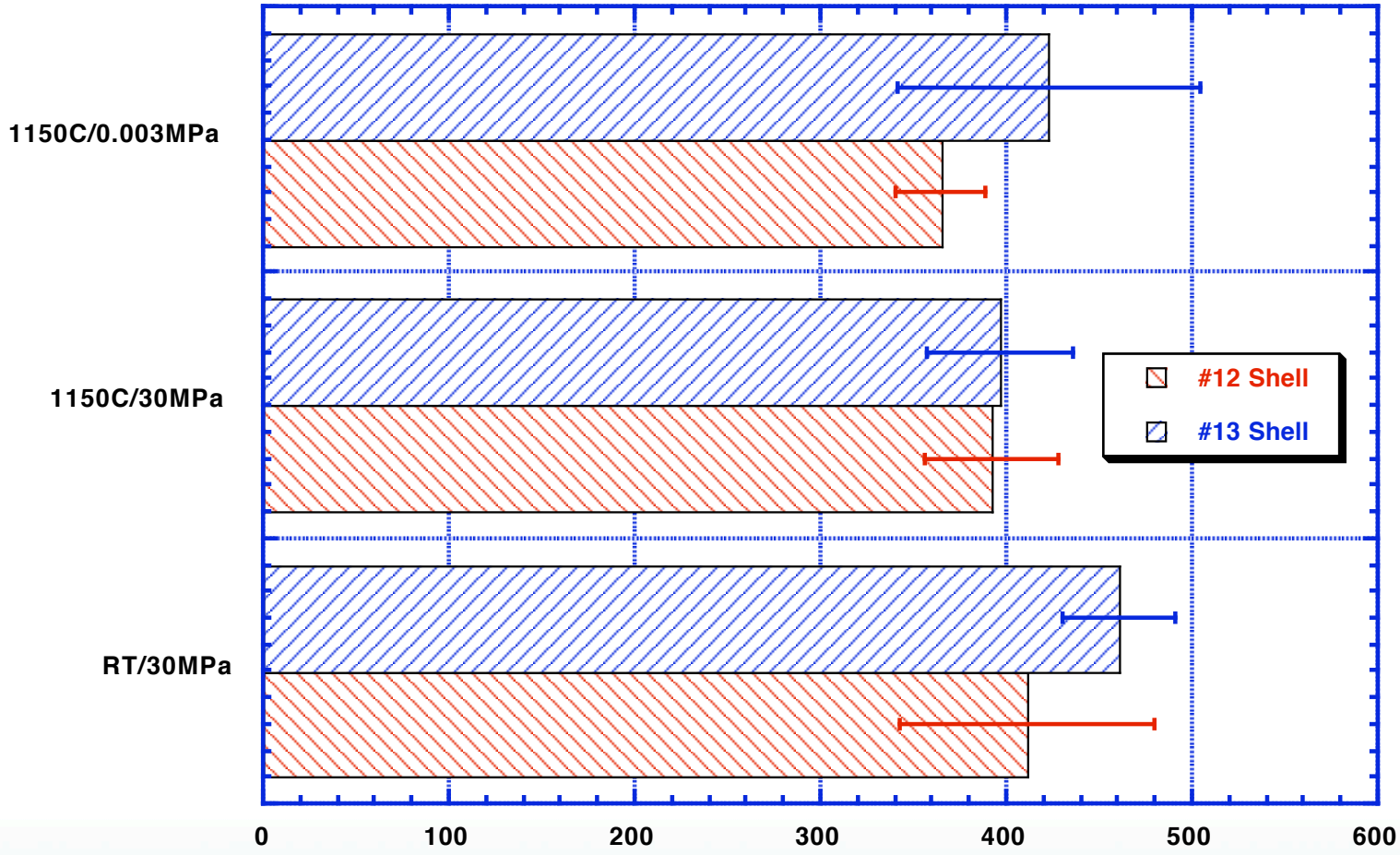
Drain cast vane shells

Samples Tested with As-Processed Surface Exhibited Lower Flexural Strength Than Those Tested with Machined Surface



