SAND2015-8091PE

Used Fuel Disposition Campaign

Mock-Up Canister and Residual Stress Measurements

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UFD Stress Corrosion Cracking Workshop
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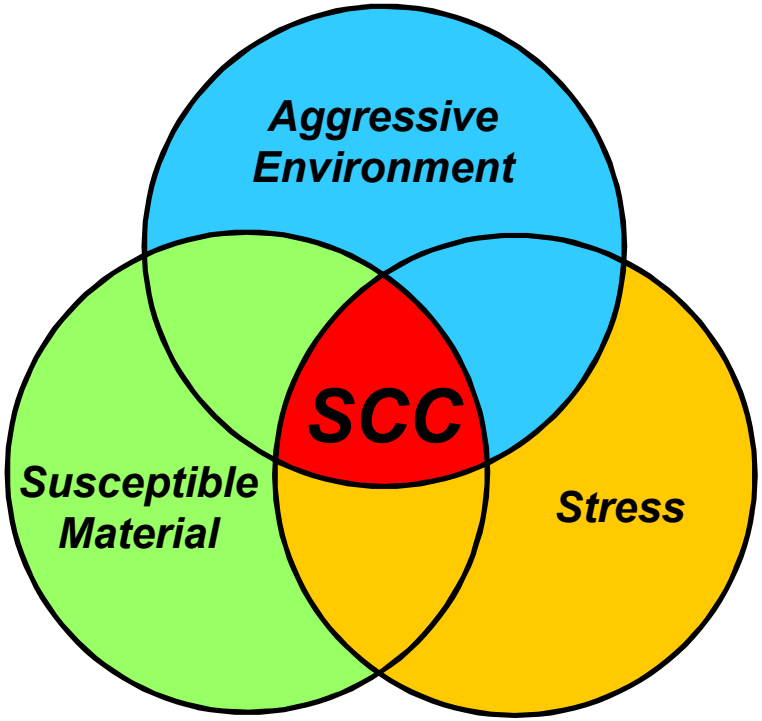
What Governs SCC Crack Initiation and Propagation



- **Questions that need to be answered:**
  1. Is the material of construction for fielded interim storage containers susceptible?
  2. Will a chloride bearing environment form on the surface of the containers?
  3. Is there a sufficiently large tensile stress to support crack initiation and propagation in fielded interim storage containers?

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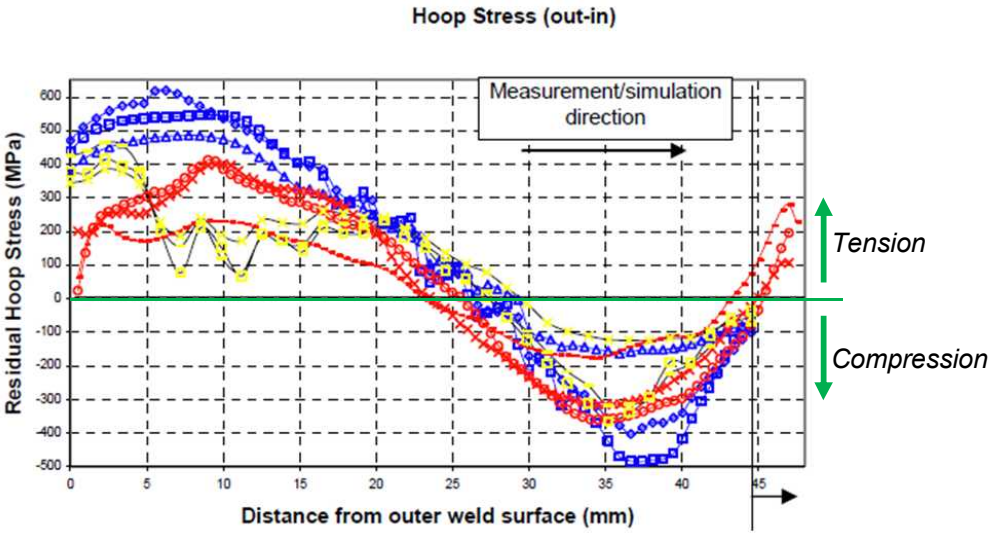
Where do we need to measure the residual stress?

