Characterization of Mechanical Performance of NT154 Silicon Nitride Microturbine Rotors

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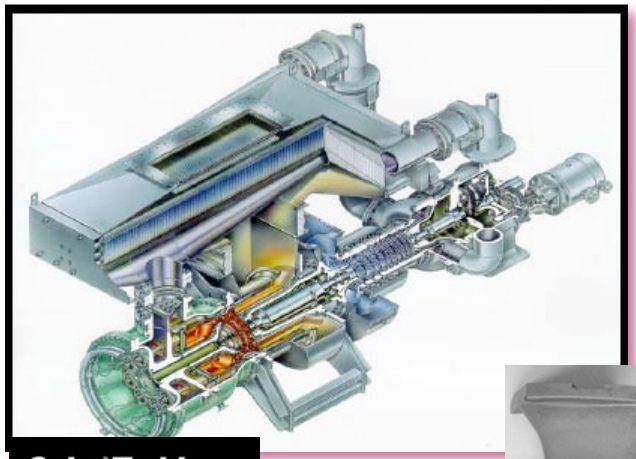
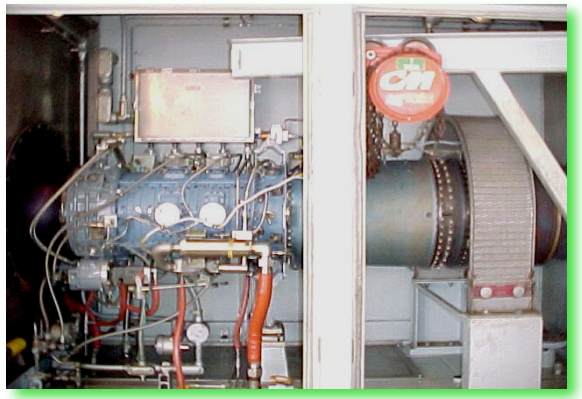
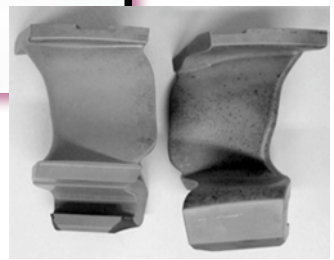
Silicon Nitride Ceramic Components Have Been Designed and Implemented for Distributed Energy Systems



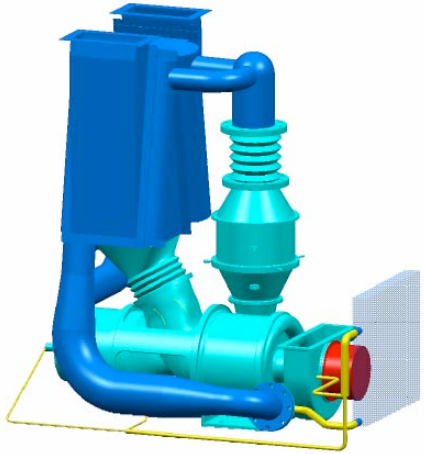
Solar Turbines
A Caterpillar Company



Rolls-Royce



PowerWorks



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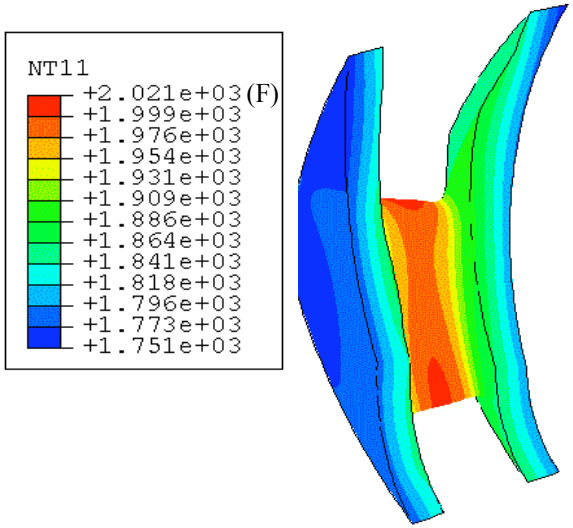
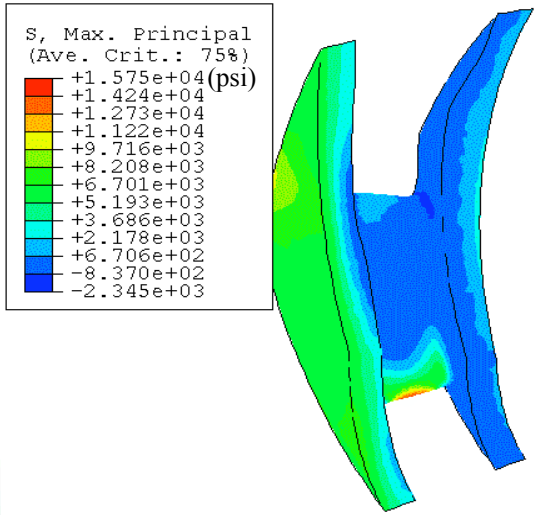
FEA Life Prediction of SN282 Integrated Vane Ring





Steady State Analysis of SN282 Vane Ring

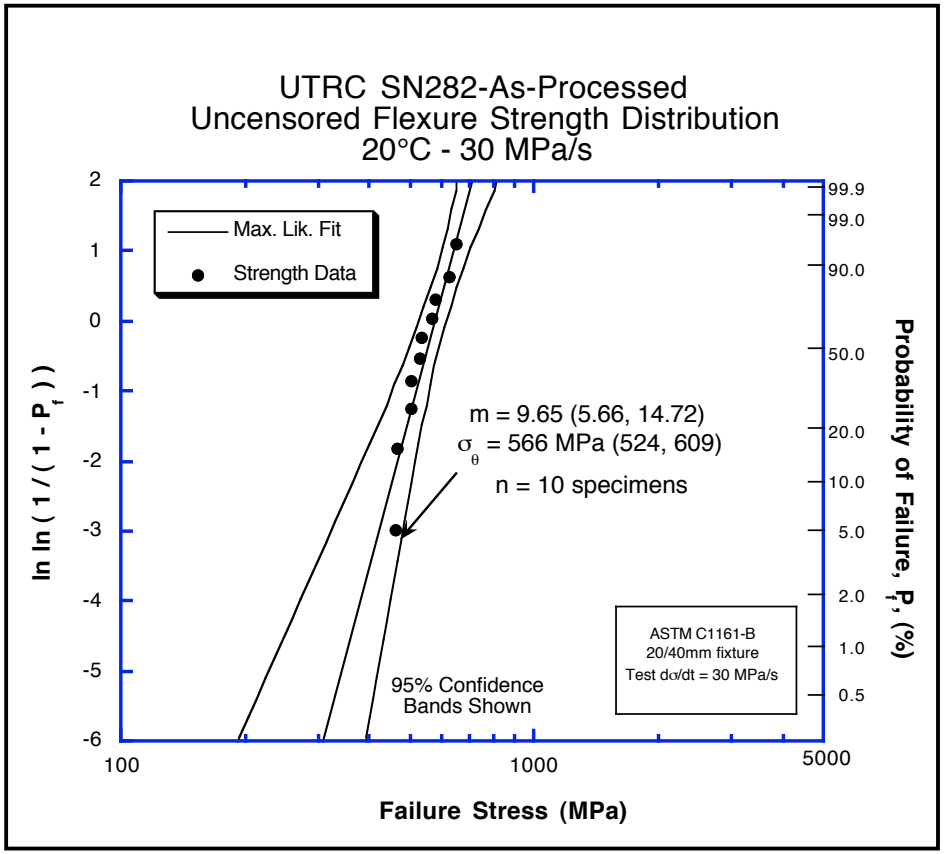
Value	Location	Silicon Nitride (SN282)	
		Average Inlet	Hot Streak
Temperature	Max. in Airfoil	2025	2200
	Min. in Airfoil	1900	1930
	Casing (approx.)	1770	1780
Stresses (ksi)	Trailing Edge	15.5	27.5
	Casing (approx.)	5 - 7	9 - 11
Failure Probability (CARES)	w/ RT Strength data	4.60E-08	3.50E-06
	w/ 1371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

