Hot Section Silicon Nitride Materials Development For Advanced Microturbines Applications

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Hot Section Materials Development For Advanced Microturbines Program

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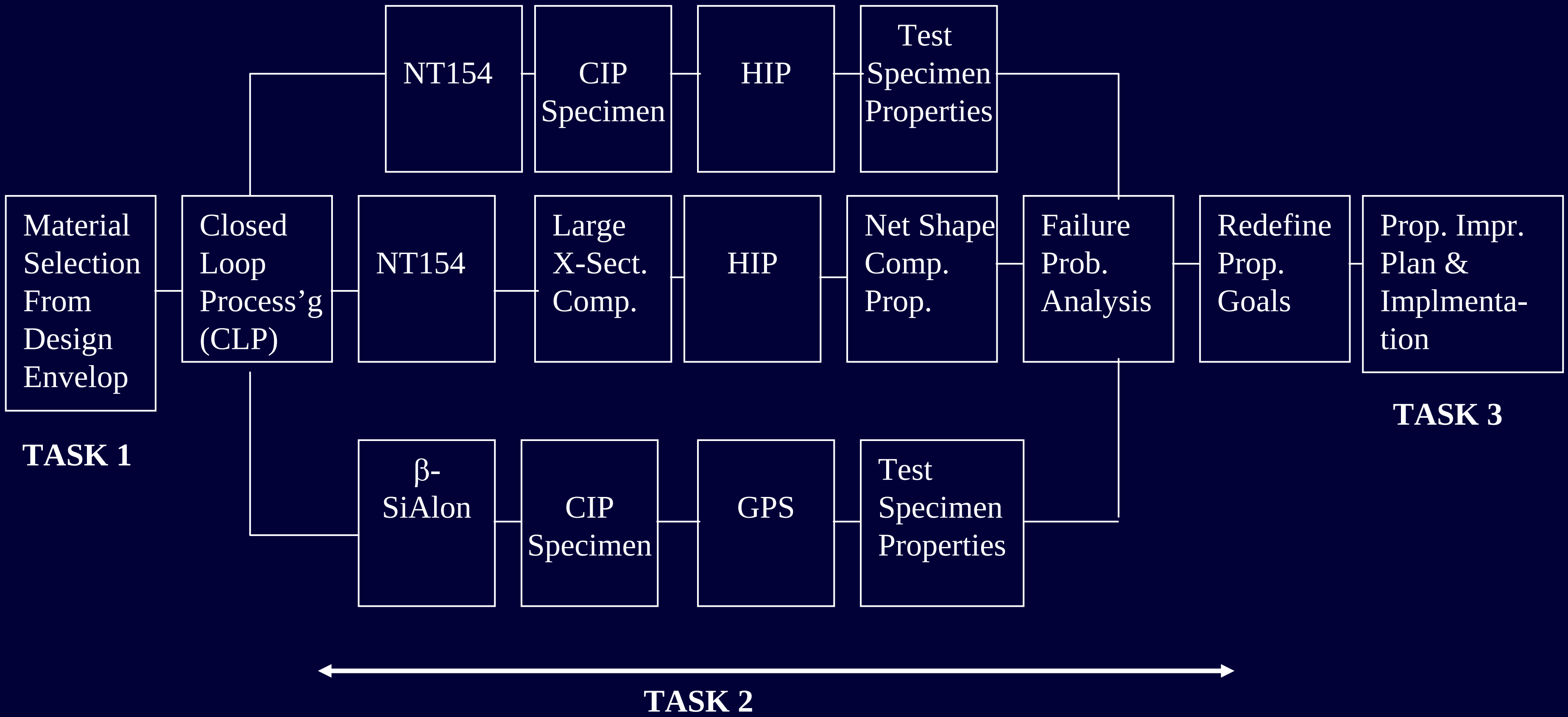
Objective

Hot Section Si_3N_4 for Advanced Microturbine Program

> Under DOE/ORNL Program, Develop and improve a cost-effective, reliable monolithic silicon nitride material for Hot Section Components in DER Advanced Microturbine Systems

> Through surface engineering, demonstrate sufficient environmental stability for operation w/o EBC -- Or compatible with EBC

Hot Section Materials Development For Advanced Turbines (Phase I)



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Material and Process Approach

Ceramic Microturbine Technology

Material Development

- Re-establish NT154
- Improve NT154
- Recession Control
- Alternate Composition

Net Shape Forming Development

- Green CNC Machining
- Casting / Molding

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Testing at ORNL

NT154 Material Qualification

- **Delivered task I tiles**
  - Testing has been completed
- **Delivered task II tiles**
  - Optimized HIP conditions for bulk material
  - Two sets of tiles
  - Room temperature fast fracture testing completed

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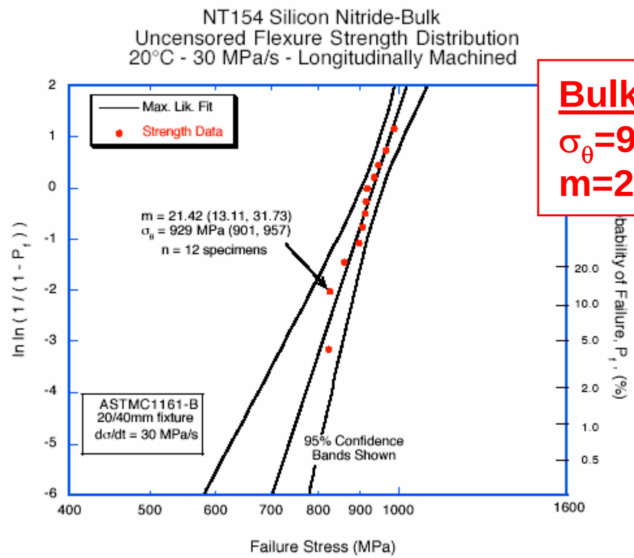
Testing at ORNL