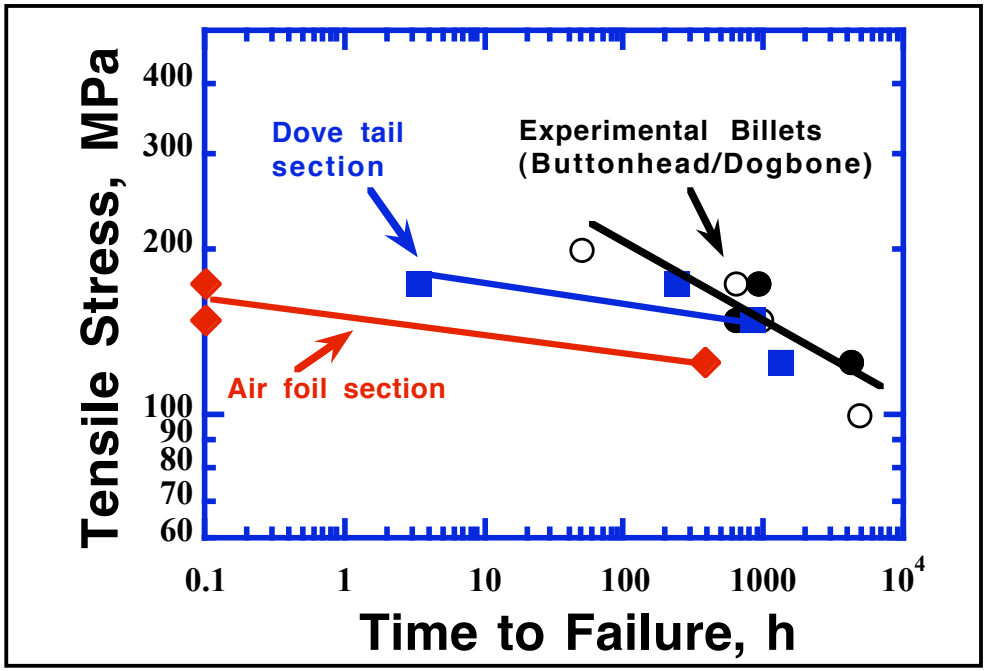
OS: As-processed outside surface **IS: As-processed inside surface**

Mechanical Properties of As-processed Drain Cast Vane Shells are More Comparable to Bulk Properties



All tested with inner surfaces as tensile surfaces

Database Generated From Ceramic Components Provides More Reliable Database for Lifetime Prediction

