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Simultaneous Texture and Strain Analysis of Additive Manufactured Parts via TILT-A-WHIRL Software

Exceptional service in the national interest

Sandia National Laboratories

Mark A. Rodriguez, Bradley H. Jared, James J.M. Griego, Lisa A. Deibler, Mark H. Van Benthem, and Raegan L. Johnson
Sandia National Laboratories, Albuquerque, NM 87185

Introduction

- Analysis of textured samples has always presented challenges for phase identification and quantification.
- We desired to make a ***turn-key*** system for complete analysis of textured materials via XRD.
- Previous developments demonstrated analysis of:
  - Texture and in-plane strain of Gold films – *Adv. X-ray Anal.* **Vol. 56**, pp. 94-109 (2013).
  - Quantitative texture of Ta dogbone bars – *Adv. X-ray Anal.* **Vol. 58**, pp. 265-273 (2015).
- We now employ **TILT-A-WHIRL** to investigate **macrostrain** in Additive Manufactured (AM) parts.

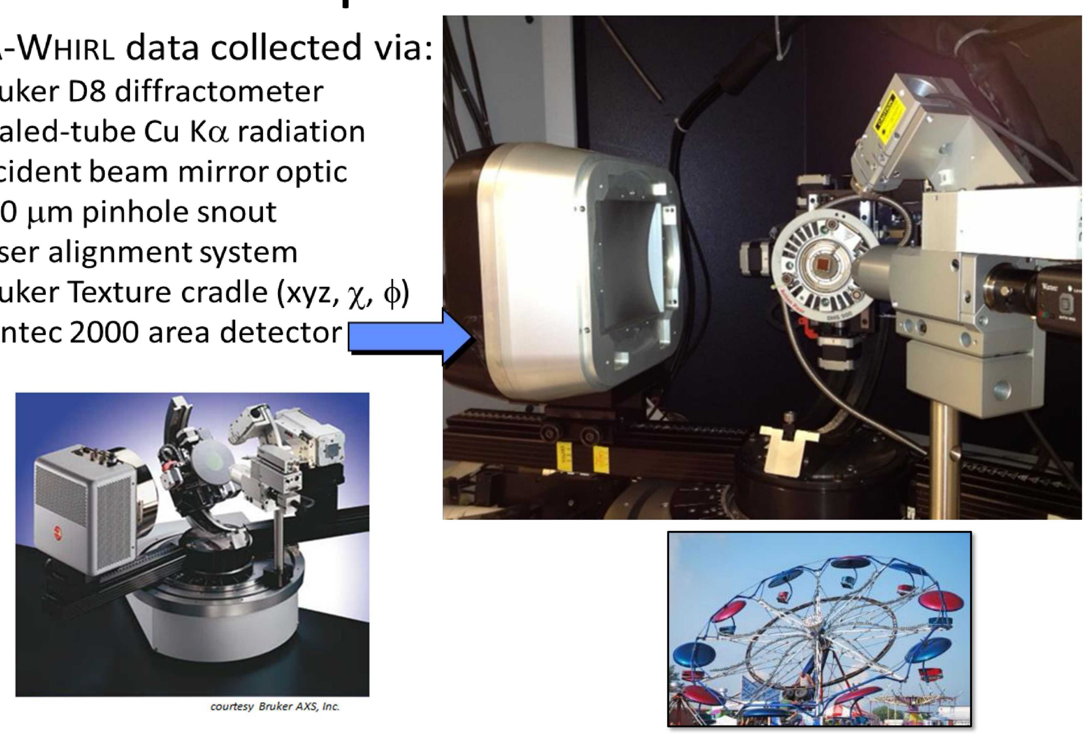
Motivation

- Additive manufactured (AM) parts are being made using metallic media (e.g. Aluminum powder).
- Samples can develop **residual stresses** near edges of complex structures.
- We have employed TILT-A-WHIRL analysis to measure both texture and residual strain on an AM part to detect macro-strain near open vias in an Aluminum test sample.
- We also wanted to investigate any **orientational dependence** of the strain.