- **Is there sufficient residual stress within the container wall to support propagation of a through-wall crack?**
- **Many complicating factors**
  - Weld procedure (start/stop, technique, etc.)
  - Weld repairs



K. Ogawa, et al, "Measuring and Modeling of Residual Streses in Stainless Steel Girth Welds", PVP 2008 61542, July 27-31, 2008, Chicago, IL.

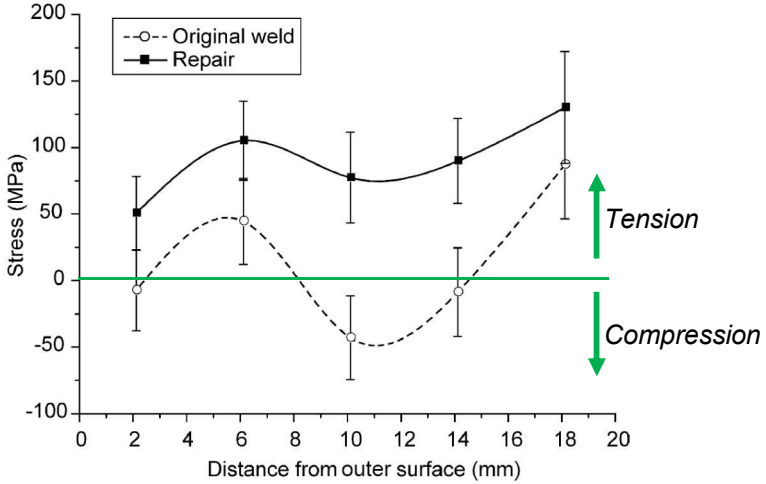
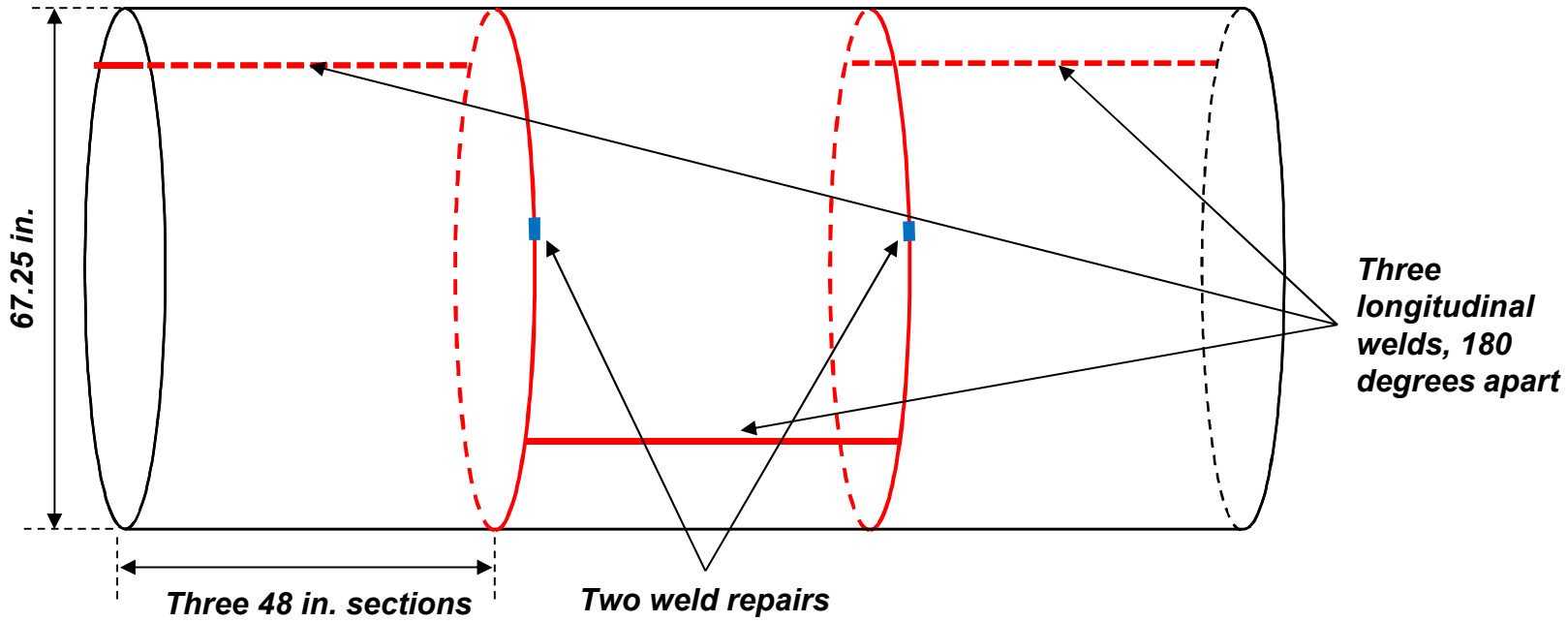


