An Approach for Evaluating Mechanical Reliability of Ceramic Gas Turbine Components

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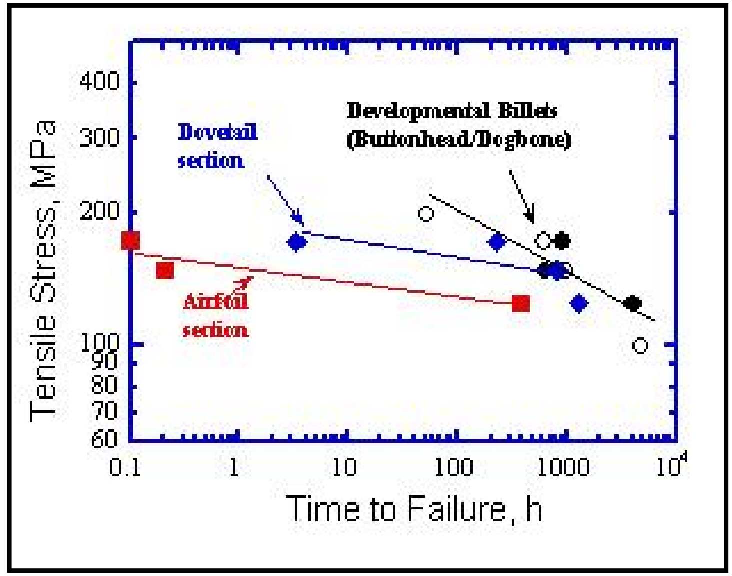
For Presentation at Turbine Power Systems Conference, Galveston, Texas, February 25-27, 2002

Work Supported by the U.S. Department of Energy, National Energy Technology Laboratory, under Contract W-31-109-Eng-38

BACKGROUND

- High performance Si_3N_4 and SiC are the leading candidates for gas turbine components.
- In spite of their potential, lack of mechanical reliability prediction has been a key factor in the inability of ceramic components to maintain their function.
- Lack of mechanical reliability prediction results from:
    - Test specimens being fabricated differently from turbine components.
    - Difficulty in duplicating gas turbine environment during laboratory testing.

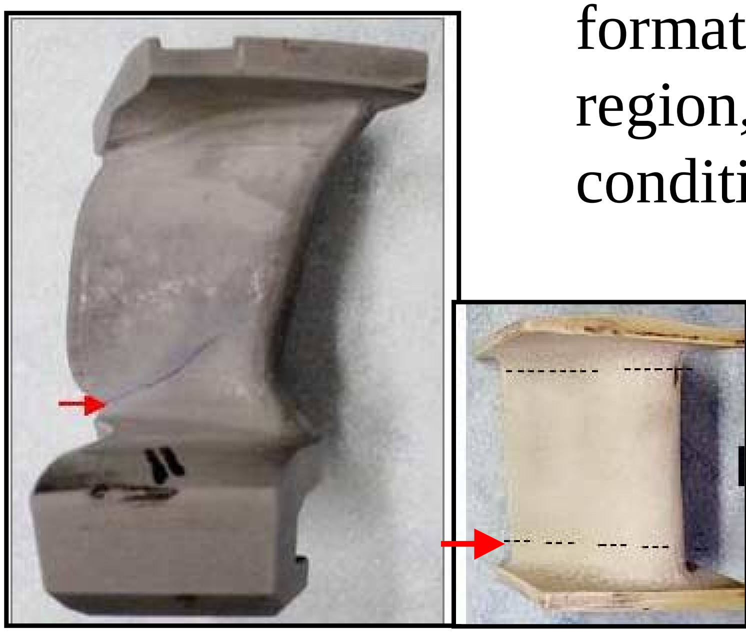
BACKGROUND (Cont.)



Poorer creep resistance was due to finer grain size microstructure and higher glassy phase content in NT164 Turbine Blades.

BACKGROUND (Cont.)

- Turbine blade airfoil/platform transition region exhibits more extent damage zone formation than middle airfoil surface region, because of different environmental conditions.



RATIONALE

- Although the use of standard test billets in laboratory testing provides beneficial property data, it is very difficult to reproduce complex microstructures of the components and non-uniform service environments to which the components are exposed.
- To address the above-noted issues, the use of miniature specialized specimens directly machined from the actual components is an approach that can provide reliable mechanical property data for performance prediction.