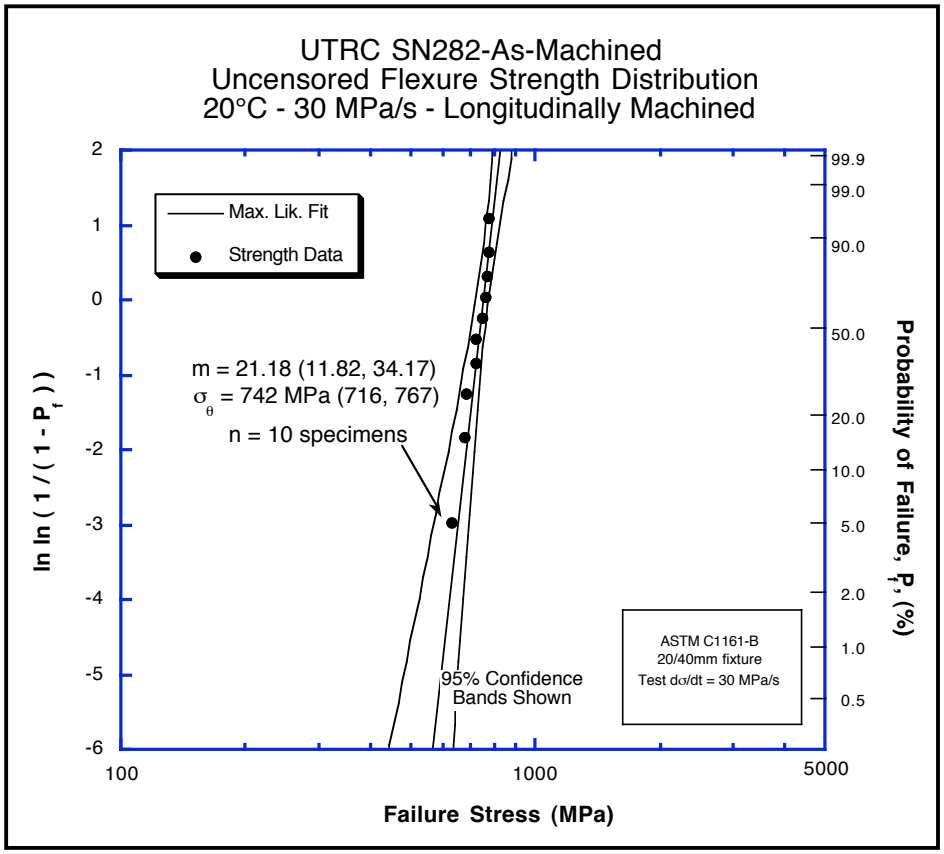
SN282: Silicon Nitride from Kyocera Industrial Ceramics Corp.

(provided by S. Jun @UTRC)

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

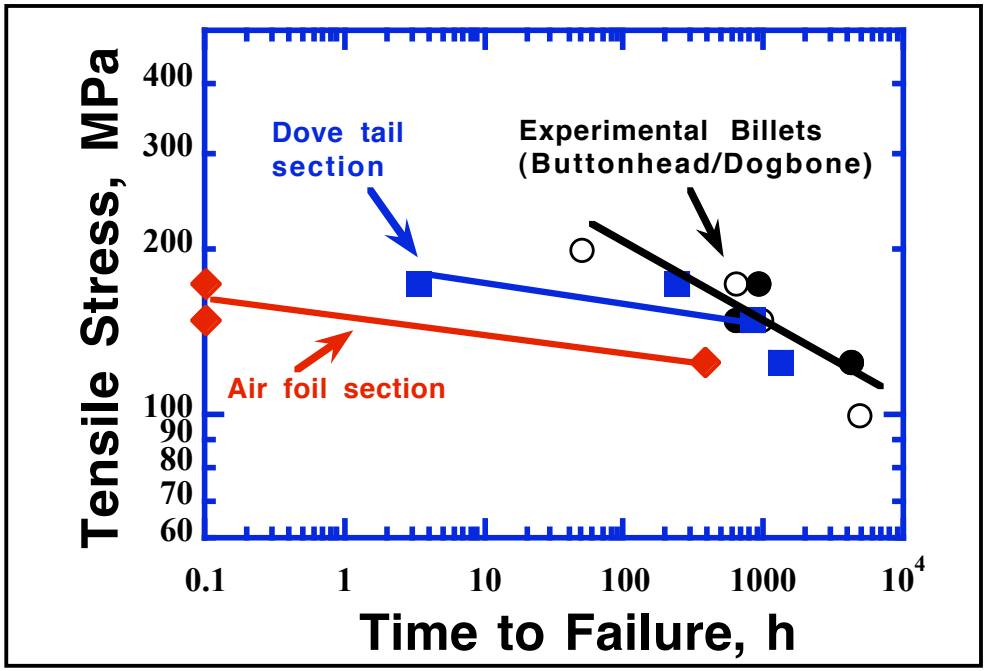
Mechanical Performance is Quite Different Between Samples with As-Processed and As-Machined Surface





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

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

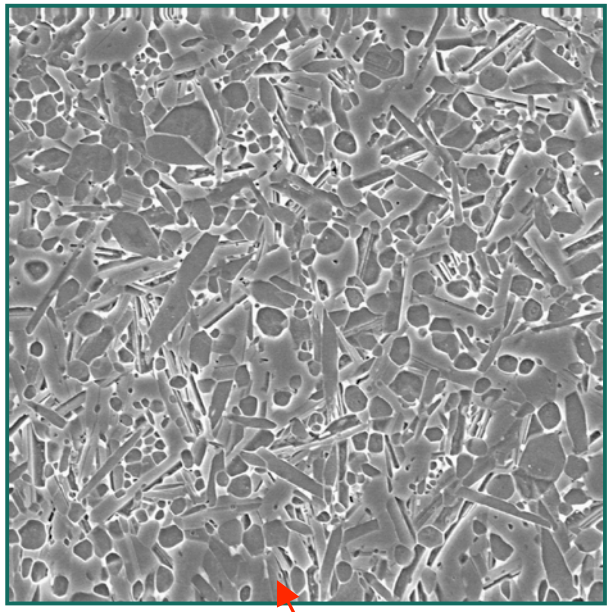


@ 1370°C in air

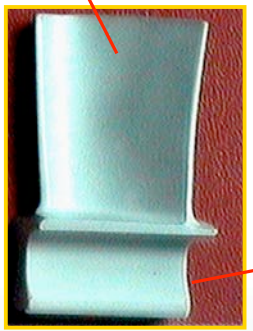
Norton NT164 first stage turbine blade

Database generated from production billets overestimated the lifetime performance of Si_3N_4 turbine blade components under application conditions

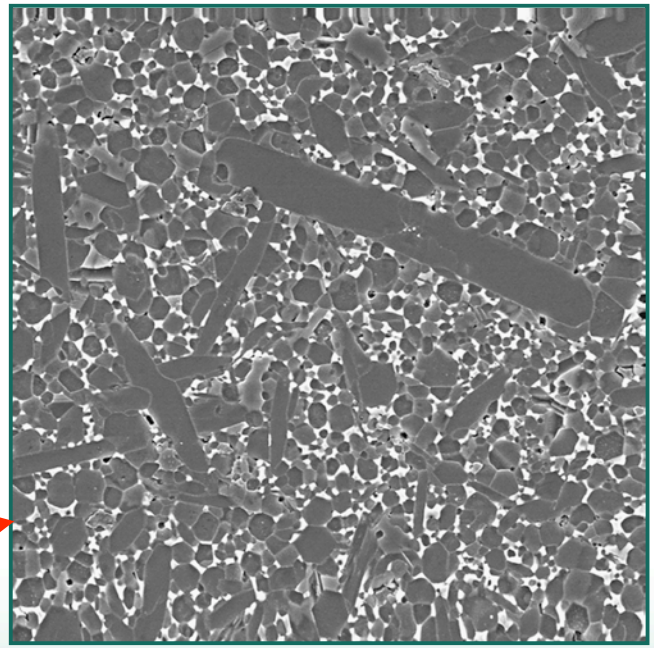
Poorer Creep Resistance Caused by the Finer Grain Microstructure and Higher Glassy Phase Content