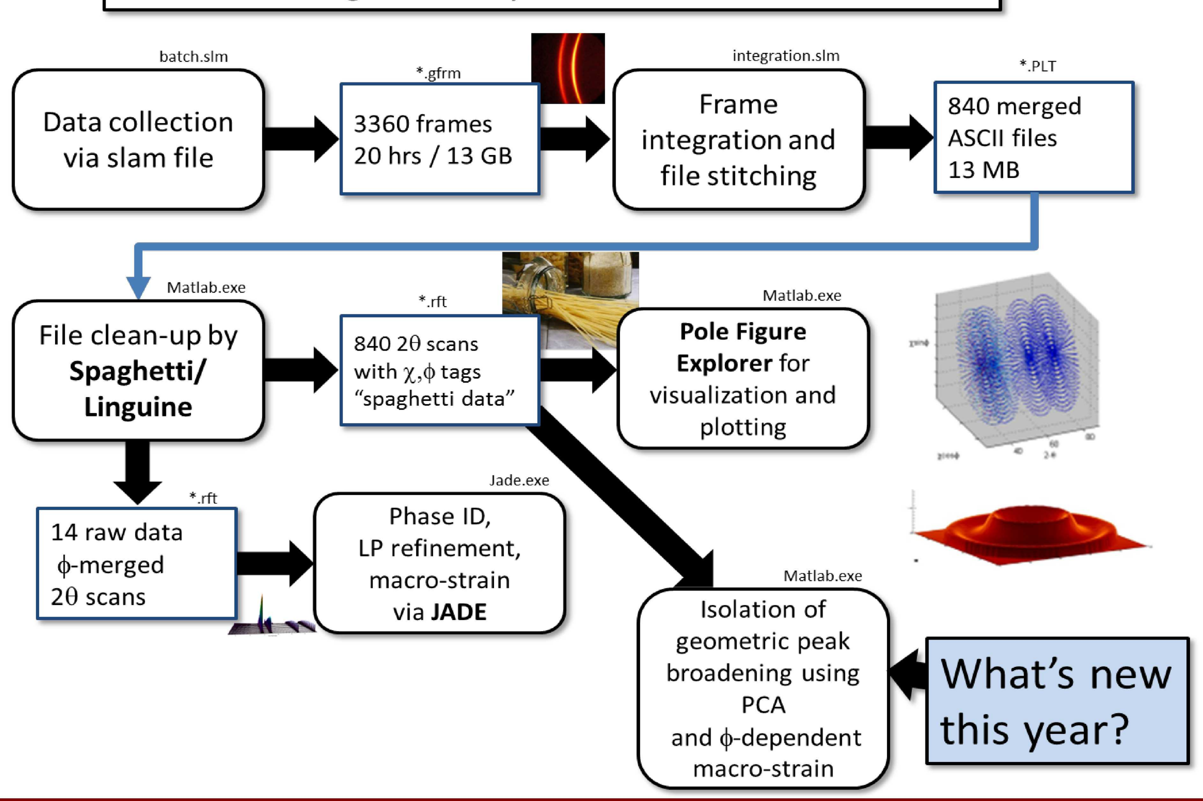
Aluminum AM test part

Experimental

- TILT-A-WHIRL data collected via:
  - Bruker D8 diffractometer
  - Sealed-tube Cu Kα radiation
  - Incident beam mirror optic
  - 500 μm pinhole snout
  - Laser alignment system
  - Bruker Texture cradle (xyz, χ, ϕ)
  - Vantec 2000 area detector