NT154 Task I

➢Room Temperature Fast Fracture Results

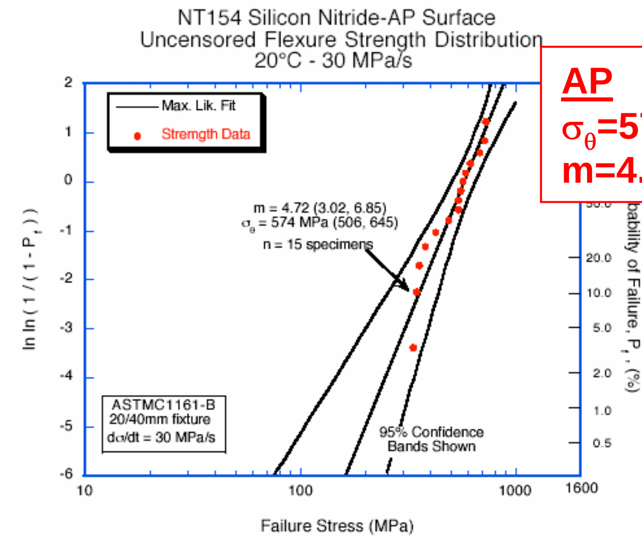
Results Obtained Consistent with the Reported Data for NT154-11C, but with a Higher Weibull Modulus



Bulk
σ_θ=929 MPa
m=21.4

NT154-11C: σ_{mean}: 948 MPa, m=8.6

As-Processed NT154 Exhibited 62% Characteristic Strength Obtained for Bulk Material



AP
σ_θ=574 MPa
m=4.7

The as-processed NT154 also exhibited a low Weibull modulus (m =4.7)

➢Need to improve as-processed (AP) properties

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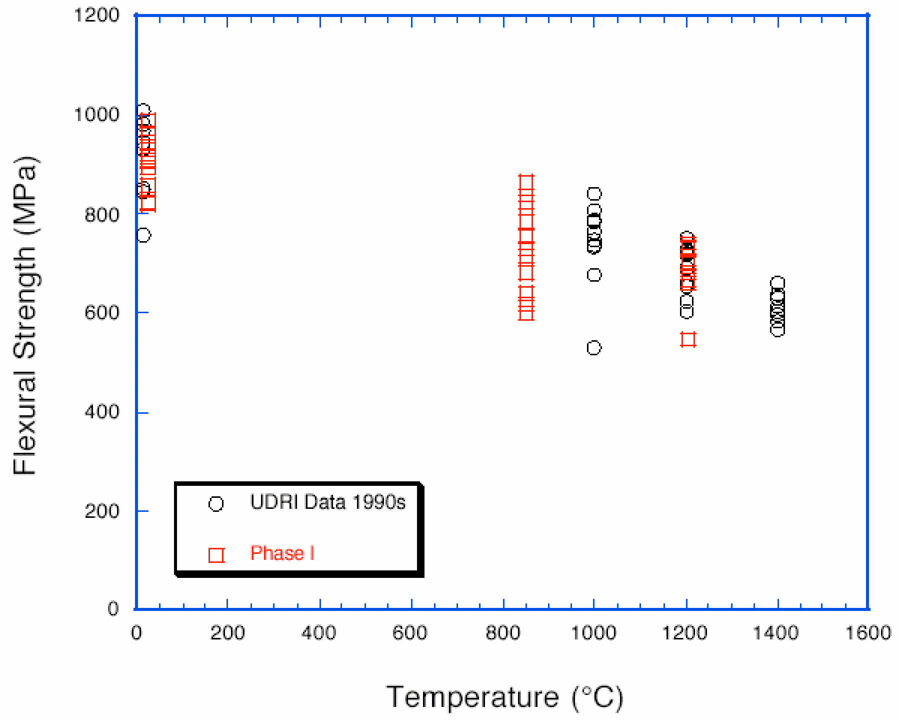
Testing at ORNL

NT154 Task I

The Mechanical Performance of NT154 Phase I Materials is Consistent to Those Manufactured in 1990s



➢**Fast fracture material properties re-established**

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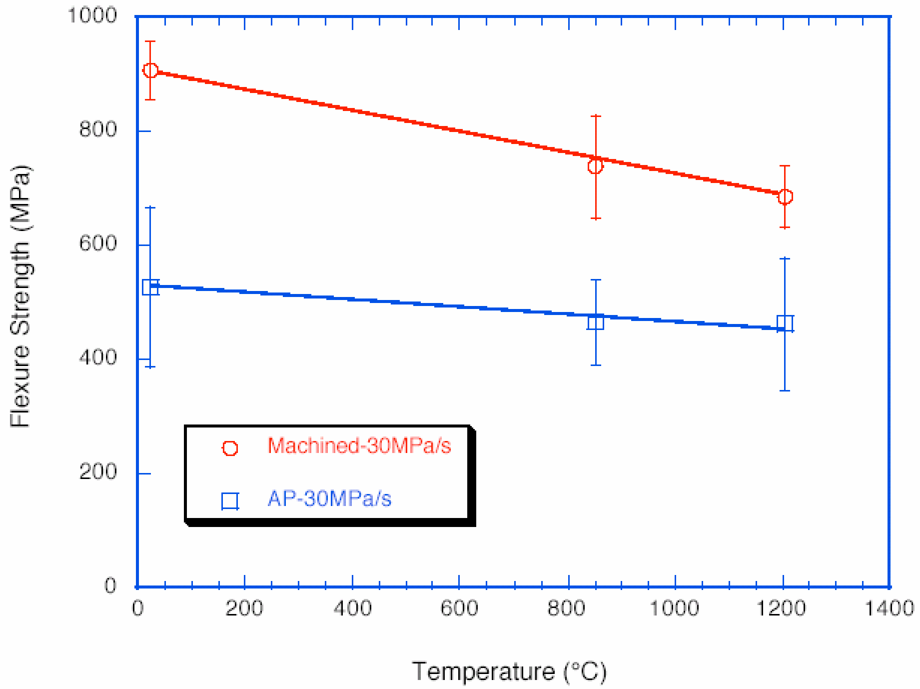
Testing at ORNL

