# Monitoring Strain Evolution within Thermal Barrier Coatings under Thermal Gradients and Mechanical Loads


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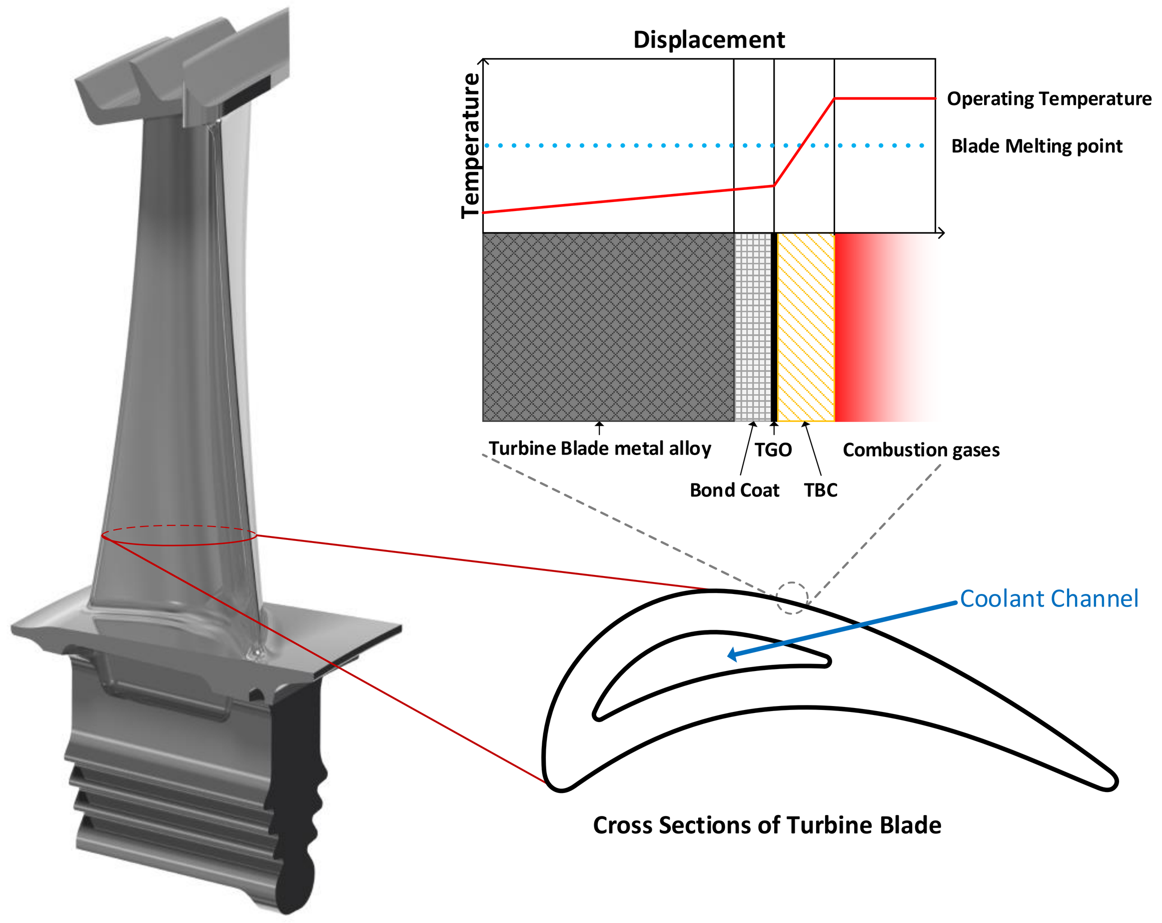
## Introduction

Turbine components are exposed to increasingly higher temperatures to increase operational efficiency. Thermal barrier coatings combined with internal substrate cooling allow for operating temperatures exceeding the melting temperatures of the turbine substrate. The thermal expansion mismatch between the different materials however, result in large residual stresses that are linked to failure. Recreating the operating conditions turbine blades are subjected to with a tubular sample geometry can help to better understand failure modes and the inter layer mechanical interactions of materials during the loading cycle.




