IEEE SW Test Workshop

Semiconductor Wafer Test Workshop

June 7-10, 2009

San Diego, CA

Brittle Fracture of Ceramics

Introduction to Mechanical Behavior of Ceramics

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OUTLINE

– Sources of ceramic fracture in the vertical probe cards

– Introduction to theory of ceramic fracture

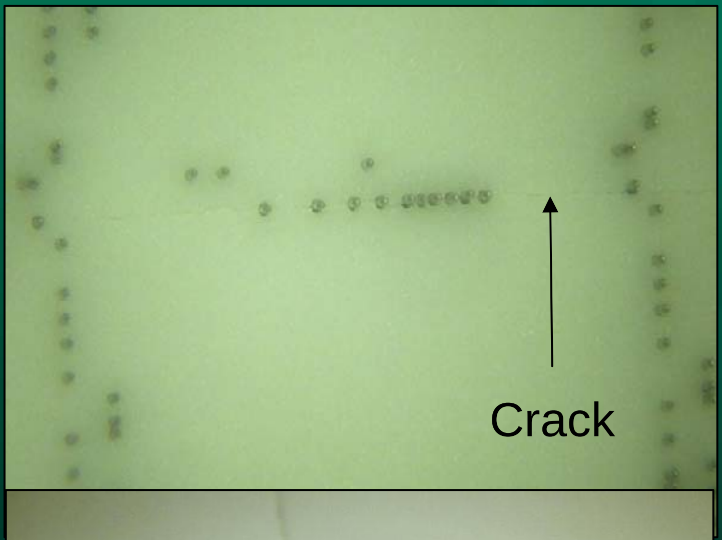
– 3-point flexural strength test of ceramics

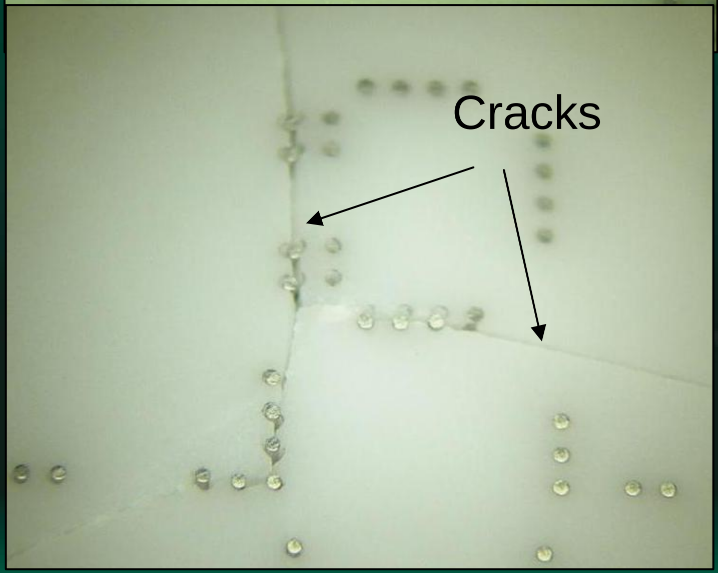
– Finite element model of ceramic specimen

– Ceramic stress intensity factor (SIF)

– Conclusion

Ceramic Fractures in Vertical Probe Cards





The major sources of ceramic fractures in the vertical standard probe card processes:

A. Inherent material properties

B. Ceramic machining –preparing of the ceramic parts:

- Grinding
- Cutting
- Drilling
- Lapping

C. Using ceramics as a part of probe card:

- Assembly Process (tightening LD screws, accidentally dropping part)
- Wafer Probing (OT wafers, high probe current, high temperature test)
- Probe Cleaning (dragging probes at high OT over cleaning pads)

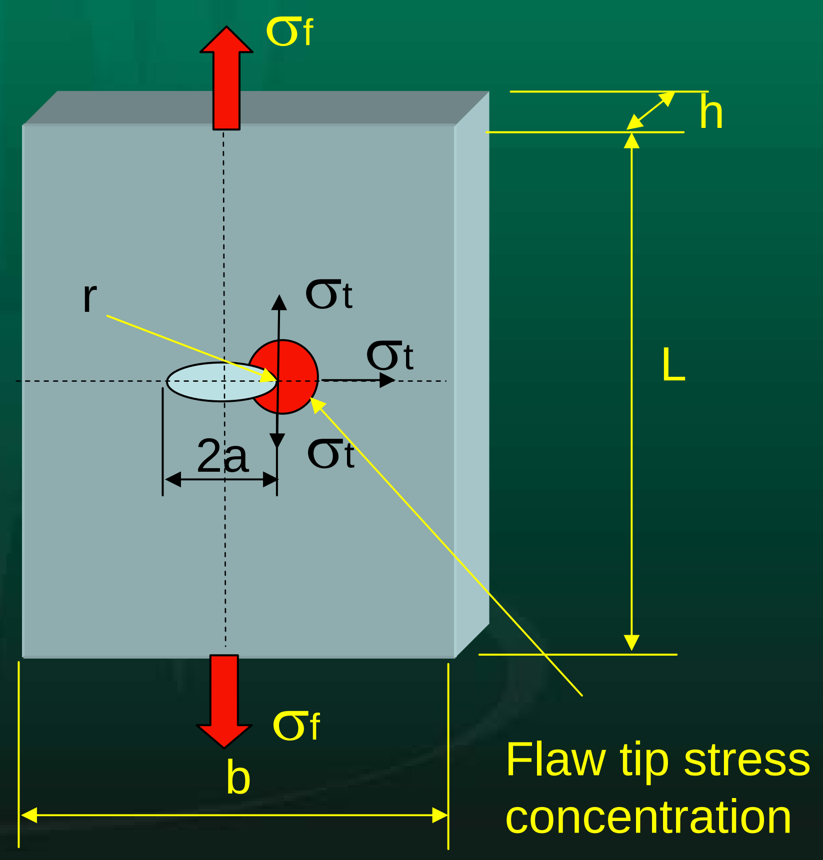
Classical Model of the Fracture Mechanics

