Hot Section Materials Development For Advanced Microturbines

Environmental Barrier Coatings Workshop
November 6-7, 2002
Nashville, Tennessee

Goddard Road
Northboro, MA 01532

SAINT-GOBAIN
CERAMICS & PLASTICS

Outline

-Perspective

-Objective

-Technology Development

-Summary

OPT DER Advanced Microturbine Systems

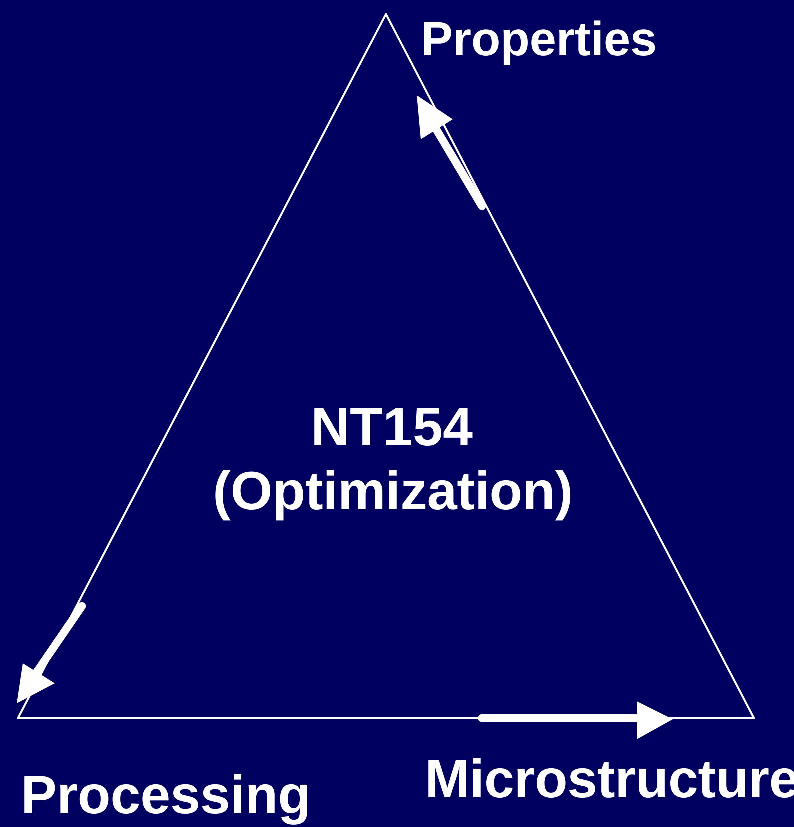
Small combustion turbines, 25 kW to 500 kW (some say 1 MW)

Goals:

- Increase efficiency to > 40 %
- Enabling technology: ceramics and EBC
- Less than 7 ppm NOx
- Durability -- 11,000 hours bet major overhaul, 45,000 hour service life
- Cost of Power, $500/kW (now ~$1,000)
- Fuel Flexible
- DOE Funding $60 M FY 2000 - 2006

Objective

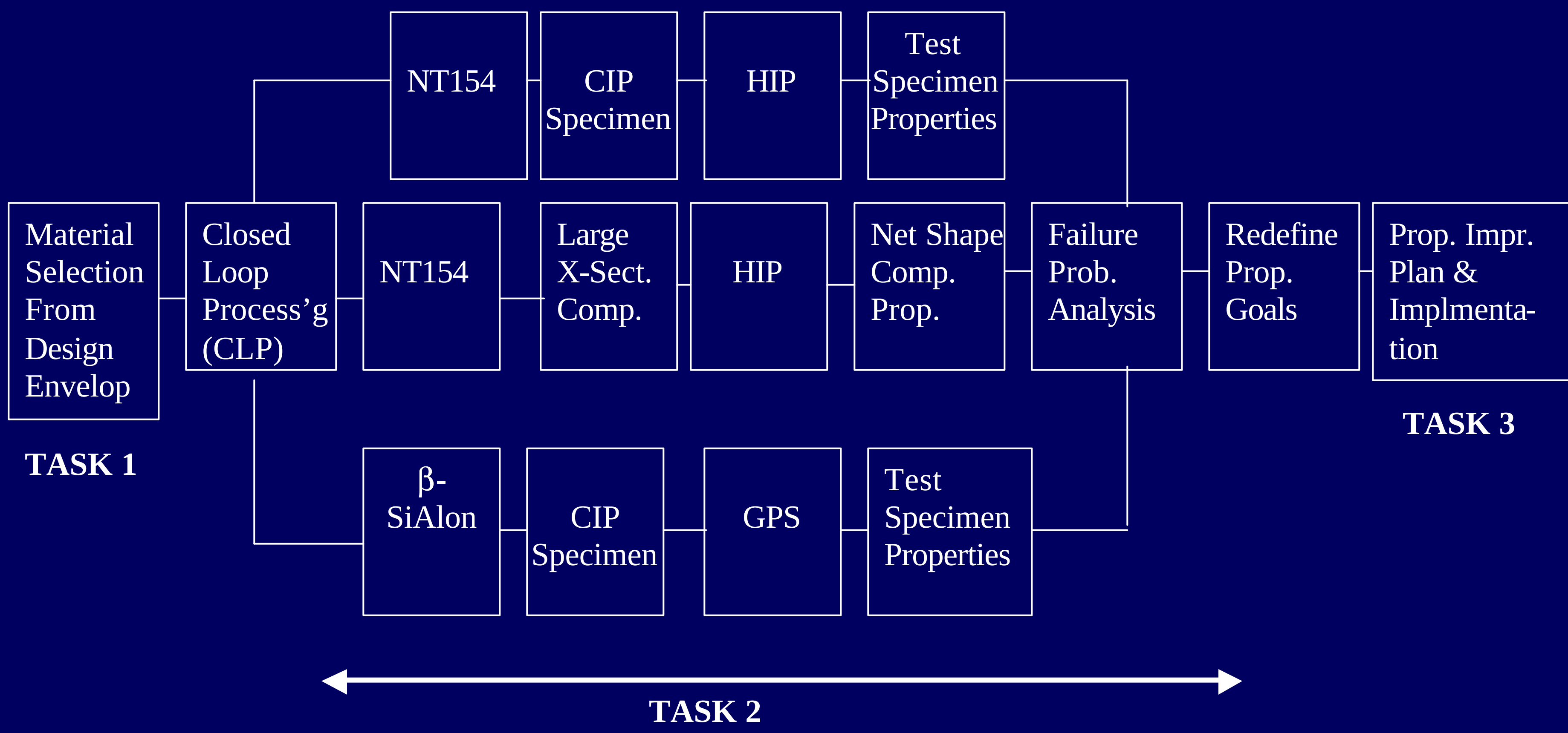
Develop and optimize a high temperature ceramic material and process suitable for microturbine applications up to 1300ºC.



