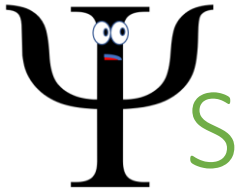
X-Ray Diffraction Measurements of Residual Stress in a Cold Sprayed Ni Coating



So Stressful (Psi)

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[2]retired/separated

Outline

- Manufacturing challenges
- Material challenges
- Plan to overcome those challenges
- Time for XRD
- What do the XRD results mean?
- What does that mean for the material?



Manufacturing Challenges: AM Combustion Liners

- Regeneratively cooled rocket engine main combustion chamber liners
- Additively Manufactured
  = Residual Stress
- Problems with the **joint** of **Cu-alloy** and **FeNi-superalloy**



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Lab-based XRD to quantify

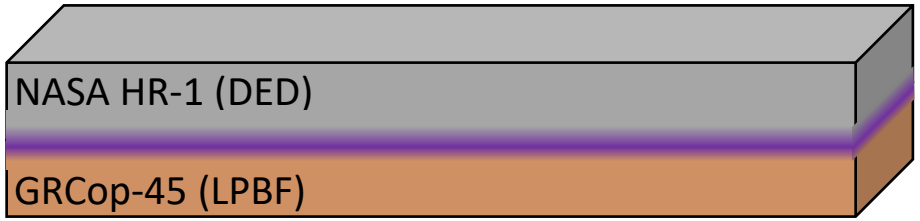


GRCop-42

NASA HR-1

Material Challenge: Cu-alloy to Ni-Superalloy Joints

- Potential formation of σ-FeCr (embrittling phase)





- Pure Ni interlayer
- If both Ni and GRCop-42 are molten here, the compositions could change
- Cold Spray the Ni bond layer

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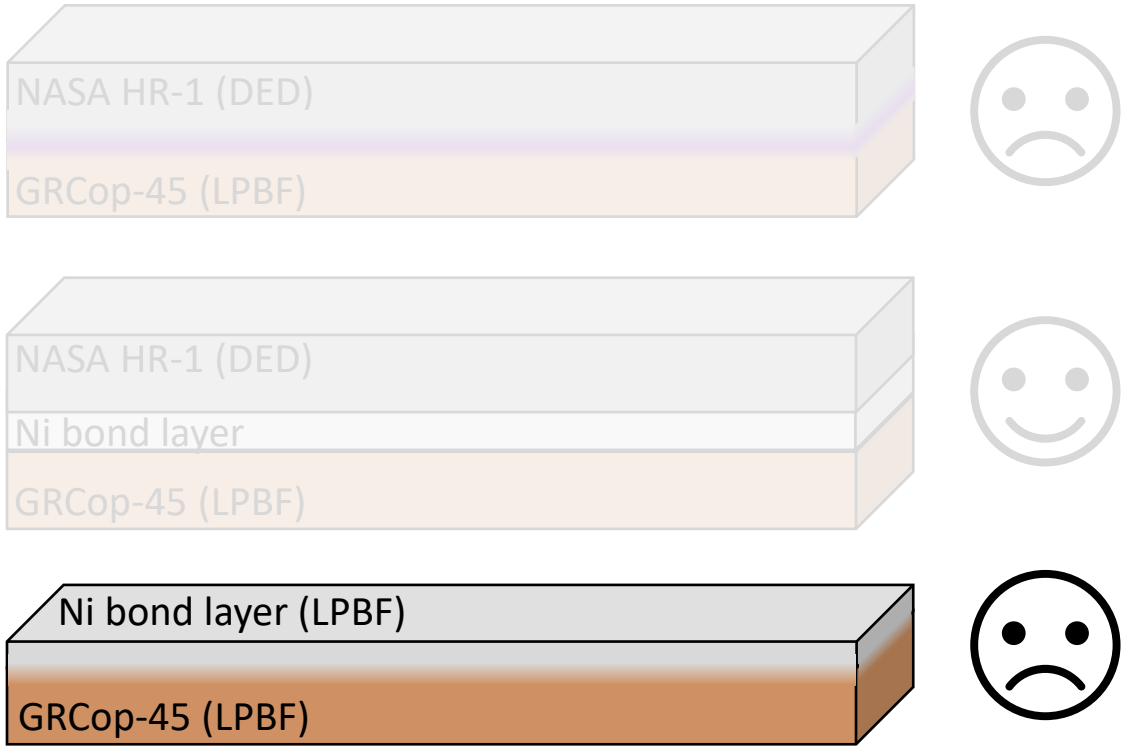
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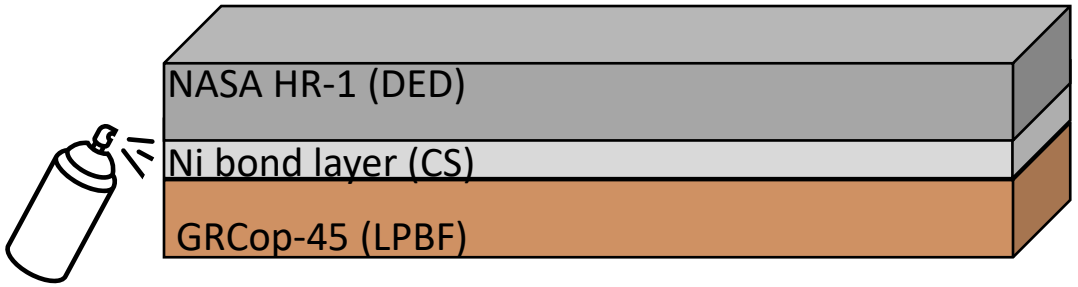
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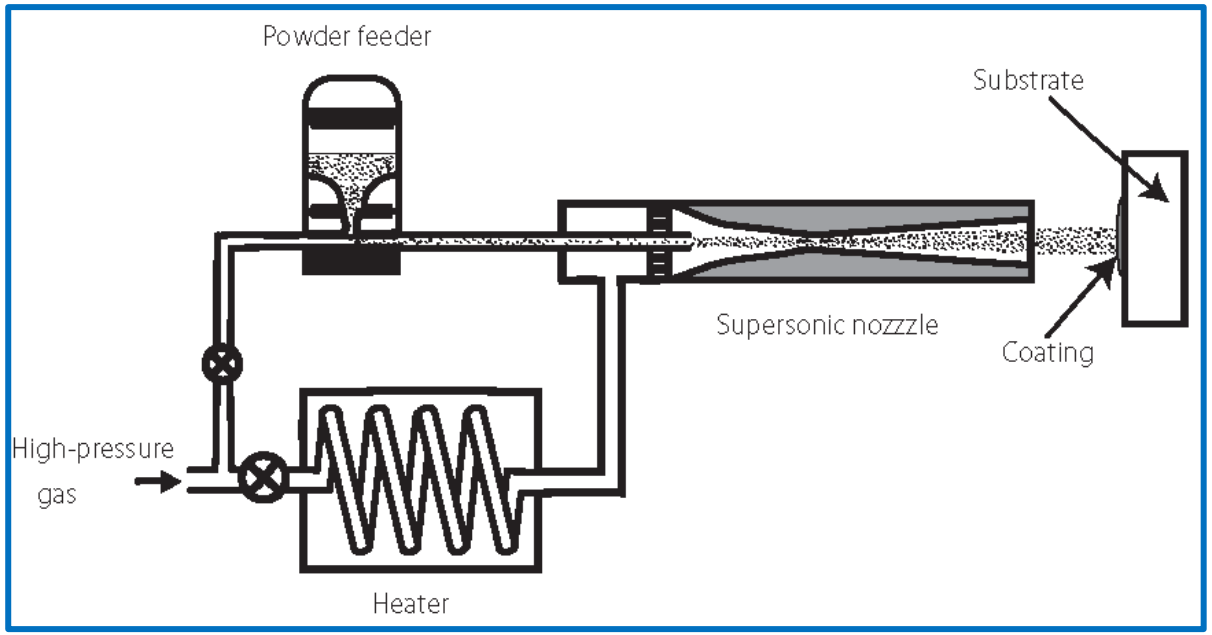
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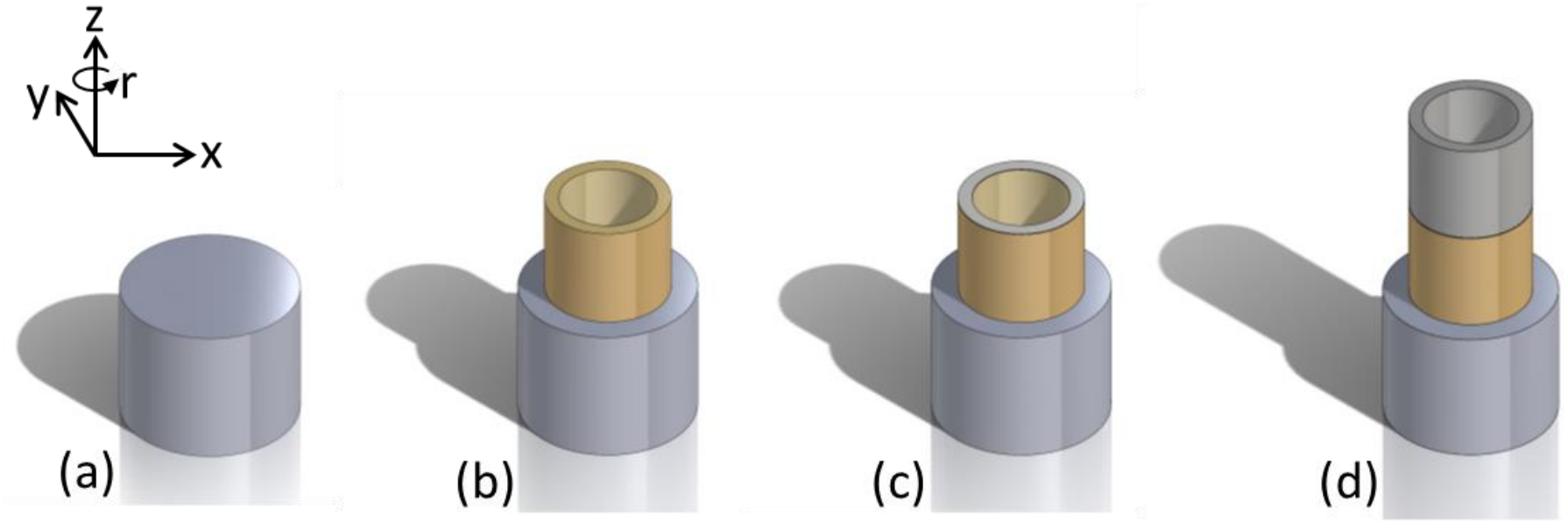