The thermal barrier coating (TBC) is adhered to the surface of the turbine blade by a nickel based bond coat and the blade is forced cooled with air by an internal coolant channel.

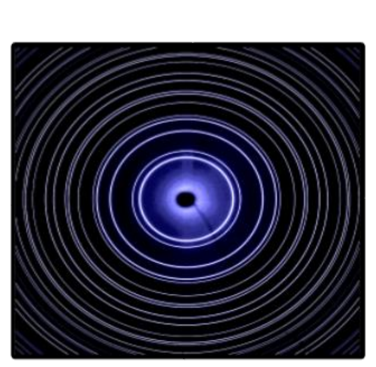
## Objective

- Develop measurement techniques to accurately obtain in-situ X-ray diffraction (XRD) strain measurements of each internal layer of the tubular sample
- Determine strain and stress behavior of coating layers under thermal gradient and mechanical loading conditions

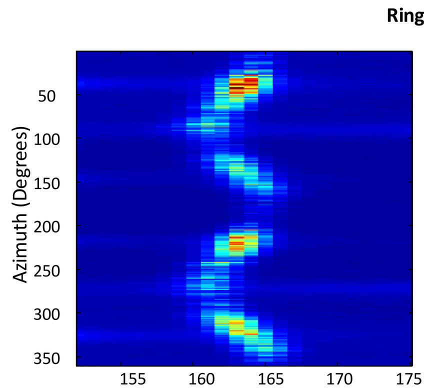
## Strain Effect on XRD Rings

As X-rays pass through a material, they diffract as rings on a 2D detector based on the crystalline structure of the material and the mechanical loading it is experiencing.

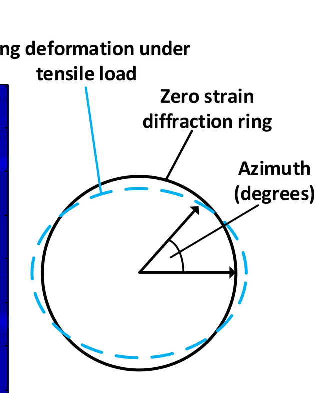
The strain induced by the mechanical loading changes the eccentricity of the diffracted ring. This change in radii is compared to the unstrained radius to find the strain experienced by the sample.