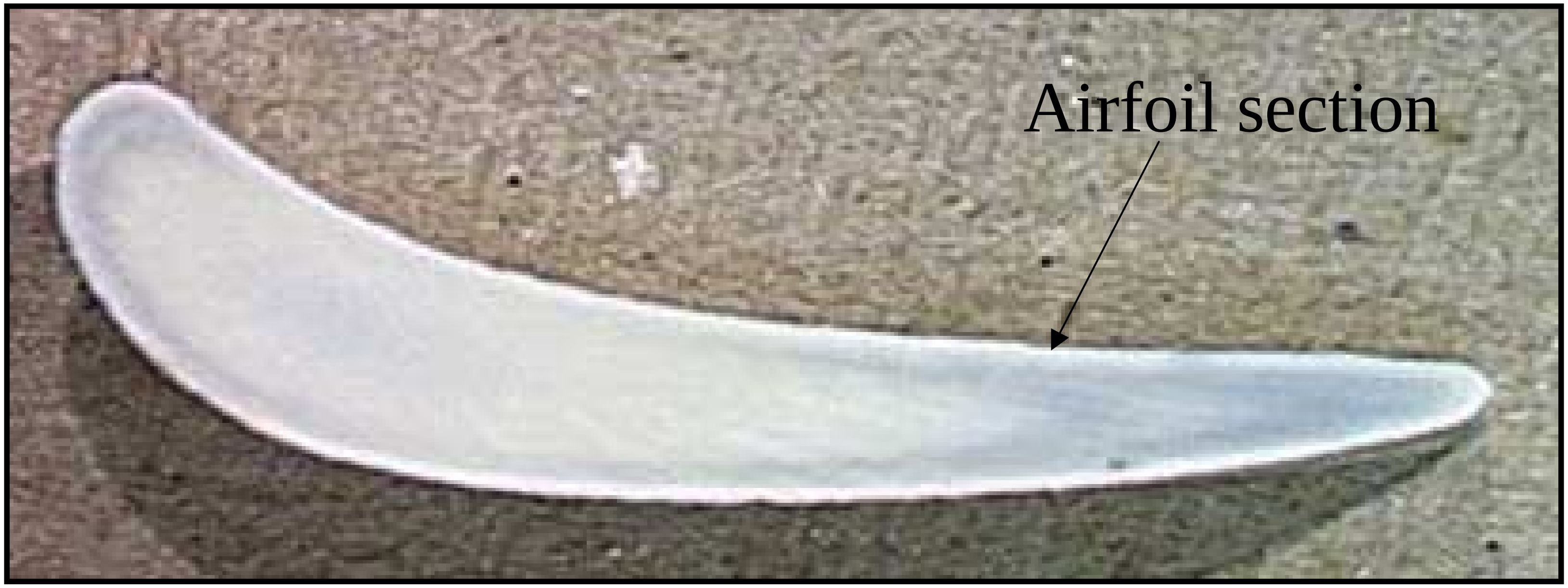
OBJECTIVE

- Develop and verify appropriate mechanical test methodology using miniature specimens for performance characterization of structural ceramics components for gas turbine applications.

TASKS

- Identify the test method and specimen geometry. Using miniature specimens, evaluate the mechanical properties of turbine components in as-received and exposed conditions.
- Perform fractography to evaluate failure modes and critical flaws.
- Compare the results of mechanical properties evaluation and fractographic characterization (using miniature specimens) with the performance of actual turbine components.
- Confirm the validity of selected specimen geometry and test methodology.

BIAXIAL TESTING

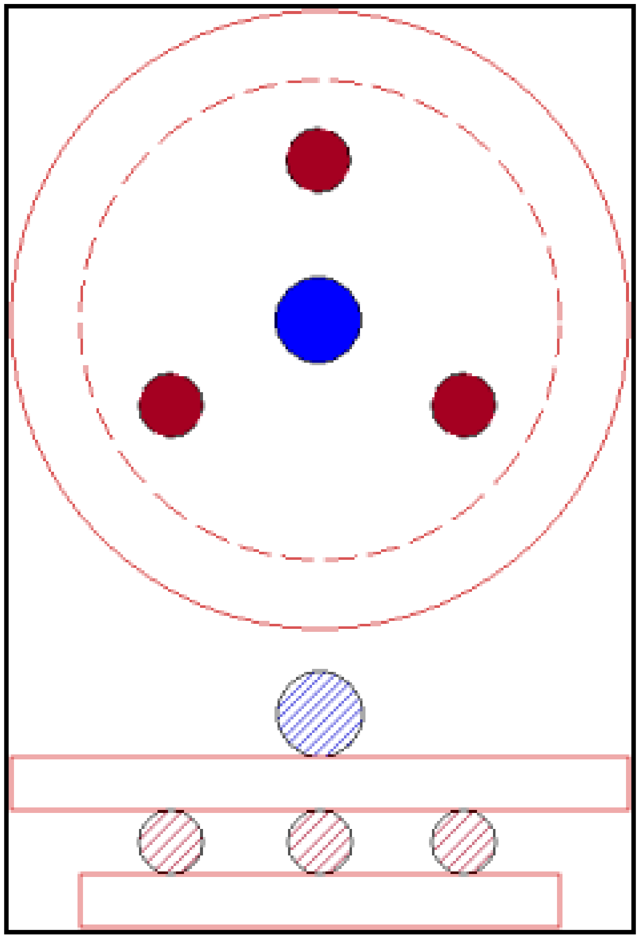


Why Biaxial Testing?

- Four point bend test are susceptible to edge failure whereas biaxial flexure test are not sensitive to edge failure.
- Miniature samples can be machined from the curved surfaces.

