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Title: Neutron Diffraction Study of Residual Stress in a Multi-Pass Gas Tungsten Arc Weld

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NEUTRON DIFFRACTION STUDY OF RESIDUAL STRESS IN A MULTI-PASS GAS TUNGSTEN ARC WELD

Thomas Sisneros, MST-8

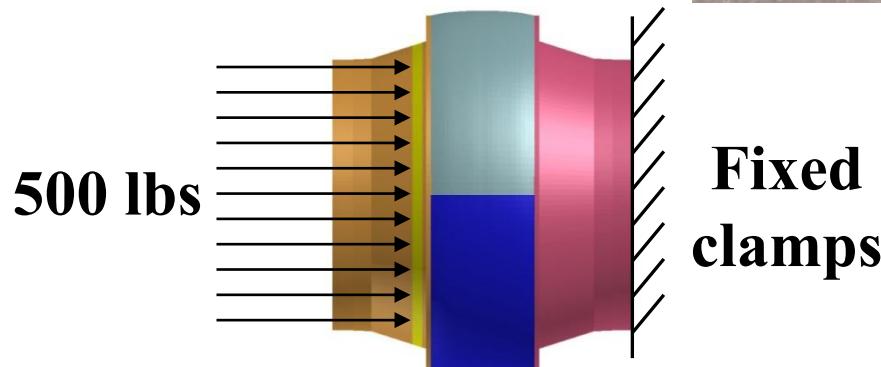
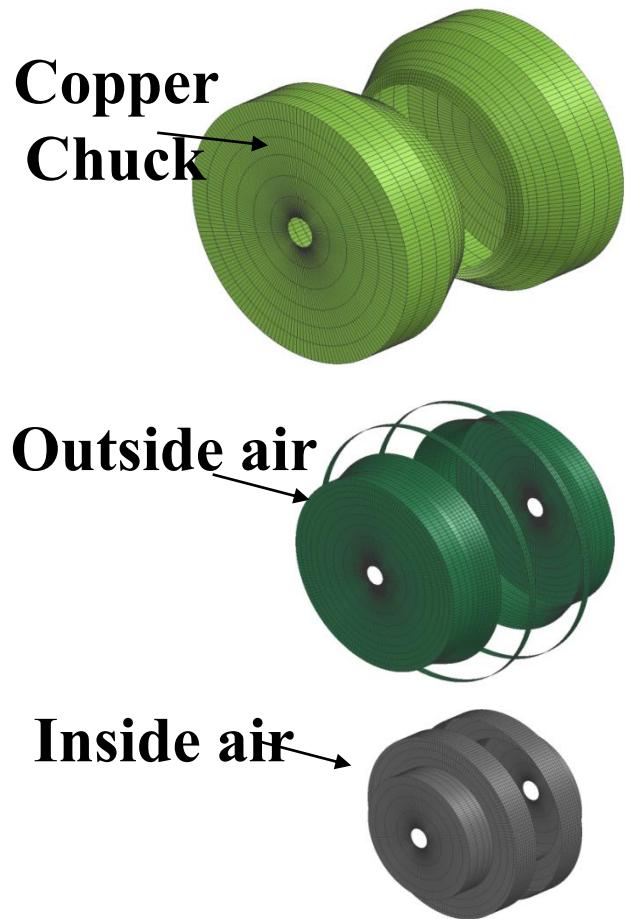
Donald Brown, MST-8