Reference zero strain powder diffraction sample

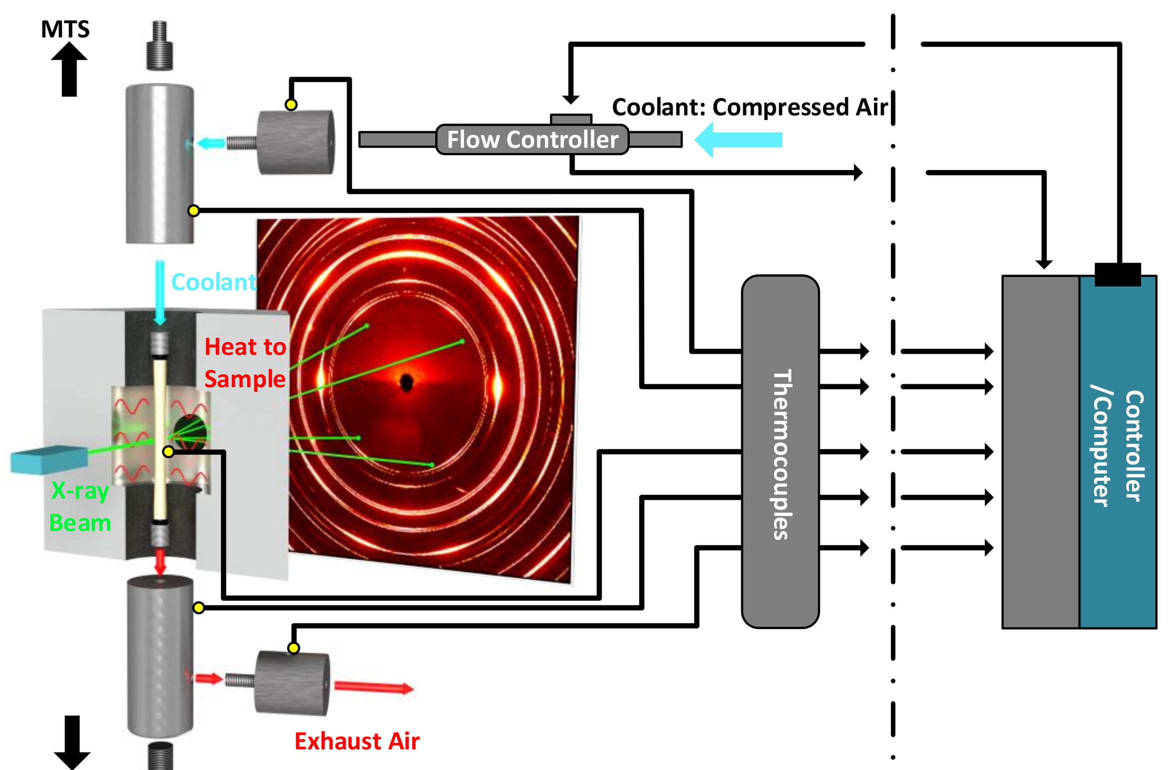



NiAl (100) response under 32 Mpa load

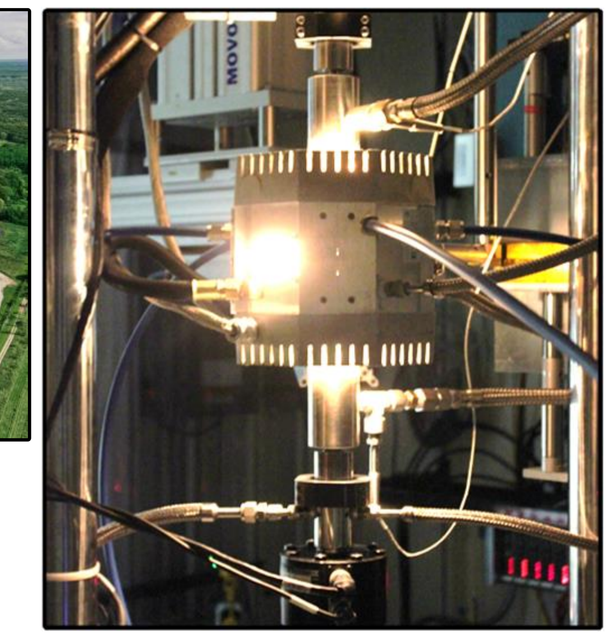



X-Y representation of ring deformation direction

## In-situ XRD Experimental Apparatus and Method



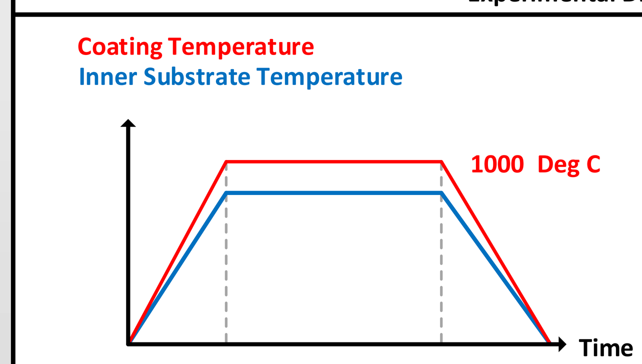

Experimental Diagram



- Constant Mechanical Load
  - 32, 64, and 128 Mpa Applied
- Outer Surface Ramped up to 1000 deg C
- Coolant Flowrate Varied
  - 30, 50, and 75 % Flow (100 SLM Max)
  - 145 deg C Maximum Calculated Temperature Gradient
- X-Ray Scan Through Coating Thickness Every 3.5 Minutes
  - Window Size 30 x 300 microns
  - 10 Window Scan