Stress Intensity Factor K_{IC}:

$$K_{IC} = C\,\sigma_f \sqrt{\pi a}$$

C=1.12 for edge flaws

K_{IC} – MPa $\sqrt{m}$



Stress Flaw Tip Concentration:

$$\sigma_t = 2\sigma_o \sqrt{\frac{a}{r}}$$

Where: $\sigma_o > 0$ and $\sigma_o <= \sigma_f$

Flexural Strength Test

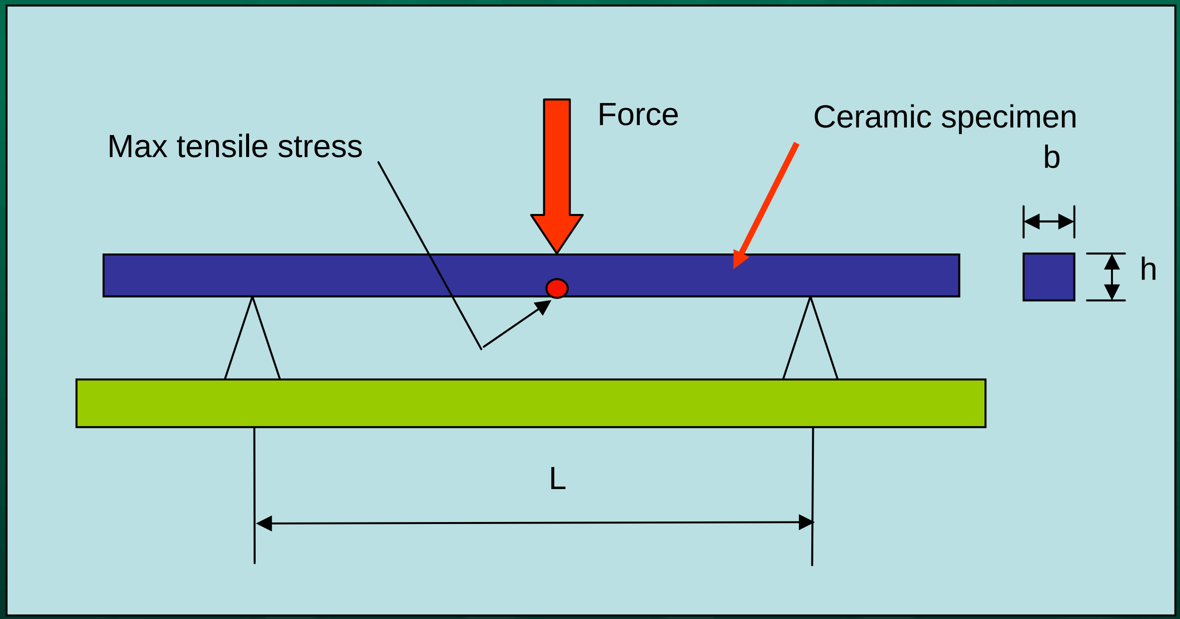
- Define and compare flexural strength of the ceramics

- Evaluate flaw size in the cross-section

- Correlate fracture toughness with flaw size

- Correlate strength received from tests with FE models

Three Point Bending Model



Stress of Rupture (Flexural Strength, Modulus of Rupture)