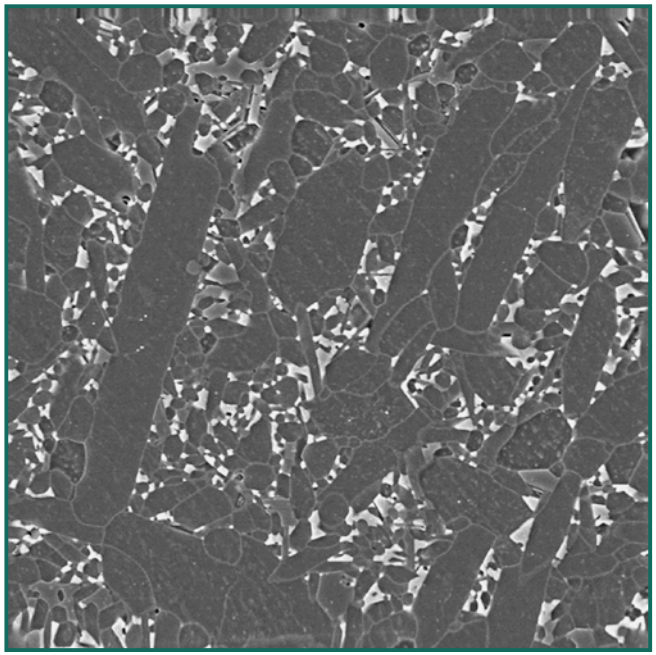


Airfoil Section



Dovetail Section





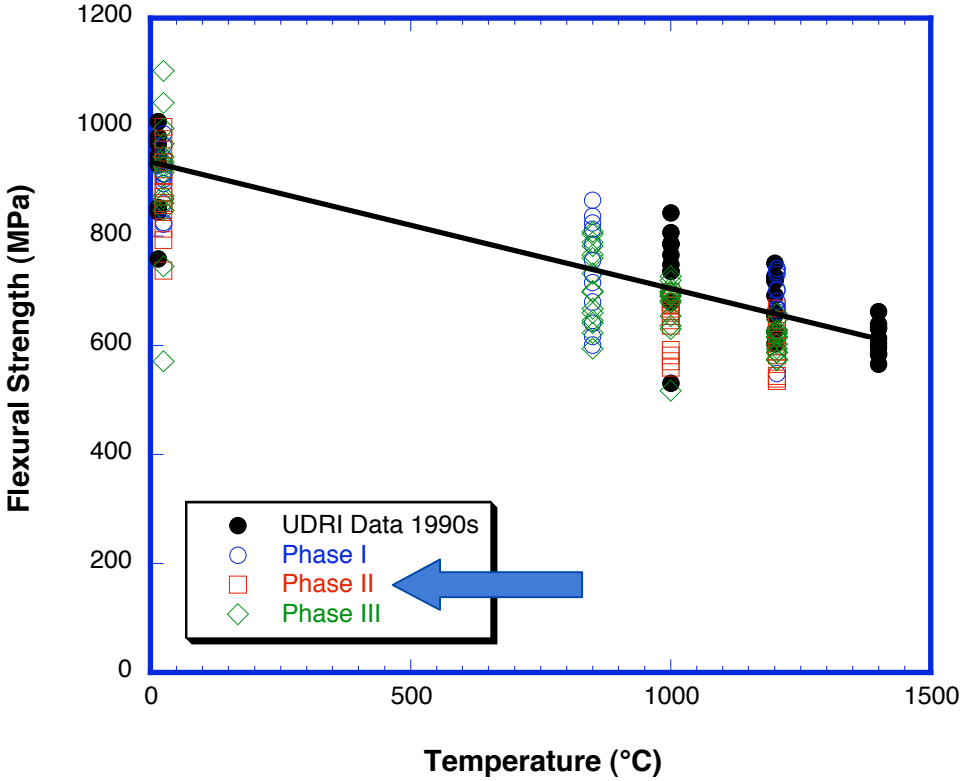
Production Rod

US DOE Awarded Saint-Gobain to Re-establish NT154 Silicon Nitride Processing and Mechanical Properties

NT154 Si_3N_4 rotor fabricated via the green machining process

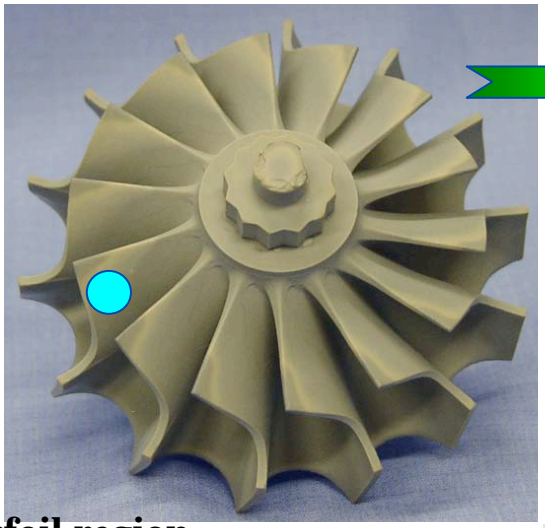
Rotor originally designed for IR microturbine system

PowerWorks
70 kWe microturbine

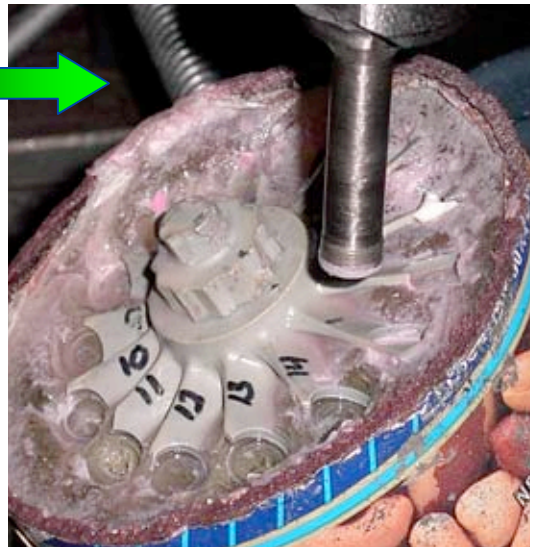


Mechanical properties of NT154 Si_3N_4 have been re-established under current DOE subcontract

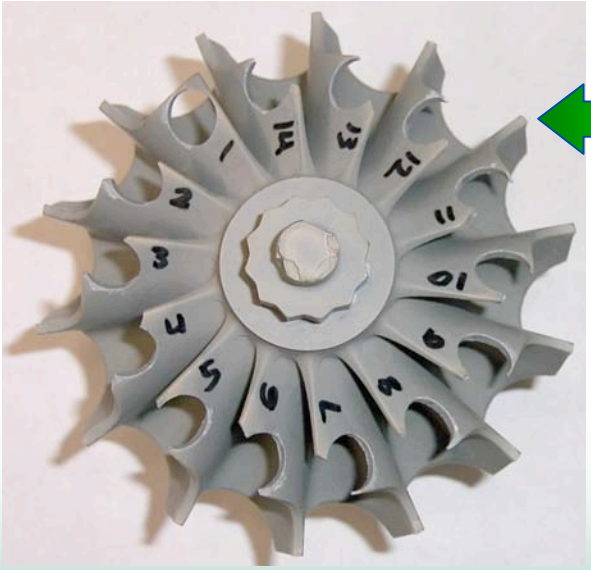
Extraction Procedures of Biaxial Disk Samples from Silicon Nitride Microturbine Rotor