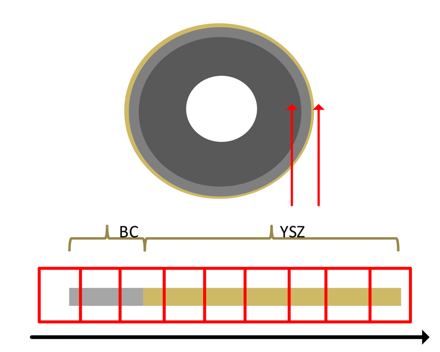
Picture of Experiment in progress (top)

Experiments were conducted at the Advanced Photon Source, Argonne National Laboratory (top left)




Thermal Loading representation for each cycle

| | |
|---|---|
| Ramp Up: | 50°C per minute to 1000°C |
| Temperature Hold: | 1000°C for 40 minutes |
| Ramp Down: | 1000°C to room temperature |




X-Ray Scan Through Coating Thickness
Window Size 30 x 300 microns
10 Window Scan

Sample
Manufactured at German Aerospace Center (DLR) in Cologne, Germany

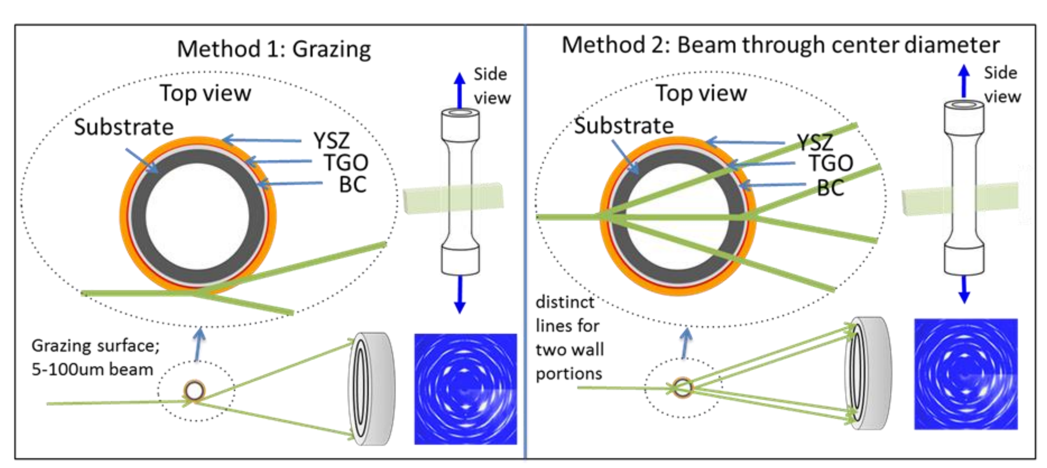
IN 100 Substrate
Outside Diameter = 8mm
Inside Diameter = 4mm