$$\sigma_f = \frac{3\,FL}{2\,bh^2}$$

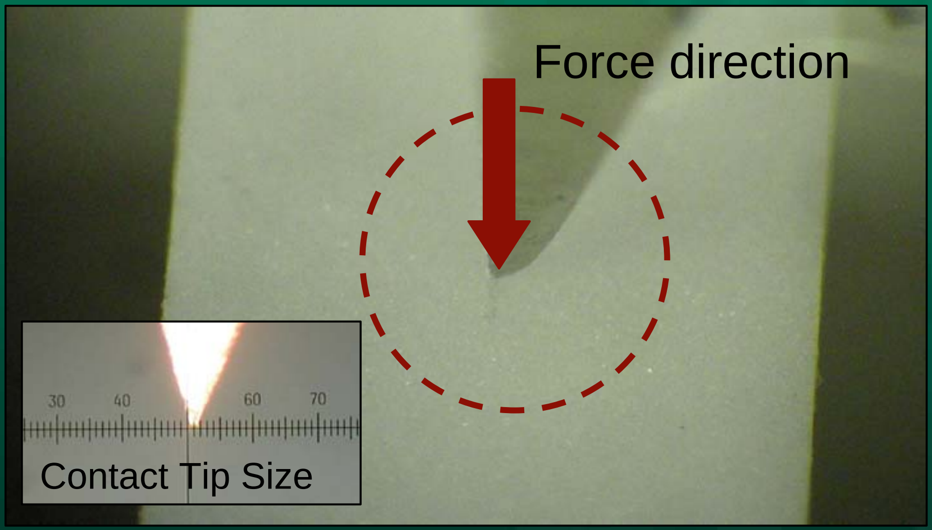
Where: F- force

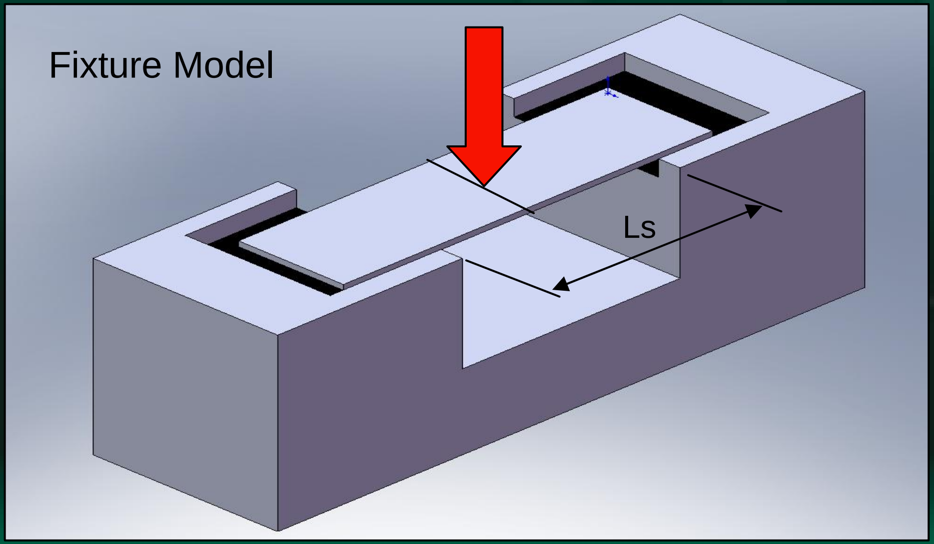
L- distance between supports

b – specimen width

h – specimen thickness

Test Description





In the ceramic flexural strength studies have been used four materials: macor, alumina, zircon and silicon nitride. The mechanical properties of ceramics are listed in table 1.

Five to twelve specimens for each material were prepared with dimensions: length=0.500”, width= 0.145”, thickness= 0.010”

The bending tests were conducted with the span length of 0.300”. All tests were carried out in an ambient temperature.

The load-force at the fracture time has been recorded.

Test Notes and Observations

- No initial cracks or preexisting large flaws on the specimens

- All specimens under the load- force spontaneously and rapidly fractured without any signs of warning, some of them cracked intermittently after 3-5 minutes

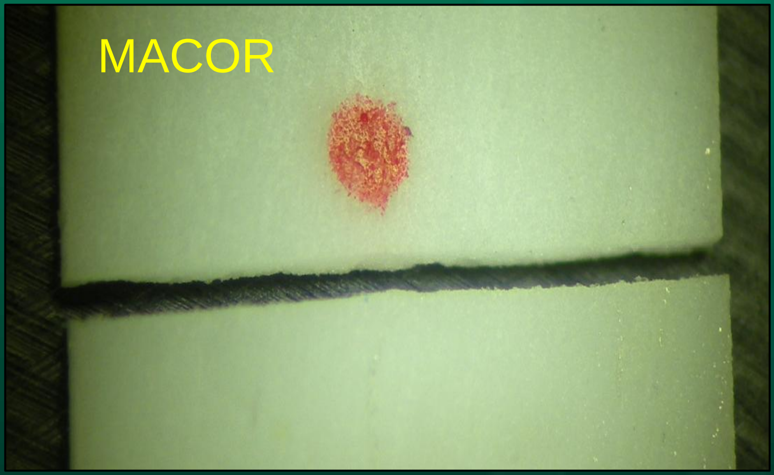
- No dents or plastic deformations on the ceramic surfaces have been observed in the area of contact force

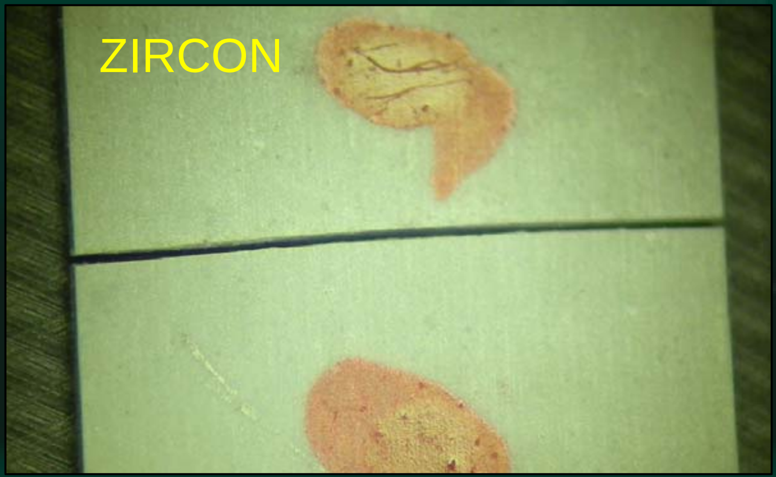
- Most of ceramic fractures occurred in the area of high stresses, in the middle of specimen

Table 1. Mechanical Properties

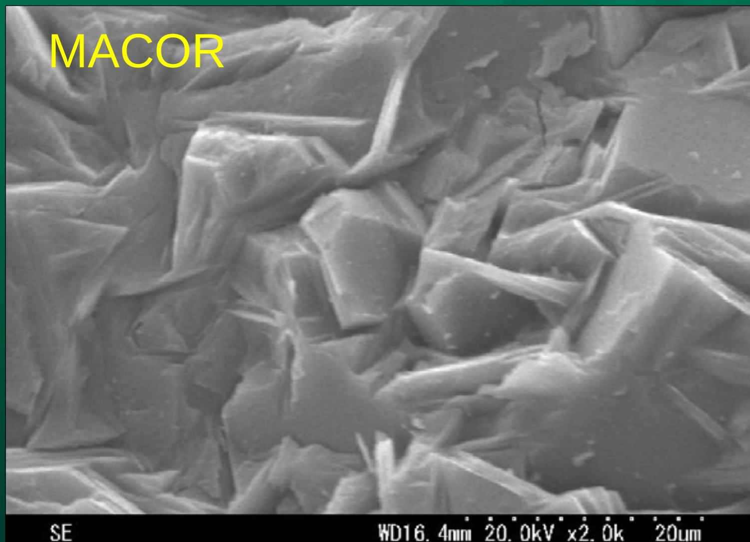
Properties of materials		Macor	Alumina	Silicon Nitride	Zircon
Density (r)	g/cm^3	2.52	3.23	3.92	4.2
Young's modulus (E)	(GPa)	66.9	380	320	175
Poison's ratio (ν)		0.29	0.24	0.28	0.4
Coefficient of Thermal Expansion	x10^{-6}/C	9.7	8.2	3.2	4.2