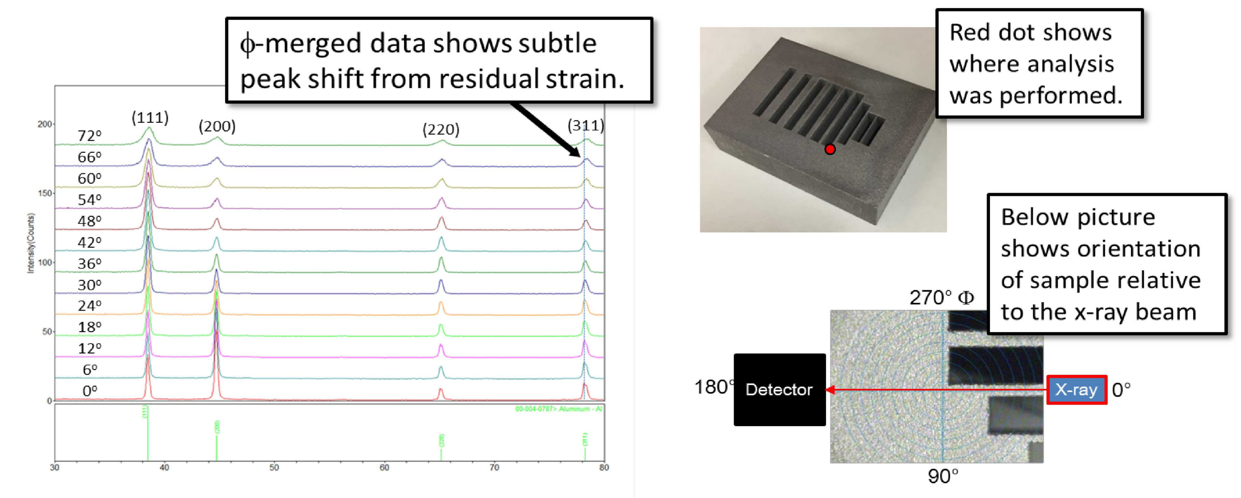


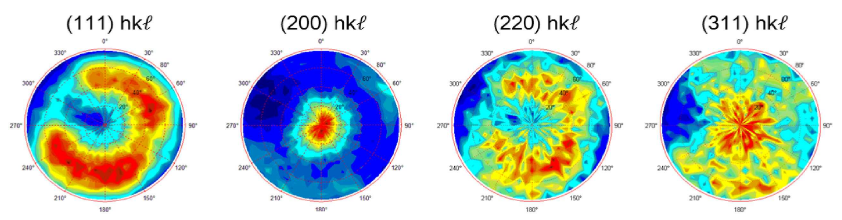
Data Processing and Analysis Flowchart for **TILT-A-WHIRL**



Results: Texture

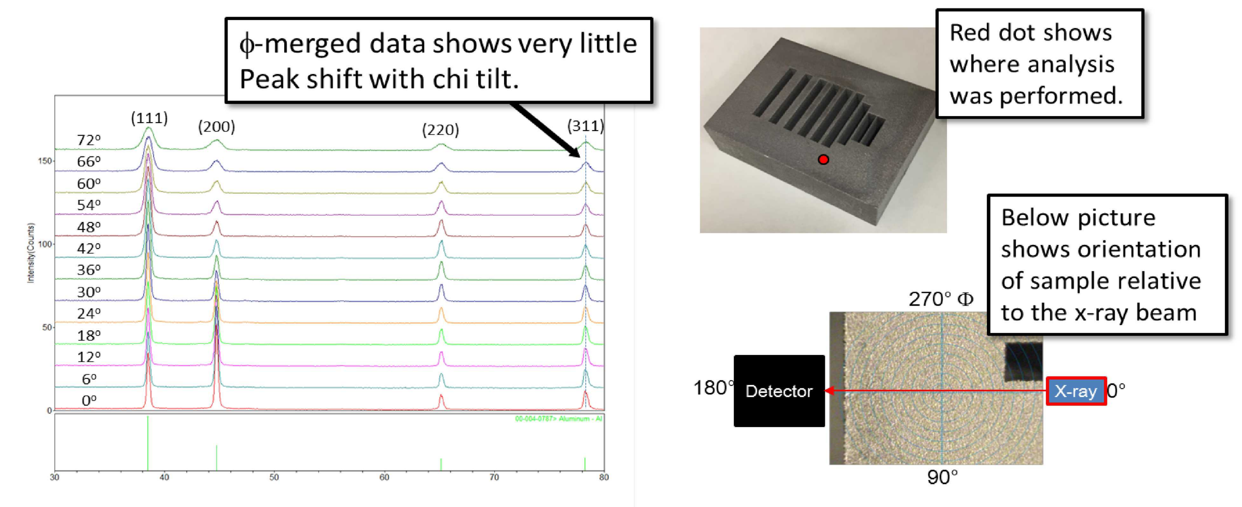
- TILT-A-WHIRL data were collected **near the corner** of a via through the part. This location was anticipated to have significant macrostrain and was designated with the label "**at corner**" to specify where the analysis occurred.