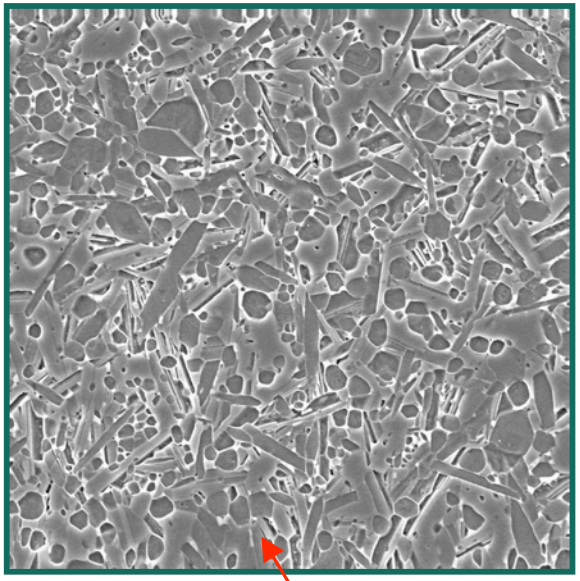


@ 1370°C in air

Norton NT164 first stage turbine blade

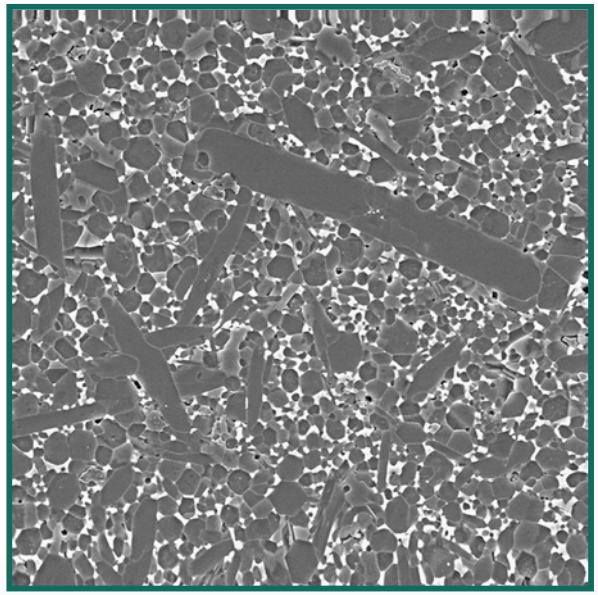
Database generated from production billets overestimated the lifetime performance of components

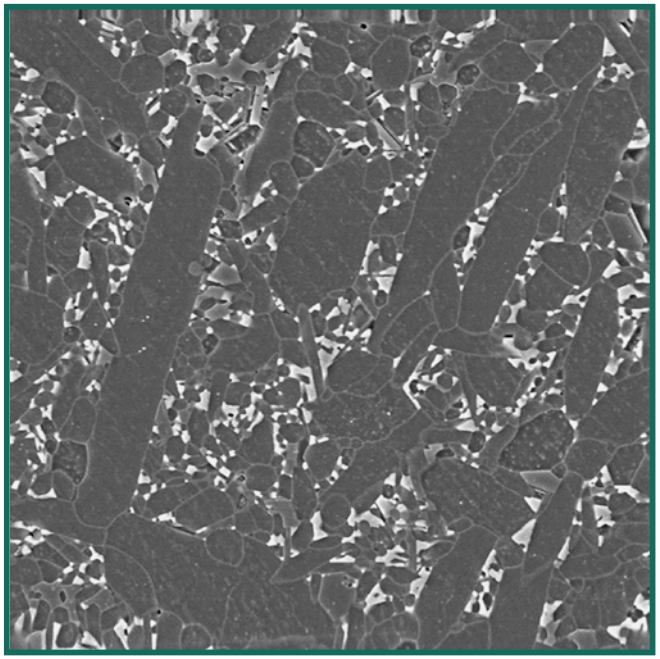
Poorer Creep Resistance Caused by the Finer Grain Microstructure And Higher Glassy Phase Content