BALL-ON-RING GEOMETRY

$$\sigma^{B}_{max} = \{3P(1+\upsilon)/4pt^2\}\ \{1+2\ \ln(a/b)+((1-\upsilon)/\ (1+\upsilon))\ (1-b^2/2a^2)\ (a^2/R^2)\}$$



Where:

P= Applied load

R= Specimen radius

t = Specimen thickness

υ = Poisson ratio

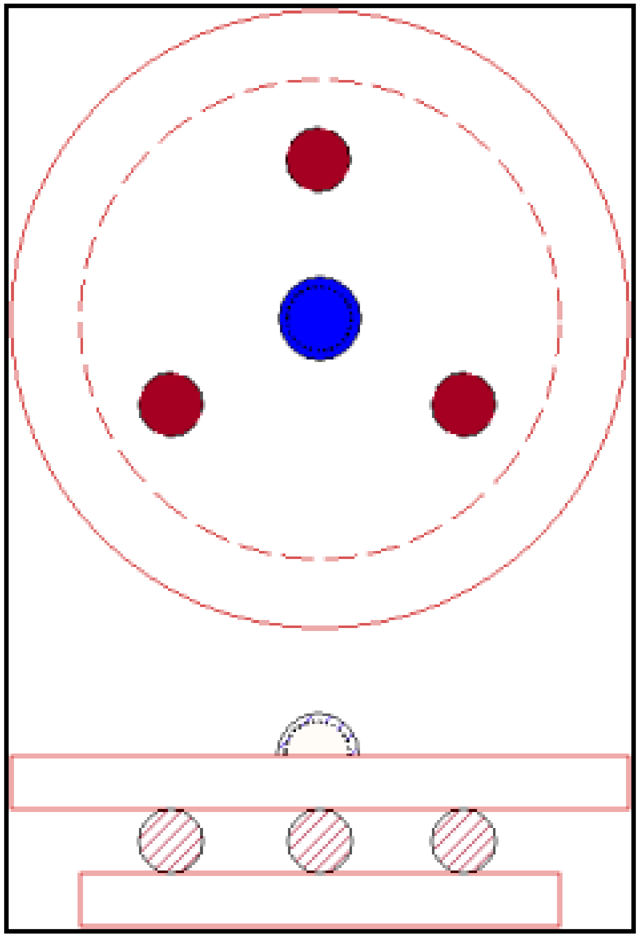
a = Radius of the support ball ring

b = Effective radius of contact of the ball on the specimen

(A. F. Kirsten & R. M. Wolley, 1967)

RING-ON-RING GEOMETRY

$$\sigma^{S}_{\mathbf{max}} = \{3P/4pt^2\}\ \{2(1+\upsilon)\ \ln(a/b)) + (1-\upsilon)\ (1-b^2/a^2)\ (a^2/R^2)\}$$



Where:

P= Applied load

b = Radius of the shell

R= Specimen radius

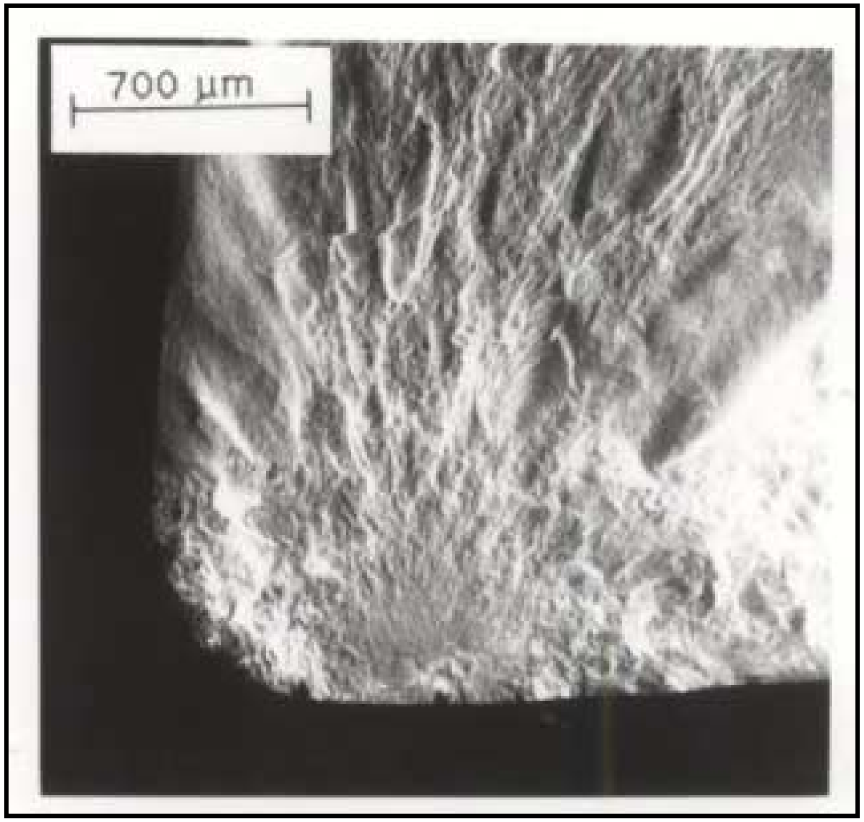
t = Specimen thickness

υ = Poisson ratio

a = Radius of the support ball ring

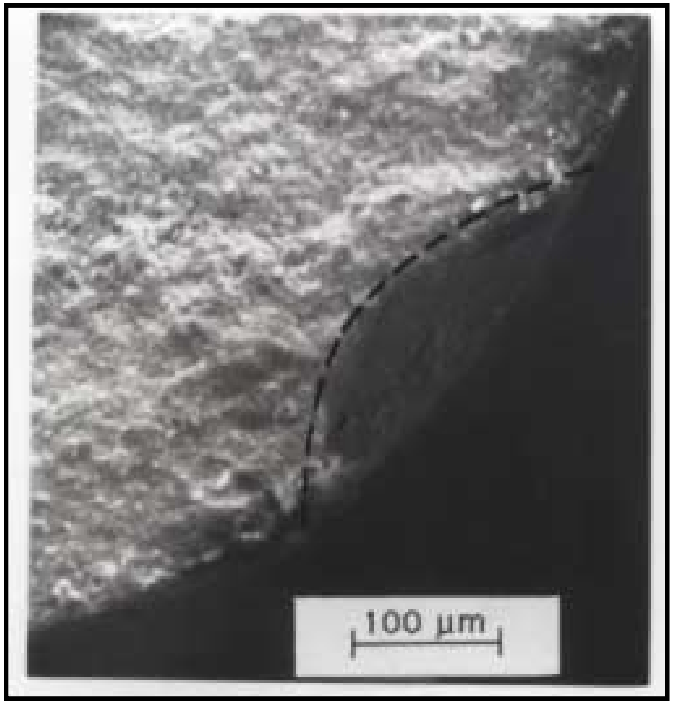
(F. F. Witman & V. P. Pukh, 1963)