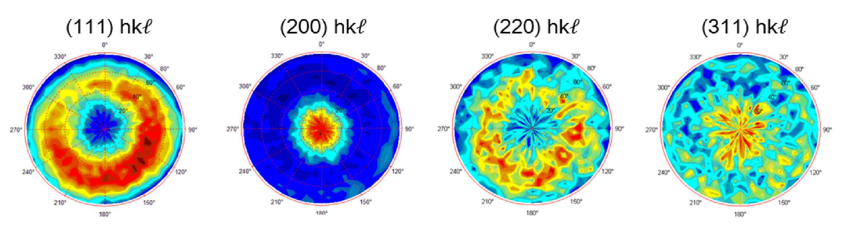




Pole figures show a (200) out-of-plane texture with in-plane fiber texture

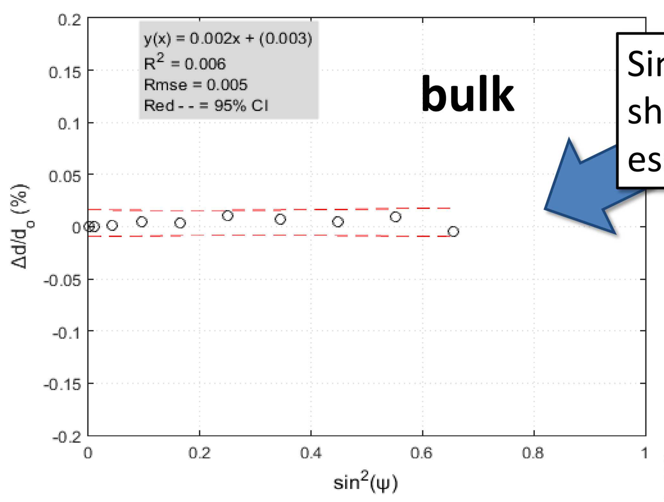
- TILT-A-WHIRL data were collected **in the bulk region** of a AM part. This location was anticipated to have lower presence of macrostrain and was designated with the label "**bulk**" to specify where the analysis occurred.



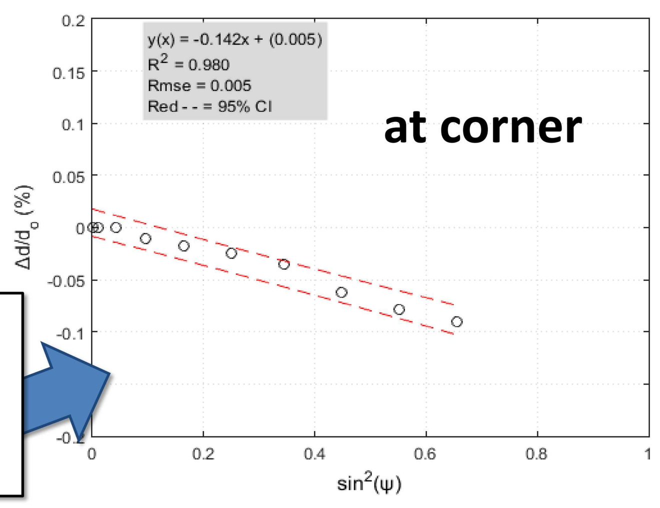


Pole figures show same (200) out-of-plane texture with in-plane fiber texture for bulk (away from edge).

Results: Macrostrain (raw ϕ-merged)



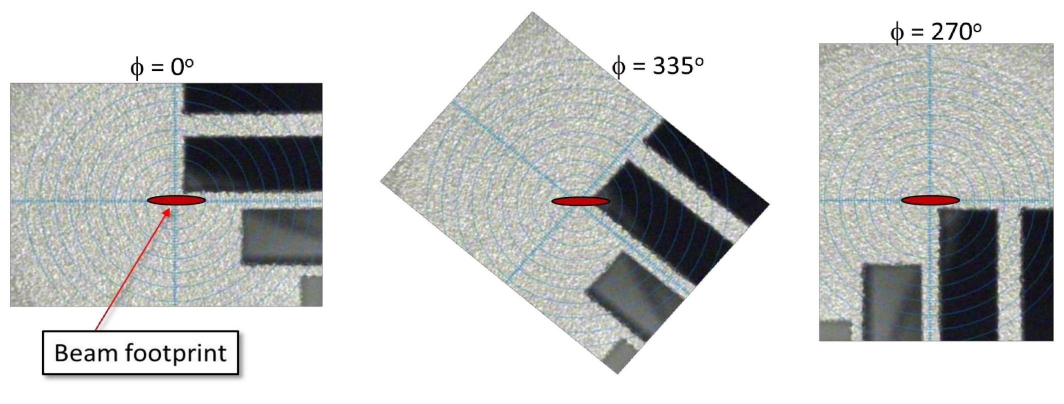
$Sin^2(\psi)$ analysis for the **bulk** location showed 0.002% strain indicating essentially no strain presence