Specific Properties

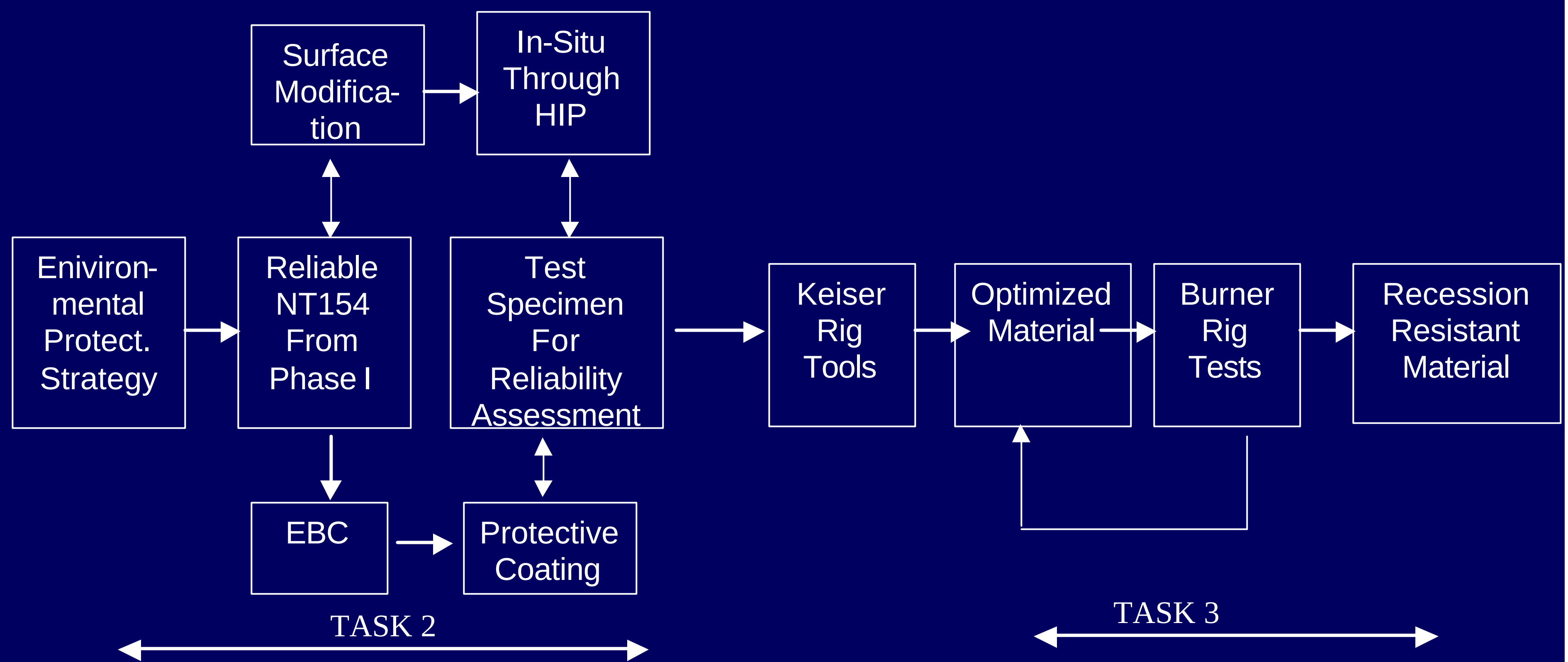
- **Fast Fracture**
  - RT – σ ≥950 MPa
  - 1300ºC σ ≥ 600 MPa
- **Fracture Toughness ≥ 6.5 MPa$\sqrt{m}$**
- **Weibull Modulues ≥ 12**
- **High Temperature Creep Rate**
  - »**1.9 x 10-8 @ 1250ºC/130 MPa**
- **Oxidation Resistance up to 1250ºC**
- **Recession Resistance in humid environment up to 1250ºC**

Hot Section Materials Development For Advanced Turbines (Phase I)



SAINT-GOBAIN
CERAMICS & PLASTICS

Hot Section Materials Development For Advanced Turbines (Phase II)



SAINT-GOBAIN
CERAMICS & PLASTICS

Ceramic Microturbine Technology

Ceramic Microturbine Technology

Material Development

- **Re-establish NT154/NT164**
- b-**SiAlON Development**

Net Shape Forming Development

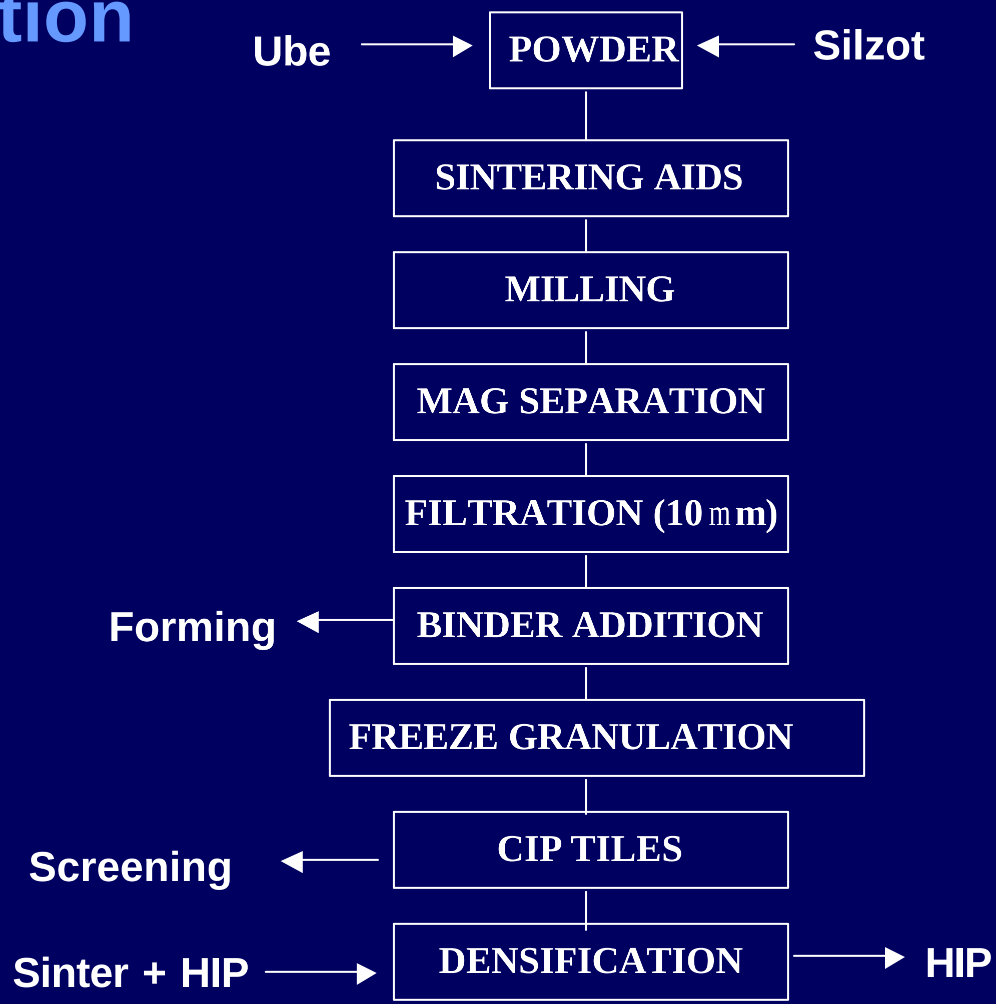
- **Green CNC Machining**
- **Direct Casting**