Bjørn Clausen, LANSCE-LC

John Milewski, MST-6

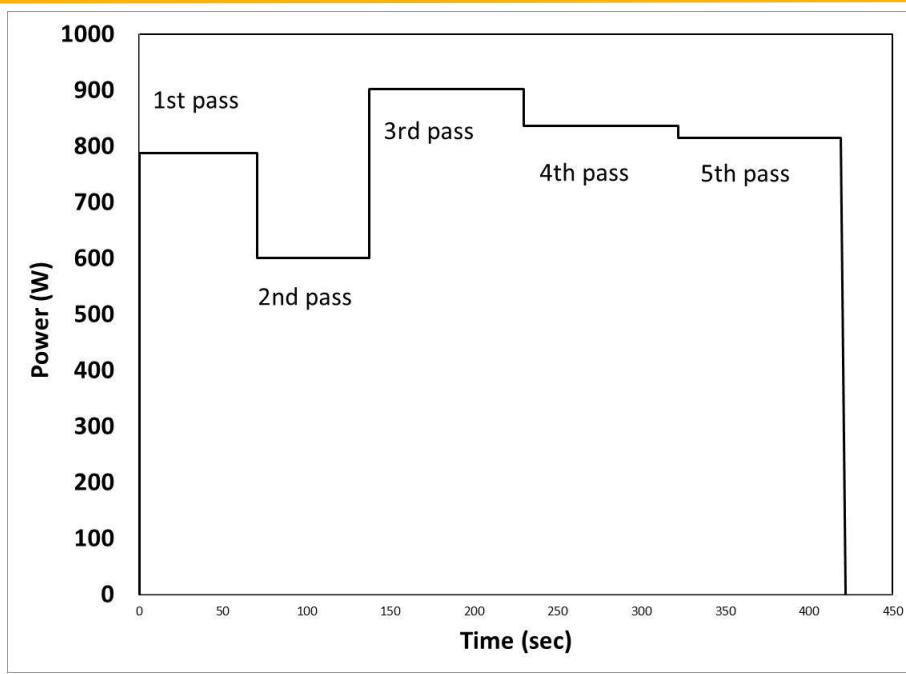
Mike Steinzig, W-2

Sample Preparation



Clamping Boundary Conditions

Welding Parameters

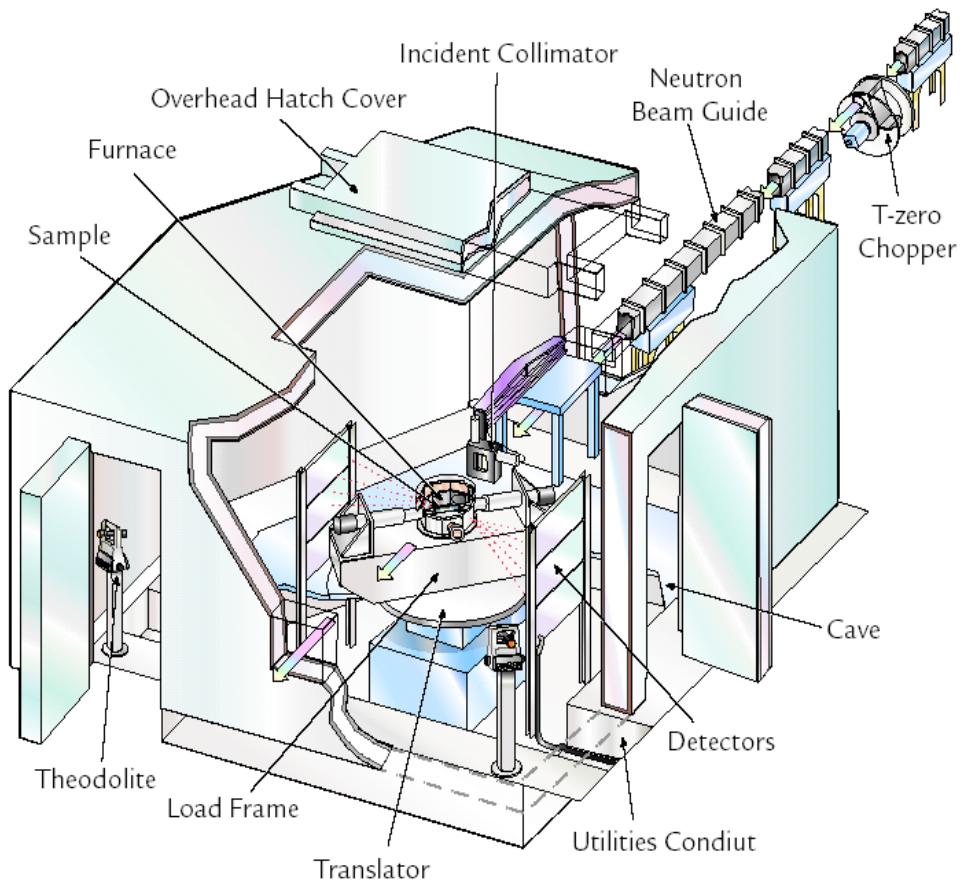


Pass	Power (W)	Speed (mm/sec)	Energy/Unit Length (J/mm)	Efficiency	QF (W)	QR (W)	AF (mm)	AR (mm)	B (mm)	C (mm)	TC Inside (°C)
1	787	1.79	472	0.60	2.00	1.00	1.33	2.7	1.5	0.20	390
2	601	2.10	487	0.81	2.00	1.00	1.33	2.7	1.5	0.20	390
3	902	1.68	767	0.85	2.00	1.00	1.33	2.7	1.5	0.20	390
4	836	1.81	711	0.85	2.00	1.00	2.00	2.0	1.5	0.20	380
5	814	1.86	692	0.85	2.00	1.00	2.00	2.0	2.0	0.10	360

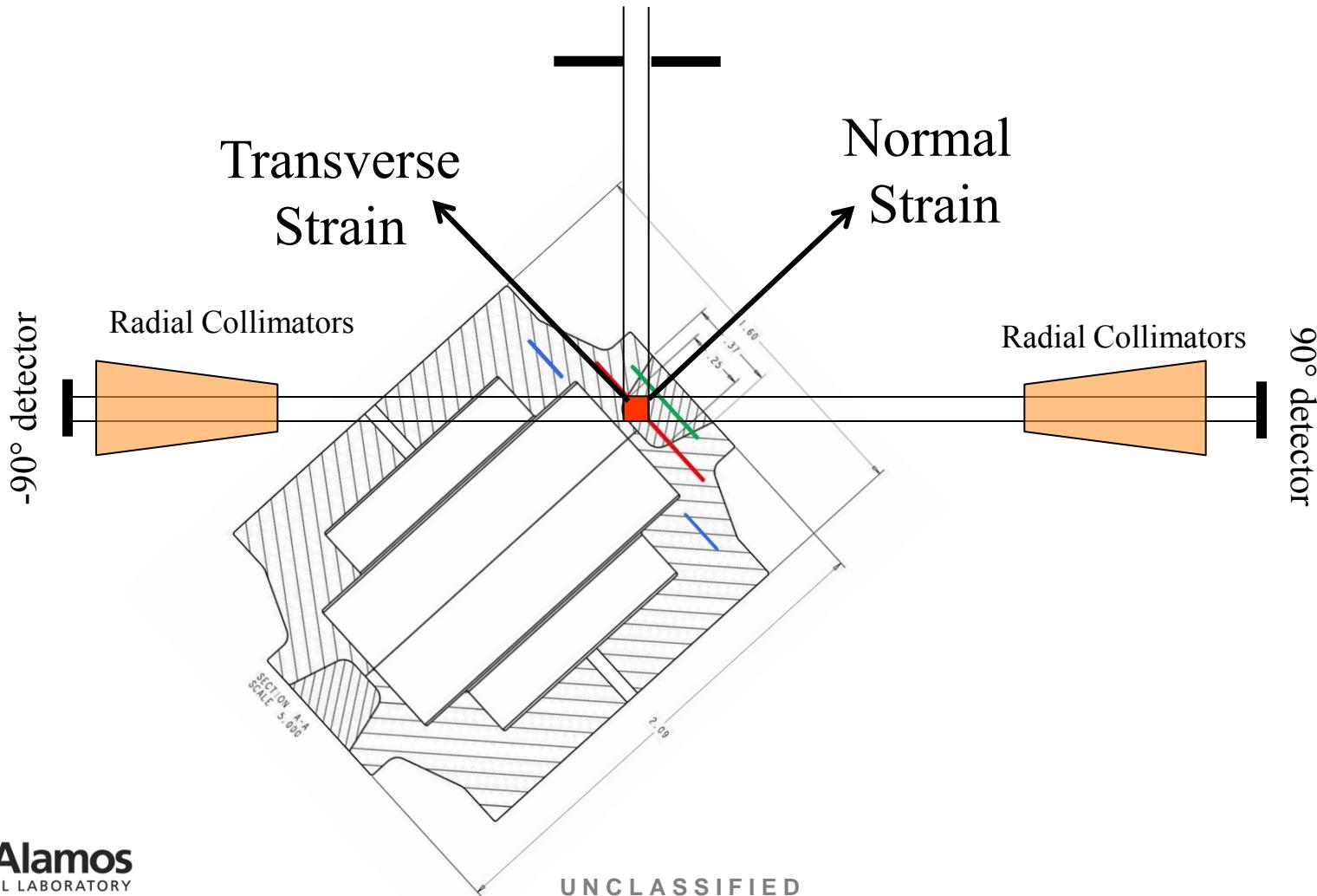
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Residual stress measurements completed using SMARTS