Airfoil Section

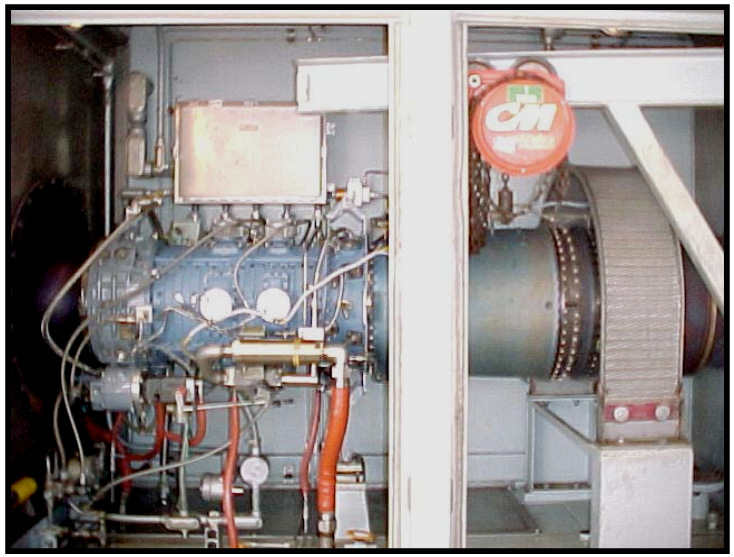
Dovetail Section



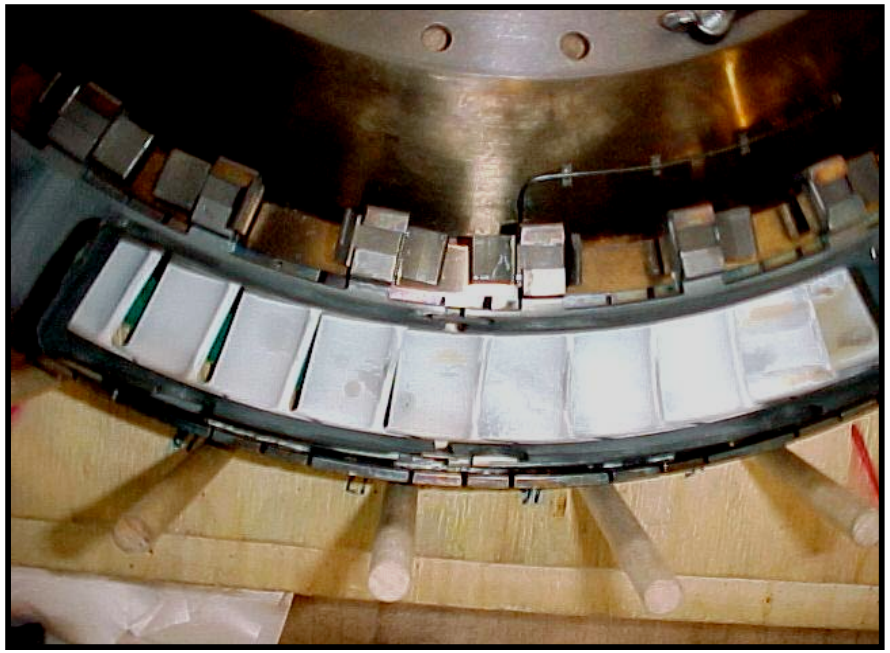


Production Rod

Component Evaluation Provides Important Understanding on Environmental Effects on Ceramic Components