Material Screening/Selection

COMPOSITIONS

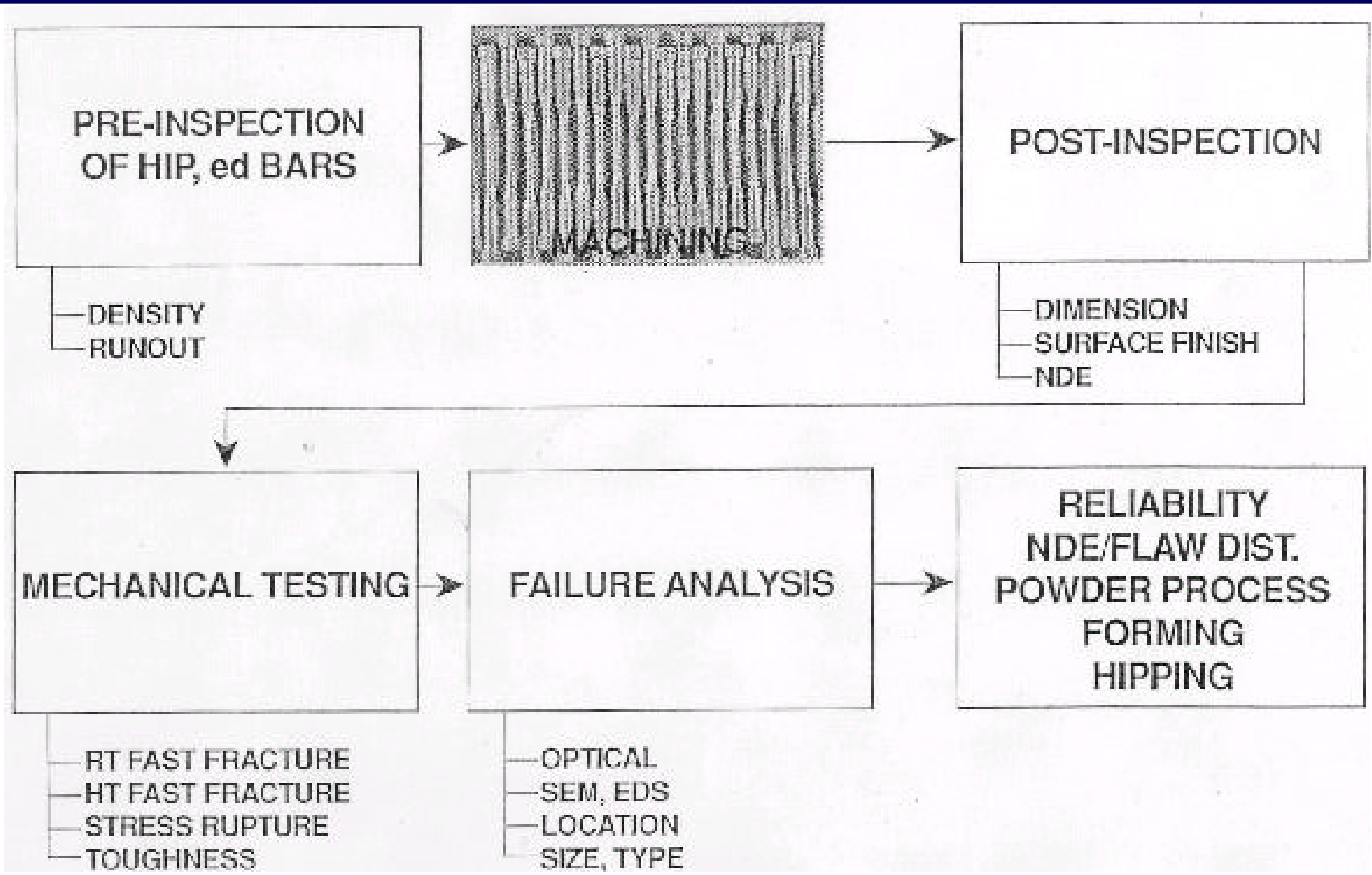
- NT154
- NT164
- β- SiAlON

CLOSED LOOP PROCESSING



SAINT-GOBAIN CERAMICS & PLASTICS

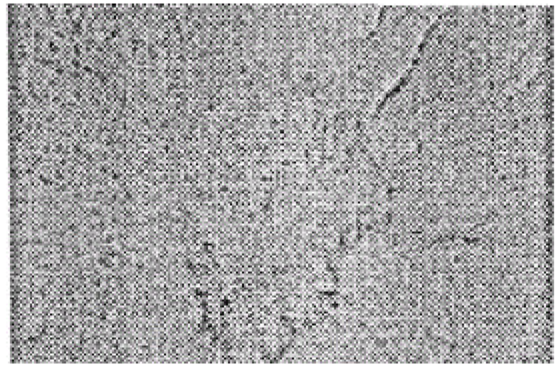
Testing and Failure Analysis



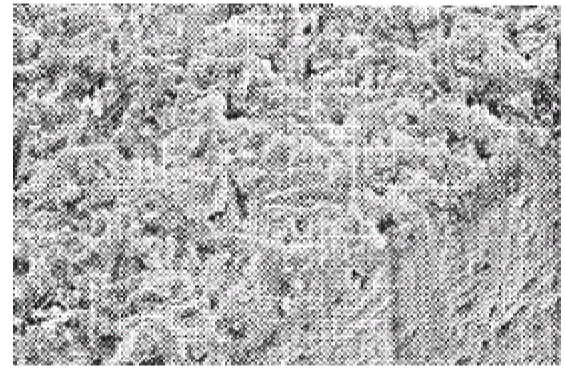
Chronology of Process Improvement

Silicon Nitride Net Shape Formed Buttonhead Tensile Test Bars

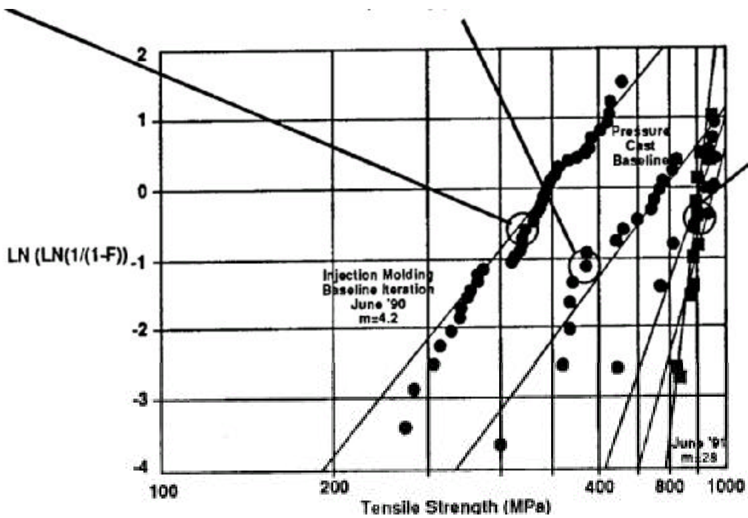
Injection molded tensile bar failed at 444 MPa due to 200μm metallic inclusion



Fracture surface of pressure cast Tensile bar which fractured at 570 MPa from 65μm agglomerate



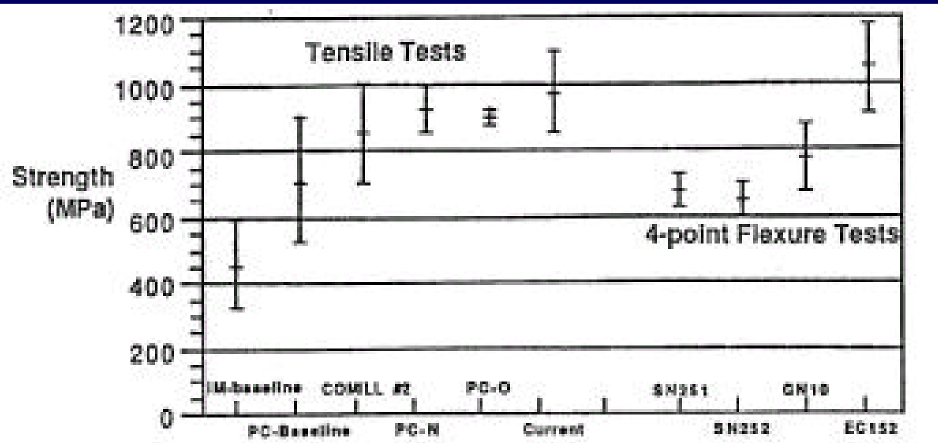
Failure origin at surface of 884 MPa Strength tensile bar centered abouta 5μm wide machining groove.



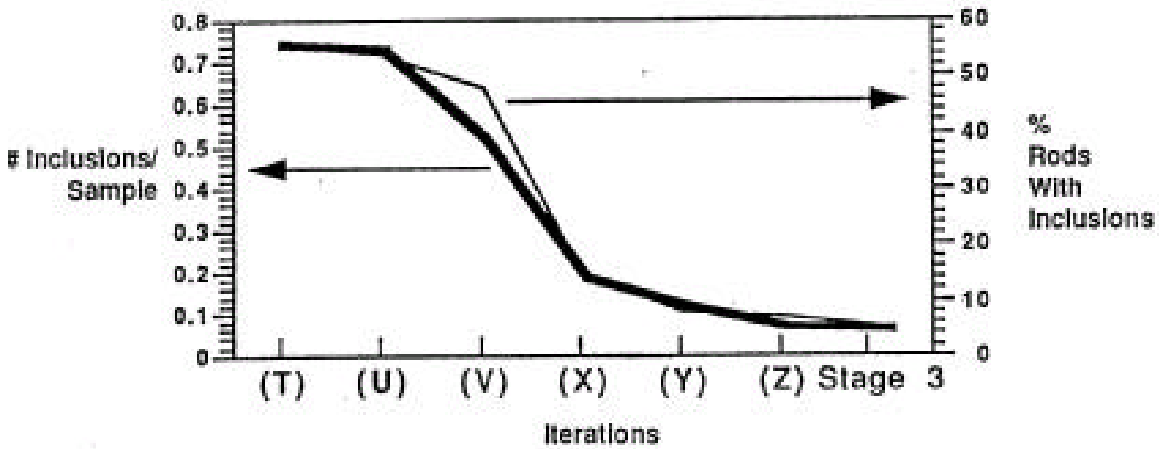
Tensile Strength data illustrating Improvements in materials processing and reliability.