- Spectrometer for **MA**terials **R**esearch at **T**emperature and **S**tress
- Spatially resolved measurements
 - Residual strains in components
- *In situ* measurements
 - Strains as a function of stress, temperature, environment, ...
- Instrument Scientists:
 - Donald W. Brown
 - Bjørn Clausen
 - Thomas A. Sisneros

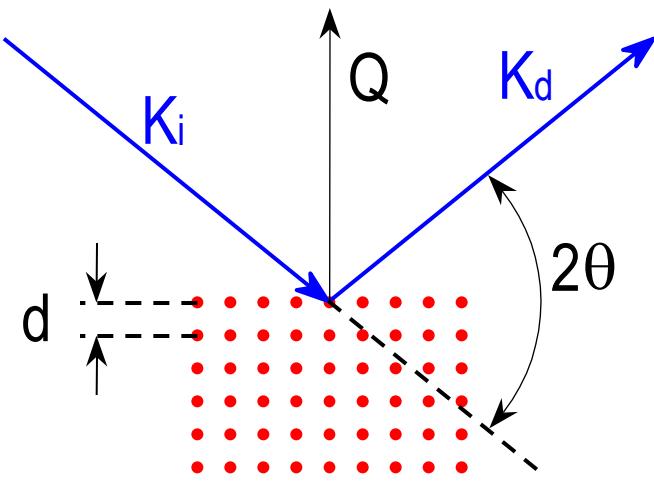


Instrument Geometry Allows 2 Strain Components to be Determined Simultaneously



Information Obtained from Diffraction Measurements

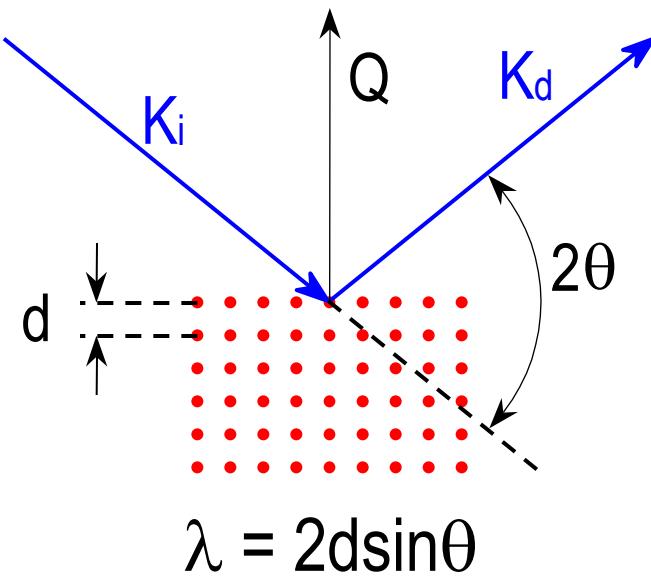
- Bragg's law relates the wavelength, the lattice spacing and the scattering angle



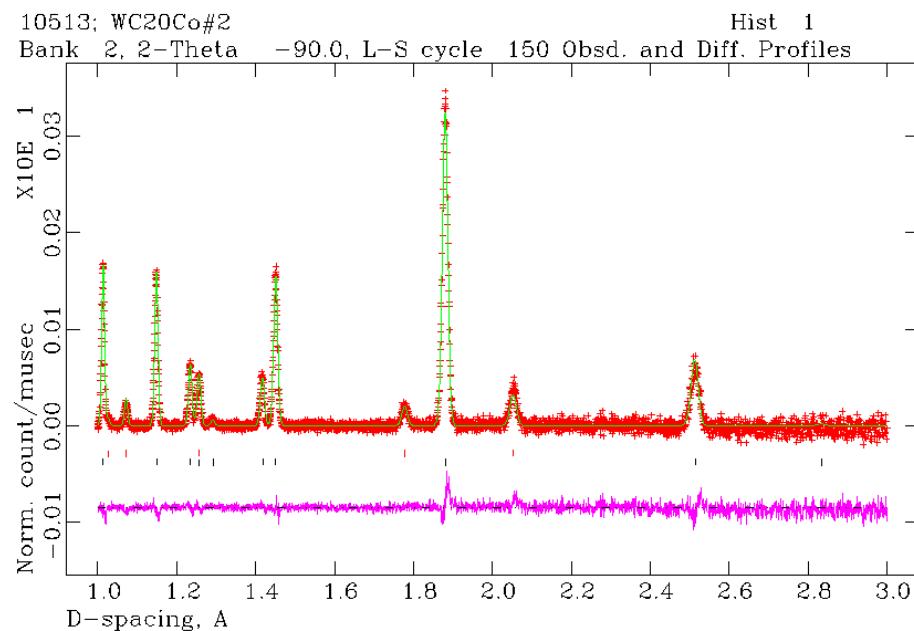
$$\lambda = 2d\sin\theta$$

Information Obtained from Diffraction Measurements

- Bragg's law relates the wavelength, the lattice spacing and the scattering angle