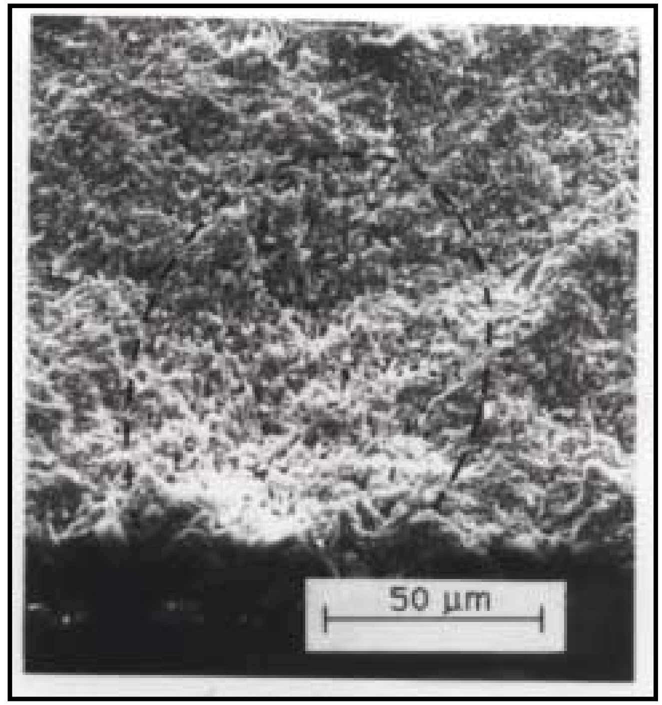
FRACTOGRAPHIC EVALUATION



Fracture markings around a failure initiating flaw

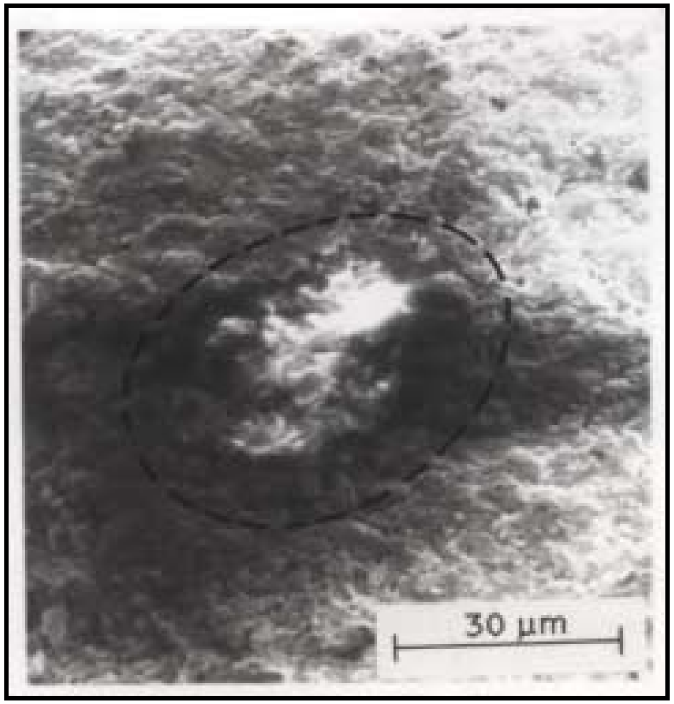
CRITICAL FLAWS

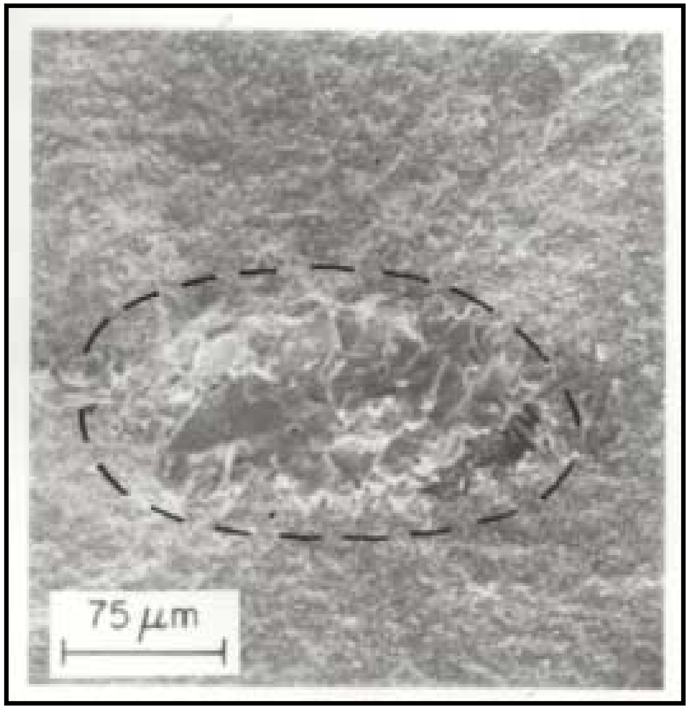




Edge Flaw **Porous Region**

CRITICAL FLAWS (Cont.)