Fig. 14. Hydrostatic residual stress profile (17.5 mm from weld centre-line).

L. Edwards, et al, "Direct Measurements of the Residual Stresses near a "Boat-Shaped" repair in a 20mm Thick Stainless Steel Tube Butt Weld", International Journal of Pressure Vessels and Piping, 82 (2005), pp. 288-298

Full Scale Mock-Up Assembled to Directly Measure Residual Stresses



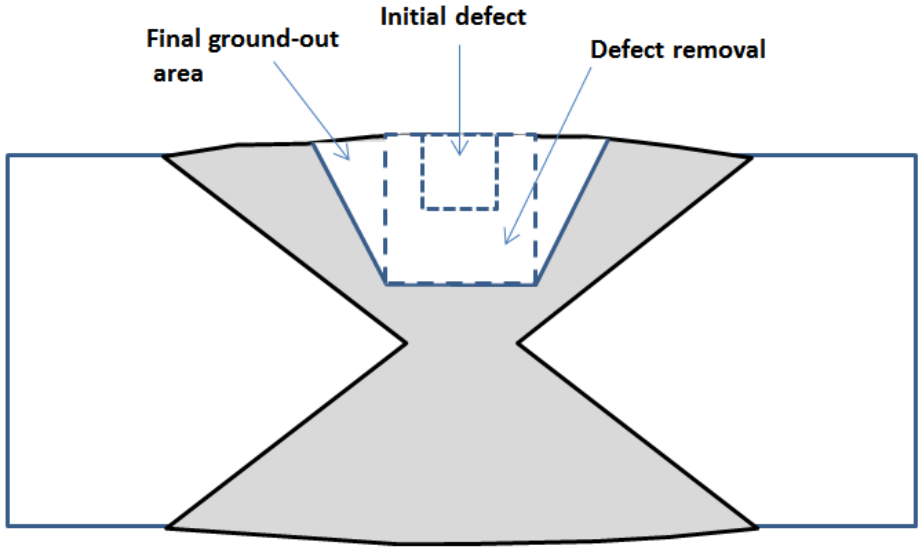
- ***Wall material: 304 SS welded with 308 SS***
- ***Wall thickness, overall diameter, weld joint geometry: standard geometry for NUHOMS 24P***
- ***Welds:***
  - *Full penetration and inspected per ASME B&PVC Section III, Division 1, Subsection NB (full radiographic inspection)*
  - *Double-V joint design, Submerged Arc welding process*

Weld Design

- **Longitudinal welds**
  - Double-V edge preparation
  - Submerged Arc welding technique, 15-16 inches/minute, 30V/400A, 45 kJ/in heat input
  - 3 passes on the ID, 4 passes on the OD
- **Circumferential welds**
  - Double-V edge preparation
  - Tacked with GTAW
  - Submerged Arc welding technique for primary passes, 15-16 inches/minute, 30V/400A, 45 kJ/in heat input
  - 3 passes on the ID, 4 or 5 passes on the OD
- **Repair welds**
  - Section of weld removed (indications made on container wall 6” from weld to indicate location)
  - Weld repair done on OD via GTAW technique
- **Full radiographic inspection done of all welds and repaired regions**
  - No indications observed on any welds

Weld Repairs on Circumferential Welds

- Welds were fabricated via submerged arc welding using a well defined protocol/schedule – very low defect density
- Manufacturer (Ranor) created a repair typical for this type of weld (simulating a local defect due to entrained slag at a weld stop/start point, etc.)
- mock defect into the container by drilling a 1/8” diameter hole partially into the center of the weld root. They then went back and “removed” that defect, by drilling out additional material using a ¼” drill, after which they ground the edges of the site such that the opening of the hole was approximately 0.5” wide. Repair completed via TIG.