Cold Spray

- Particles (1 – 50 µm) are supersonically accelerated in a gas jet and impact a substrate
- The particles plastically deform and adhere (without melting) to the substrate surface
- So many variables and stresses; important to look at Residual Stresses

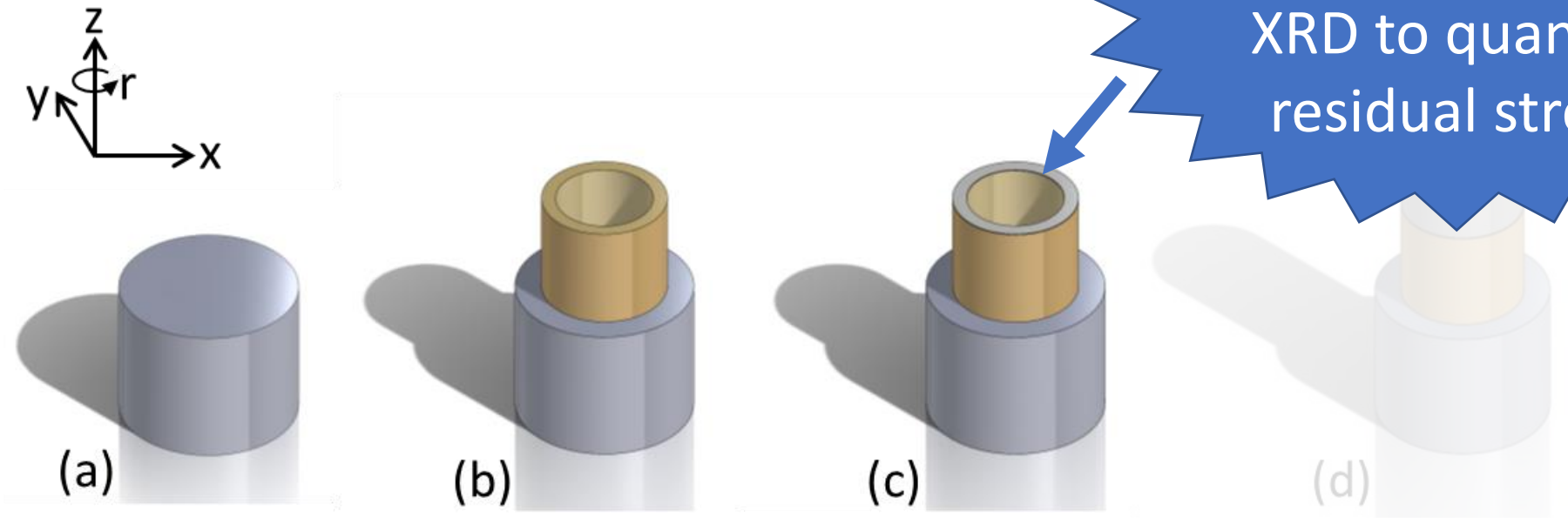


The Build Plan



a) 316 SS cylinder for the build plate
b) GRCop-42 cylinder deposited by Laser Powder Bed Fusion AM
c) Pure Ni bond layer Cold Sprayed
d) NASA HR-1 cylinder deposited by Directed Energy Deposition AM

The Plan Didn’t Work Fully

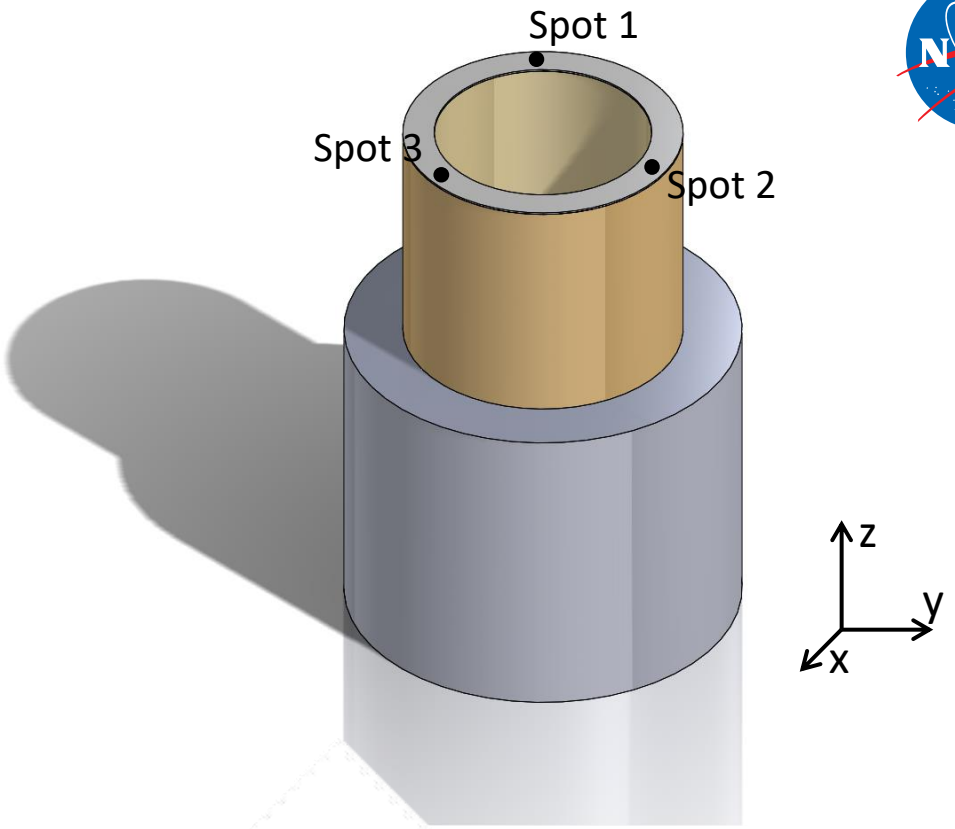


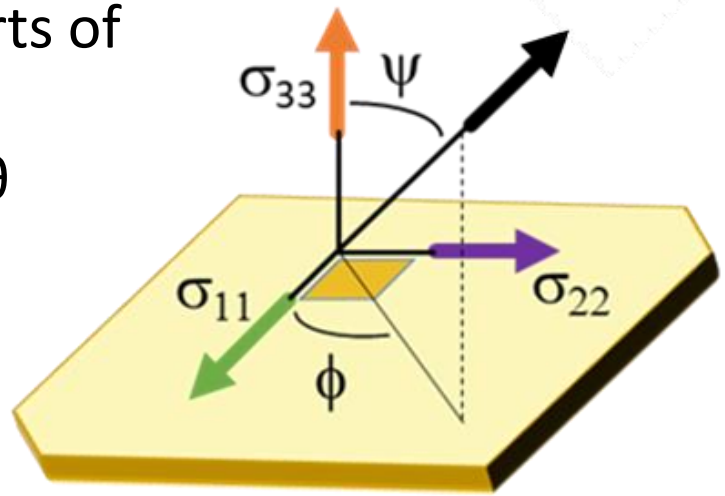
Debonding of Ni layer, need XRD to quantify residual stress