NiCoCrAlY Bond Coat
80 µm EB-PVD Coating

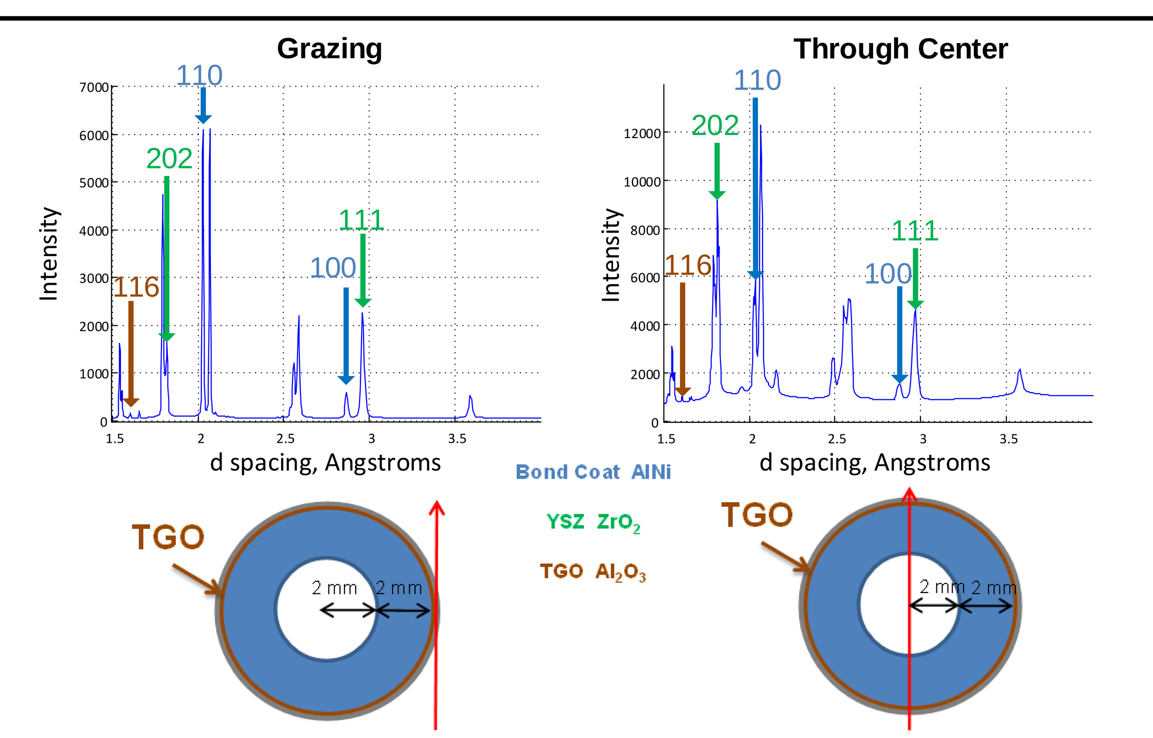
α-Al2O3 Oxide Layer (TGO)
As-Coated 0.5 µm Thickness

Yttria Stabilized Zirconia (YSZ)
EB-PVD 240 µm Coating

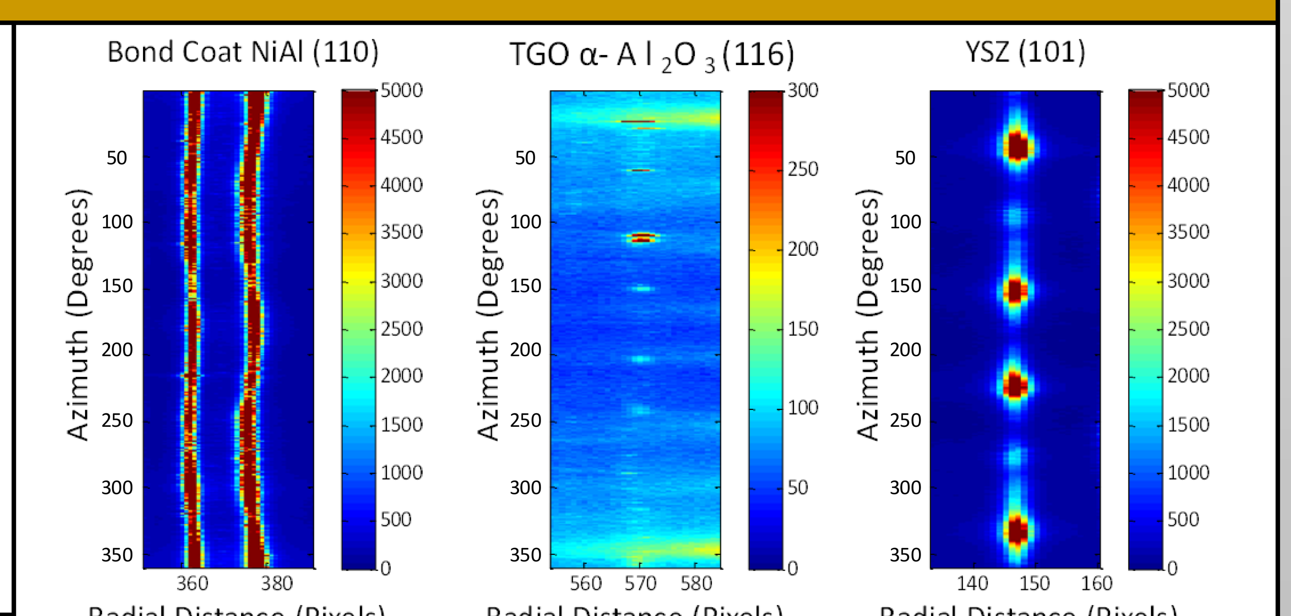
## Tubular Sample Strain Measurement Results