SAINT-GOBAIN
CERAMICS & PLASTICS

Chronology of Process Improvements

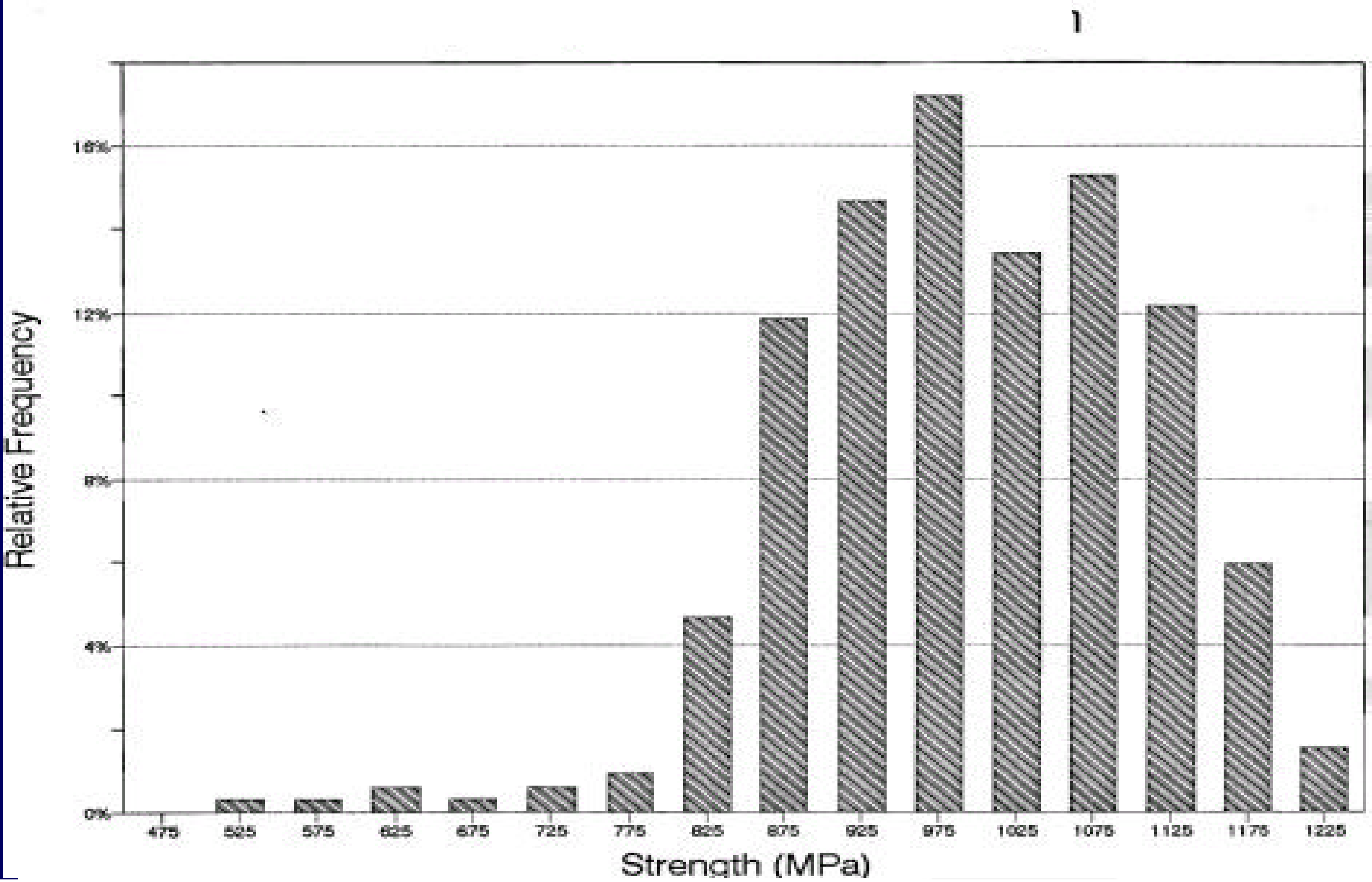


a) Tensile Strength Improvement - NCX5102



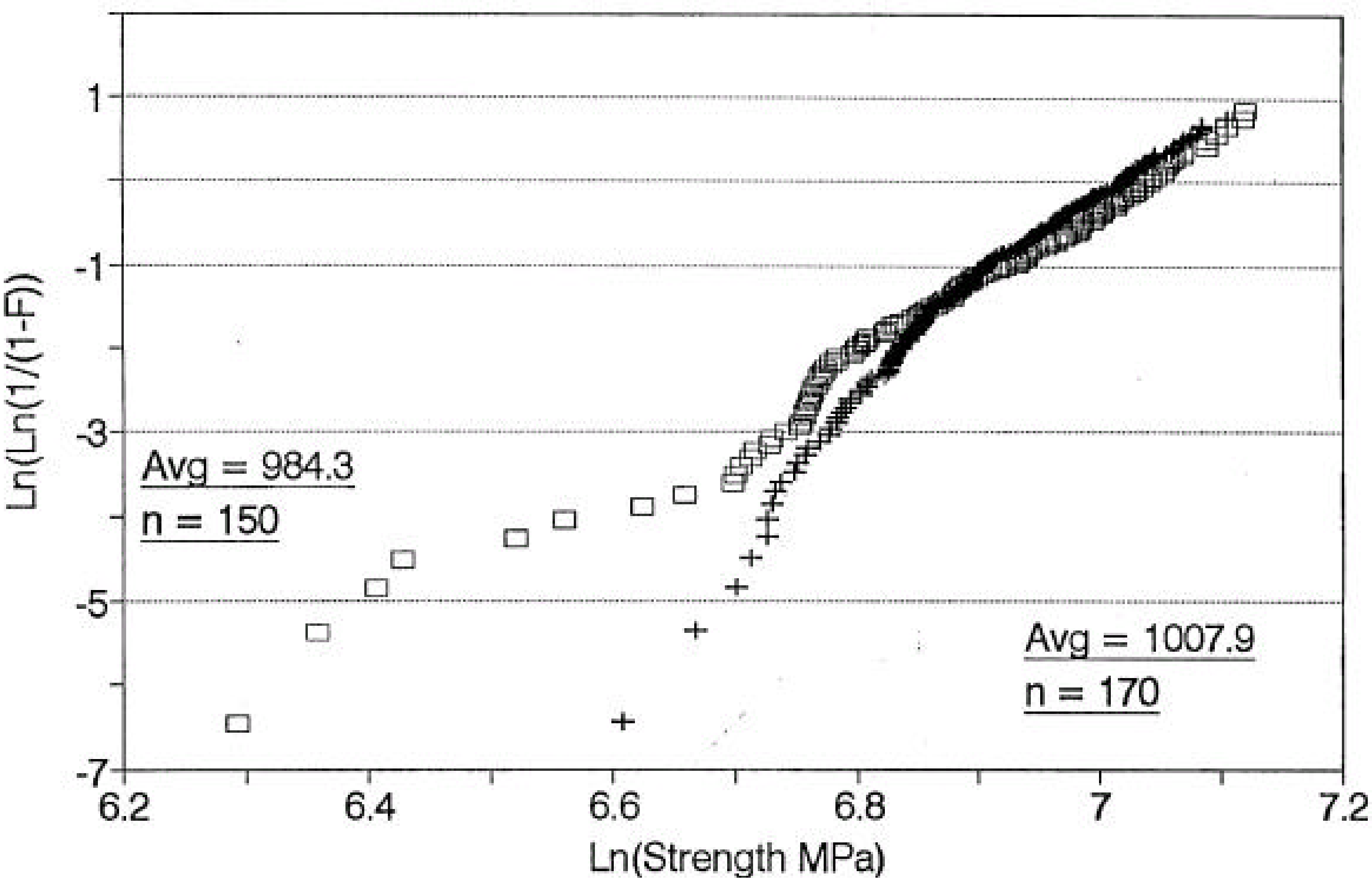
b) Flaw Reduction

Frequency of Failures vs. Strength