NT154 Task I

The NT154-11 w/ As-Processed Surface Exhibits Less Temperature-Dependence of Strength Than the Bulk



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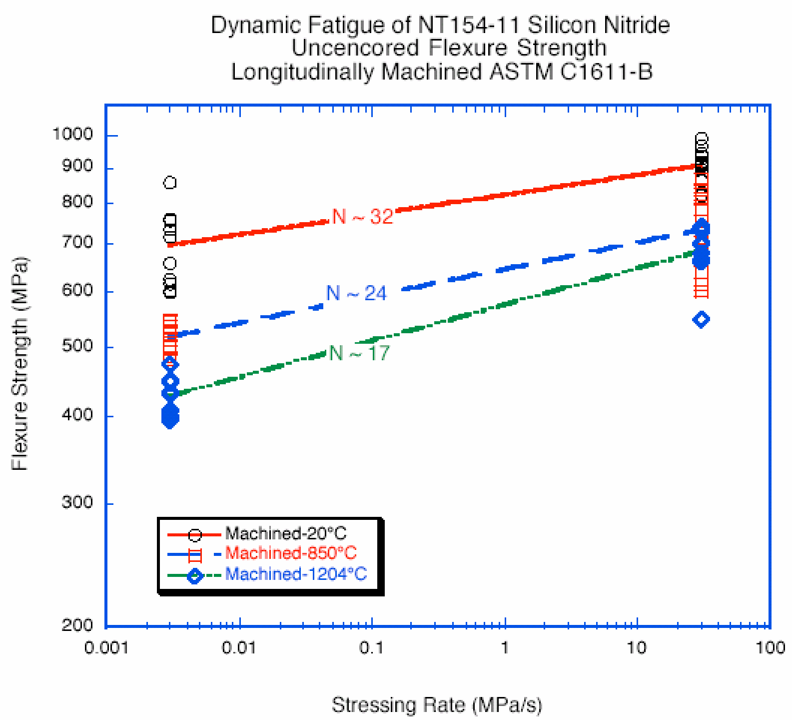
Testing at ORNL

NT154 Task I

The NT154 Task I Materials Exhibited Low Dynamic Fatigue Exponents Between 20 and 1204°C



➢Fatigue exponents similar to historical data

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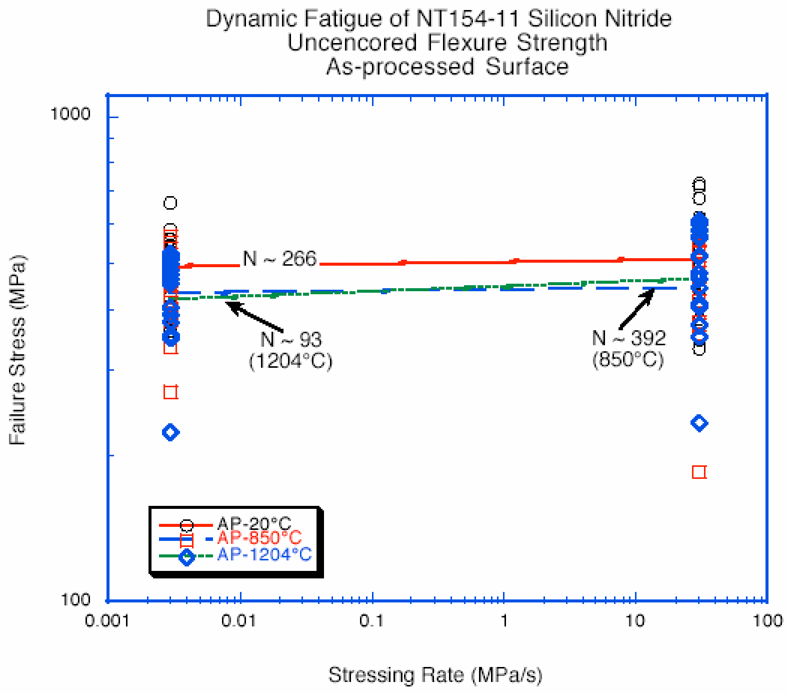
Testing at ORNL

NT154 Task I

However, the NT154-11 with As-processed Surface Exhibited High Dynamic Fatigue Exponents up to 1204°C