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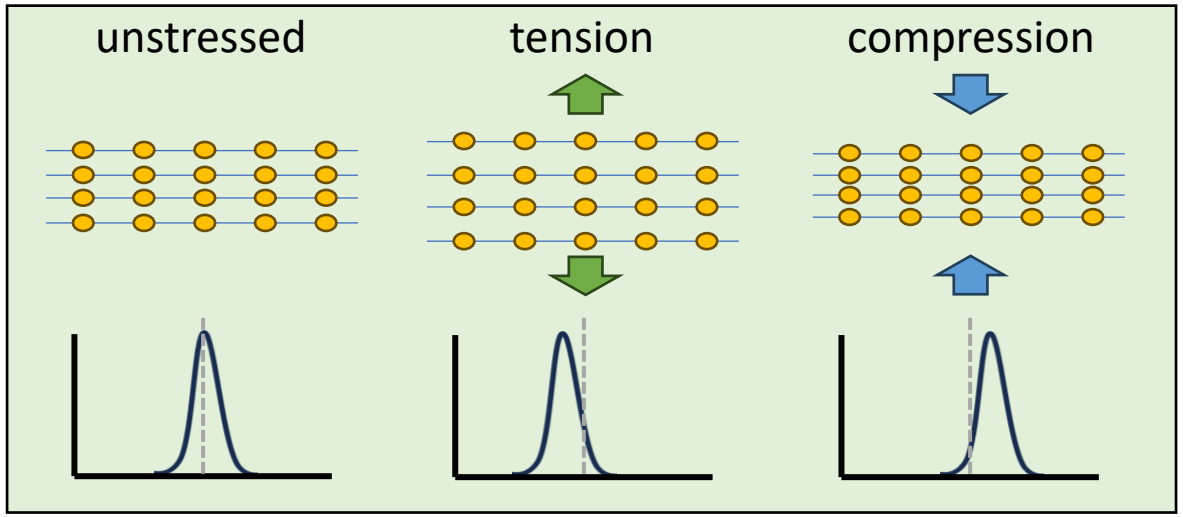
XRD Time!

- 3 locations around the cylinder
  - And a 99.999% pure Ni powder
- $Sin^2\psi$ Method:
  - 1D XRD detector is used to acquire a select portion of the Debye-Scherrer ring, then the incident angle (ψ) and rotation angle (ϕ) are changed to acquire the remaining parts of the ring.
  - Unstressed Ni (222) peak at 123.1 °2θ