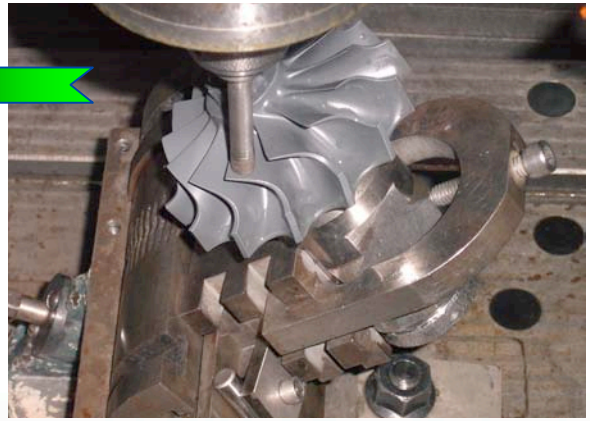


Airfoil region

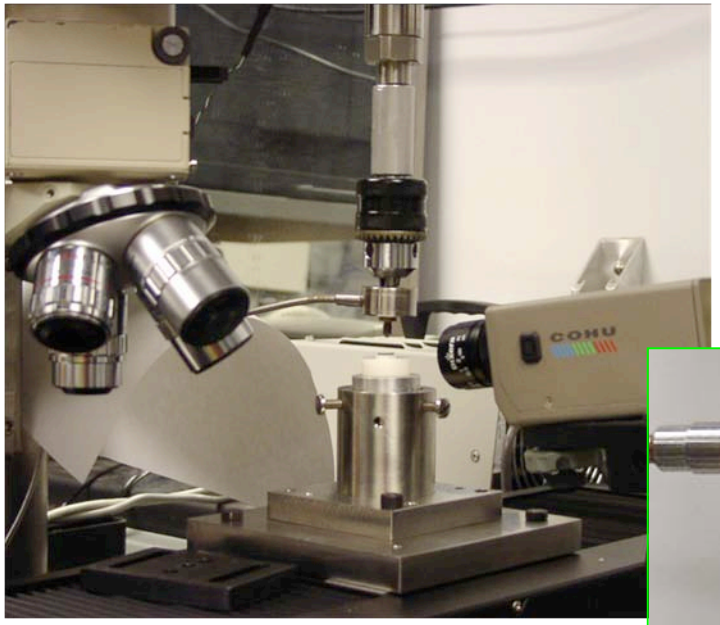


Hub region



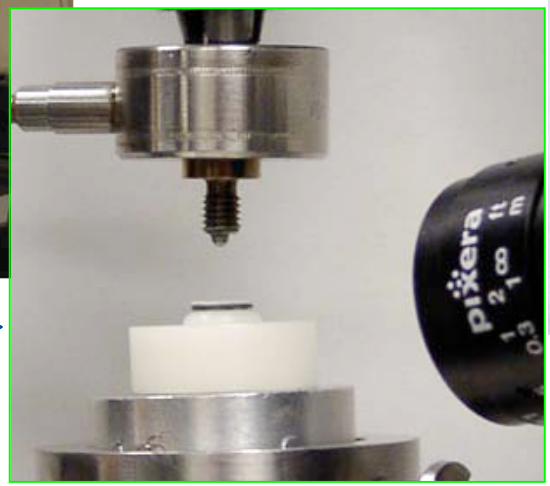


Test Methodology Developed Supports the Development and Implementation of Complex-Shaped Ceramic Components in Distributed Energy Systems