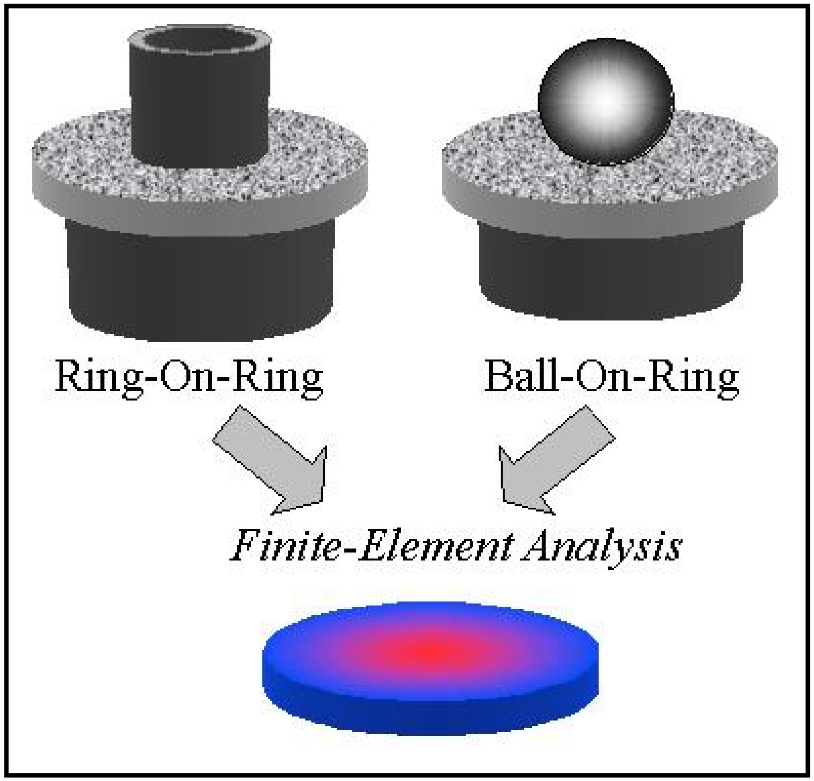


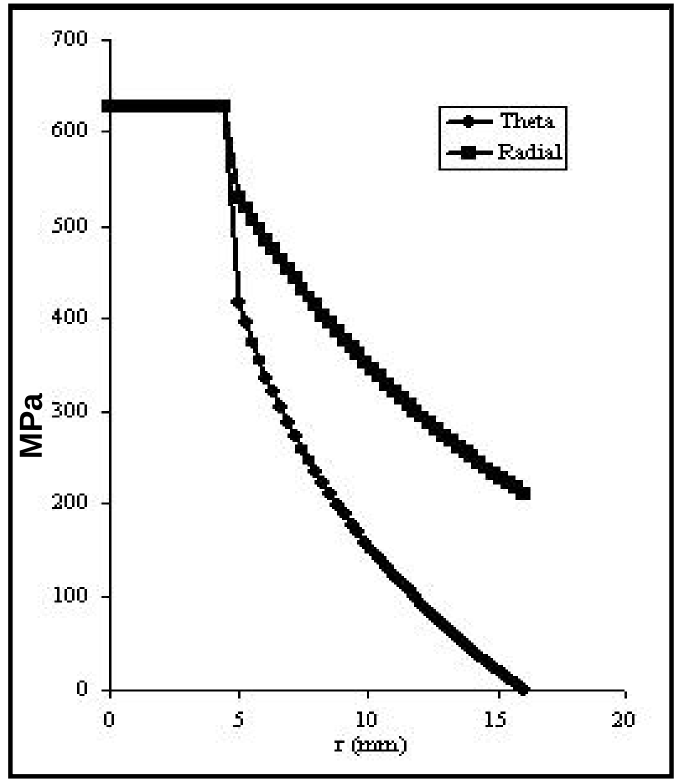


Degraded Region

Metallic Phase

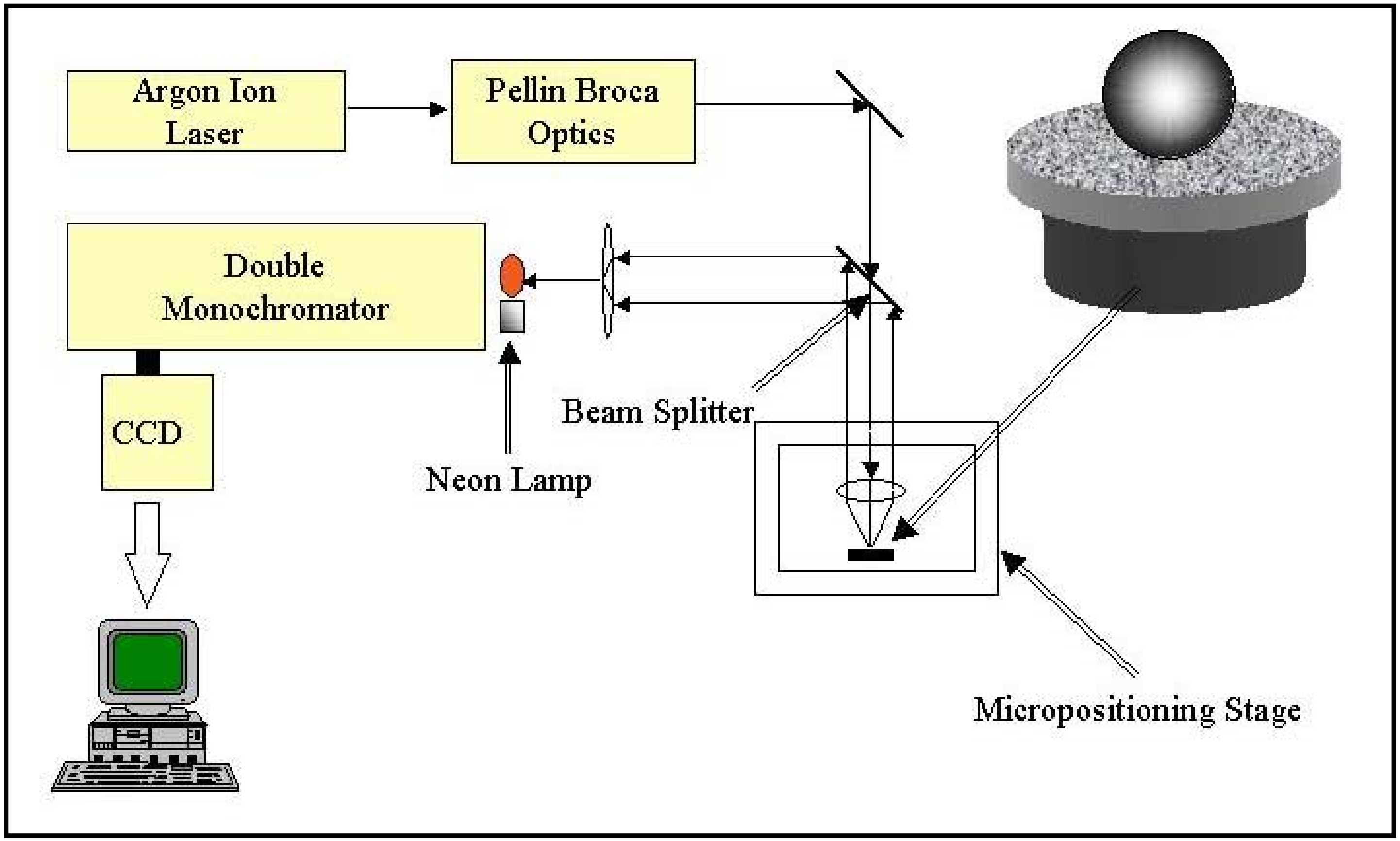
STRESS PREDICTION: FEA





PIEZOSPECTROSCOPY EVALUATION

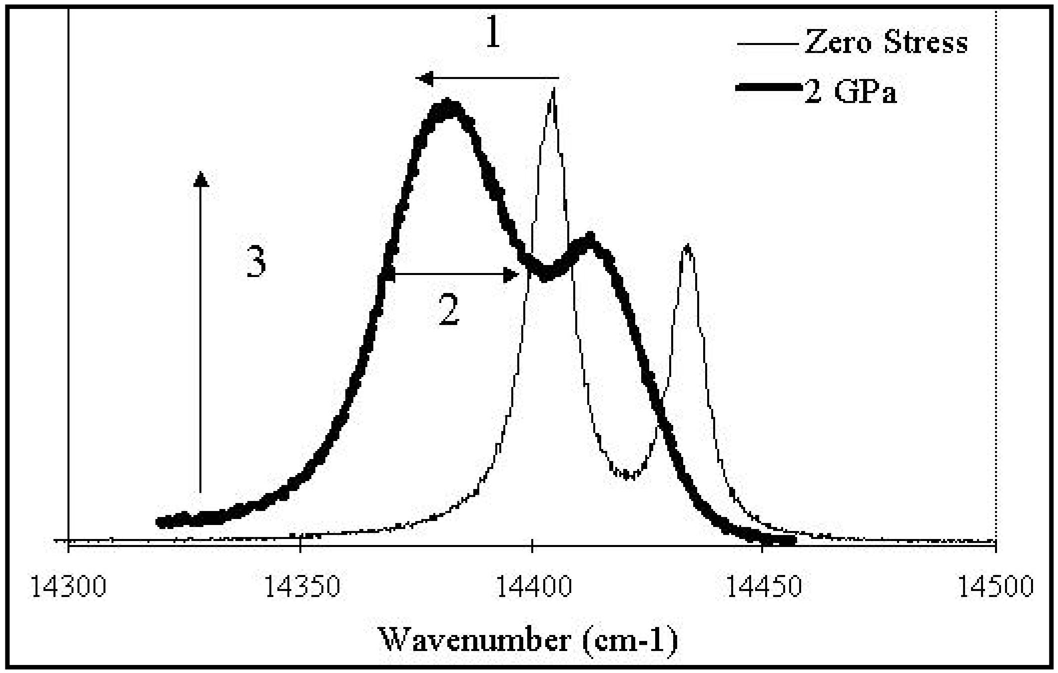
Piezospectroscopy to measure and verify stress profiles in alumina specimens.



TECHNIQUES UTILIZES OPTICAL FLUORENCE

- A transition metal ion has energy levels associated with its unpaired d-shell electrons (or f-shell for rare earth ions).
- When the ion is substituted into a crystal, these energy levels will split and shift depending on the point symmetry the ion experiences and the strength of the crystal field.
- Cr^{+3} is always present in sapphire in small quantities.
- The fluorescence of alumina is extremely intense (e.g., Ruby lasers).

CHARACTERISTIC PEAKS ARE SHIFTED BY STRESS