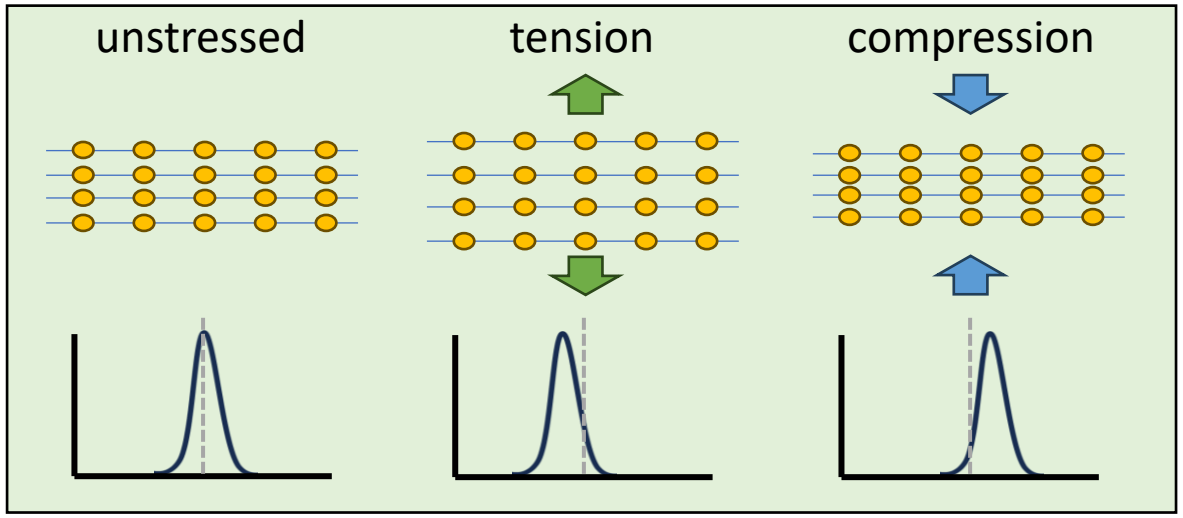


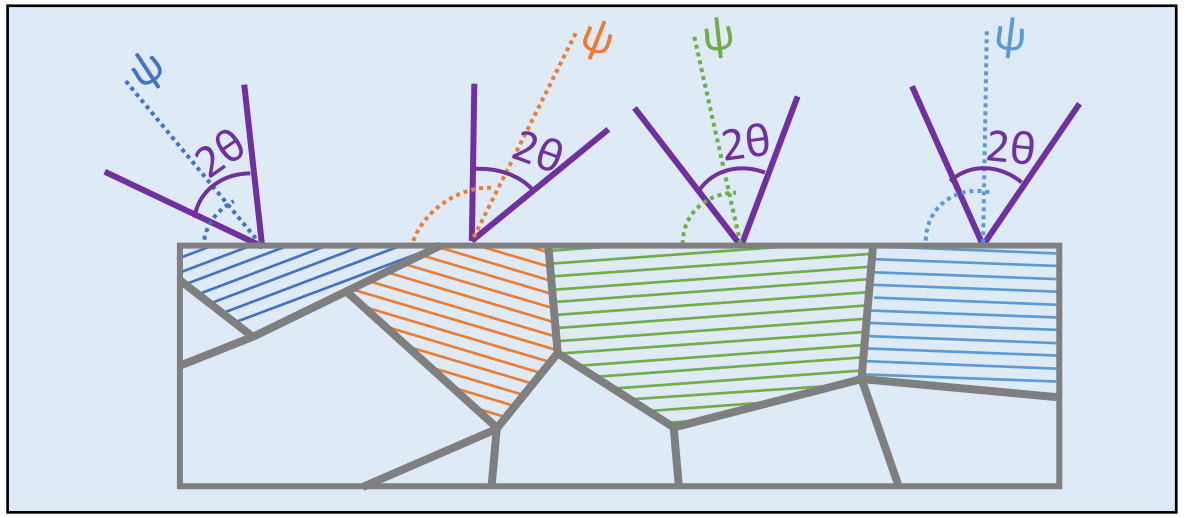


Parts of the $Sin^2\psi$ Method

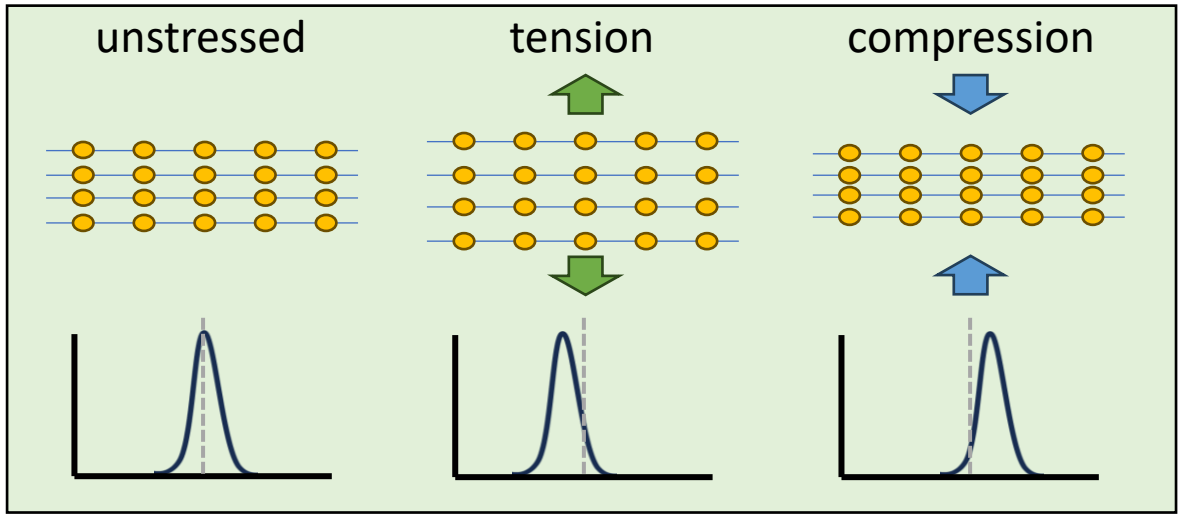


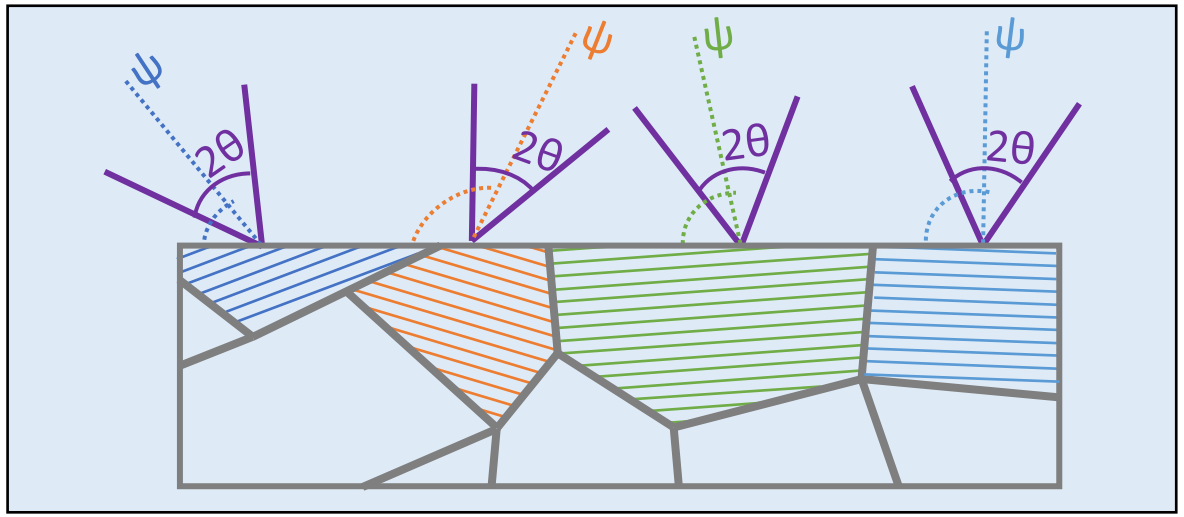