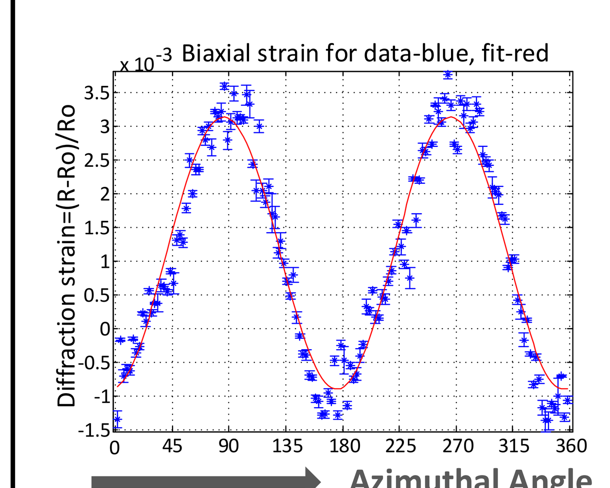

Additional diffraction caused by the beam passing through the center of the sample is shown above.



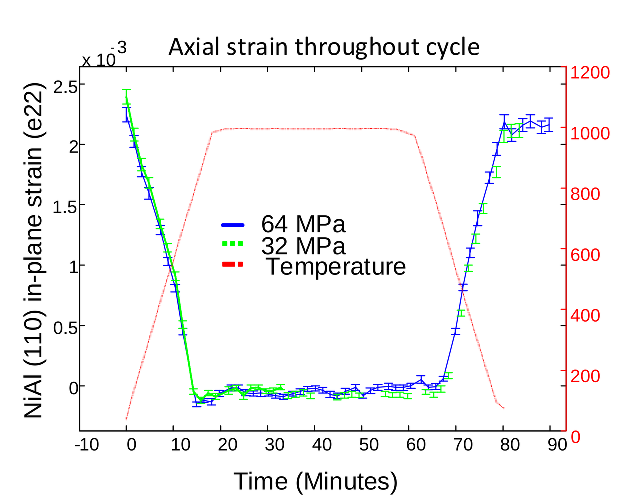

The Bond Coat, TGO, and YSZ were identified in both the scans through the center of the sample as well as the scans near the surface. Noise is more prevalent in through-center scan due to the diffracted X-ray beam passing through the material more than once.




The diffracted rings were integrated azimuthally to create a radial plot. Shown are the Bond Coat, TGO and YSZ Rings. The double bell curve shown in these lines indicates that strain is being experienced by the material.