$$\varepsilon_{hkl}^{el} = \frac{d_{hkl} - d_{hkl}^0}{d_{hkl}^0} = \frac{d_{hkl}}{d_{hkl}^0} - 1$$



Stresses from Measured Strains

$$\sigma_i = \frac{E}{(1+\nu)(1-2\nu)} [(1-\nu)\varepsilon_i + \nu(\varepsilon_j + \varepsilon_k)], \quad i, j, k \in r, h, a$$

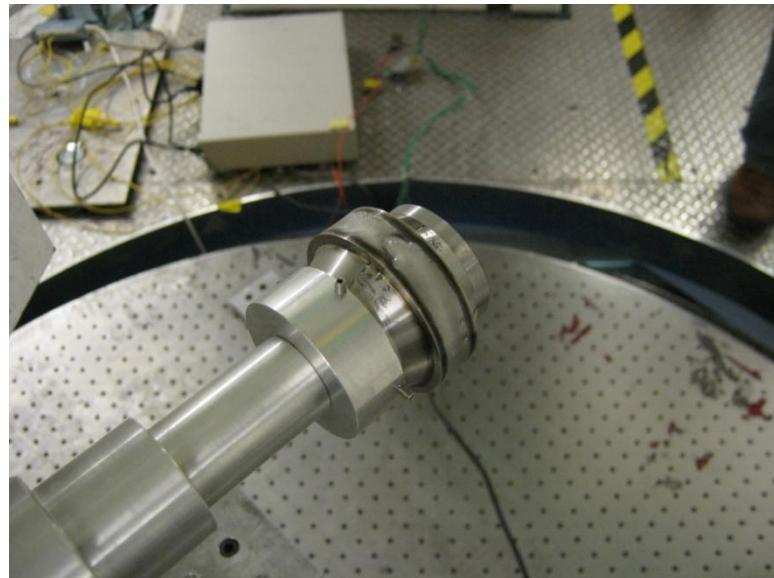
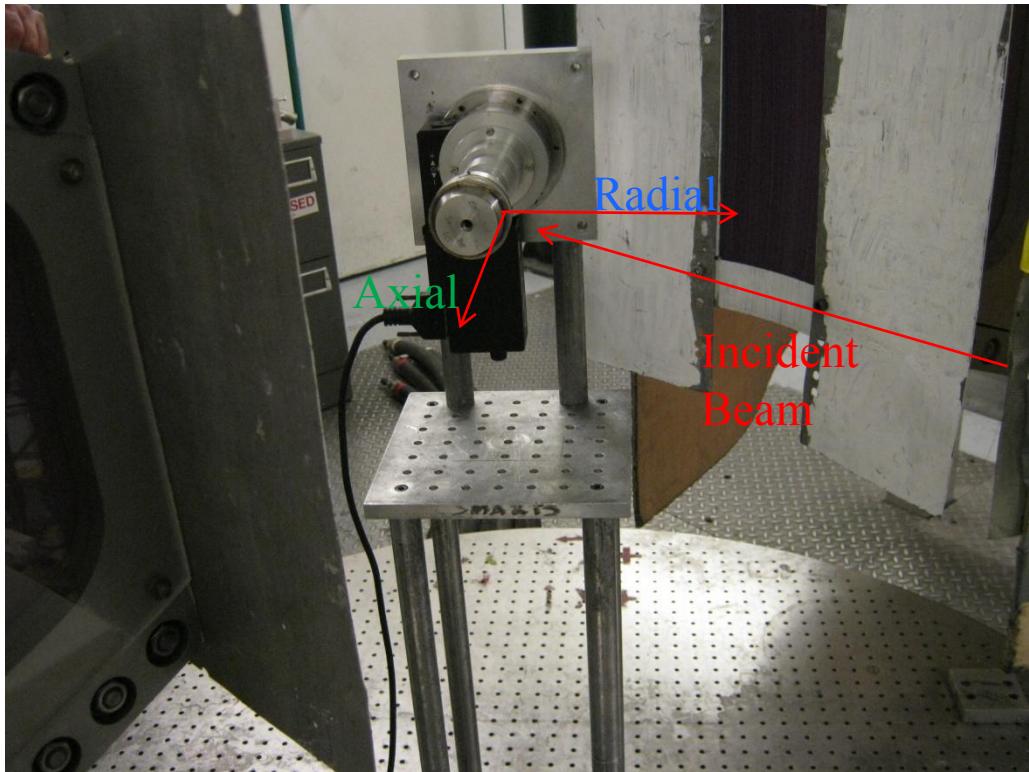
- Three normal stress components can be calculated from the three measured normal strain components via Hooke's Law
 - The measured strains have to be representative of the bulk