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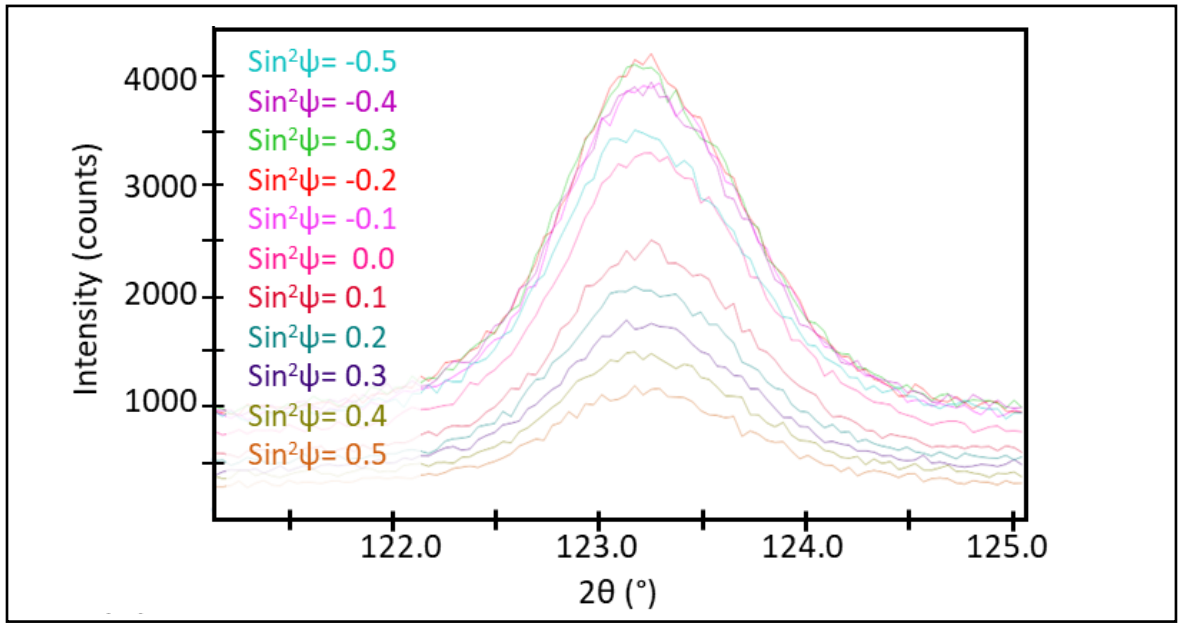




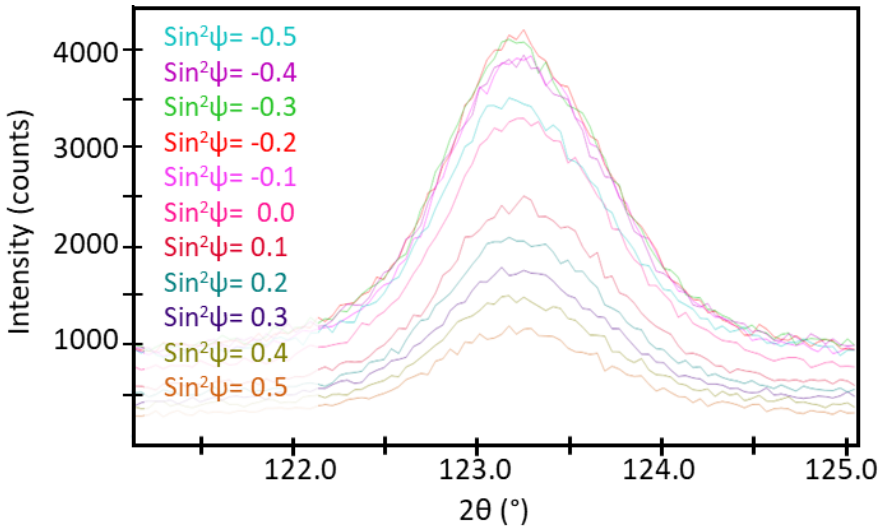
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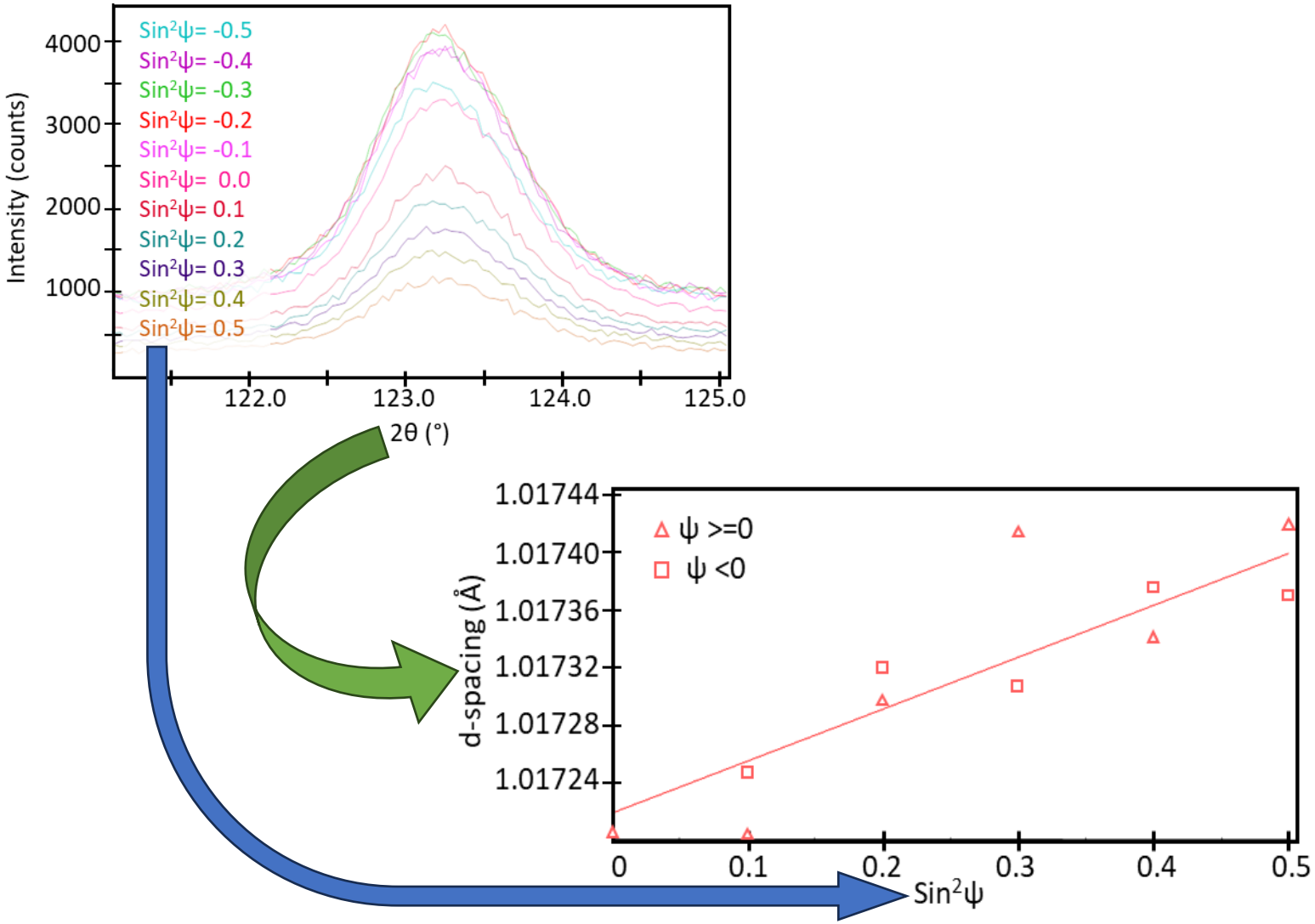