CERAMICS & PLASTICS

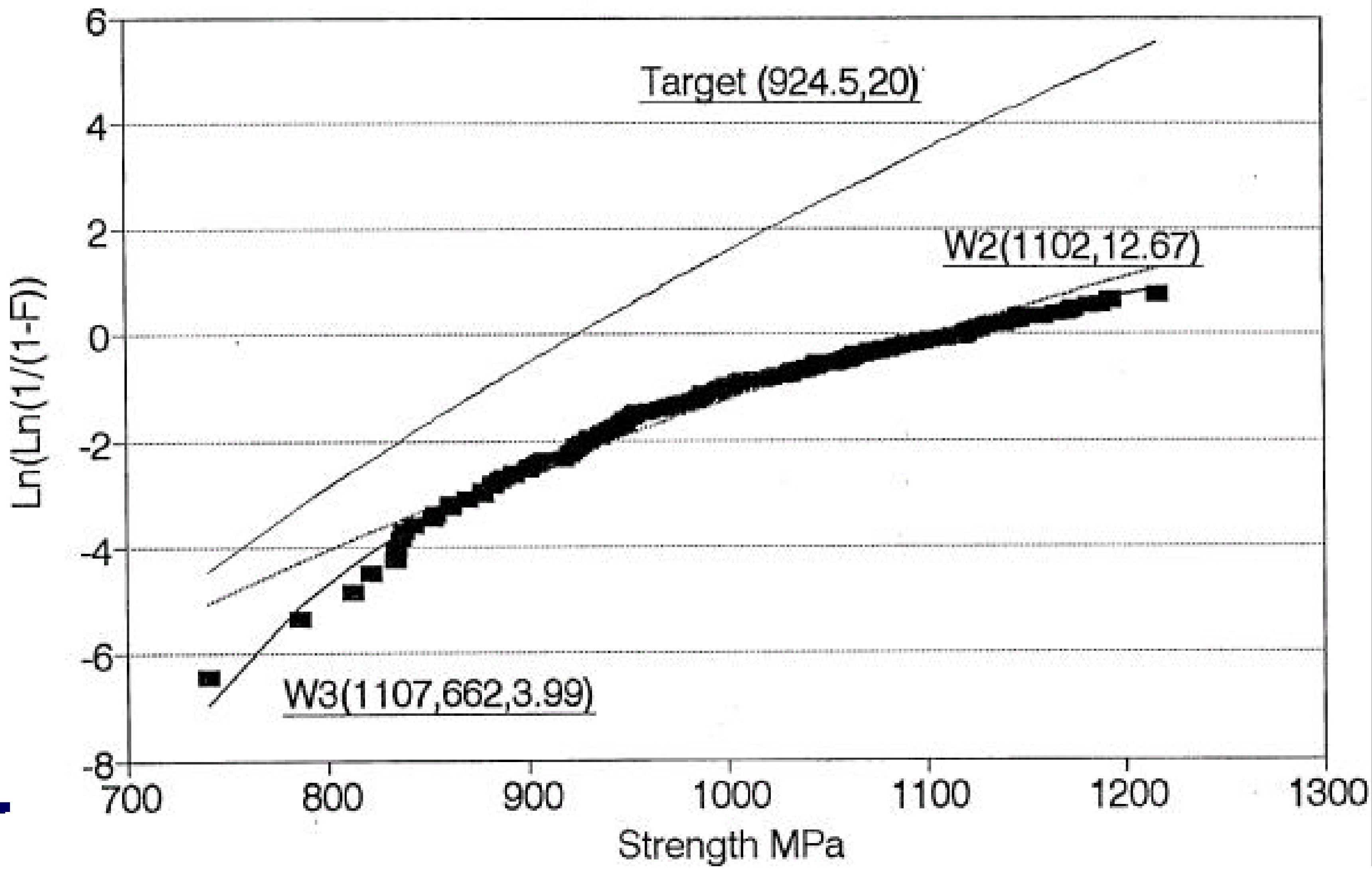
Competing risk Weibull Analysis
Ti & Machining Damage vs Rest.



SAINT-GOBAIN
CERAMICS & PLASTICS

Competing-risk Weibull Analysis

Target, Weibull 2p and 3p fit to data.