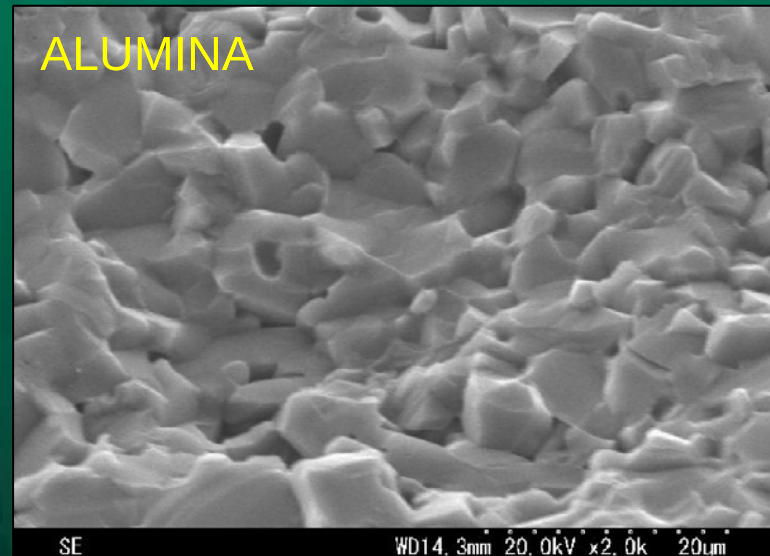
Images of Fractured Specimens

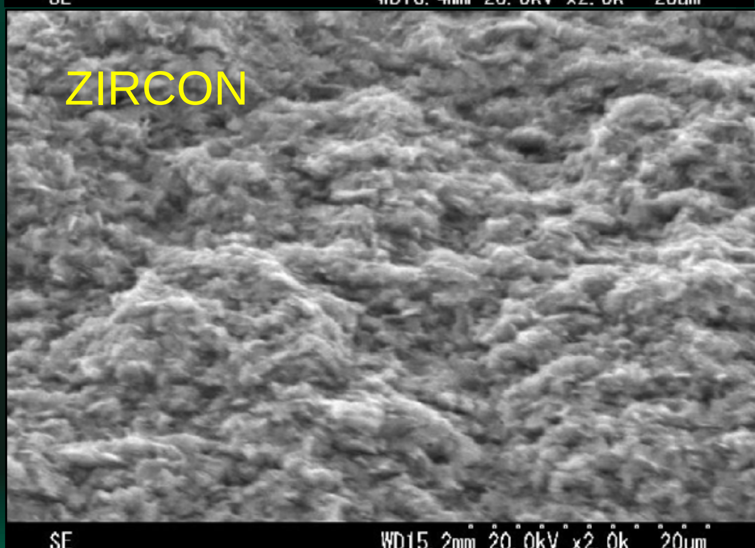




SEM Pictures of Cross-Sections







Data Analysis

The fracture strength was calculated based on collected fracture force data for each of specimen.

A graphical interpretation of strength distribution has been developed using Weibull probabilistic method.

The strength distribution has been shown on one plot for specimen comparison.

The finite element model was developed to validate the max bending stresses of alumina.

The fractographic observation was employed to determine the size of flaws and stress intensity factors.

Weibull Analysis

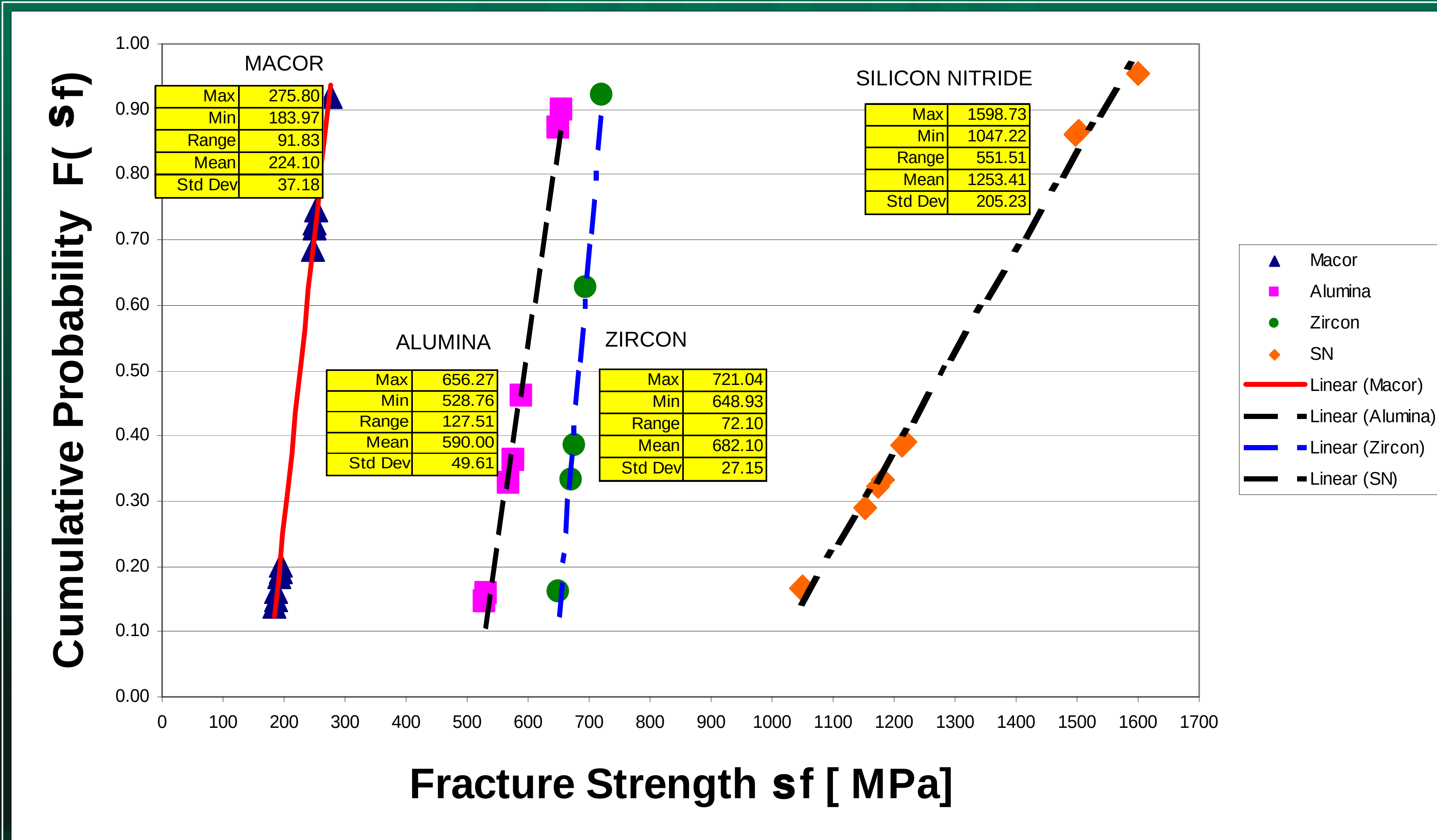
The fracture strength distributions of test readings have been shown in Weibull probabilistic plots. The cumulative probability was calculated using the median rank method. The strength distribution of tested materials shows a straight line calculated based on shown equation below. Two calculated Weibull parameters, scale and shape, are shown in table 2