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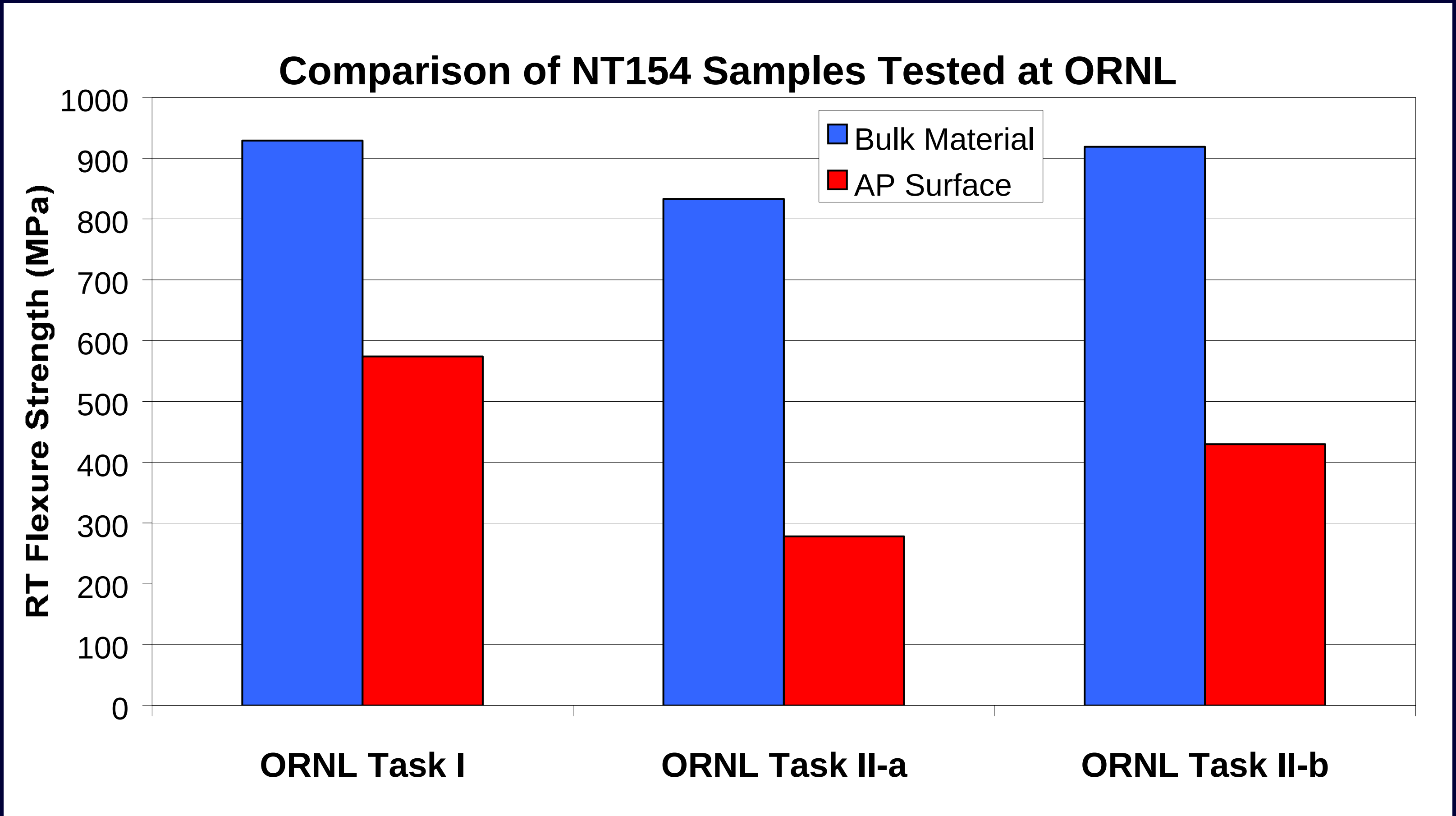
Testing at ORNL

NT154 Data



- **Continued need to improve as-processed (AP) properties**

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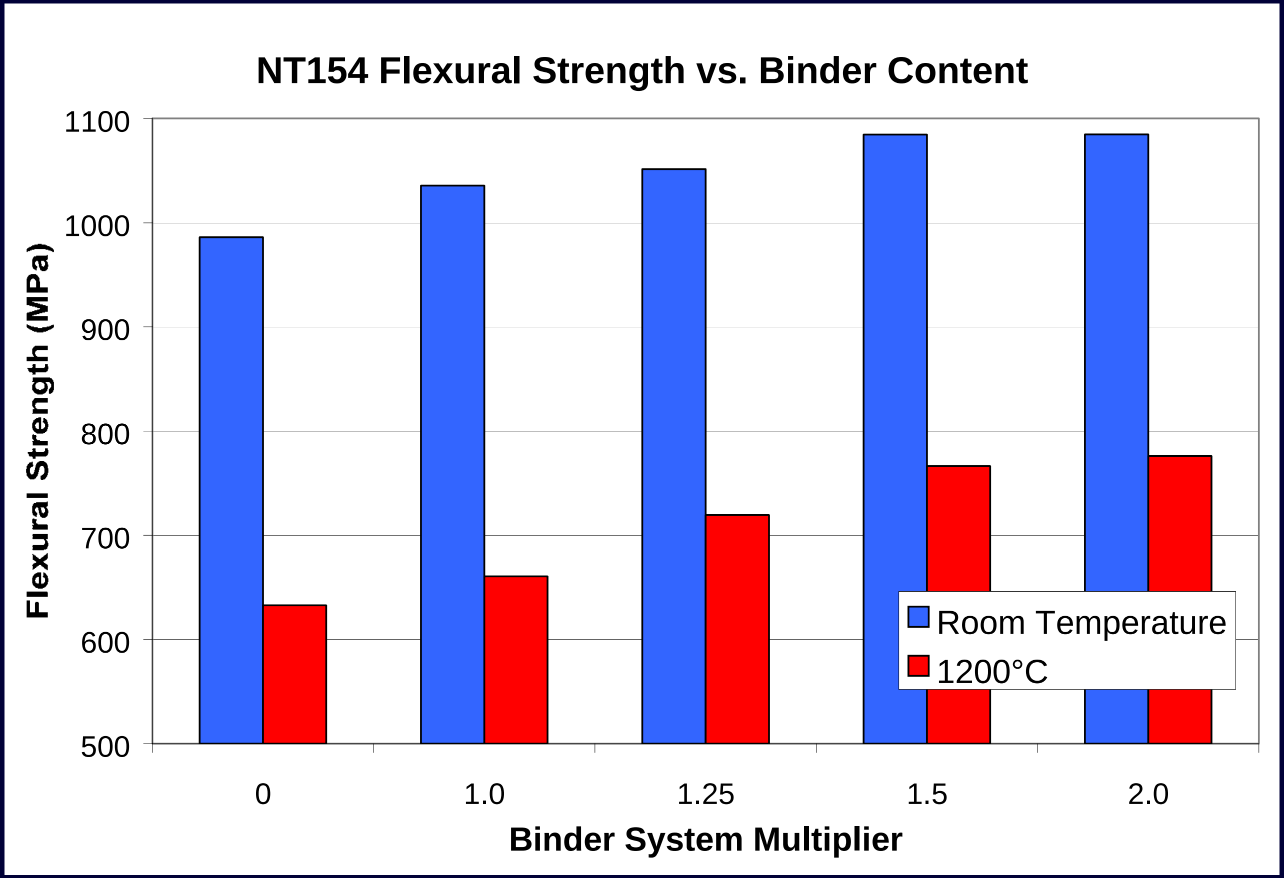
High Temperature Strength