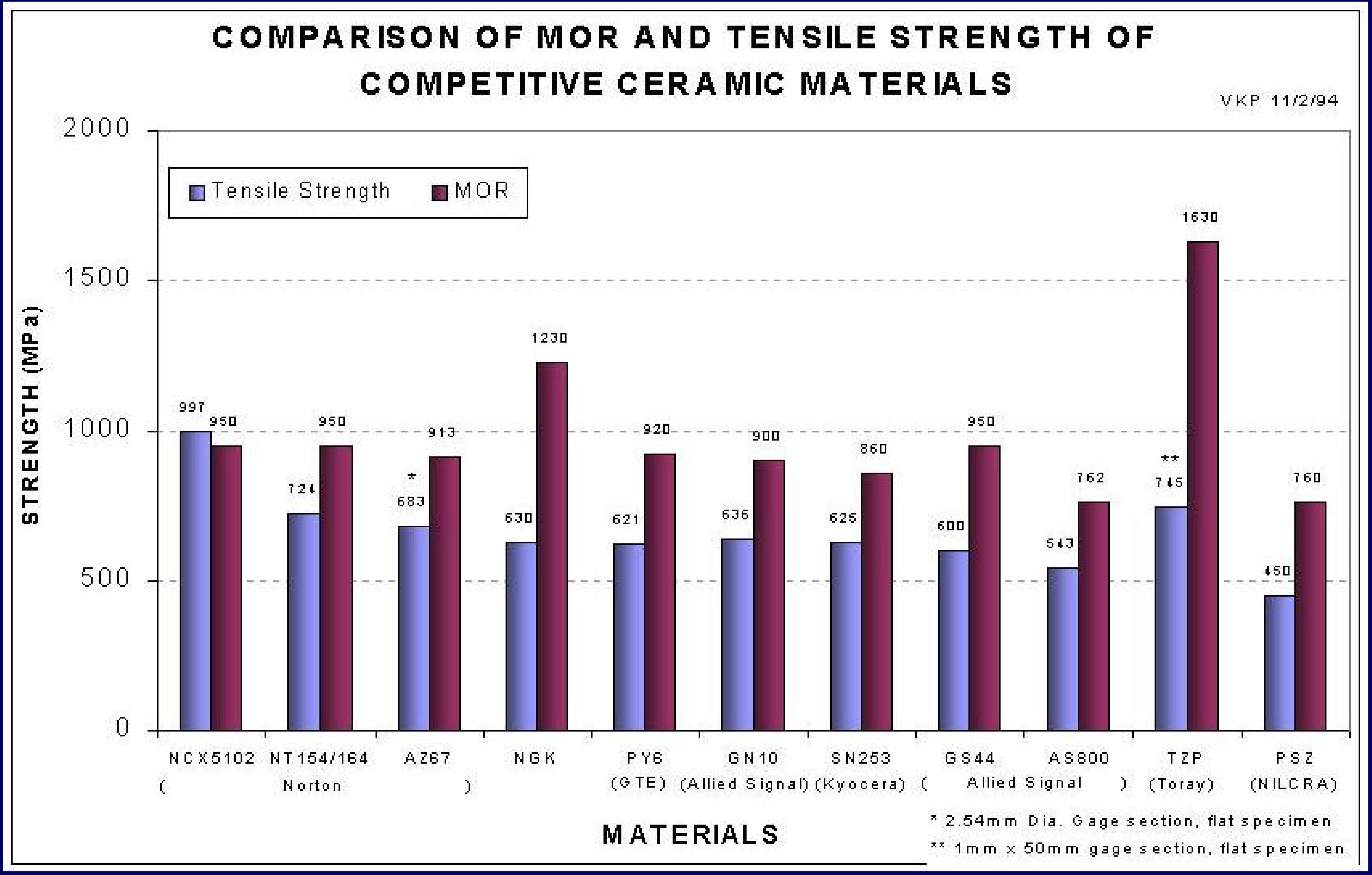


Closed Loop Qualification Flexure Testing

CLM#	R.T. FLEX. Avg. (PSI)	H.T. FLEX. Avg. (PSI)	A.P. R.T. Avg. (PSI)	K_{IC} MPa X M 1/2
X01	157,217	104,428	57,350	6.25
X02	161,110	109,253	84,970	6.33
X03	156,042	103,587	68,300	6.32
X04	154,974	92,748	51,110	6.46
X05	147,785	110,272	56,580	7.11
X06	147,350	107,609		6.91
X07	167,895	104,690	80,240	6.42
X08	152,136	106,646	94,073	5.76

SAINT-GOBAIN
CERAMICS & PLASTICS

Comparison of MOR and Tensile Strength Database for Competitive Materials



SAINT-GOBAIN CERAMICS & PLASTICS

GREEN/SHAPE FORMING

Green Machining

Colloidal Isopressing (CI)

- MILLING (Tri-Modal)
- ↓ FILTER/ MAG. SEP.
- ↓ COAGULATION
- ↓ FILTER PRESS
- ↓ CI BLANK → Green Machine 5 Axis CNC

Direct CIP

- MILLING (Tri-Modal)
- ↓ FILTER/ MAG. SEP.
- ↓ BINDERIZE
- ↓ SPRAY DRY
- ↓ CIP BLANK → Green Machine 5 Axis CNC

Green Machine
5 Axis CNC

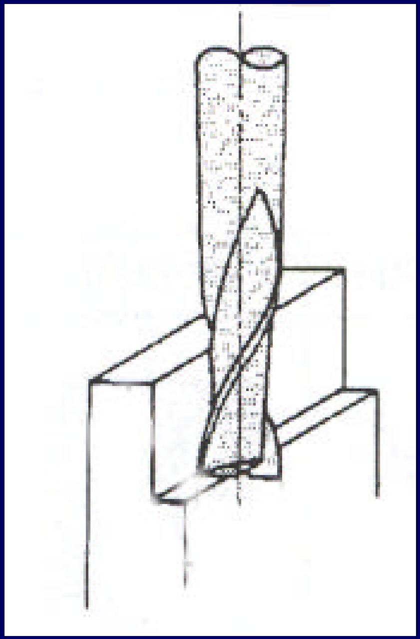
SAINT-GOBAIN
CERAMICS & PLASTICS

Test Setup