$$\boxed{F(\sigma_f) = 1 - \exp[-(\frac{\sigma_f}{\sigma_s})^{m_\sigma}]}$$

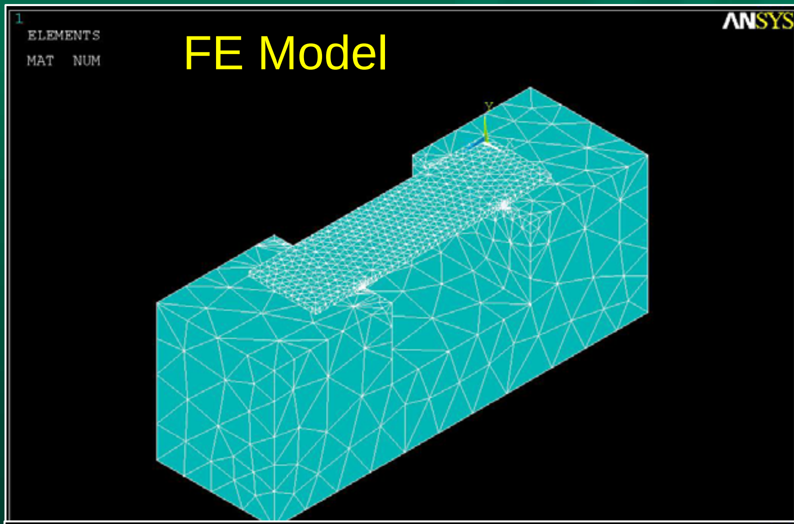
Table 2 Weibull parameters

Material	MACOR	ALUMINA	ZIRCON	SILICON NITRIDE
Scale parameter σ_s[MPa]	241.4	613.3	694.9	1352.0
Shape parameter m_σ[MPa]	6.1	12.4	25.4	6.7