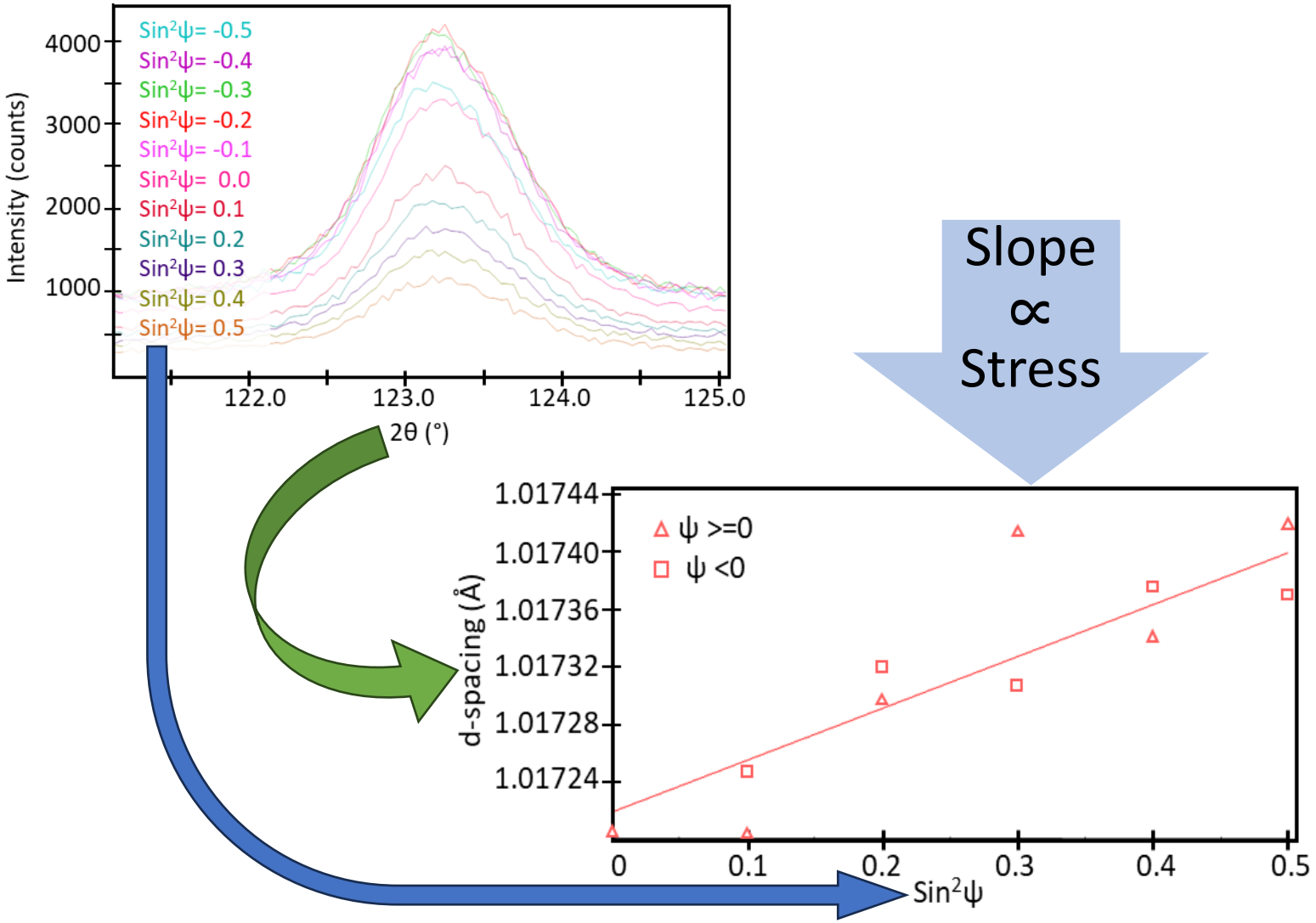
Other Parts of the $Sin^2\psi$ Method



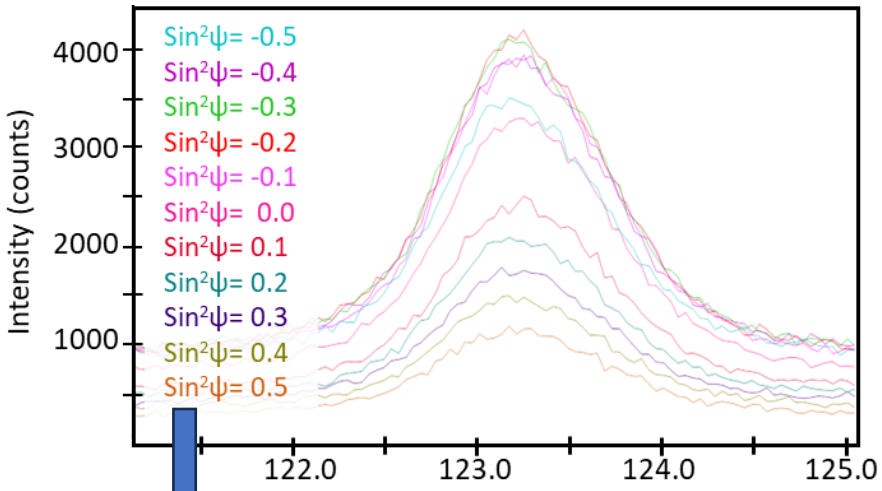
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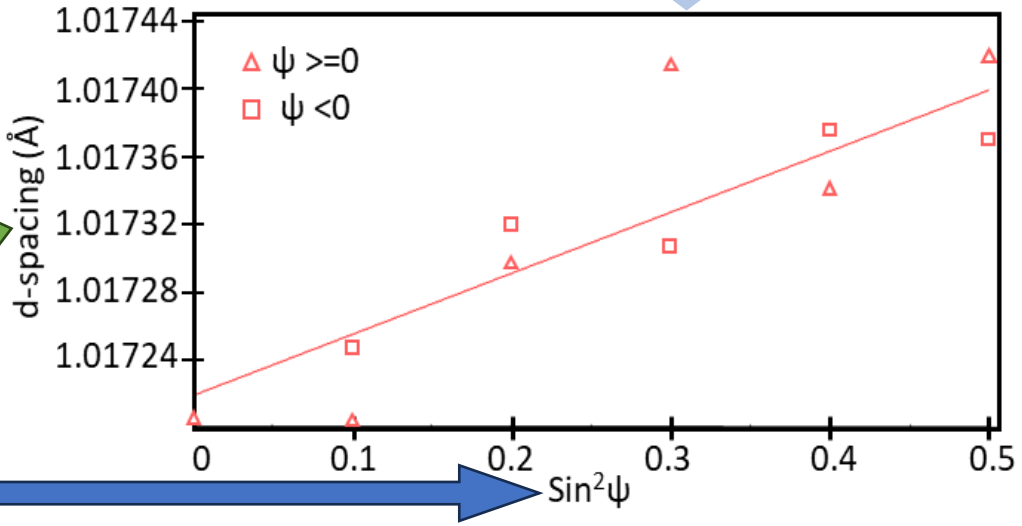
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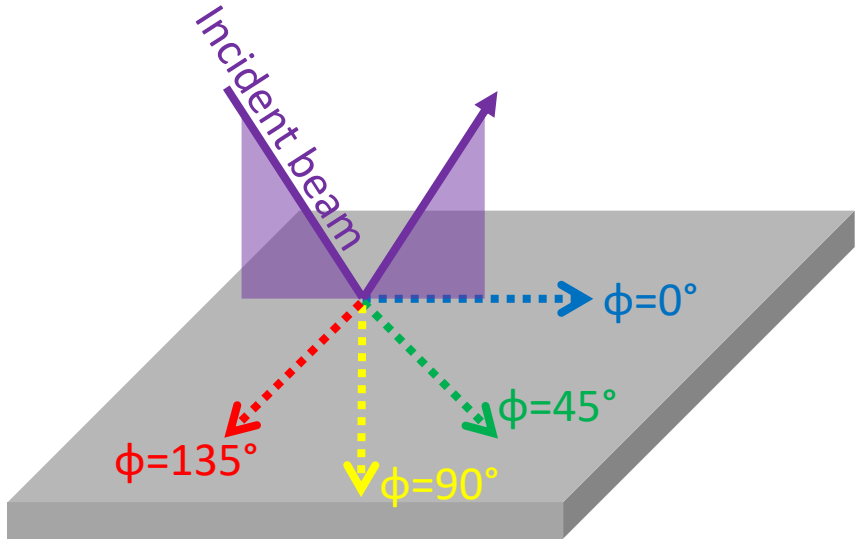