SAINT-GOBAIN
CERAMICS & PLASTICS

Test Conditions

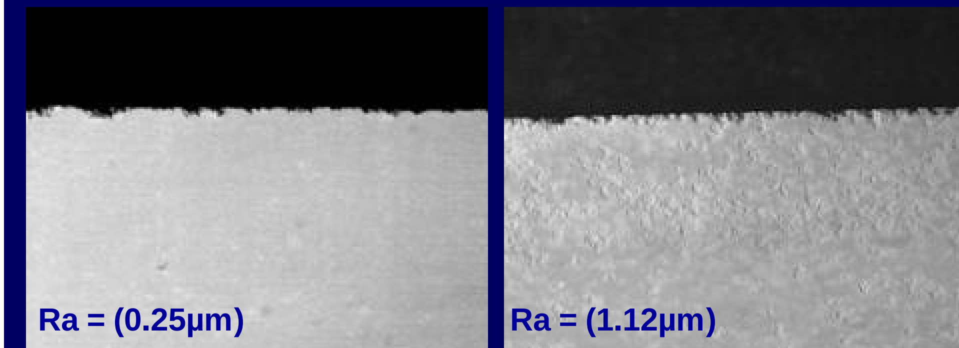
- **4-Fluted end milling tools**
  - High Speed Steel
  - Carbide
  - Carbide coated with TiN
  - Carbide coated with thin diamond film
- **Surface speed: 120 m/min**
- **Table speed: 0.127 m/min**
- **Depth of cut: 0.6mm (rough)**
  0.2mm (finish)
- **Length of cut: 25mm**



SAINT-GOBAIN
CERAMICS & PLASTICS

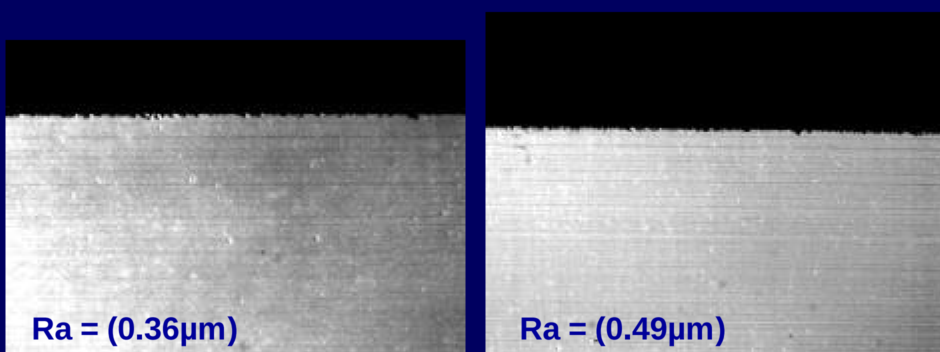
Machined Surface (NT154-6B)

New After 1.8m



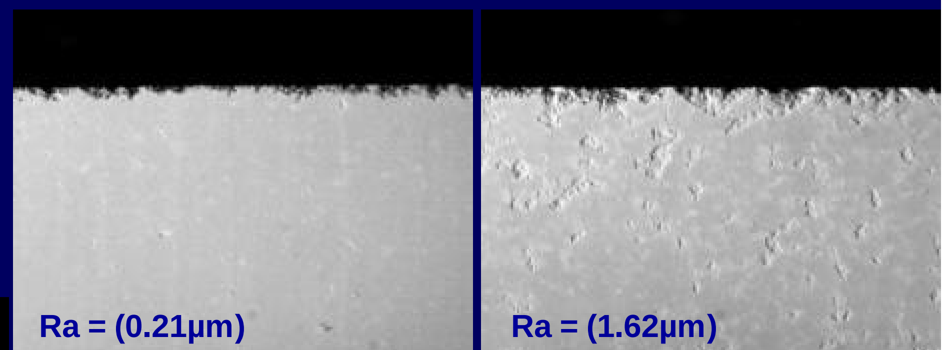
Carbide

New After 1.8m



Diamond Coated

New After 1.8m



TiN Coated

- **Green Machining Optimized**
- **CNC Machining Trial of Rotor**

SAINT-GOBAIN
CERAMICS & PLASTICS

Direct (Starch) Casting

Develop a high solids shear thinning acqueous suspension

- Solids loading (52-58 v%)
- Pourable (shear thinning, <1 Pa/s @ shear rate 10/5)
- De-airable (no trapper air bubbles)
- Adequate wet green strength (1-2 MPa)
- Minimal shrinkable after drying (<2%)