Distribution of Fracture Strength



FE 3-D Bending Fixture Model



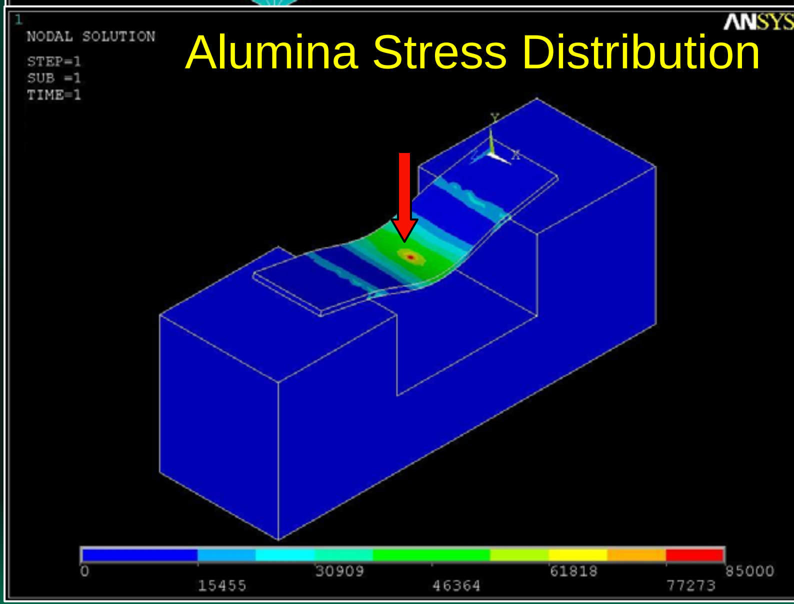
Fracture force = 2.57 lbs

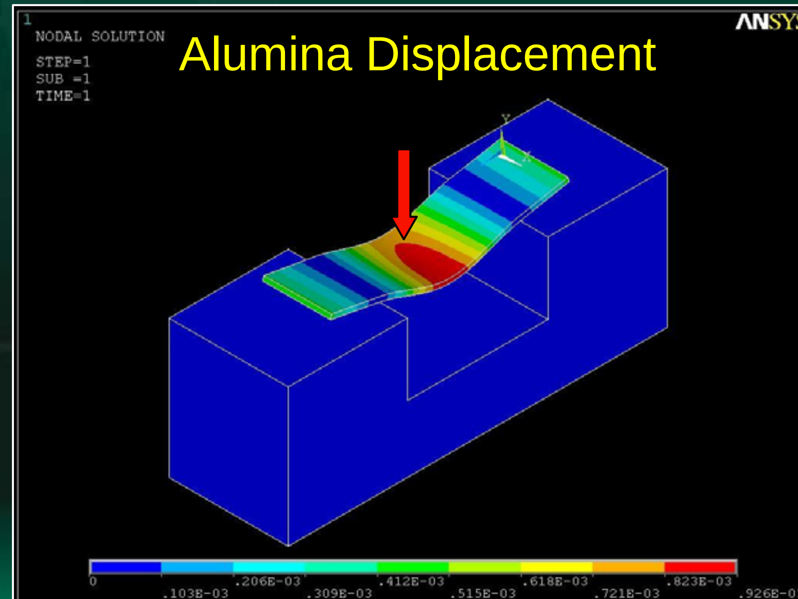
Max Stress at contact point = 586 MPa

Max displacement = 0.00092 in

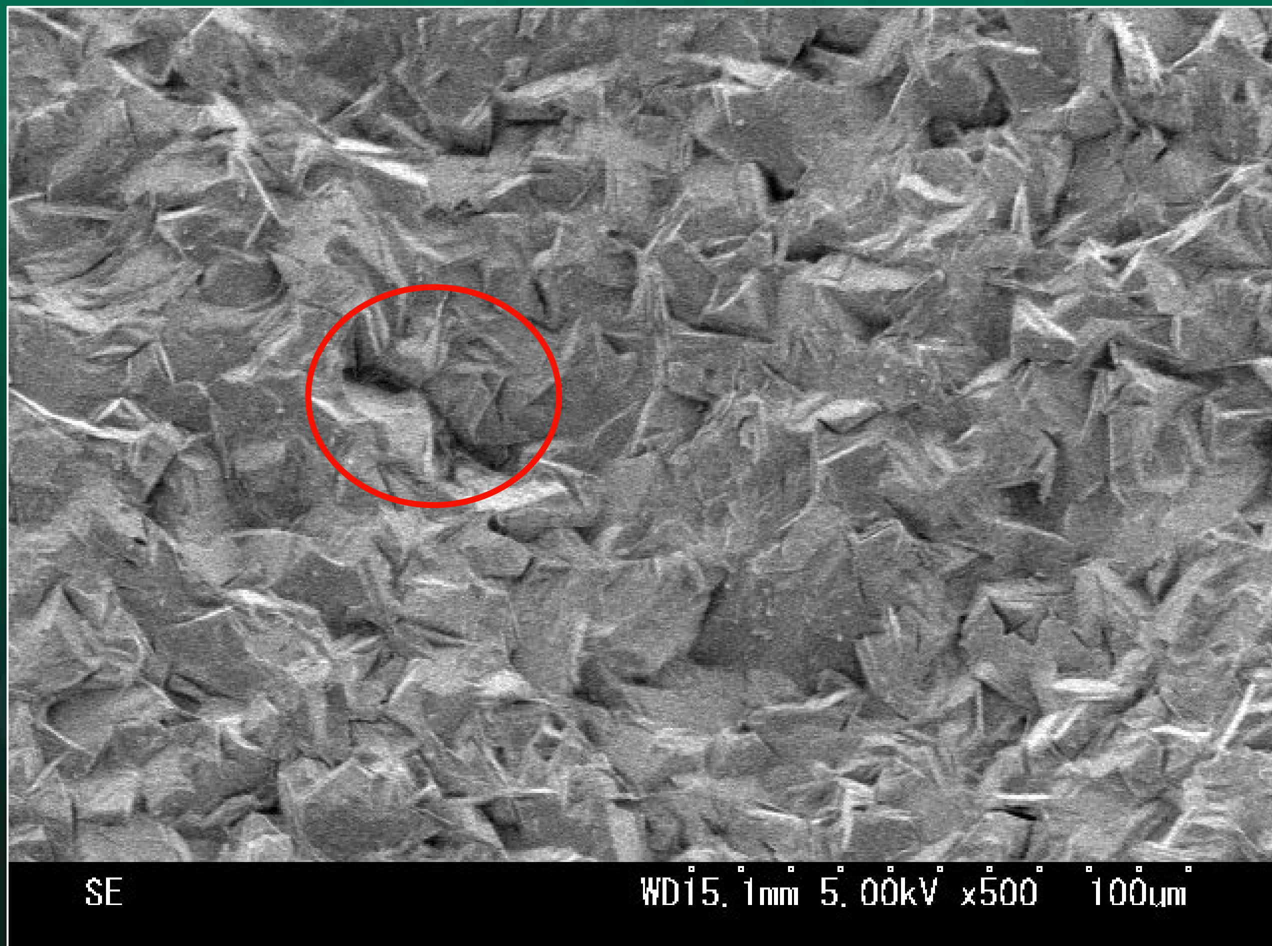
The calculation discrepancy:

$\varepsilon = [(\sigma_{mean} - \sigma_{ansys}) / \sigma_{mean}] \times 100\% = 0.67\%$