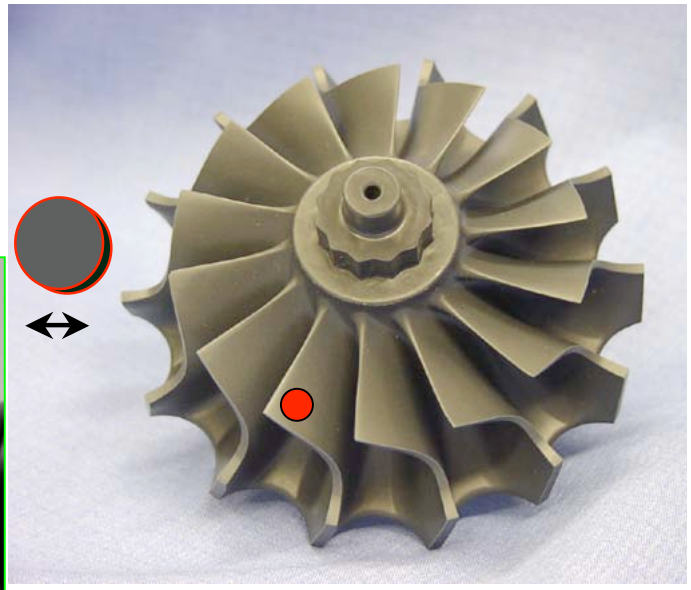


Evaluation of As-processed Surface Properties

Dia. ~ 7-8 mm
t = 0.5 mm

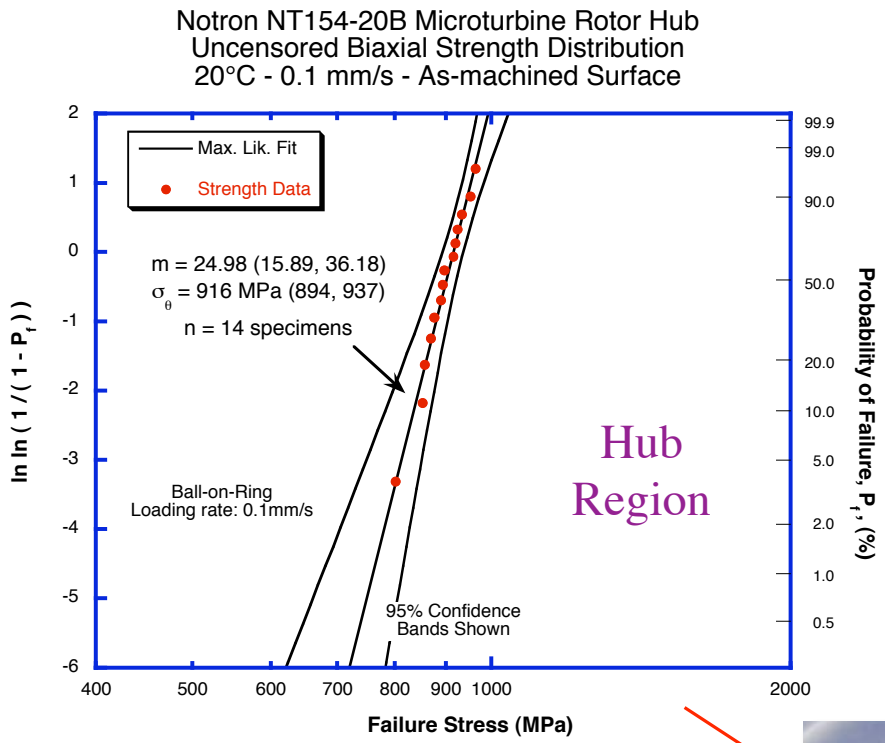


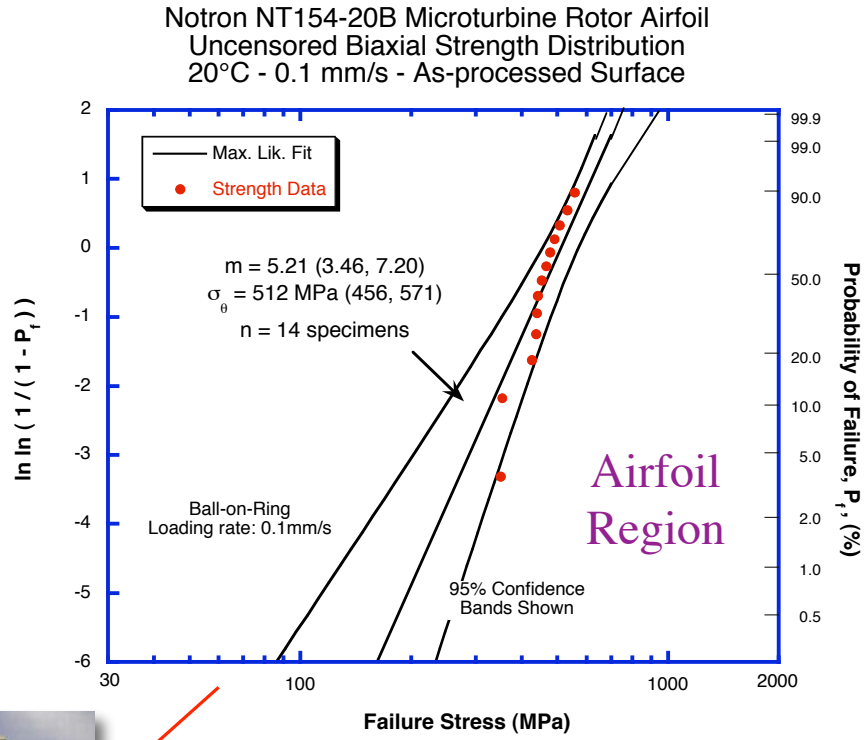
Controlled by personal computer with LabView program

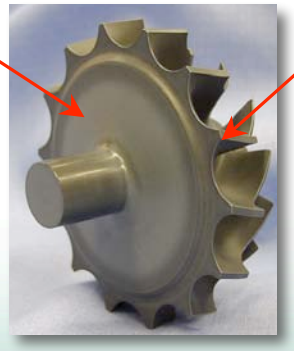


Phase identification by X-Ray Residual Stress Microstructure Characterization

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



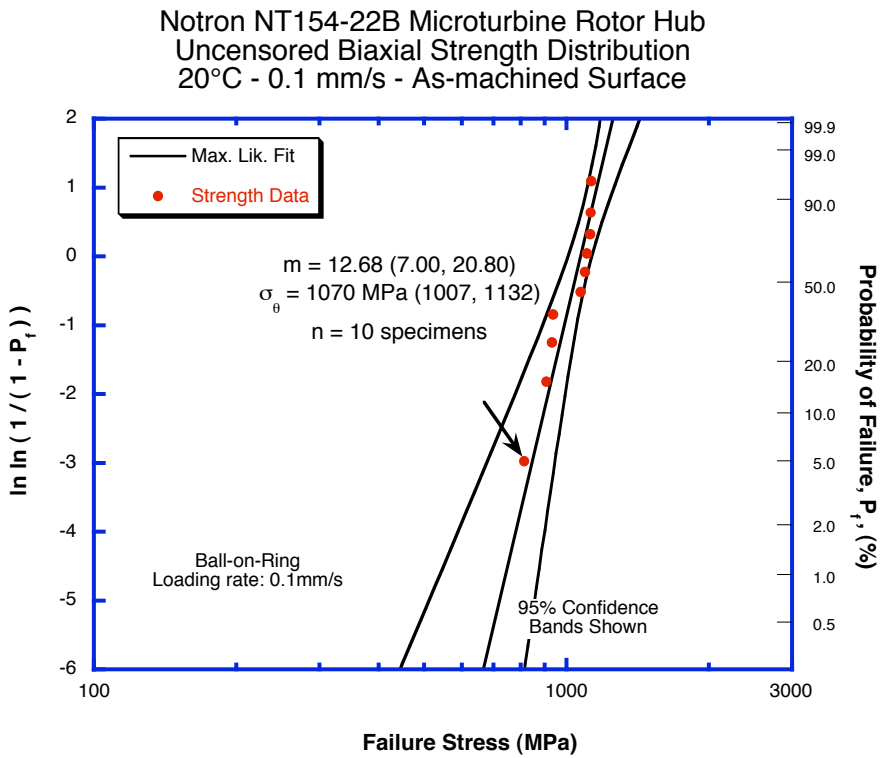


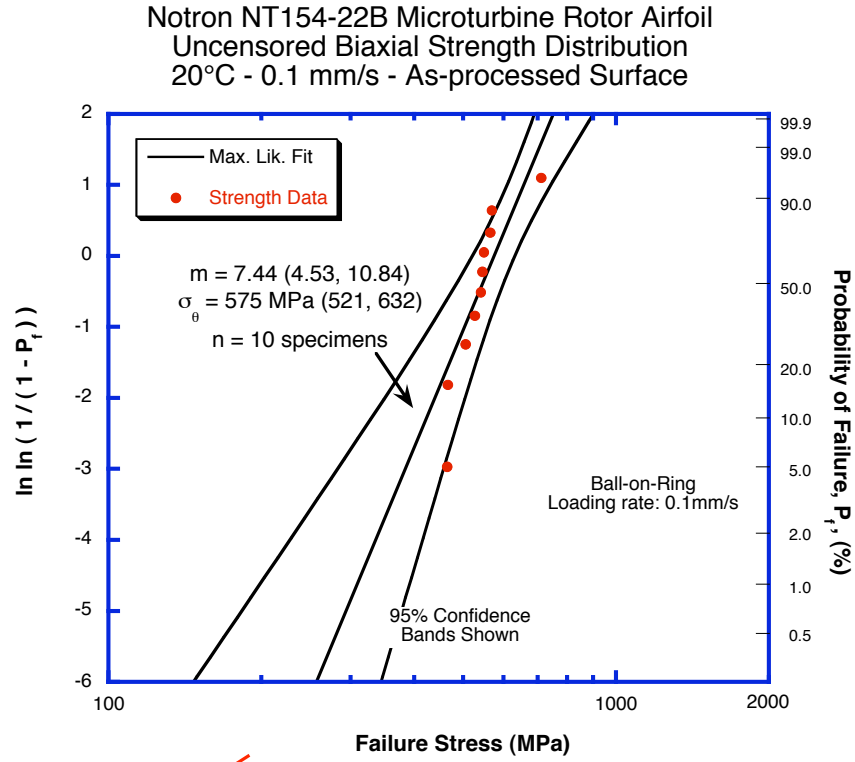


The σ_θ of as-processed airfoil discs is ~44% lower than those with as-machined surface