Influence of Binder Level on Properties

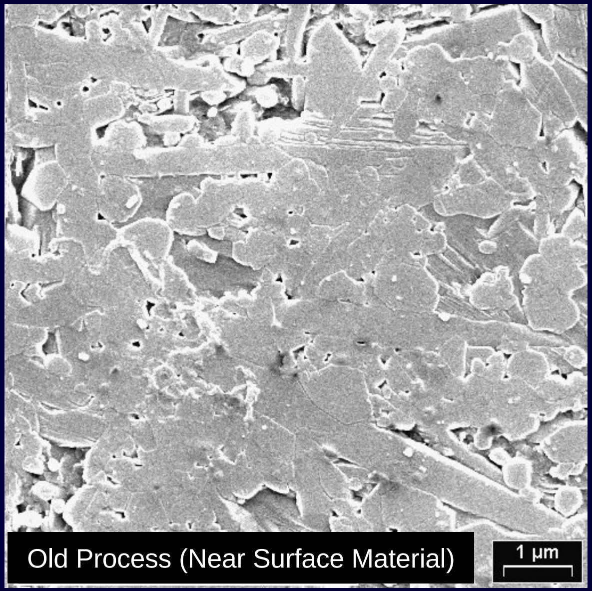
- Mechanical Properties (Bulk Material)



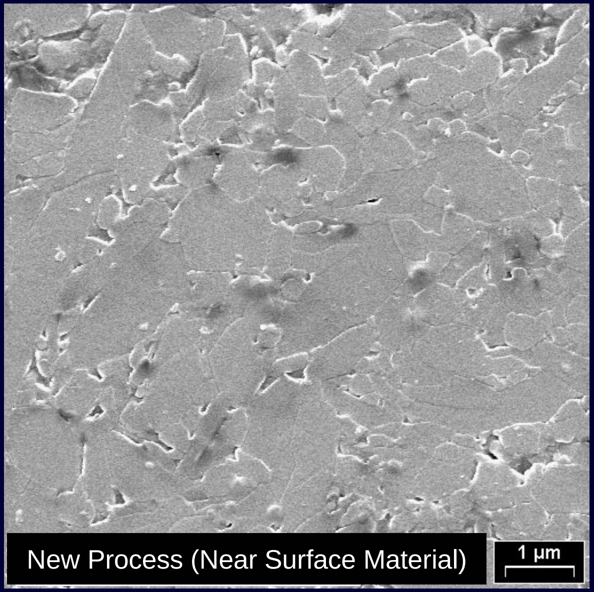
As-Processed Surface

Proprietary New HIP Process

- **Looking to reduce the Si3N4 interaction with the HIP glass**
  - Influence on the near surface material
- **Initial experiments done in a laboratory scale HIP**
- **Etched microstructure of the near surface material**



Old Process (Near Surface Material)



New Process (Near Surface Material)

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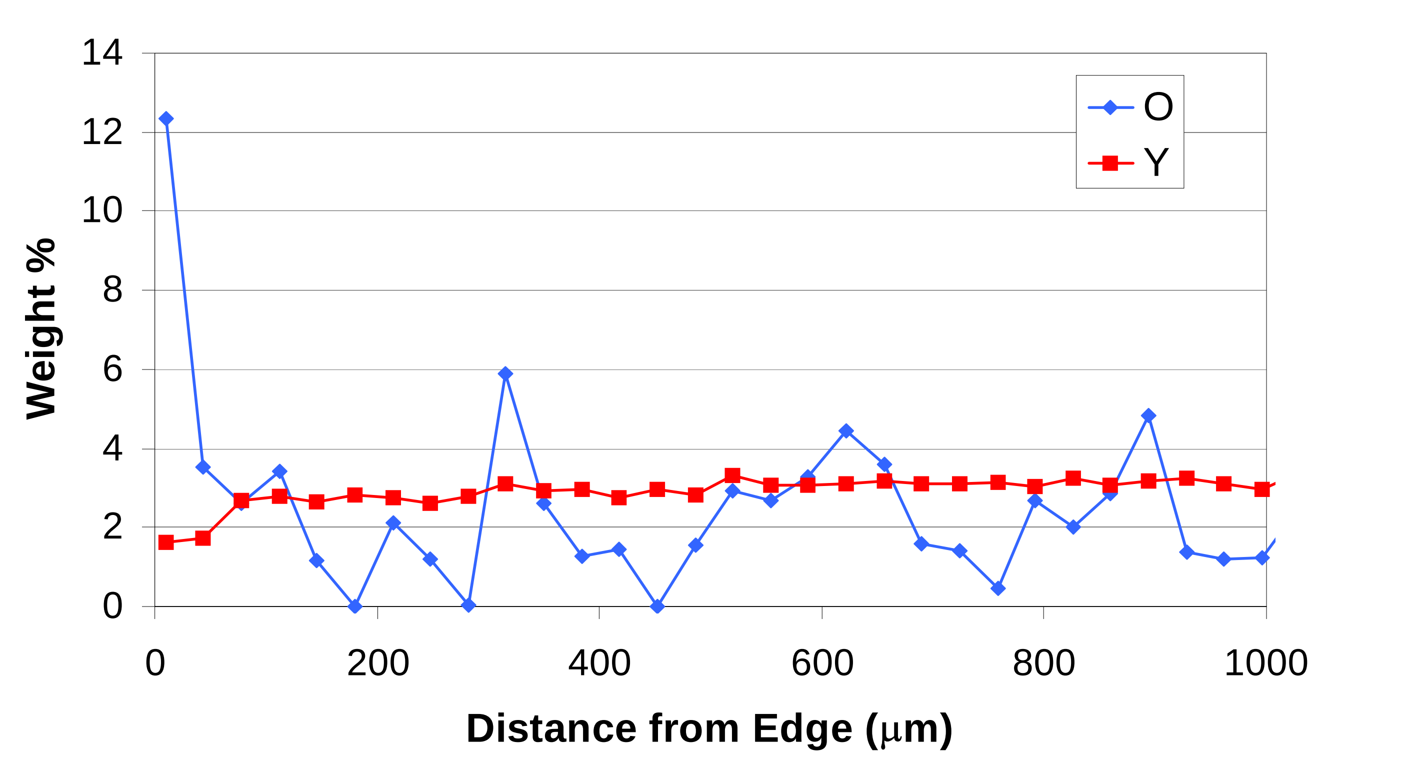
As-Processed Surface