Stresses from Measured Strains

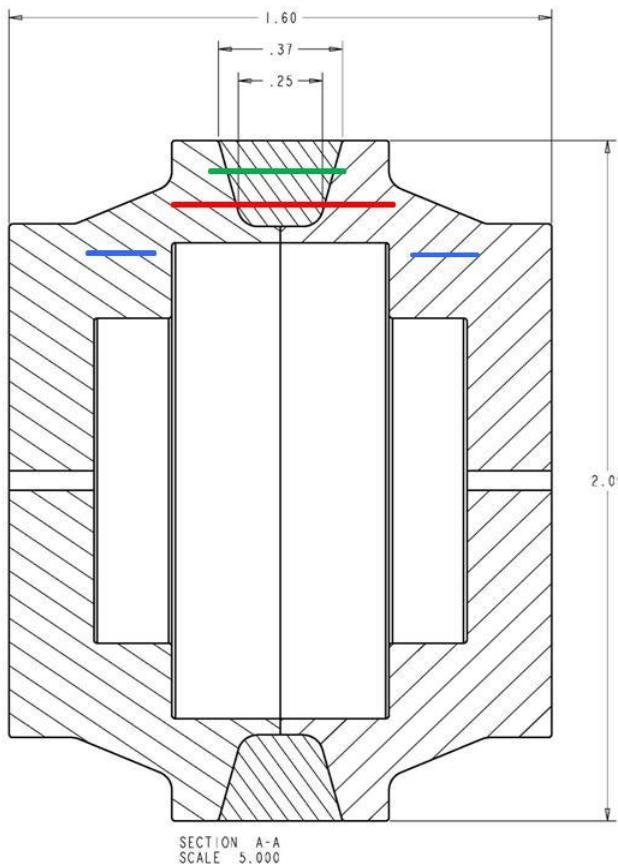
$$\sigma_i = \frac{E}{(1+\nu)(1-2\nu)} \left[(1-\nu)\varepsilon_i + \nu(\varepsilon_j + \varepsilon_k) \right], \quad i, j, k \in r, h, a$$

- Three normal stress components can be calculated from the three measured normal strain components via Hooke's Law
 - The measured strains have to be representative of the bulk
- Since we cannot measure shear strains, there is no information about shear stresses
 - If the three measured strain components are not along the principal strain directions, there will be unknown shear stresses
 - If six or more normal strain components are measured one can determine the full strain and stress tensors

Measuring Axial and Radial Strain Components

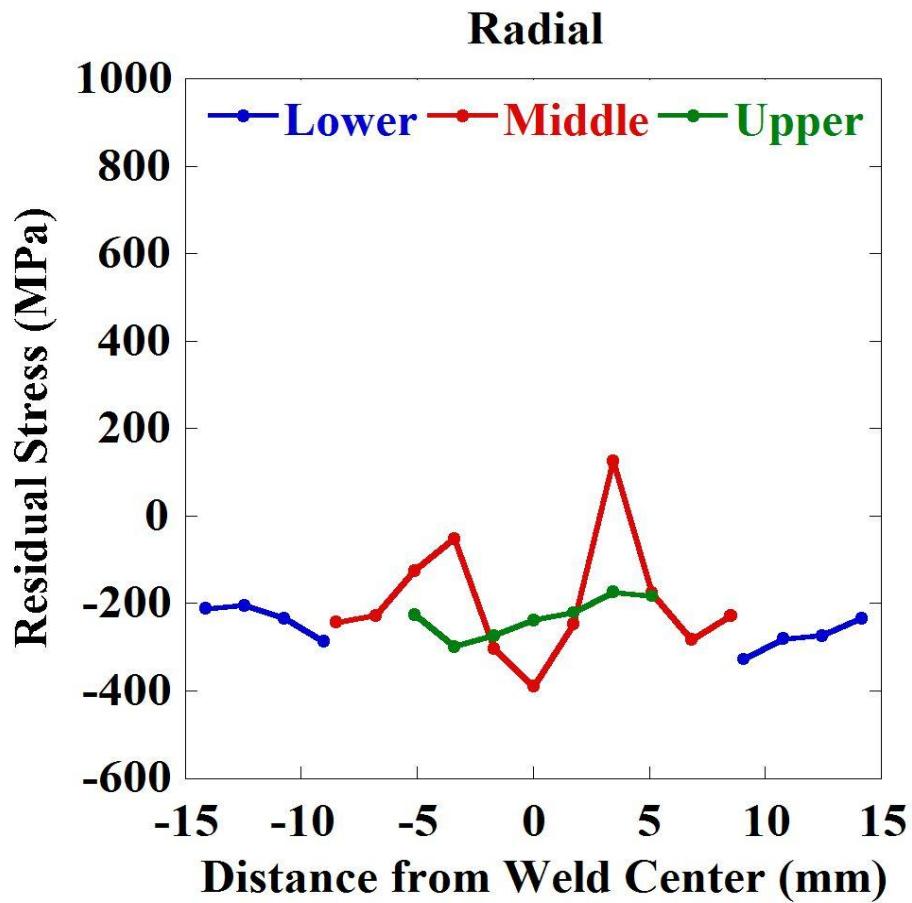
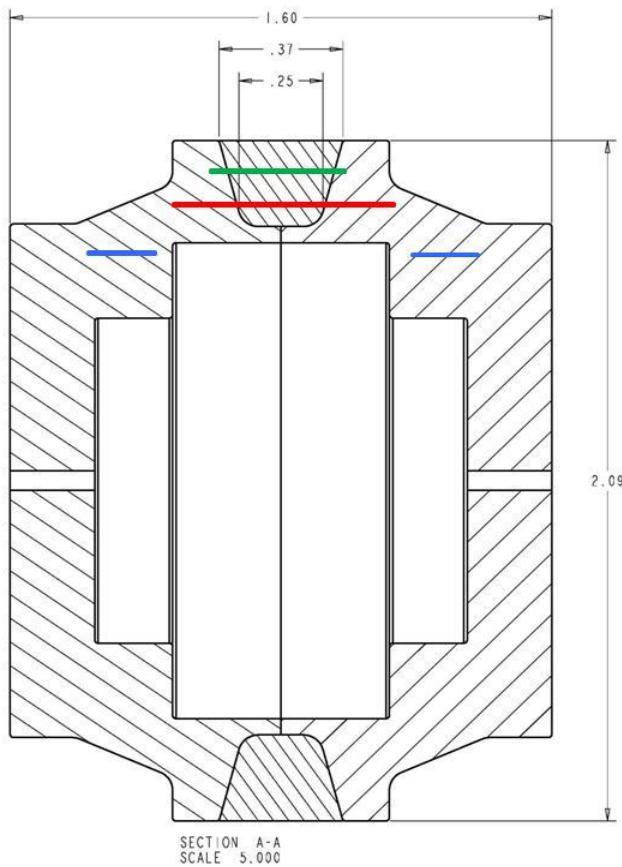