$Sin^2(\psi)$ analysis for the **at corner** location showed **-0.142%** in-plane *compressive* strain indicating a significant strain at corner region

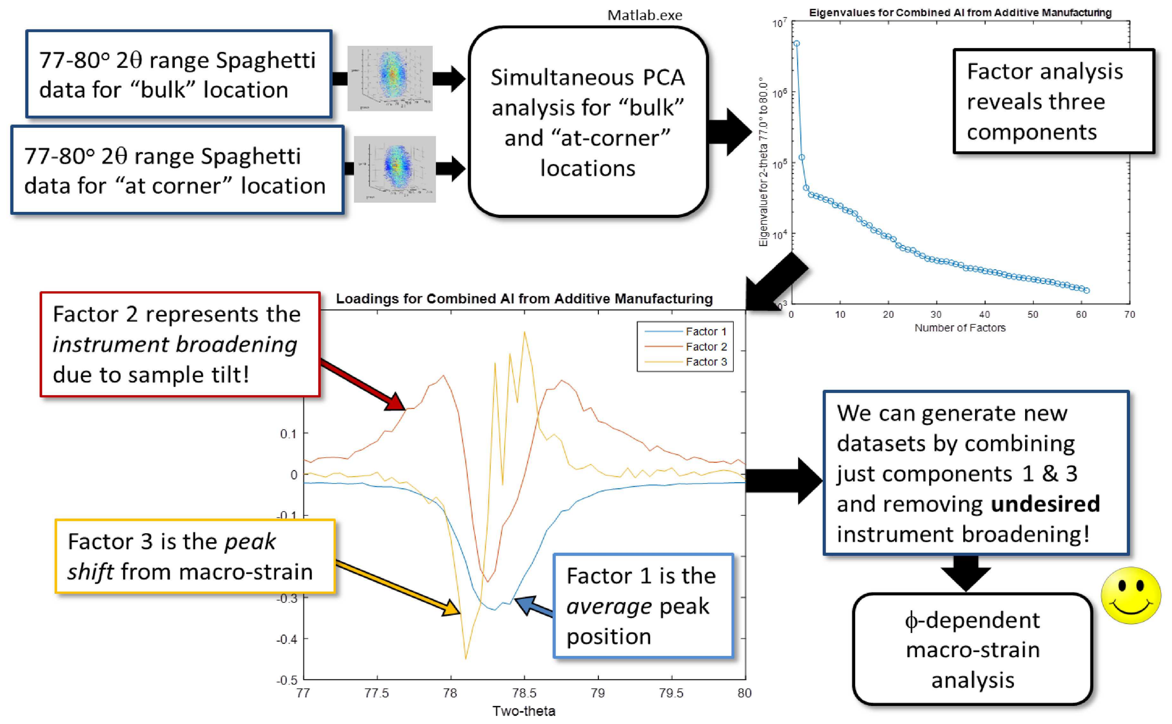
Results: ϕ-dependent Macrostrain

What if we wanted to look at rotational dependence of strain?