Proprietary New HIP Process

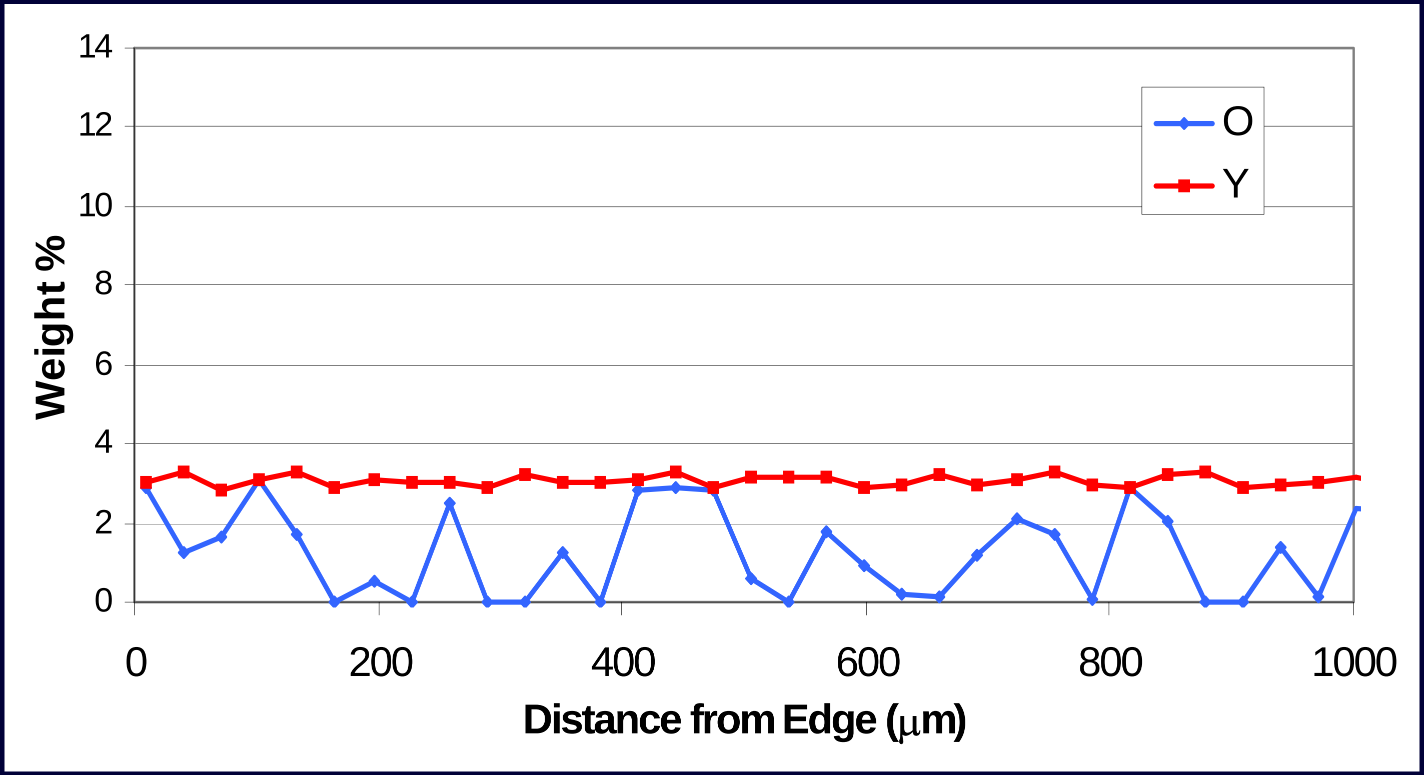
- Microprobe (Old Process)