Model 501K Turbine
Exxon - Mobile, AL - 6/29/99



200 hr Interval - Exxon - 6/29/99

Rolls-Royce

Honeywell uncoated AS800 vanes

Honeywell

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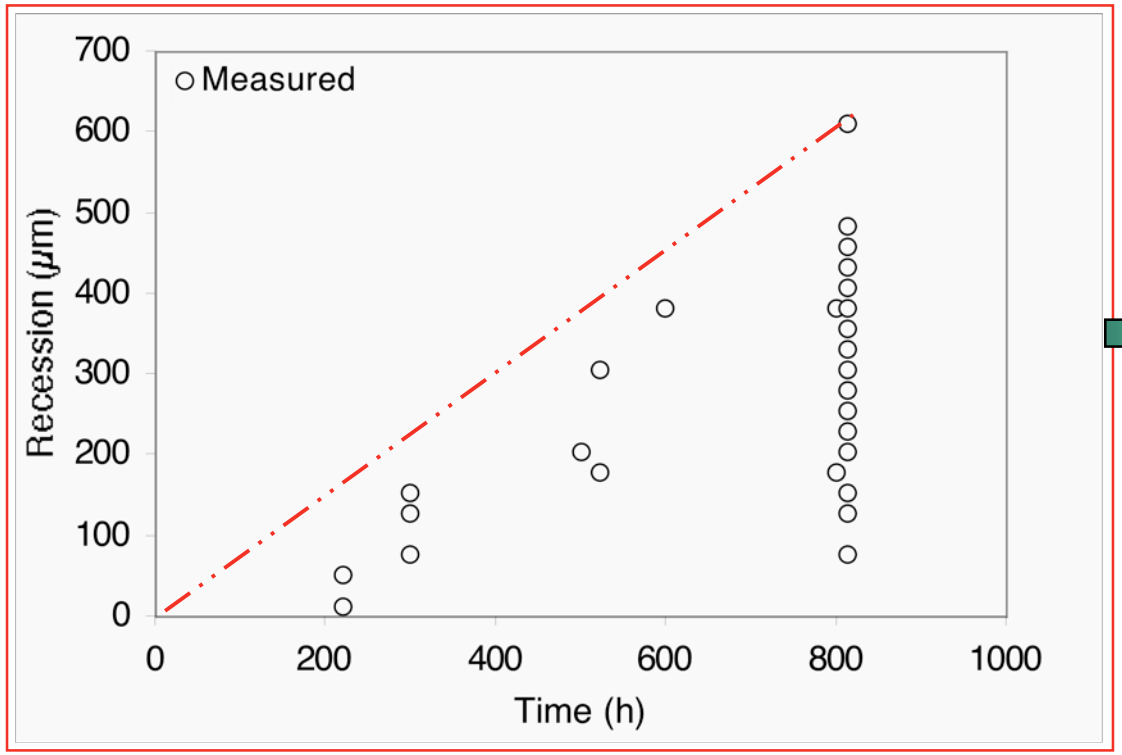
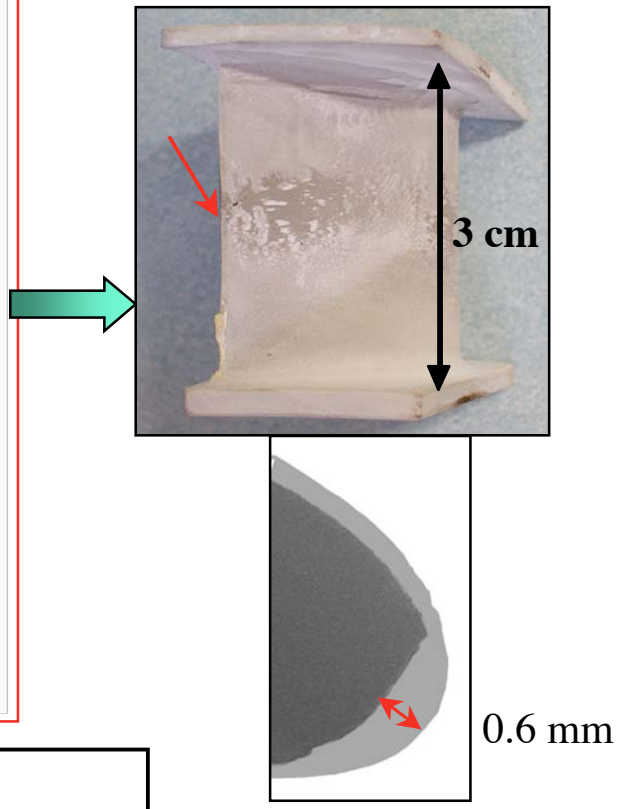
U. S. DEPARTMENT OF ENERGY

Significant Material Recession of Airfoils Was Measured for Midspan of The Trailing Edge Region