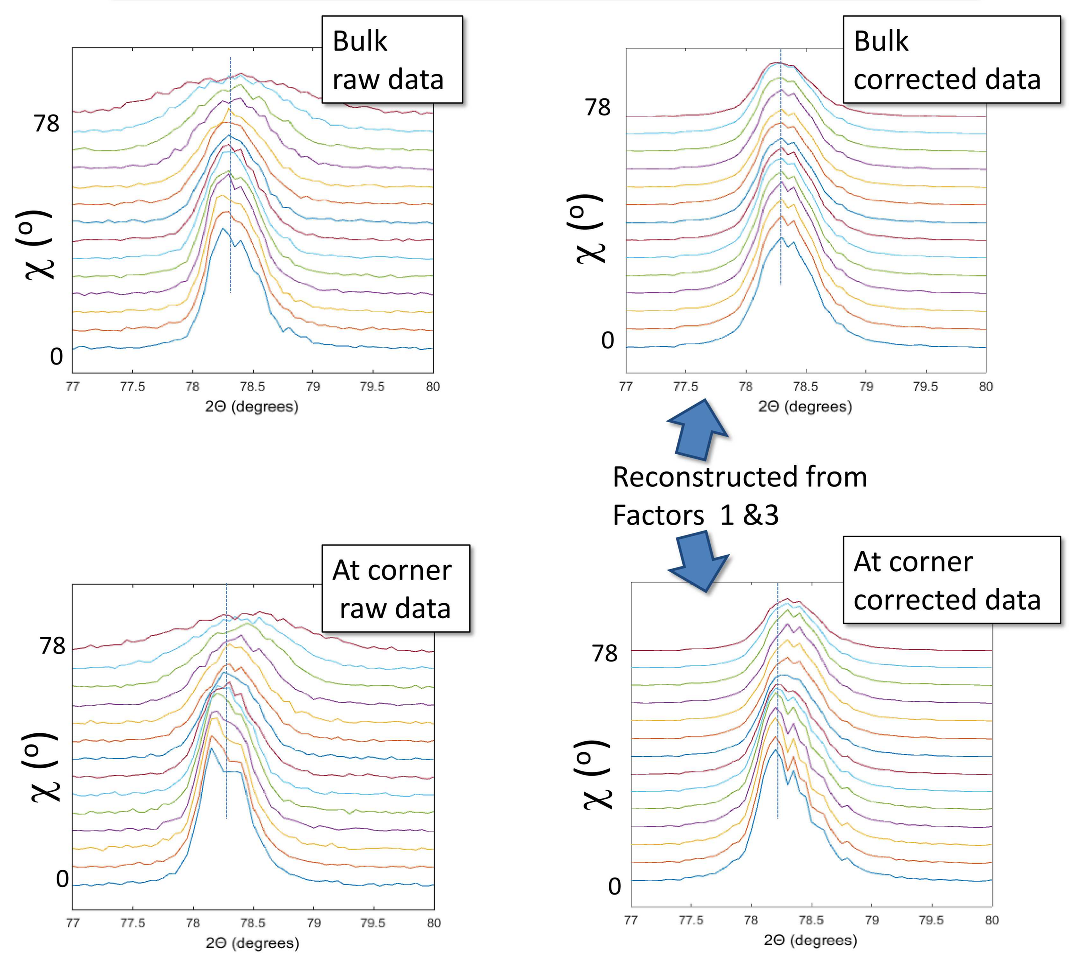


- The Tilt-A-Whirl spaghetti data already exists, we can use it.
- We need to look at $sin^2(\psi)$ as a function of ϕ.
- Maybe Principal Component Analysis could help here?

What if we did Principal Component Analysis (PCA) on all the Aluminum (311) peak raw data?

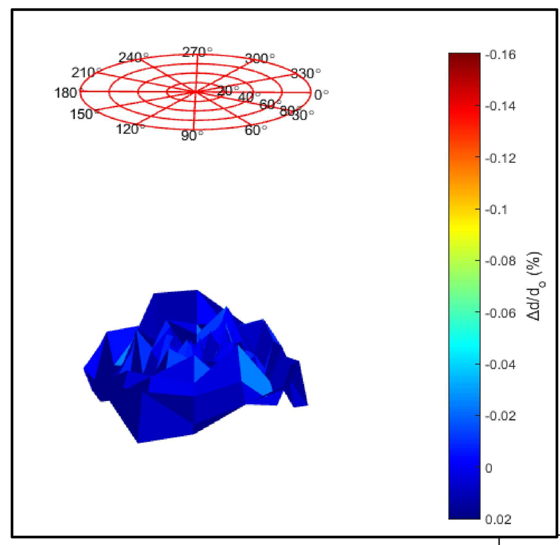


Comparison of ϕ-merged Al (311) peak data before and after instrument broadening factor removal



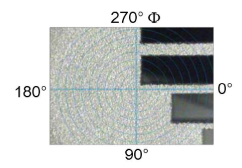
Extraction of the broadening component allows for easy visualization of peak shift in data