- The peak shift gives the mean hydrostatic stress and information about the stress state.
- The peak width measures the distribution of stress within the probed volume.

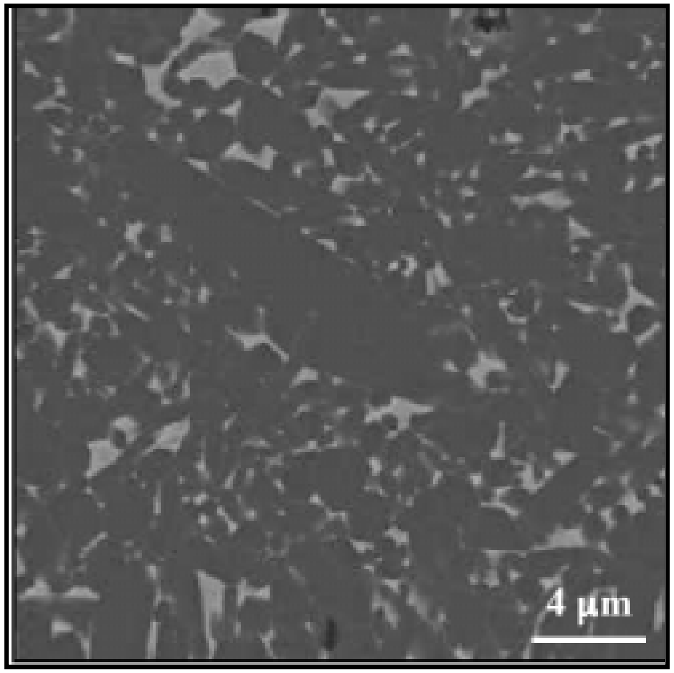
TECHNICAL ACCOMPLISHMENTS

- A critical review of the relevant literature to evaluate the state-of-the-art in mechanical and microstructural characterization and performance evaluation of ceramic turbine components using miniature specimen geometry has been initiated and continued.
- A Si_3N_4 (AS800) plate has been received and specimen fabrication for mechanical testing and microstructural characterization has been initiated.
- A finite element analysis has been initiated to characterize the state of stress in specimens loaded in a biaxial mode. Specifically, the effects of loading configurations and fixture alignments on stress variation will be evaluated to select appropriate testing configuration.