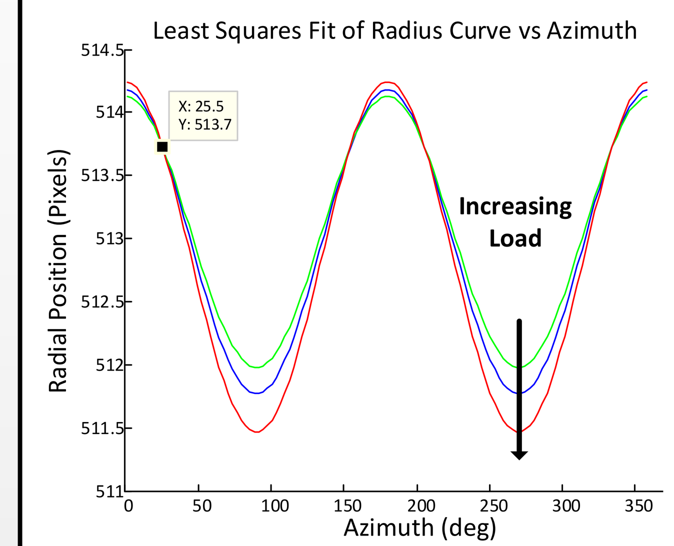


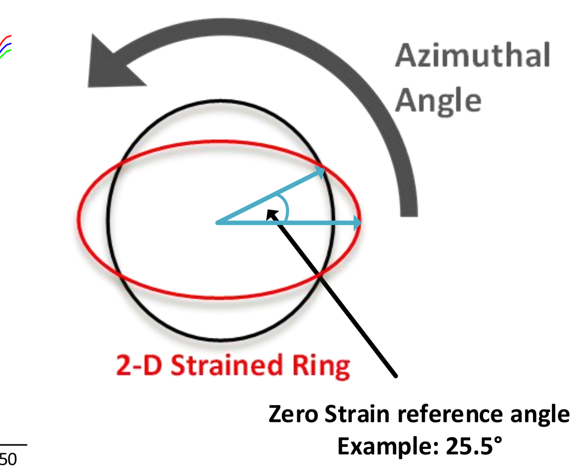

Strain fit for NiAl (111) at 128 Mpa load and a 40 Liters/minute (40%) flow rate.




Through cycle strain plots of NiAl (110) at 32 and 64 Mpa load with a 30 Liters/minute (30%) flow rate.

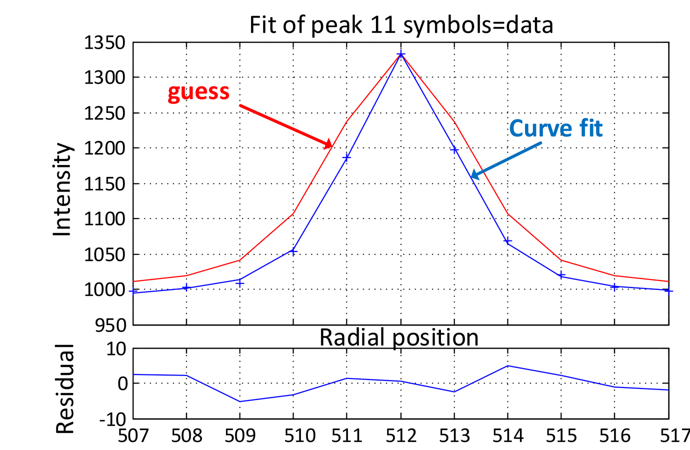
## Analysis




The mechanical loading is varied to determine the zero strain reference angle. This zero strain angle is independent of temperature.

The radial position around the azimuth angle is then measured for each experiment. With this, the strain is then calculated based on the radial displacement around the azimuth.

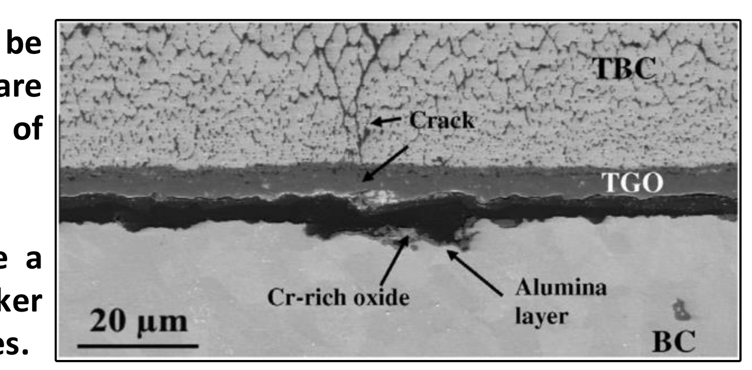



Along the azimuthal angle for the specified ring, the highest intensity point is peak fitted to find the change in eccentricity of the diffracted ring which is then used to calculate strain.

## Future Work

Strain measurements will be conducted on samples that are pre-aged to study effects of TGO growth.

The aged samples will have a more developed and thicker TGO layer due to added cycles.




Crack formation in an aged sample, by M. Bartsch et al., 2008

## References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