The as-processed airfoil discs also exhibited lower Weibull modulus

Consistent Mechanical Properties Obtained From NT154 Si_3N_4 Microturbine Rotors

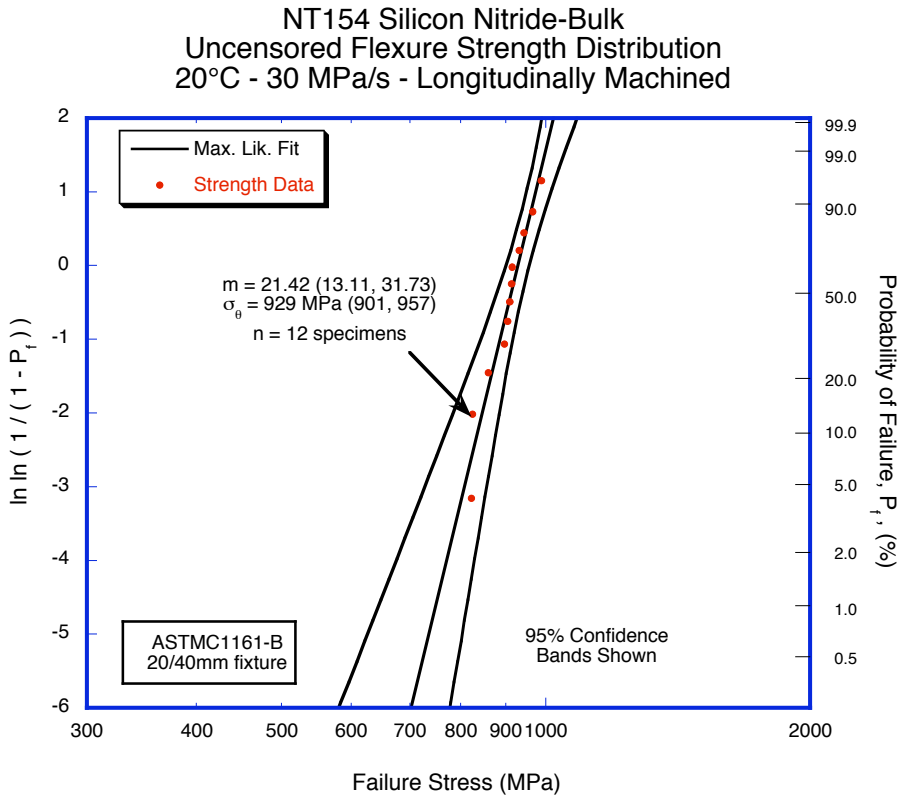


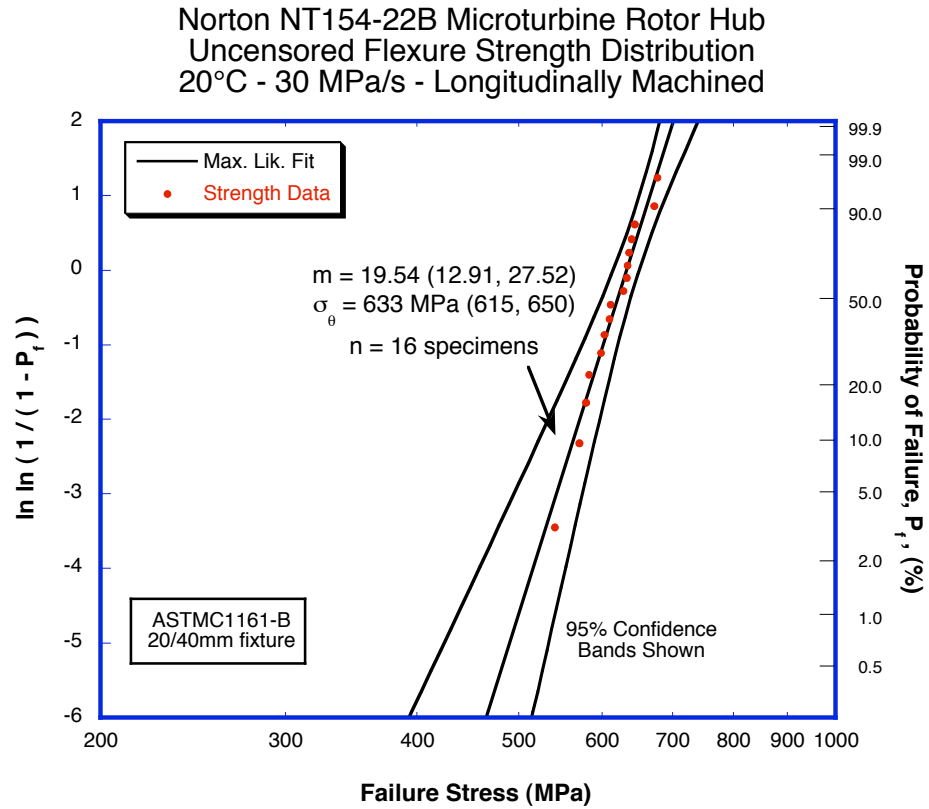


Hub Region

Airfoil Region

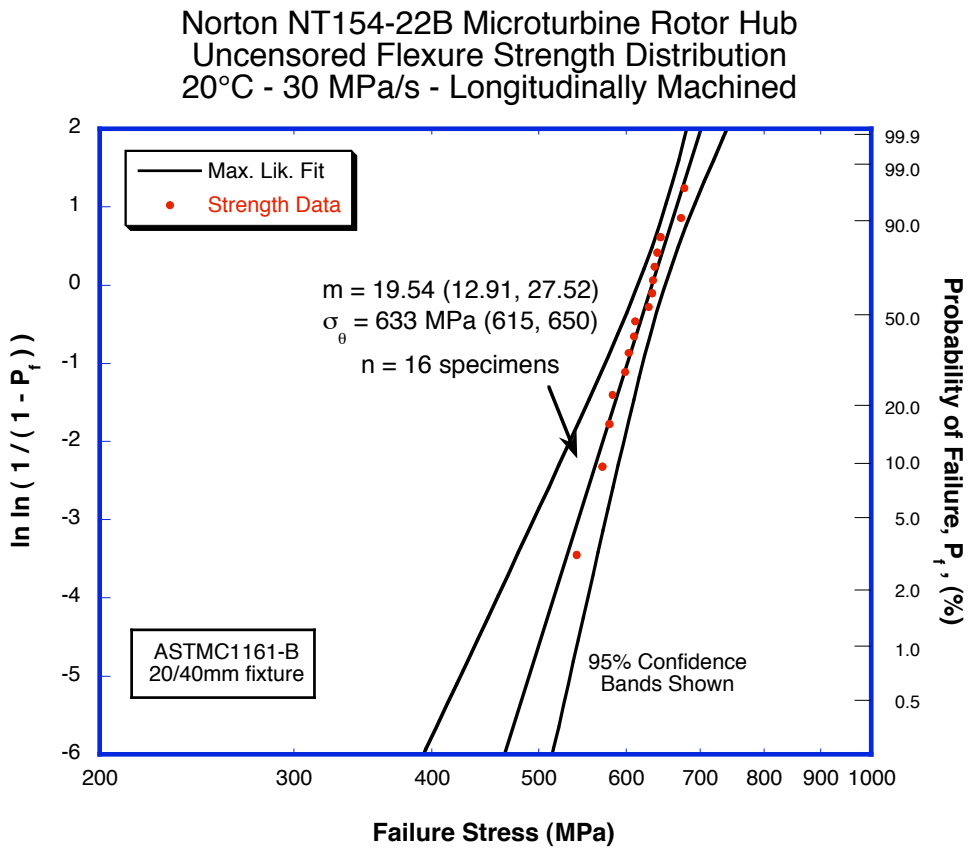
Flexure Strength of Specimens Machined from Microturbine Rotor is Inferior to Those Obtained from Production Billets





Application of data of machined MOR bars from production billets would over-estimated as-processed component reliability and lifetimes

Flexure Strength of Specimens Machined from Microturbine Rotor Hub Consistent to That Estimated From Biaxial Discs