AS-RECEIVED Si_3N_4 (AS800) PLATE

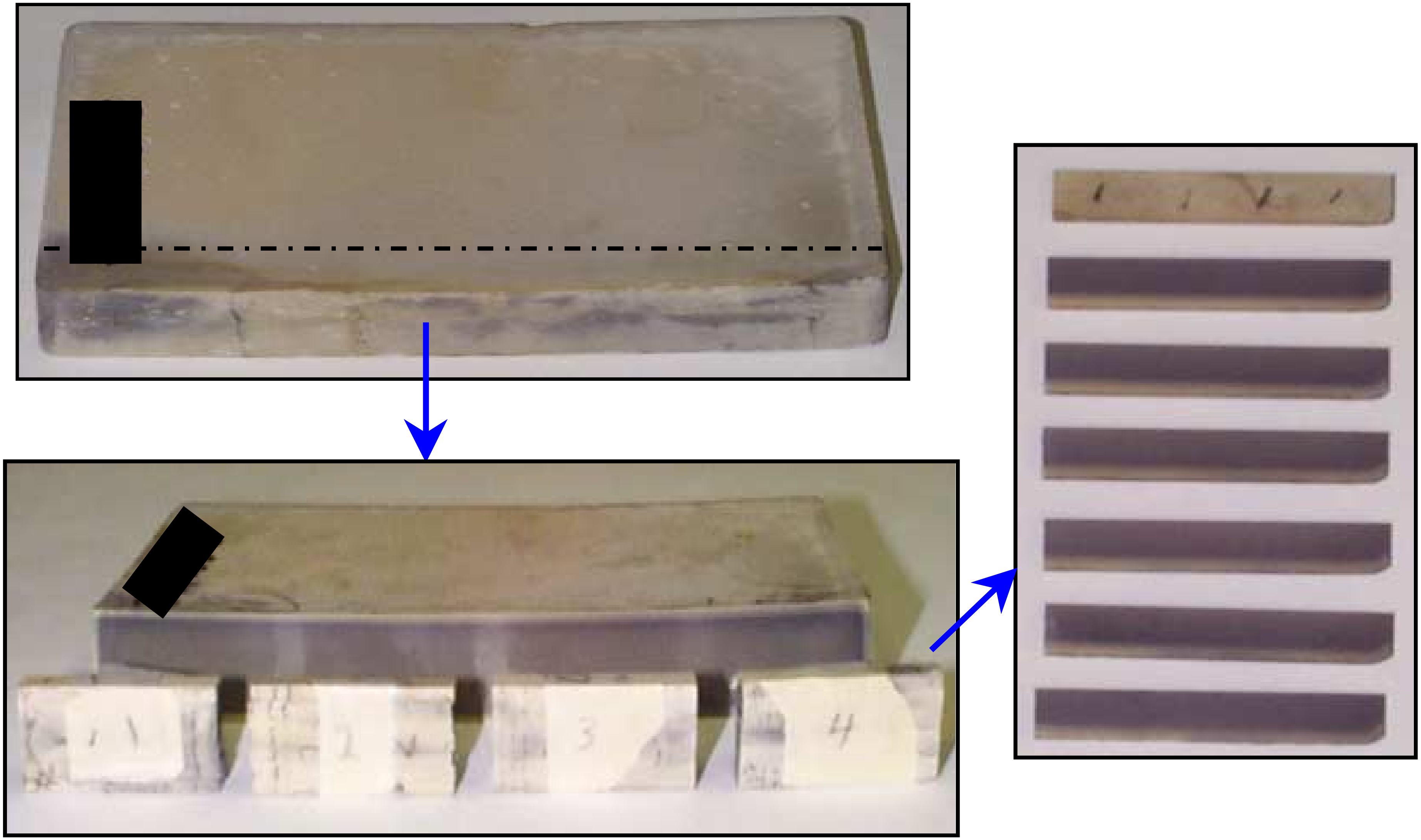
MICROSTRUCTURE OF AS-RECEIVED Si_3N_4 (AS800) PLATE

Honeywell AS800 (w/ 10 wt.% Y_2O_3-SrO-La_2O_3)



Phase(s) in the as-received material:
Si_3N_4, H-phase ($Sr_2La_4Y_4(SiO_4)_6O_2$)

Flexure Bars Machined From Si_3N_4 Test Billet



FUTURE PLANS

- Collaborations with industrial partners will be established. This will allow us to obtain appropriate turbine components (for mechanical testing) and necessary guidance for the development of the test methodology
- Appropriate biaxial test methodology (miniature specimen geometry, testing mode) will be selected, analyzed by a finite element analysis, and verified by stress measurement using piezospectroscopic evaluation technique.
- Mechanical properties will be evaluated by the selected test methodology using miniature specimens from a test billet and subsequently from actual turbine components. The results from the test billet and the components will be correlated to improve understanding of biaxial test methodology.

FUTURE PLANS (Cont.)

- Fractographic evaluations will be performed to evaluate failure modes and critical flaws. Correlations will be established between the critical flaws and mechanical properties for reliability prediction.
- Results of mechanical properties evaluation and fractographic characterization will be compared with the performance of the actual turbine components to assess the applicability of the test methodology.