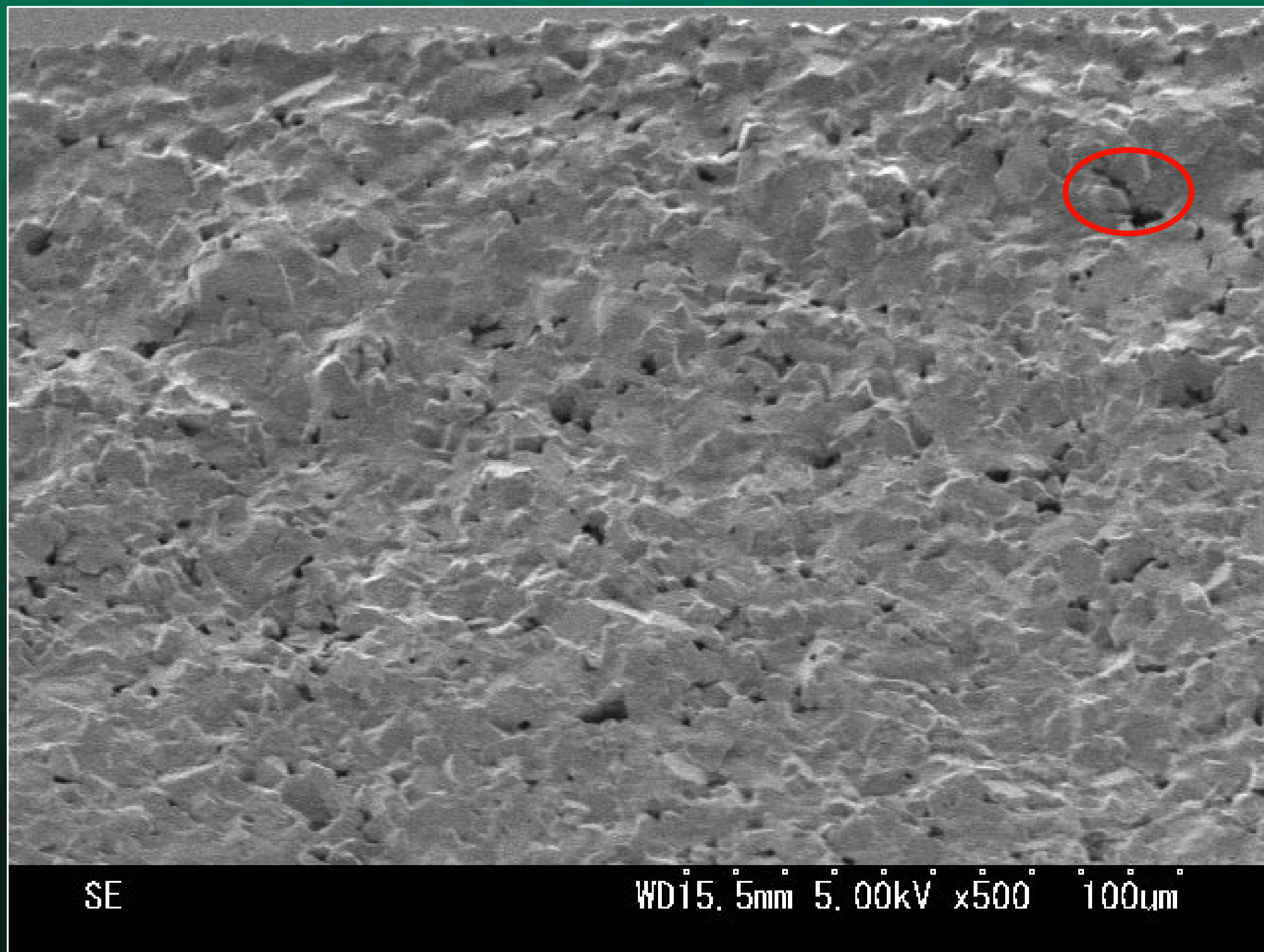


Macor Fractographic Observation



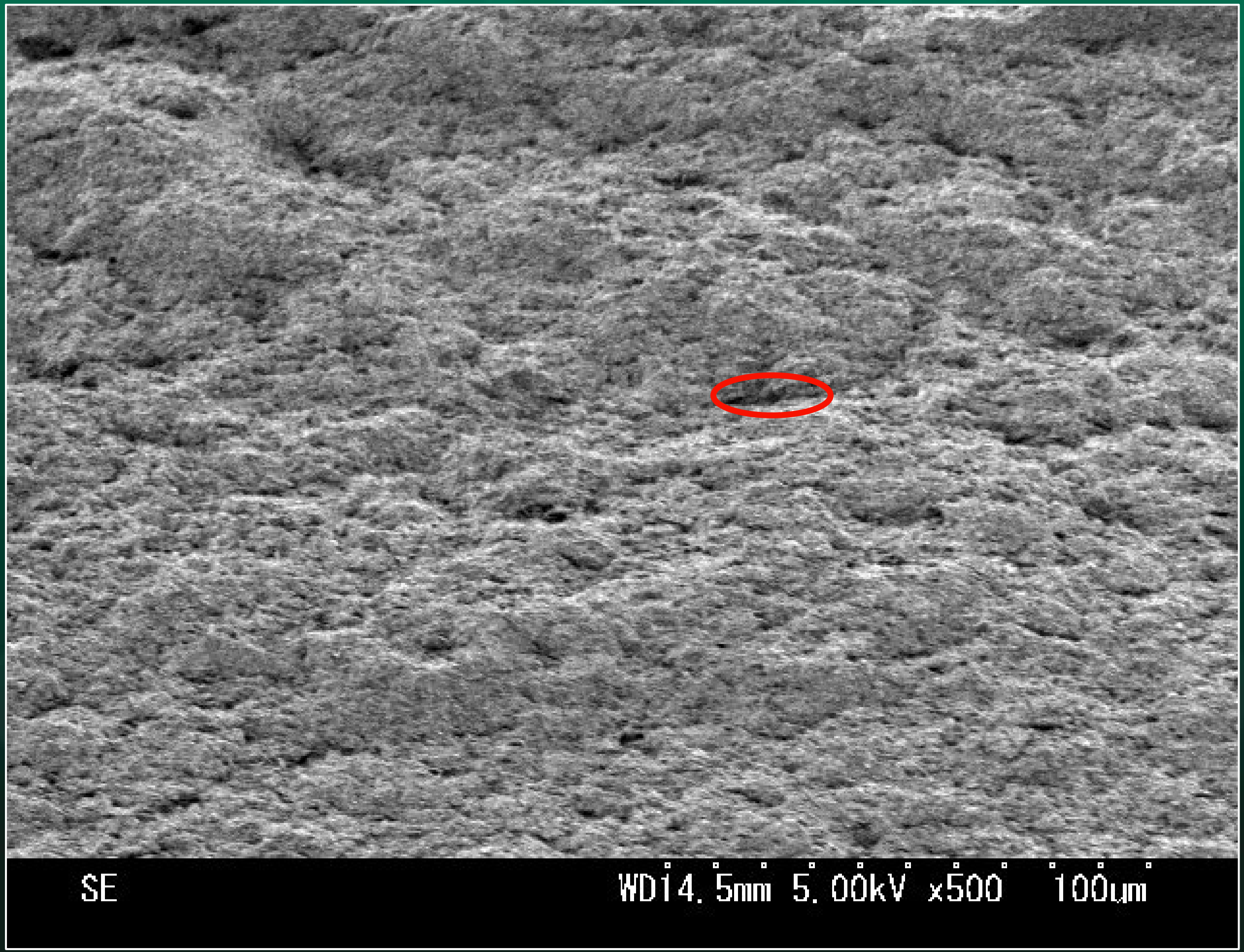
Flaw size = 50 µm, K_I= 1.8 MPa $\sqrt{m}$