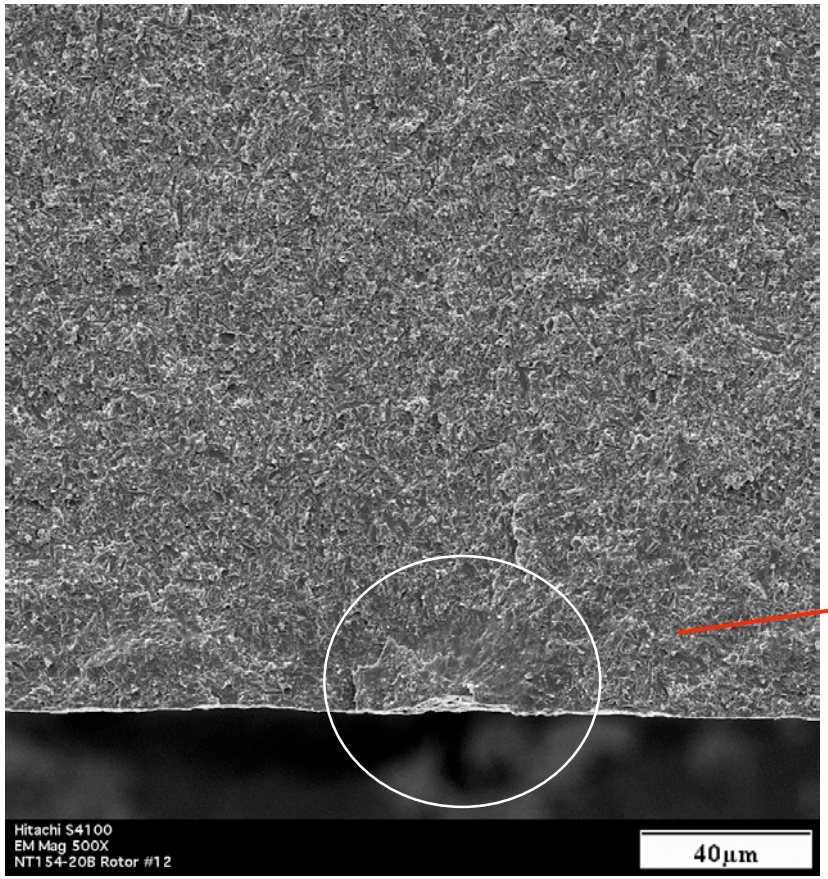
NT154 Silicon Nitride Microturbine Rotor (#22B)

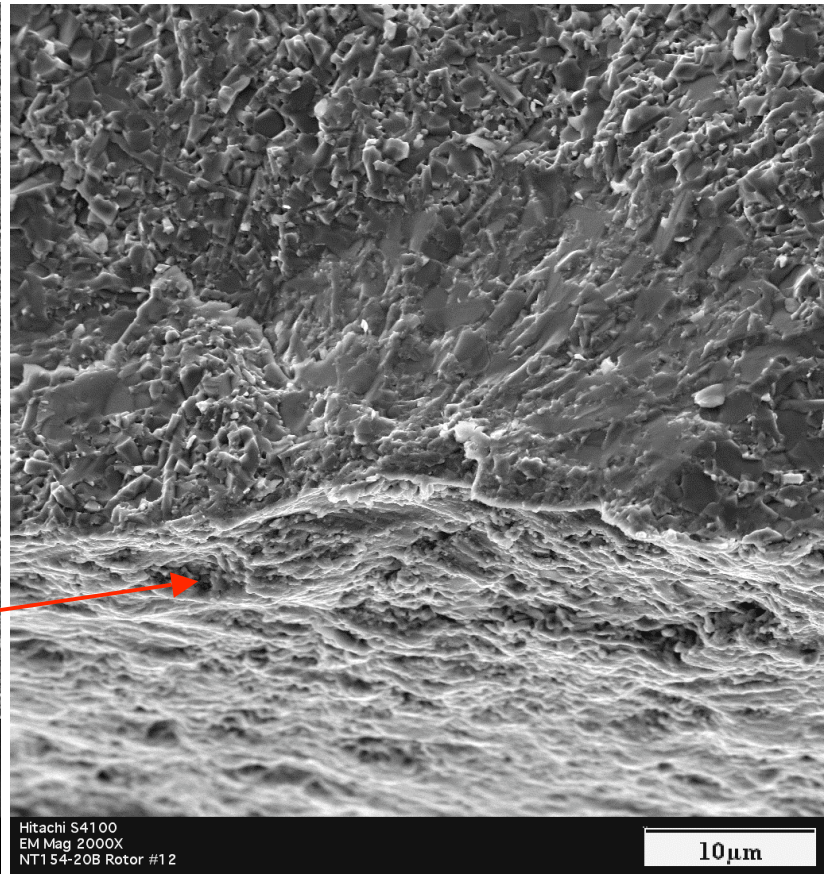
Hub region biaxial discs (As-machined surface):
m = 12.68 (7.00, 20.80)
σ_θ = 1070 MPa (1007, 1132)

$\sigma_\theta \sim 660$ MPa

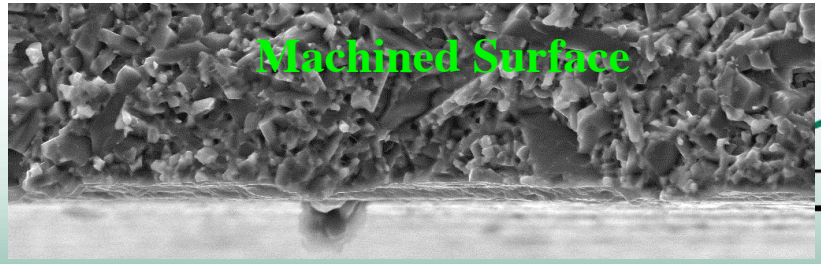
Application of data of biaxial discs could quantitatively estimate the flexure strength for material from the same component

Strength Limiting Flaws Observed in AR NT154 Rotor are Surface Pits or Machining Flaws