Transverse Measurements

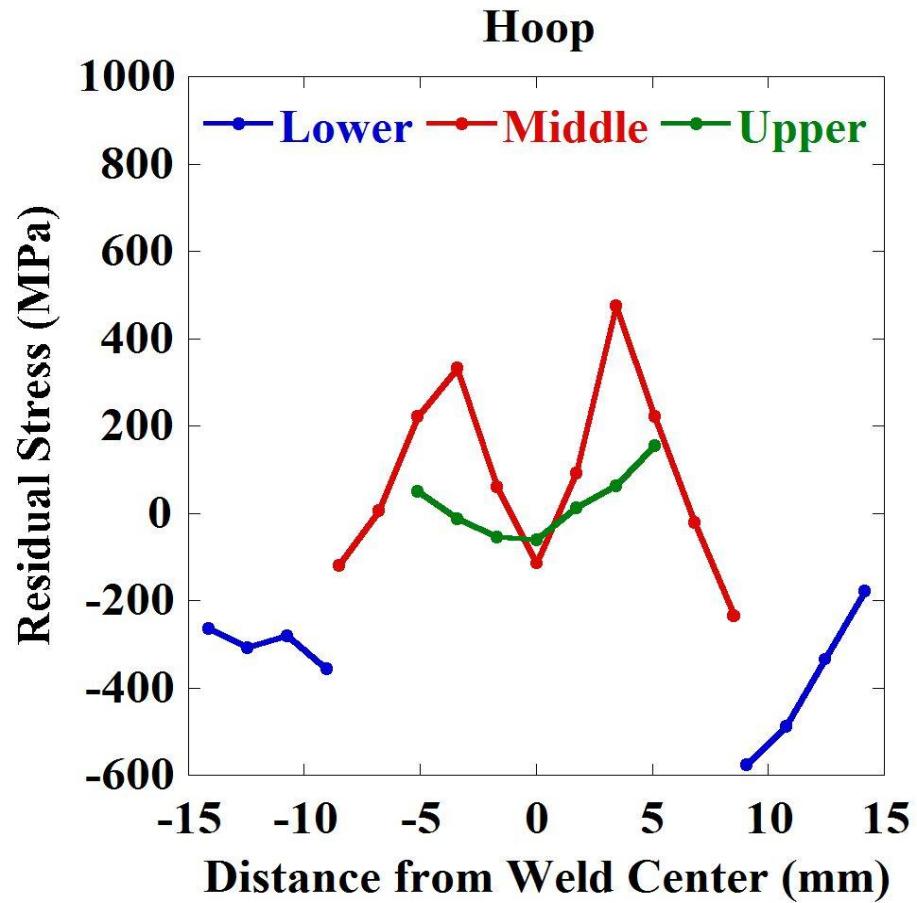
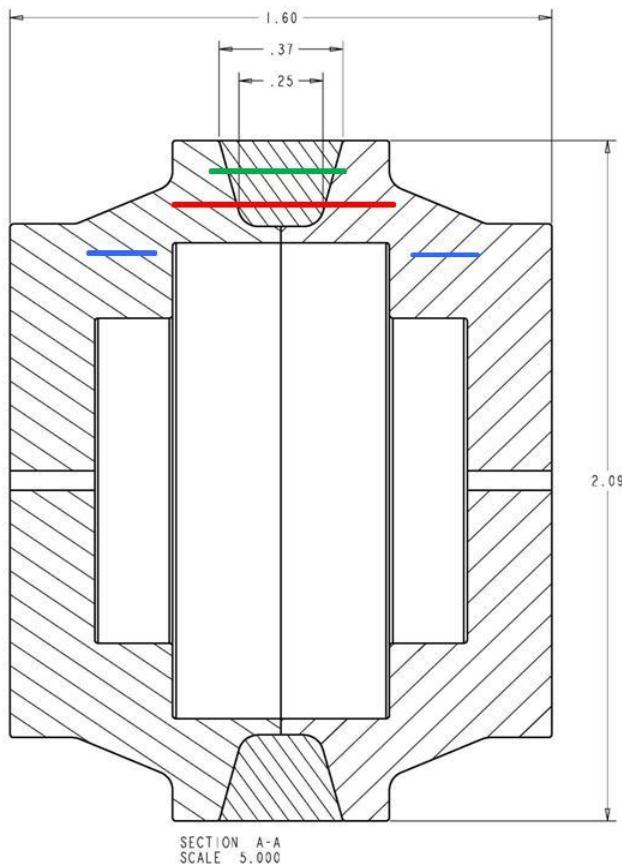


- Scans transverse to the weld were completed at three different depths: **Upper**, **Middle** and **Lower** positions using a 2mm x 2mm x 2mm gauge volume
- Scan transverse to weld, 90° from the Weld stop in the direction of weld travel