SAINT-GOBAIN
CERAMICS & PLASTICS

Direct (Starch) Casting

- Net shape mold fabrication
  a) Pattern
  b) Net shape mold fabrication with RTV
- Slurry De-airing at 25 Hg. Of vacuum
- Casting
  a) Mold Filling by pouring
  b) Mold Filling under pressure
- Automated Mold Set Up

Direct Casting in RTV Mold

SAINT-GOBAIN
CERAMICS & PLASTICS

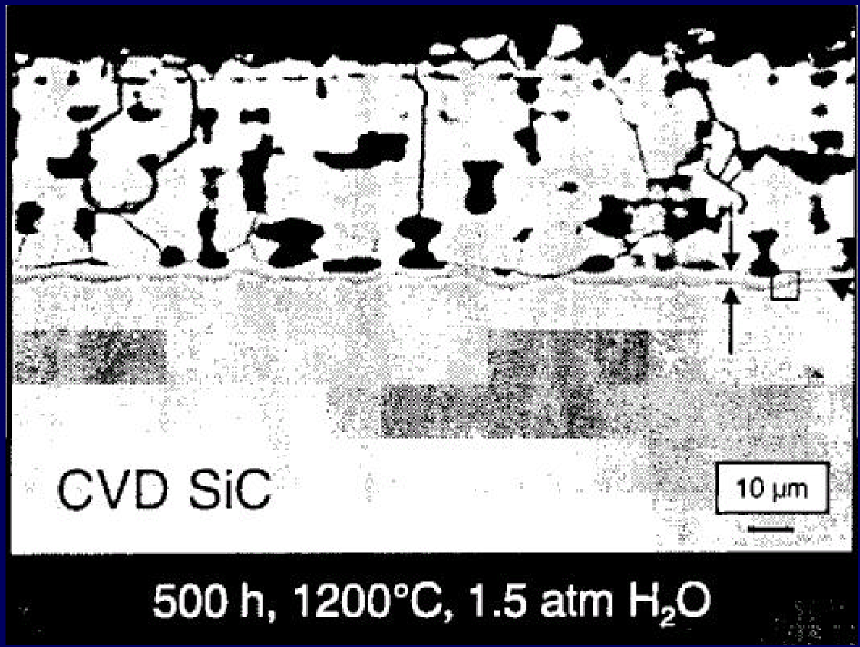
Phase II - Objective:

Investigate various approaches to recession resistance improvements:

APPROACHES

- **Composition Adjustment**
- **Surface Engineering**
- **Environmental barrier coatings (EBC)**

Recession of Silicon Nitride



SAINT-GOBAIN
CERAMICS & PLASTICS

Phase II: Recession Control

Material Selection

Criteria

- **Low oxygen permeability**
- **CTE match with NT154**
- **Low Young's Modulus**
- **Good temperature stability**
- **Does not sacrifice fast fracture and creep properties**
- **Low partial pressure for high temperature Si gases species for silicate based solutions (ex. $Si(OH)_4$, SiO)**
  - **SiO2 (high tridymite), PSiO = 1.29E-10 ATM**
  - **Al6Si2O13, PSiO = 1.93E-14 ATM**

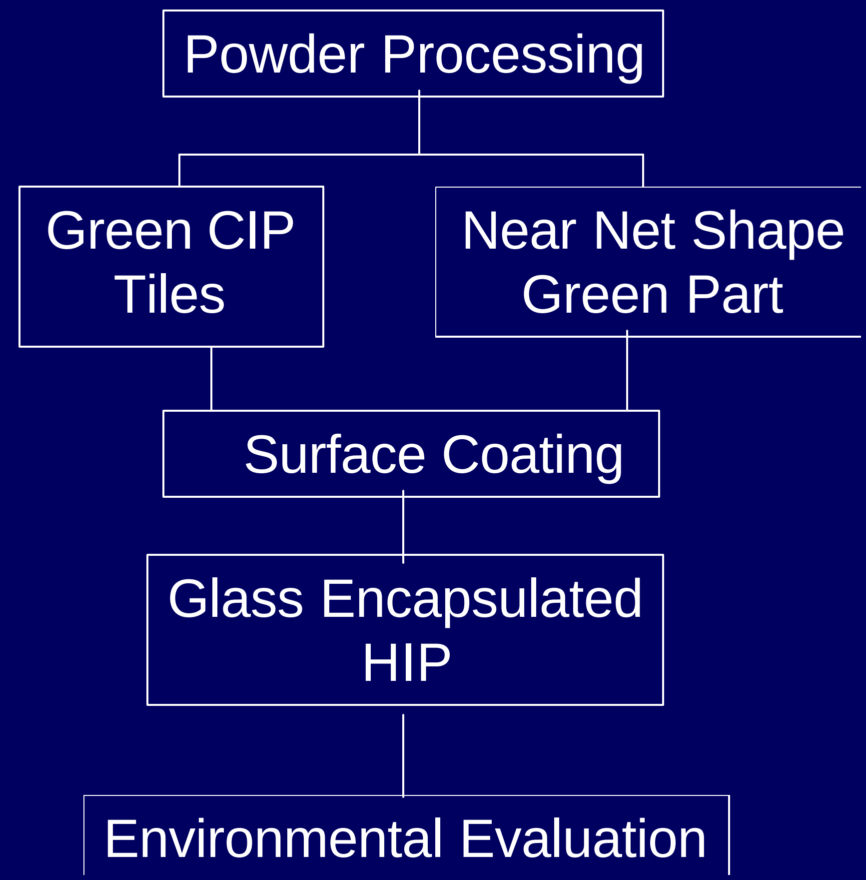
SAINT-GOBAIN
CERAMICS & PLASTICS

Phase II – Recession Control

Surface Coating

- Reactivity with Substrate
- Oxidation Resistance
- Coefficient of Thermal Expansion vs Substrate
- Influence on Fast Fracture and Creep Properties

Surface Engineering



Summary

- **NT154 process established and sample delivered to ORNL.**
- **Material development plan includes:**
    a. Test tiles
    b. Test coupons from net shape formed components
- **Recession control strategy involved surface modification**