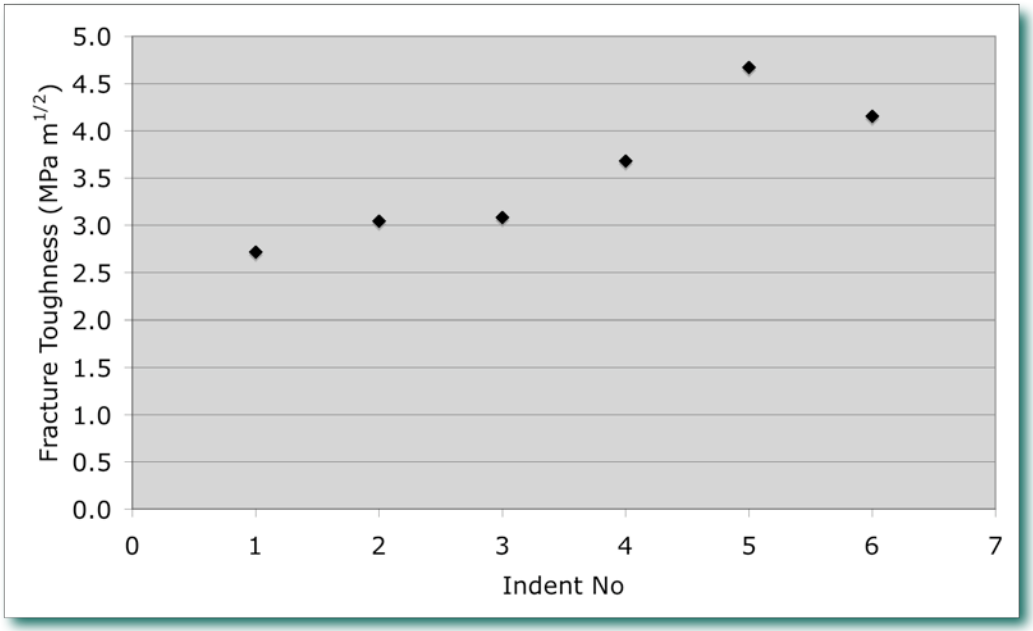


As-processed Surface

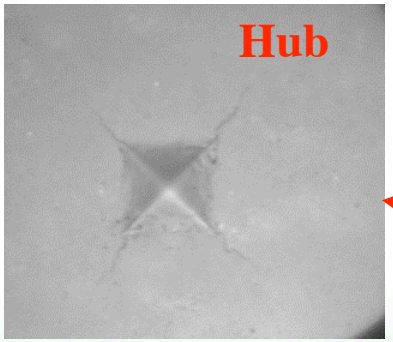


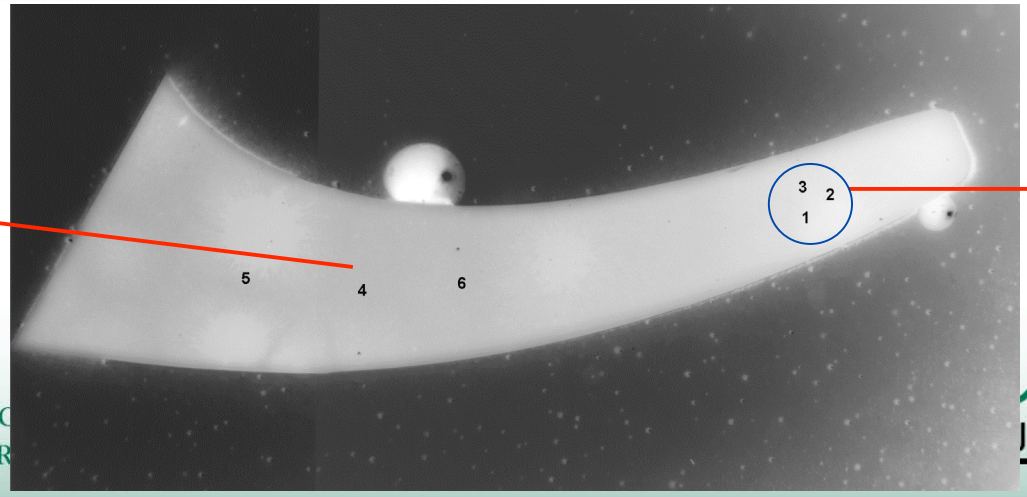
Airfoil Region Material Exhibits Lower Fracture Toughness Values Than That From Hub Region

Mechanical properties vary within the same airfoil region

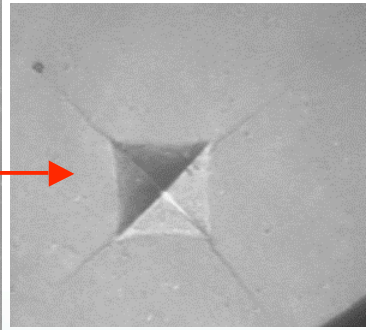


Hub

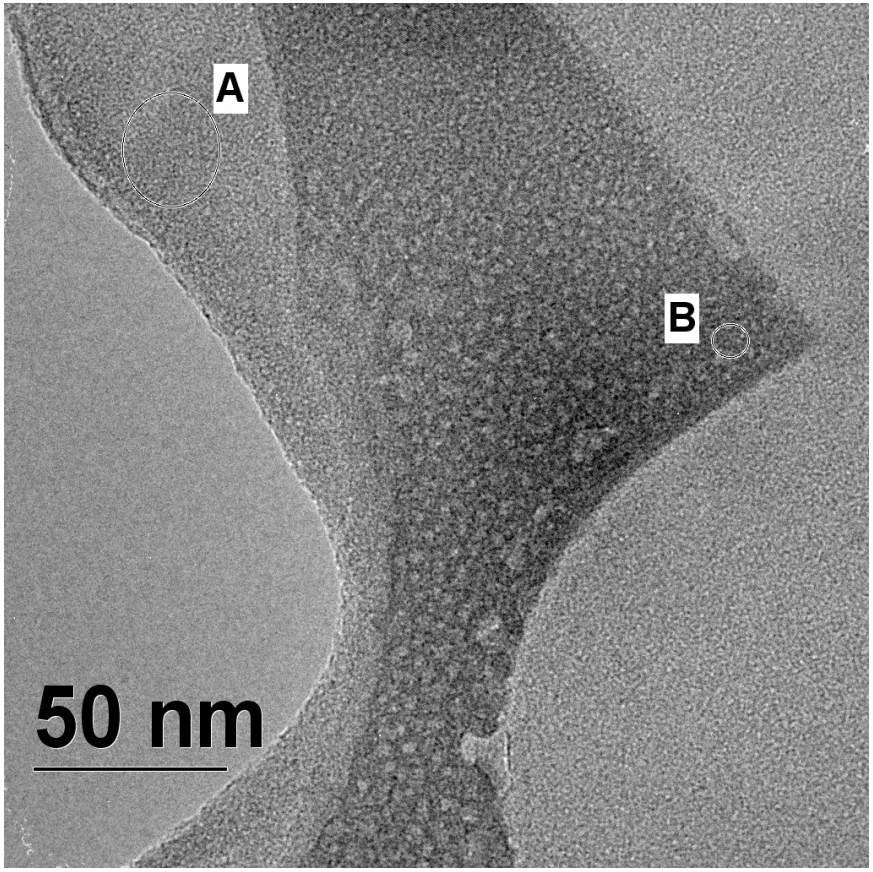


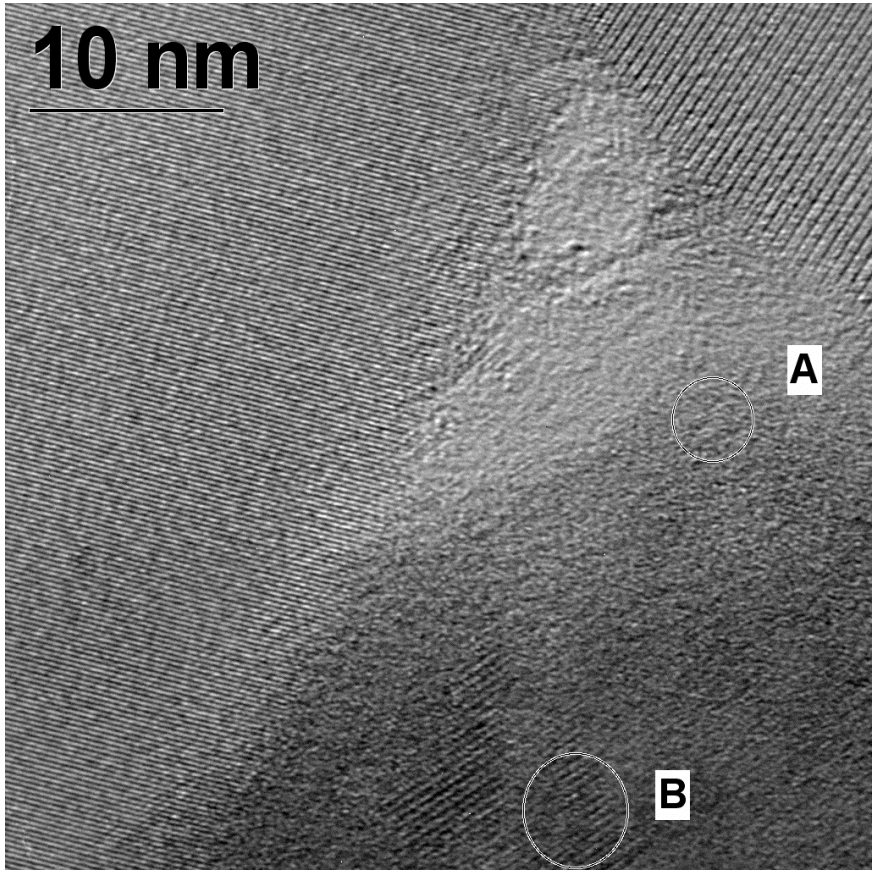


Airfoil



Substantial Content of Glassy Phase Observed in Airfoil Region Material Region





Glassy phase enriched with Si and O, which could possibly result in degradation in mechanical properties

Summary

- There is a critical need of ceramic components database for advanced probabilistic component designs and life prediction. ***"Component Subtask"*** provides key efforts and supports to implement the ceramic components for advanced microturbine systems.

- Processing and Mechanical properties of NT154 silicon nitride have been re-established under the current DOE subcontract effort. Consistent mechanical performance observed for all three-phase materials.

- Mechanical performance obtained for as-received airfoil discs are not comparable to those obtained from hub region with as-machined surface, in part, due to differences in the type of strength limiting flaws as well as in microstructure and chemical composition in as-processed subsurface region.

- Biaxial testing approach could provide a reliable flexure strength estimation for material from the same component .