Alumina Fractographic Observation



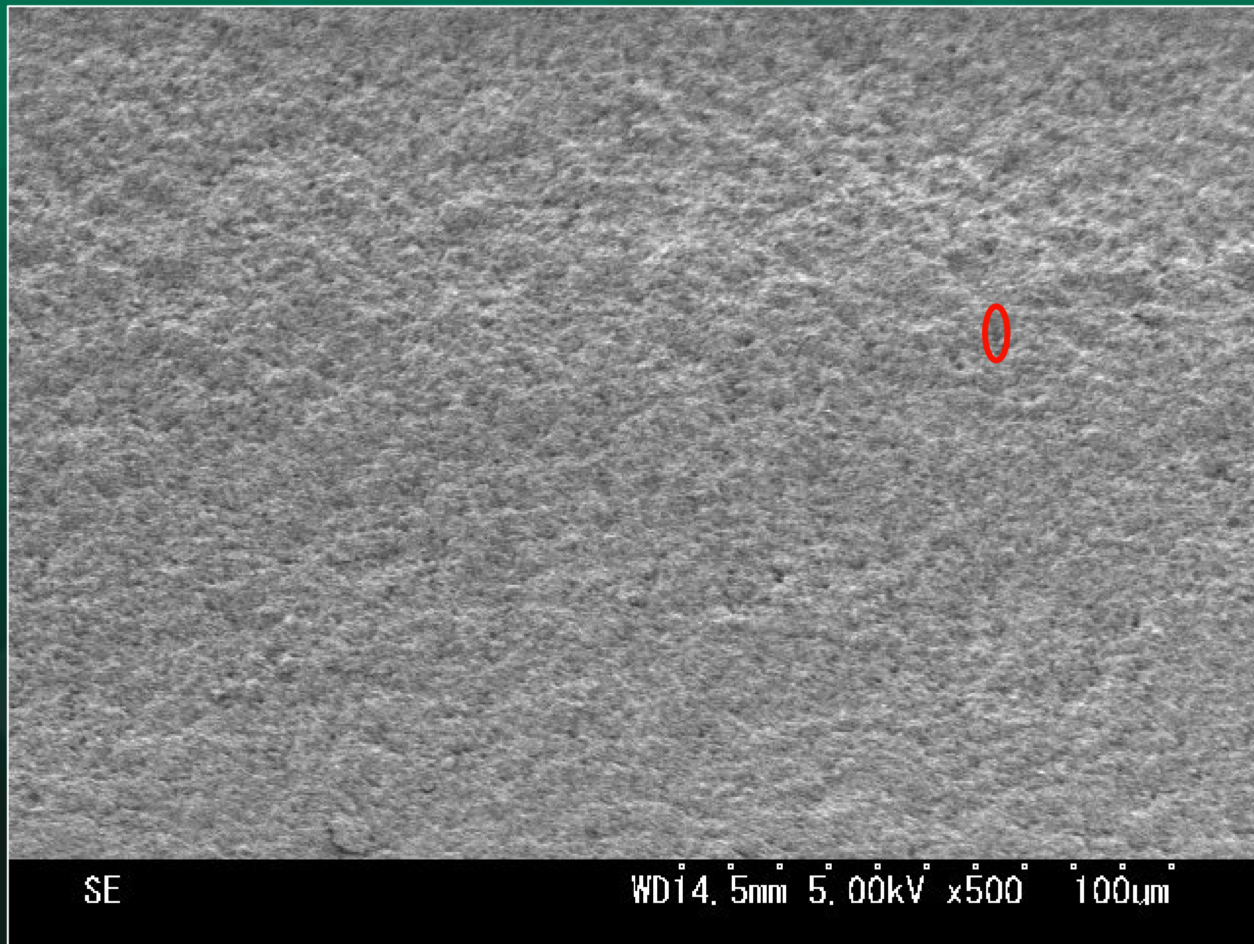
Flaw size = 25 µm; K_I= 3.7 MPa $\sqrt{m}$

Zircon Fractographic Observation



Flaw size = 25 µm; $K_I = 4.6 \text{ MPa} \sqrt{m}$

Si_3N_4 Fractographic Observation



Flaw size = 15 μm; K_I= 5.7 MPa $\sqrt{m}$

Test Comments

- The SEM images reveal different crystal structure and configuration

- Smallest constituent elements and flaws increase the flexural strength and stress intensity factor

- Cross-section of zircon shows a considerable similarity to cross-section of silicon nitride

- Zircon shows a good fracture strength and fracture toughness comparing with macor and alumina

Properties of materials		Macor	Alumina	Zircon	Silicon Nitride
Measured Min Flexture Strength (sf)	MPa	183	528	648	1047
Measured Flaw Size	µm	50	25	25	15
Stress Intensity Factor (K_{IC})	MPa em	1.8	3.7	4.6	5.7

Summary / Conclusions

In the present study the 3-point bending ceramic test was carried out to clarify the relation between strength and flaw size at a fracture origin.

The 3D bending model of ceramic has been created to study and to correlate the stress concentration and material displacement of fracture materials.

The SEM images of broken ceramic specimens were used to understand material structure, to determine size of flaws and stress intensity factors.

Acknowledgments

Shoichi Asanuma - TOTO USA Inc

Frank Scanlon - TOTO USA Inc

Shigeru Shimizu – TOTO USA Inc

Joe Miller - Potomac Photonics Inc