Other Parts of the $Sin^2\psi$ Method



Slope ∝ Stress

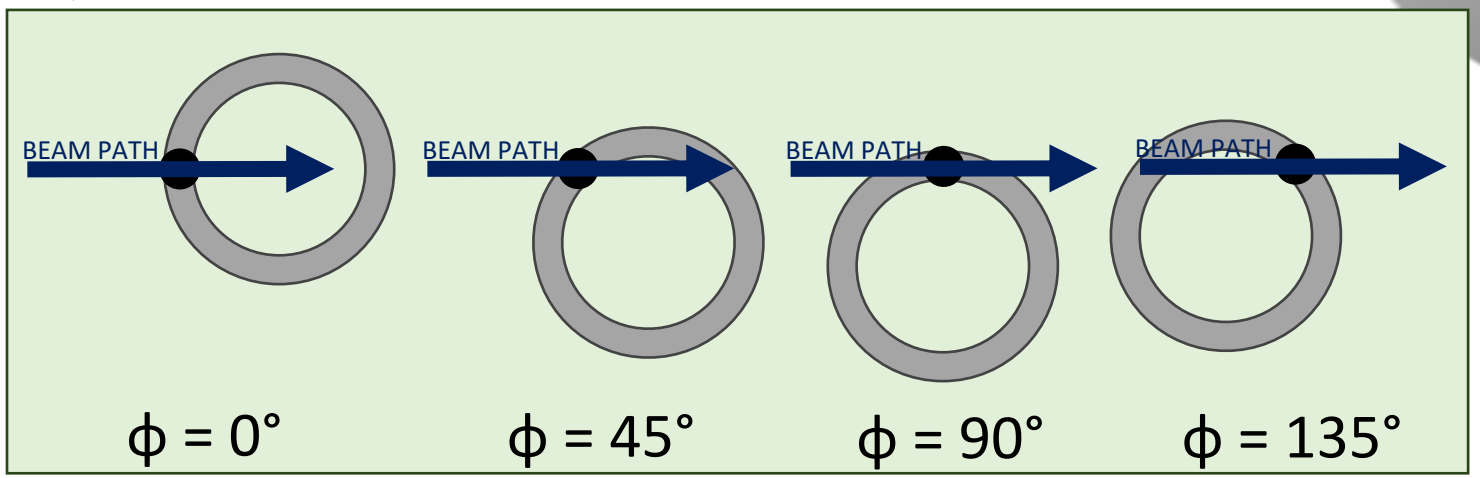


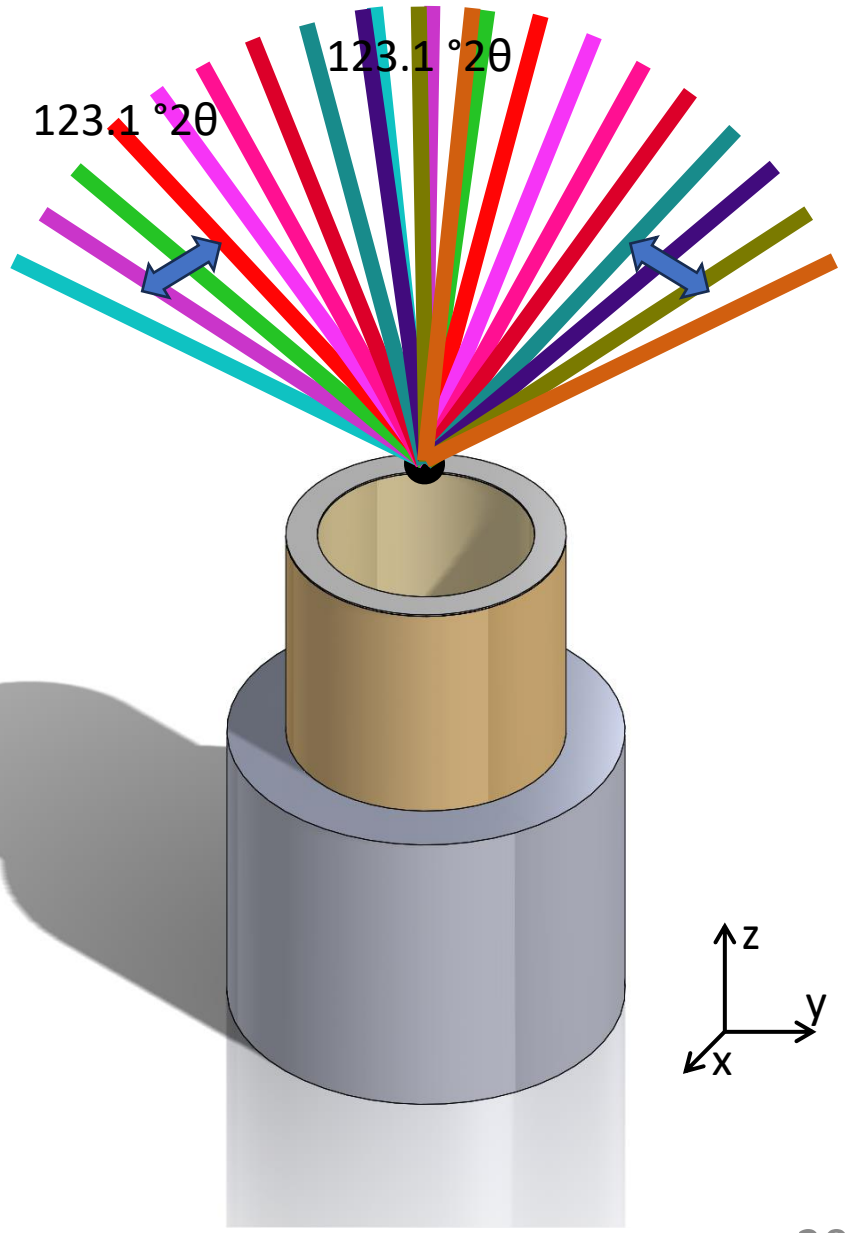


Collect at different ϕ angles to get different stress directions

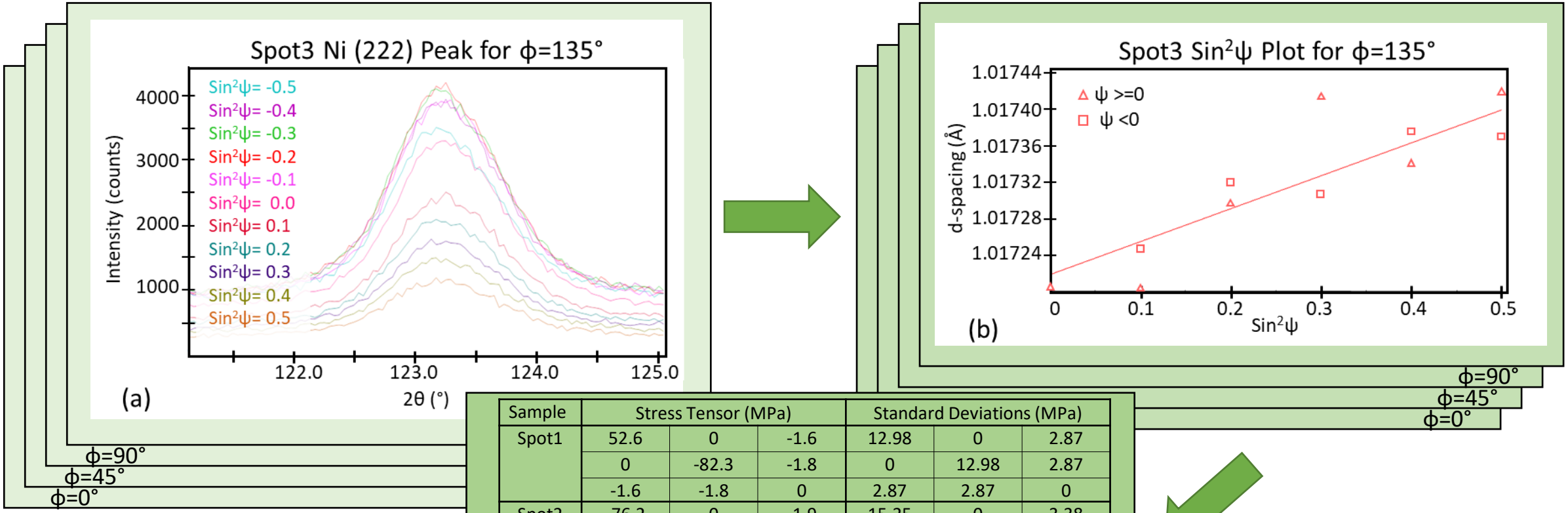
$Sin^2\psi$ Method on our Sample

- At each (3 total) spot on the cylinder, 44 measurements
  - Ni (222) peak at 123.1 °2θ
  - +ψ and -ψ → 11 Sin^2 values
  - ϕ = 0°, 45°,90°, and 135°





Lots of Data for Each Spot



Sample	Stress Tensor (MPa)			Standard Deviations (MPa)		
Spot1	52.6	0	-1.6	12.98	0	2.87
	0	-82.3	-1.8	0	12.98	2.87
	-1.6	-1.8	0	2.87	2.87	0
Spot2	-76.2	0	-1.9	15.25	0	3.38
	0	61.1	3.3	0	15.25	3.38
	-1.9	3.3	0	3.38	3.38	0
Spot3	71.5	0	-1.4	11.34	0	2.51
	0	-61	-3.5	0	11.34	2.51
	-1.4	-3.5	0	2.51	2.51	0
Ni powder	7.8	0	0	14.79	0	0
	0	10.7	0	0	13.51	0
	0	0	0	0	0	0

Stress Tensor to Principal Stresses

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Ni powder	7.8	0	0	14.79	0	0
	0	10.7	0	0	13.51	0
	0	0	0	0	0	0

- Minimal ψ-splitting, negligible shear
- Makes more sense in relation to the sample



Sample	Principal Stresses (MPa)		Standard Deviations (MPa)		Rotation
	σ1	σ2	σ1	σ2	
Spot 1	56.2	-82.3	12.98	12.98	44.2 °
Spot 2	-76.2	61.1	15.25	15.25	54.2 °
Spot 3	71.5	-61	11.34	11.34	44.8 °
Ni Powder	7.8	10.7	14.79	13.51	-