As-Processed Surface

Proprietary New HIP Process

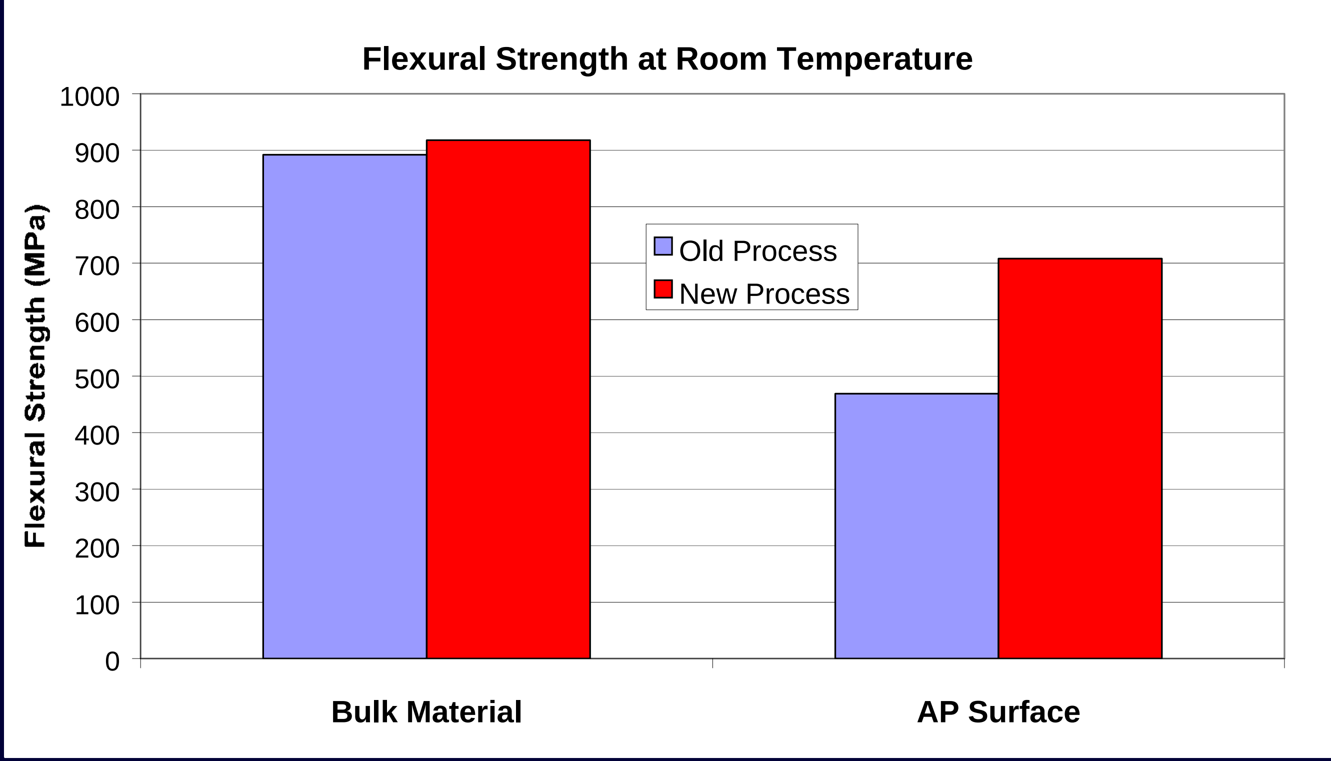
- **Microprobe (New Process)**



As-Processed Surface

Proprietary New HIP Process

- ➢**Significant improvement in AP strength**
  - Important for net-shape turbine components



➢**50% improvement in AP strength!**

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As-Processed Surface

Conclusions

- **Interaction between NT154 and the HIP glass**
- **New HIP process minimizes interaction with the HIP glass**
- **In process of scaling up new process to production HIP**
  - Initial experiments result in a decrease in AP properties for both the old and new processes
  - The new process still provides up to a 50% improvement compared to the old process
  - Issue appears to be with the near surface microstructure

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Net Shape Forming

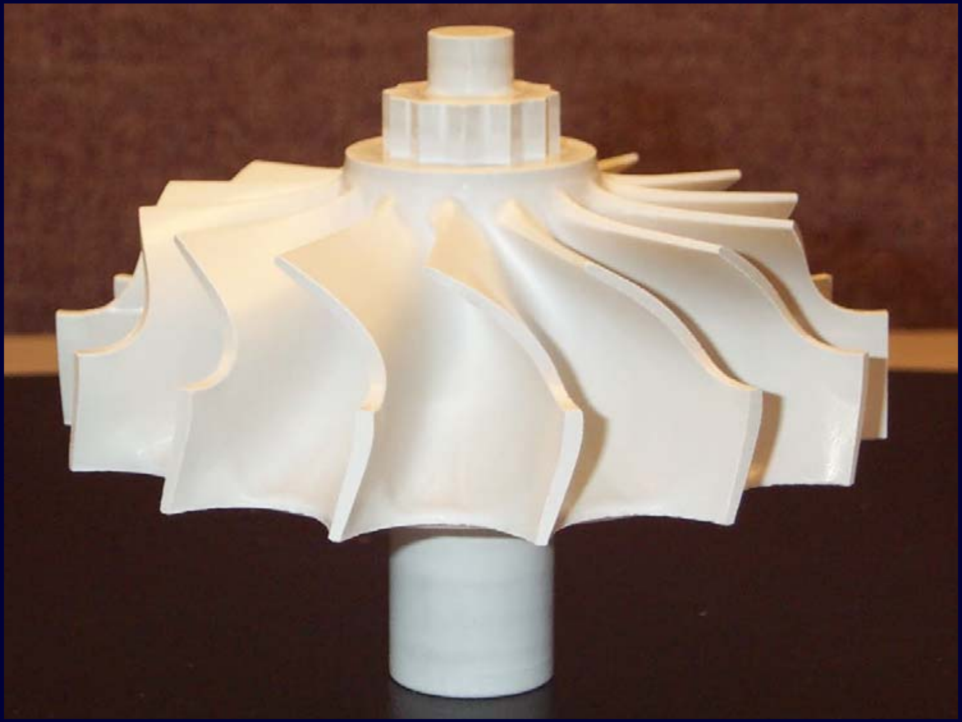
Green Machining

- **Developed green-machining process**
- **Completed two demonstration axial rotors**
- **Green dimensions within 0.003” of nominal**
- **Dense surface roughness**
  - Hub: 35-40 μin
  - Blades: 55-75 μin
- **Uniform/isotropic shrinkage**
- **High yield**
- **Flexible prototyping process**