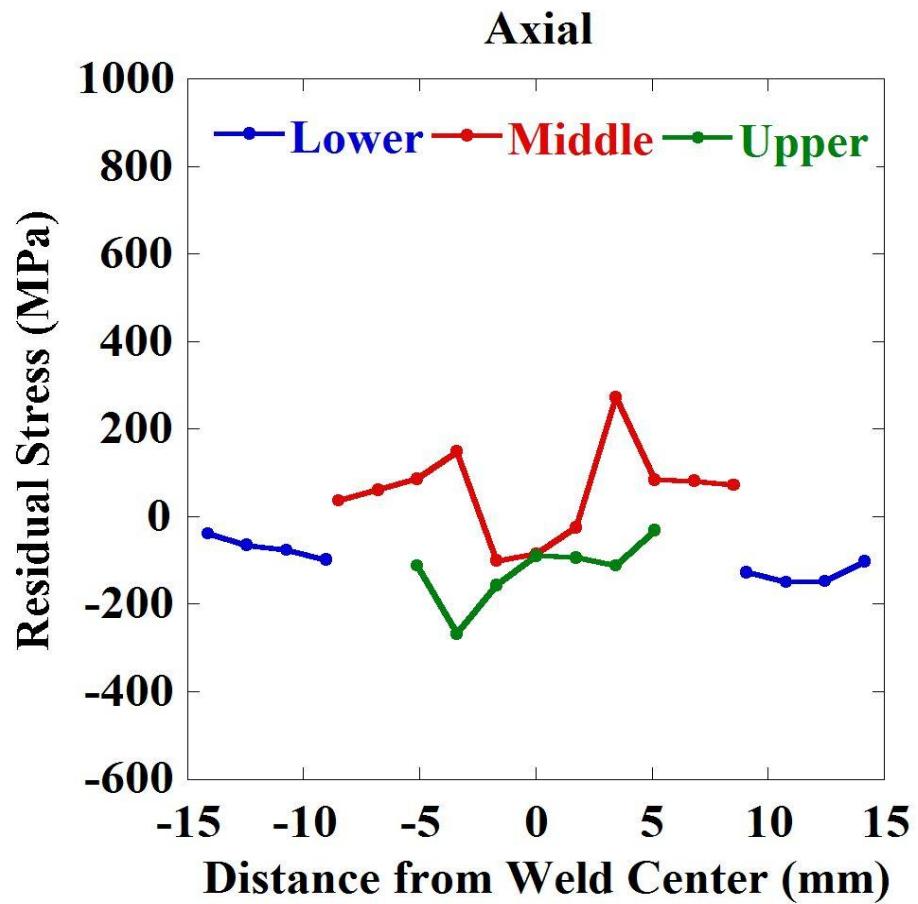
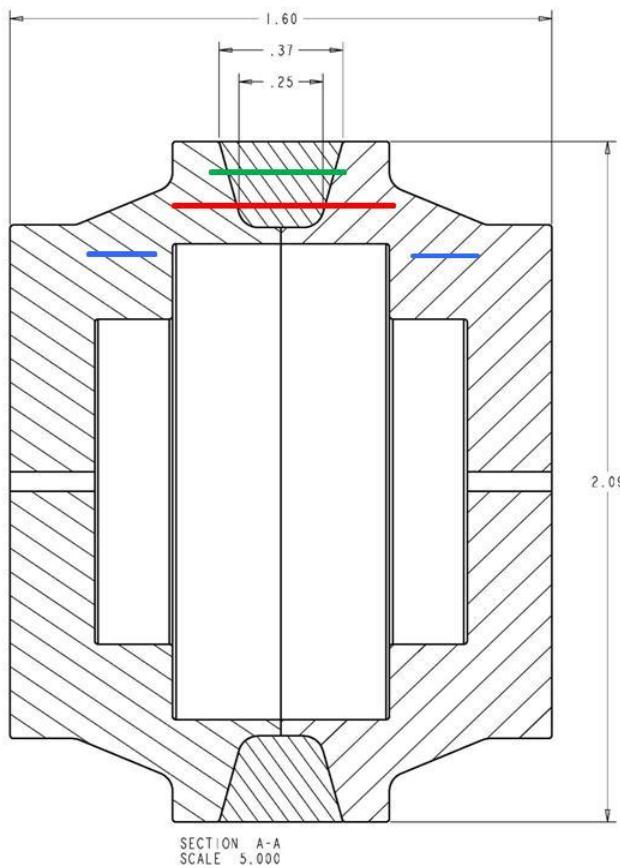
Neutron Diffraction Shows Strong Tensile Hoop Stress at Weld Middle line



Neutron Diffraction Shows Strong Tensile Hoop Stress at Weld Middle line

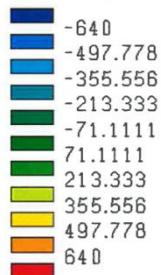


Neutron Diffraction Shows Strong Tensile Hoop Stress at Weld Middle line



Circumferential Hoop and Axial Stress

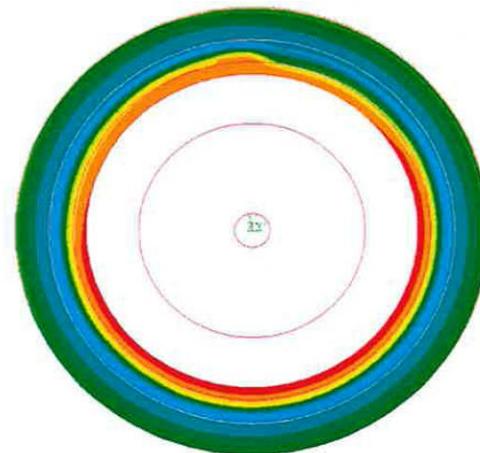
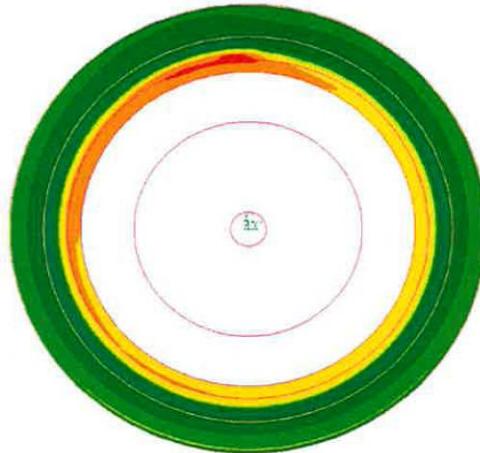
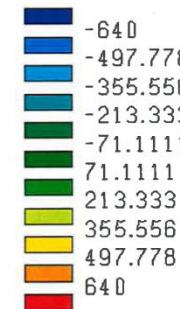
Min = -348.1
Max = 775.5



Center of Weld

$d = 3.3 \text{ mm}$

Min = -502.7
Max = 696.9!