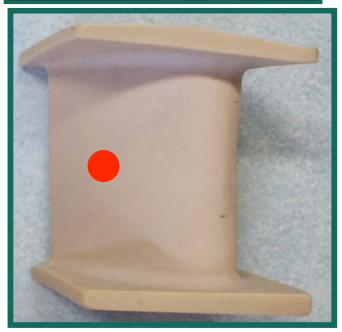


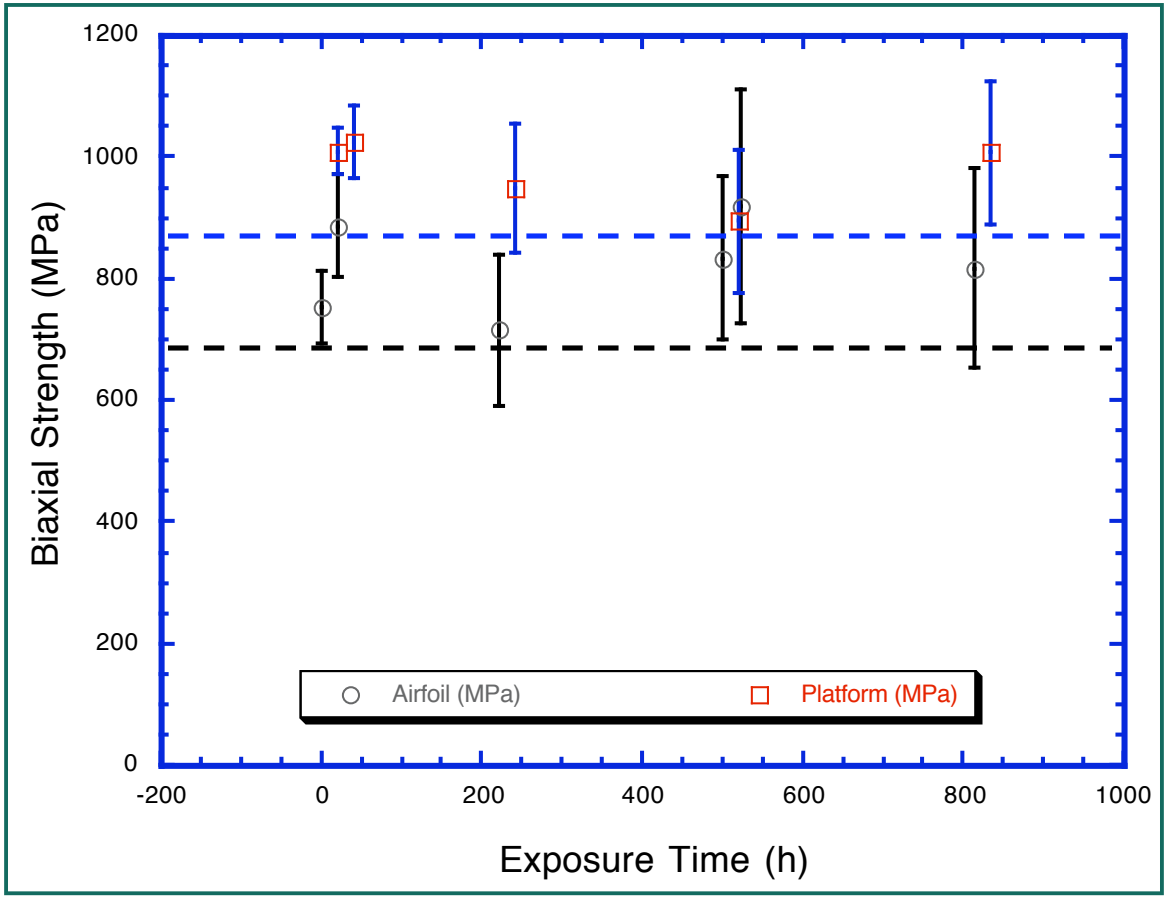


Cross-section:
815 h/Vane 78

Conclusion:
An environmental barrier coating (EBC) is needed to protect Si_3N_4 components from gas turbine environments

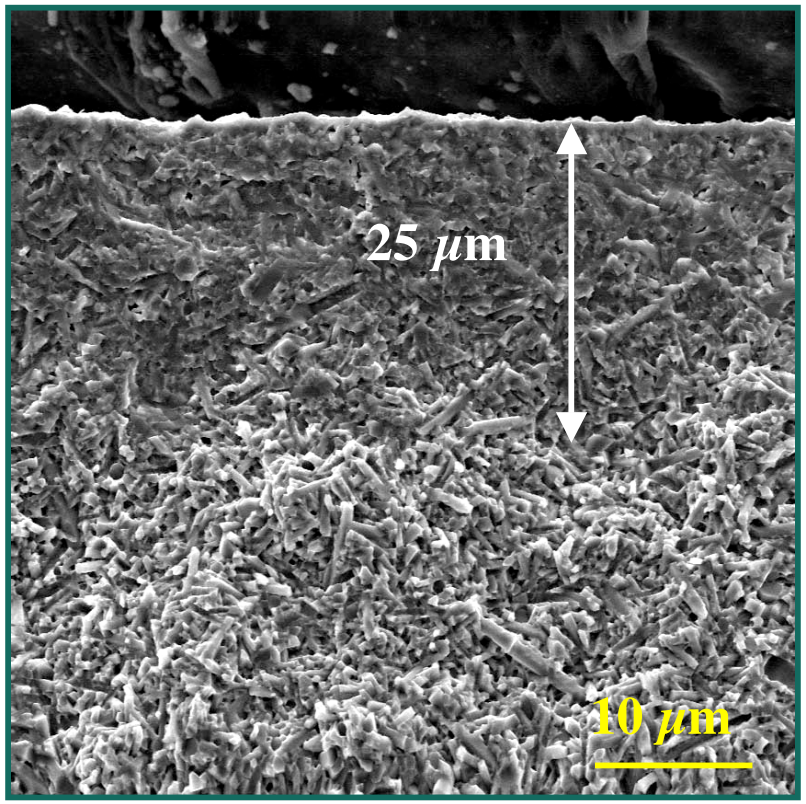
Specimens From Airfoil Sections Exhibited Relative Low Strength Than Those From Platform Sections