Net Shape Forming

Green Machining

- ➢Ingersoll-Rand design
- ➢Machining completed on four prototypes
  - Machining time reduced by ~20%



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Net Shape Forming

Green Machining

- **Surface roughness on green rotors**
  - Blades: 25 μin
  - Bottom face: 30 μin
- **CMM on green rotors**
  - Dimensions within 0.004” of nominal
  - Concentricity within 0.002”
  - Blade surface locations within 0.003”
- **Rotors to be HIPed**
  - Use new process for improved AP
  - Shrinkage uniformity
  - Surface roughness change
  - CMM
- **Material property evaluation at ORNL**
- **Test in Ingersoll-Rand microturbine?**

Net Shape Forming

Direct Starch Casting

➢Objective

Develop a complex shape forming method using highly loaded starch containing ceramic suspension

➢Optimization

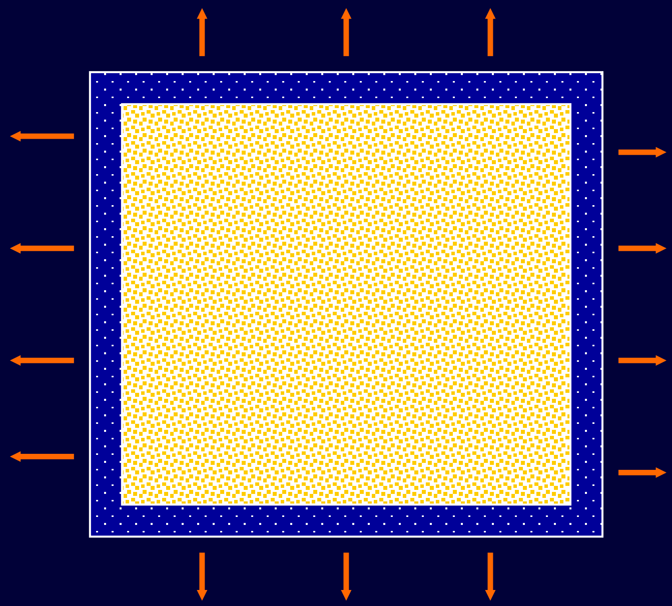
- Improve density and minimize internal porosity
- Increase green strength
- Improve surface finish

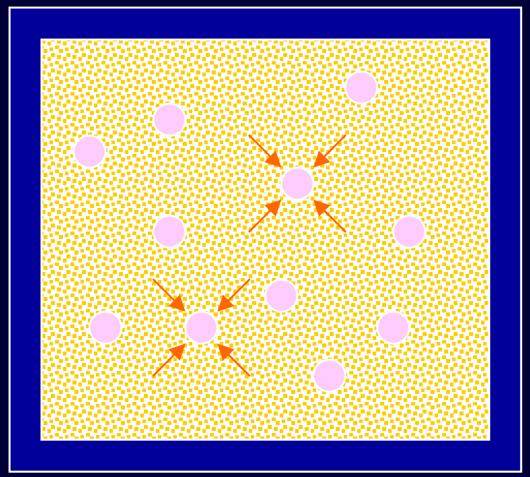
Net Shape Forming

Direct Starch Casting

WATER MIGRATION

STARCH PARTICLE





POROUS MOLD

ROOM TEMPERATURE

NON POROUS MOLD

T= 60°C

SLIP CASTING (DRAINED)

→ **DRYING SHRINKAGE**

DIRECT STARCH CASTING (UNDRAINED)

→ **NO DRYING SHRINKAGE**

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Net Shape Forming

Direct Starch Casting

Properties of HIPed Material

	CIPed NT154	Standard Starch	Starch B
Average Surface Roughness (μin)	40-50	92	46
Flexural Strength (MPa)	955	791	1002
Weibull Modulus	13	9	17

- **Improvements seen with standard starch compared to past results**
- **Further improvements seen with Starch B**
  - However, shrinkage is present
- **Surface roughness improvement demonstrated using new AP process**
  - 34% decrease for standard starch (not shown in table)
- **Further work would study the casting of complex shapes**

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Recession Control

- **Keiser Rig testing at ORNL**
  - Baseline NT154 samples (uncoated) being tested
  - Preliminary test conditions
    - 1200ºC
    - 3% or 20% H2O
    - 10atm total pressure, 1.5atm water vapor pressure
    - Up to 2500 hours
- **Initial HEEPS coating analyzed**
  - In-situ process to modify surface during HIP
  - Y2SiO5 dip-coat
  - Occasional cracking is evident by optical microscope
  - Spot XRD suggests Y2SiO5 layer no longer exists
- **Initial Ceramatec coatings analyzed**
  - Proprietary coatings on dense NT154 tiles
  - Cracks are evident by SEM
  - Further process improvement necessary

Conclusions

- NT154 has been re-established
- Improvements in high temperature strength
- Improved AP strength through new HIP process
  - Need to reproduce results in production HIP
- Prototyping of microturbine rotors through green machining
- Improvements seen in starch casting
  - Properties comparable to baseline NT154
- Key microturbine OEM’s contacted
- Three invention disclosures filed

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Microturbine Plan For FY2004

➢Phase II - Develop Novel Recession Control Technique

- ORNL program continuation to develop an innovative protective layer
- "HEEPS" *(In situ)* and EBC approaches

➢Continue Material and Forming Advancements

- Continue to evaluate AP properties
- Continue to evaluate green-machining approach
- Direct casting improvements

➢Prototypes in Support of OEMs

- Mechanical testing of a component at ORNL
- Plans to work with Microturbine manufacturers
- Cost analysis

NT154 Radial Microturbine Rotor
Ingersoll-Rand Design