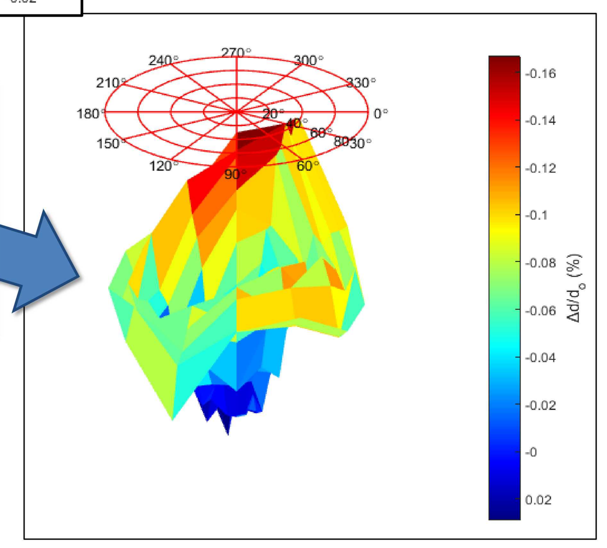
Results: Reconstructed strain plots via Factors 1 and 3 (no broadening)

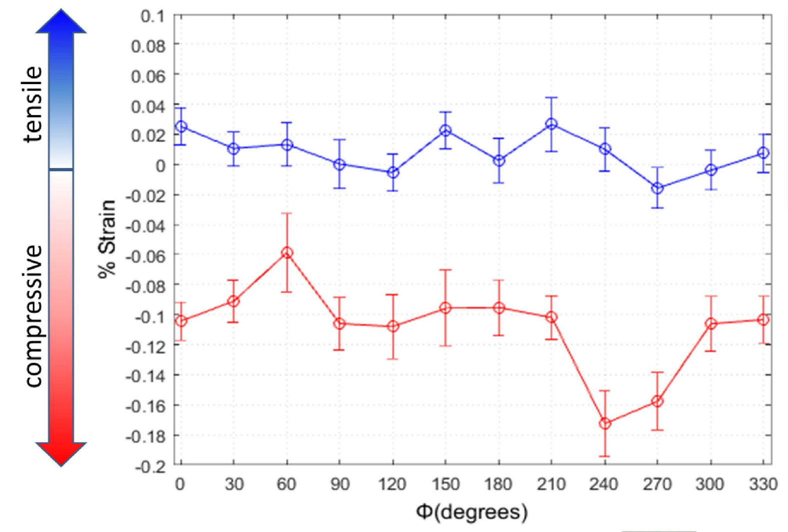


$\Delta d/d_o$ for the **bulk** location showed a very flat surface indicating low strain and no ϕ-dependence.

$\Delta d/d_o$ for the **at corner** location showed variety of in-plane compressive strain values and a significant ϕ-dependence.

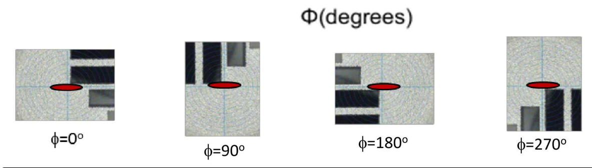






ϕ-dependence of strain for the "**bulk**" dataset showed values that oscillated about the zero strain condition with a window of -0.03 to +0.04%.

ϕ-dependence of strain for the "**at corner**" dataset showed: *typical* strain of 0.11%, a **min** at -0.06% (ϕ=60°), a **max** of -0.17% (ϕ = 240°). There appears to be a significant variation in strain with phi rotation.



The red oval shows an approximate location of X-ray beam spread at the higher χ angle tilts. The highest strain is observed when the beam footprint rests along the edge of the thru-via.

The distribution of the beam footprint can affect the resulting measured strain value. ϕ-dependent macrostrain data can help sort out this issue.

Summary

- Diagnosis of residual stress in an AM part has demonstrated the presence of in-plane compressive strain near the thru-via of a manufactured Aluminum part.
- Strain behavior shows a ***ϕ-dependence*** near the thru via which can be associated with the beam footprint on the sample. In-plane strains varied by as much as ~0.11 % (minimum to maximum) depending on ϕ angle.
- Principal Component Analysis of the Al (311) peaks revealed the ability to isolate the profile into three components: ***average*** peak profile, tilt ***broadening***, and ***peak-shift*** due to strain.

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