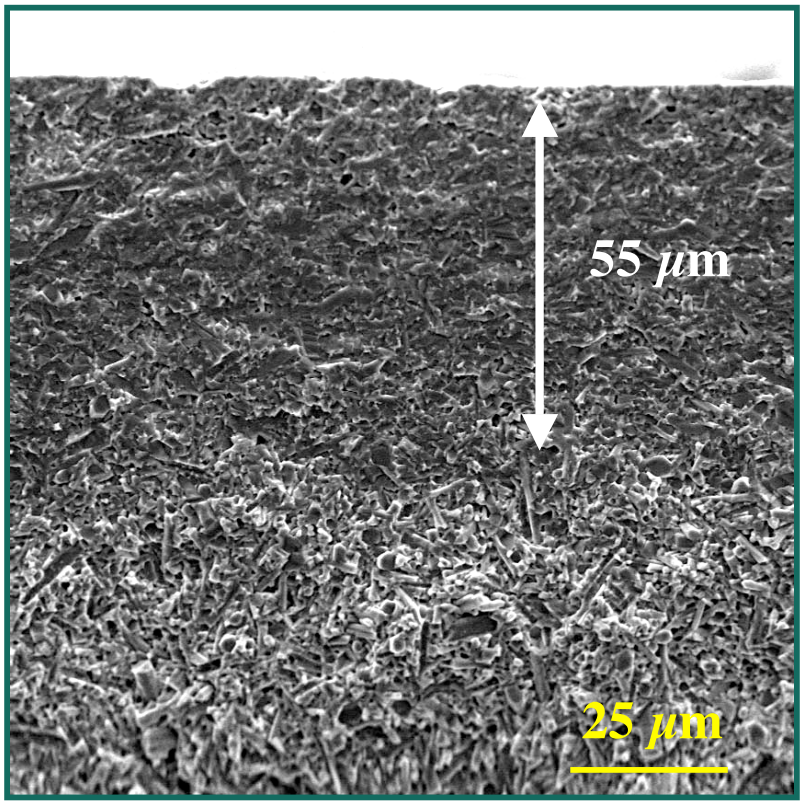


Scatter in strength data from airfoil sections increases with exposure time

Brittle Damage Zone Developed due to Environmental Exposure Contributed to the Strength Degradation



222 h Specimen



522 h Specimen

Depth of damage zone remained relative constant after 500h test

Increase in strength scatter may arise from the variation in brittle zone

Summary

- There is a critical need of ceramic components database for advanced designs and life prediction.

- ***"Component Subtask"*** provides key efforts and supports to implement the ceramic components for advanced gas turbine and microturbine systems.

- Several evaluation approaches were employed to evaluate the mechanical properties of complex-shaped ceramic components.

- Mechanical properties obtained from as-received components are not comparable to those obtained from production billets, in part, due to differences in microstructure and chemical composition.

- Component verification also provides important information on how the mechanical properties and microstructure influenced by the turbine environments.