Interpreting the Results

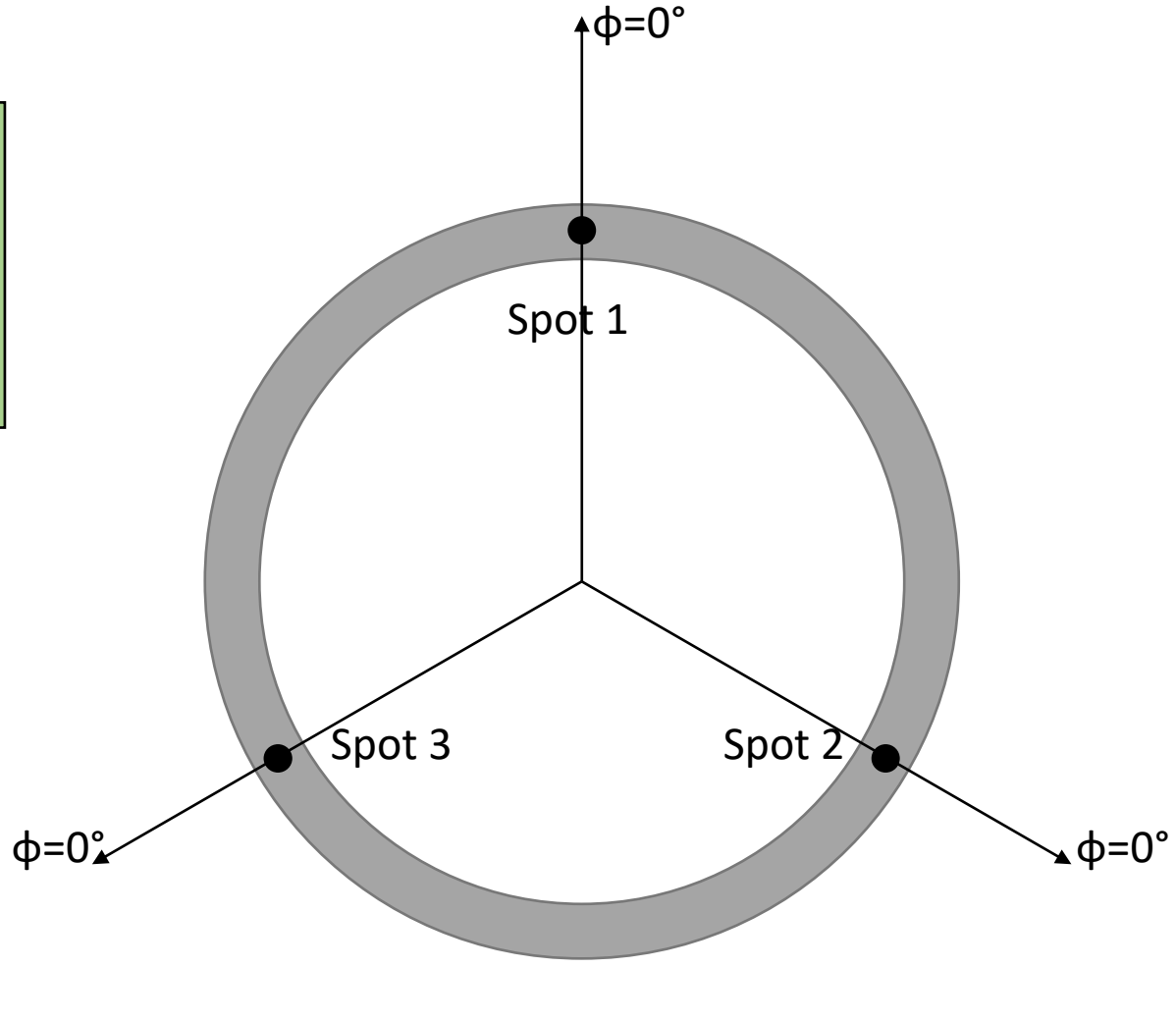
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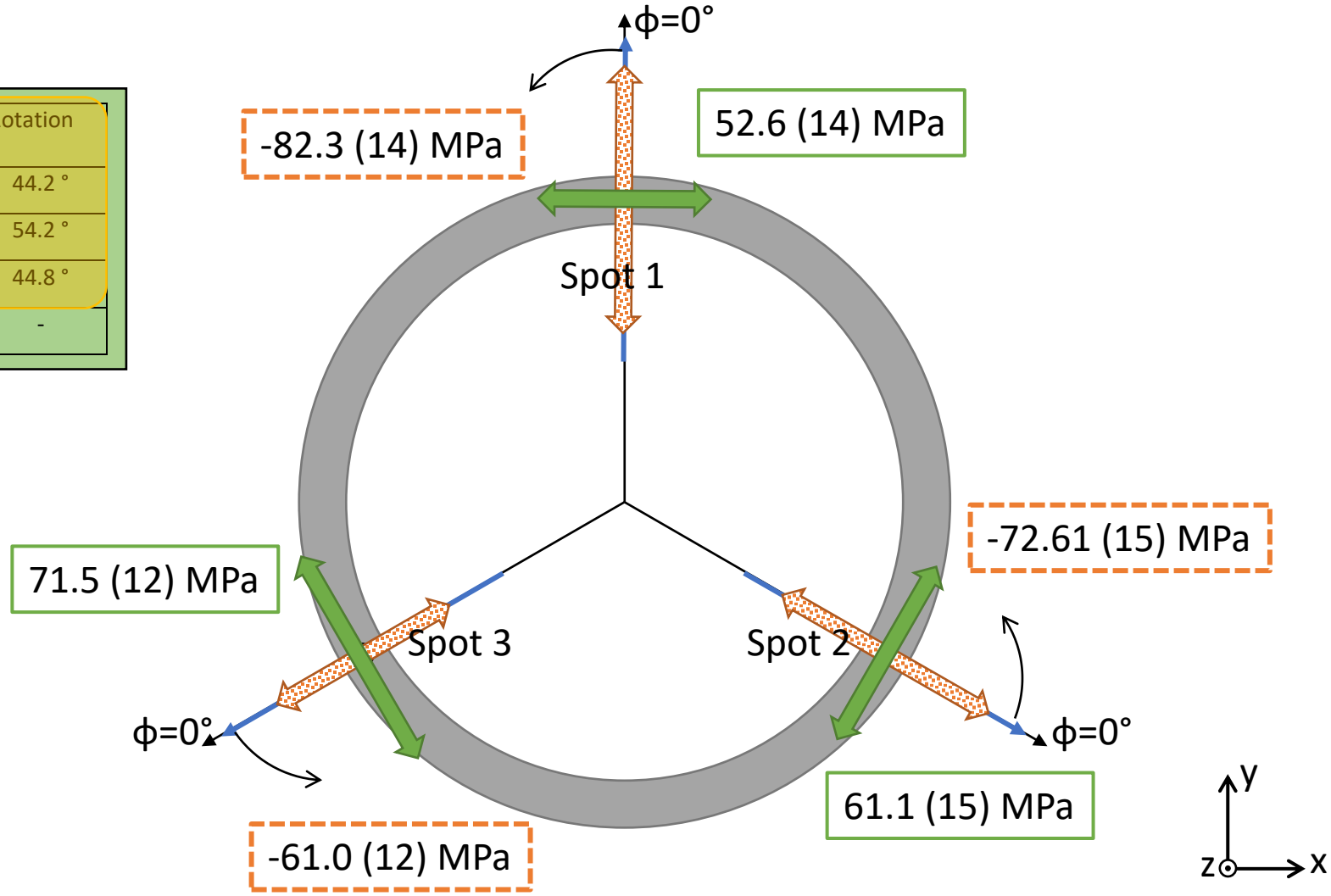
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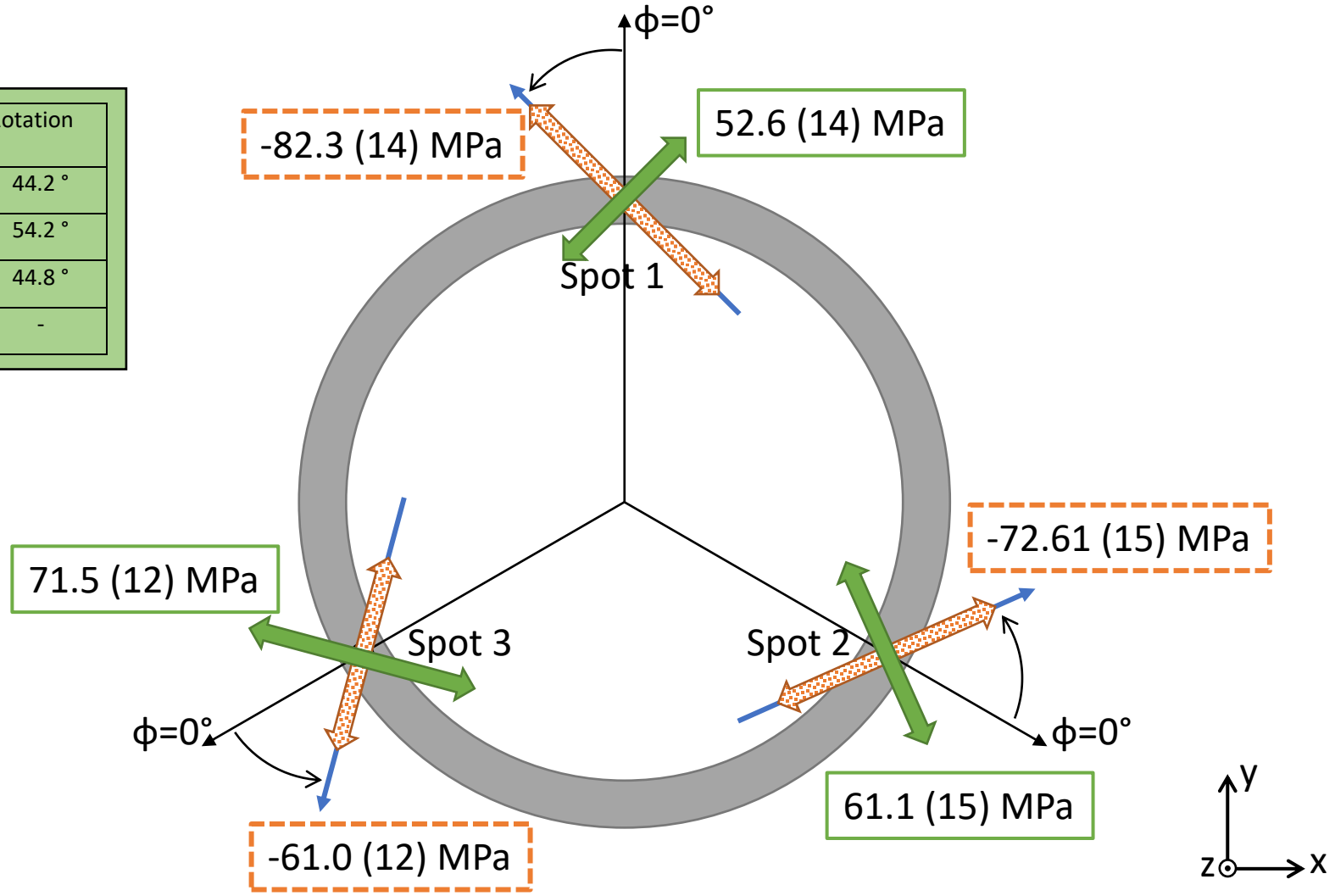
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Rotational symmetry corresponds with applying the CS Ni on a lathe



Conclusions for this Study

- Similar measurements on heat-treated cylinders:
  - Stresses close to the yield stress of GRCop-42 were measured
- Cold Spray stream affected the rotating cylinder during application, likely shifting the Ni powder particles as they hit the surface.

- Conclusion: delamination resulted from residual stresses from CS process that were too close to the yield stress of GRCop-42

- Future work:
  - These results are being used to improve bimetallic interface models that are being developed at NASA Ames Research Center
  - NIST plans to use these results, combined with neutron diffraction, to confirm and expand to interior residual stresses

Conclusions for this Study and Beyond!

- Important to measure and model stresses in complex AM parts
  - AM imparts significant strains in the materials
  - XRD can be used to quantify the strains
  - Invaluable to consider stress orientations and part geometry to understand the results

Questions?



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