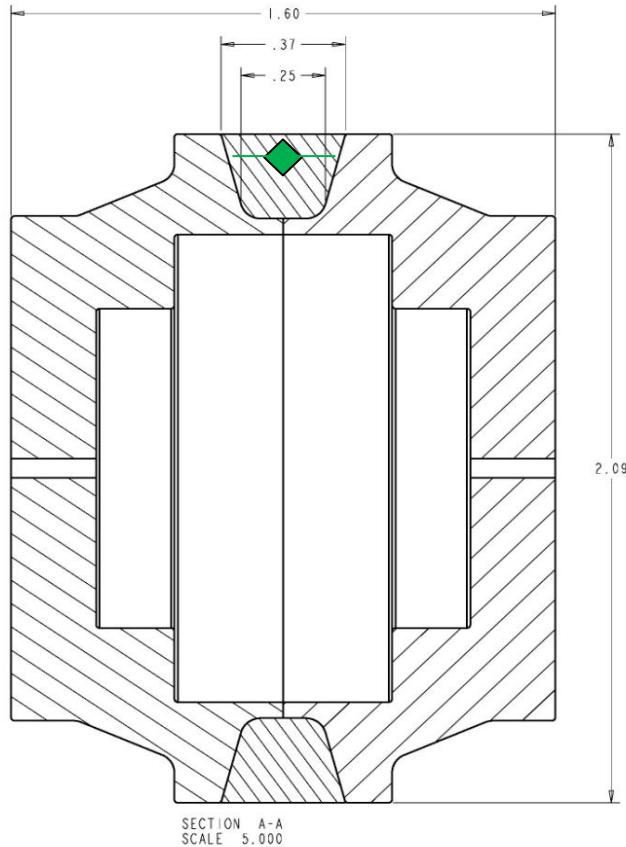


Hoop stress

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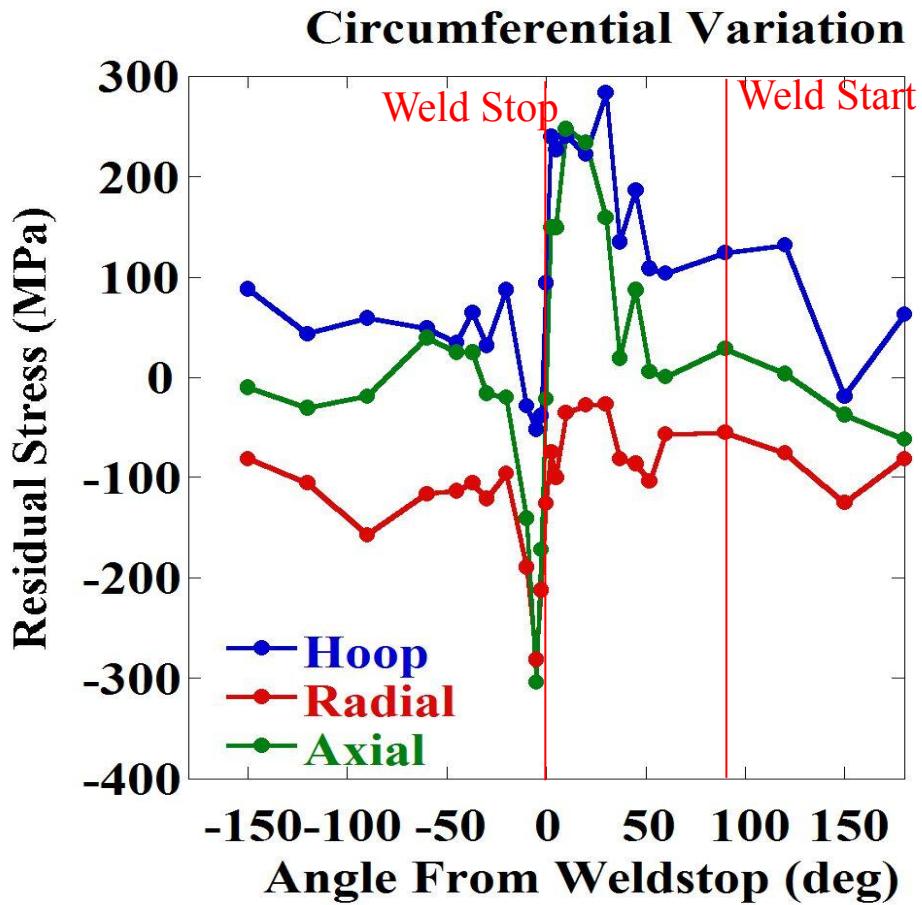
Axial stress

Circumferential Measurements



- Circumferential Scans were completed at the **upper** position using a 2mm x 2mm x 2mm gauge volume
- Vessel 11: Weld start located 95° WRT to weld stop

Neutron Diffraction Shows Circumferential Variation of Stress



Conclusions

- Residual stress neutron diffraction measurements were performed on model specimens welded using Gas Tungsten Arc
- Chemical Strains are very important and should be accounted for.