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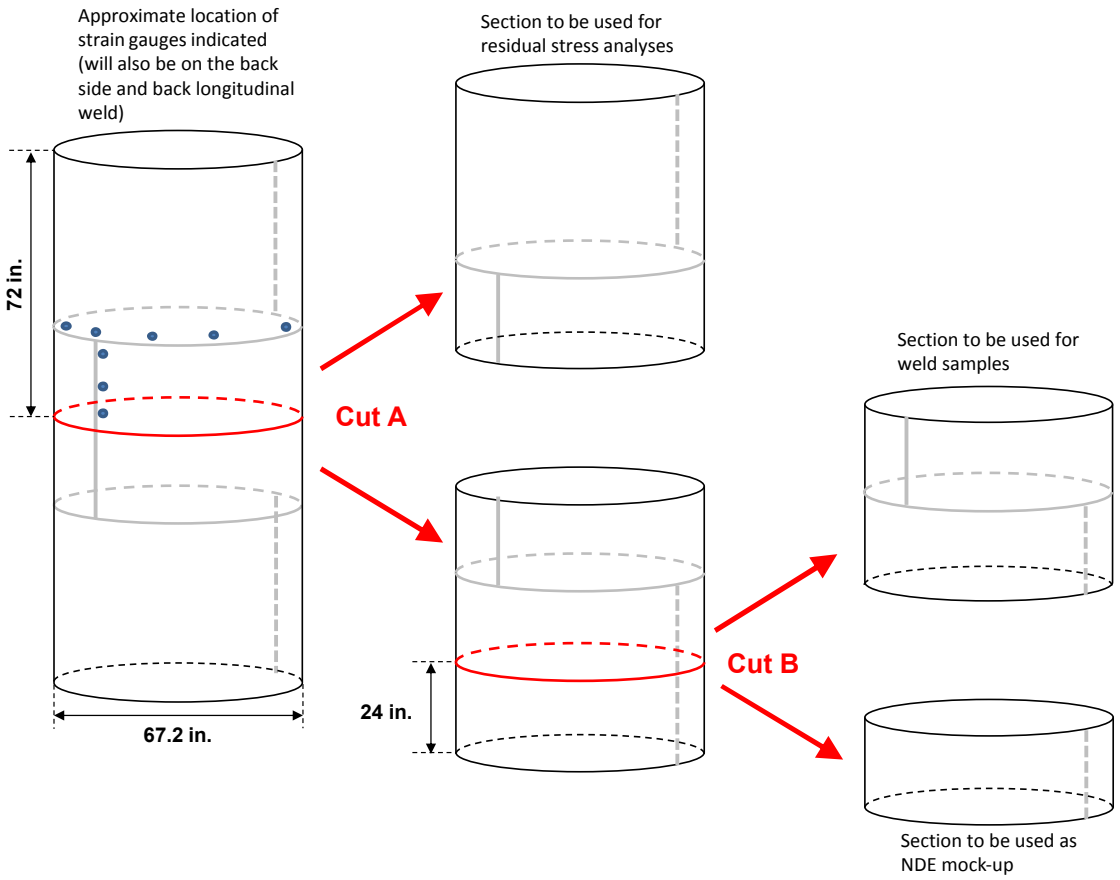
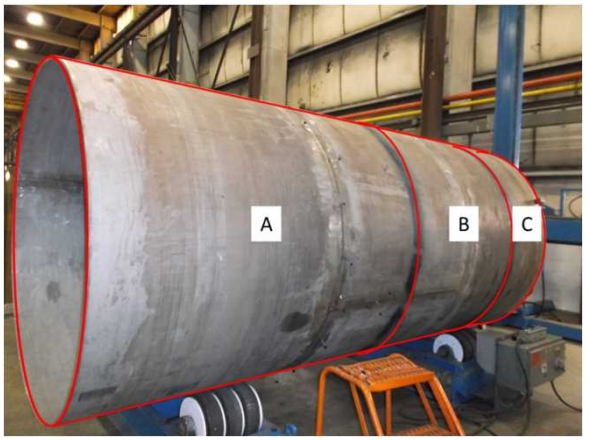
Subdividing the Container in Preparation for Analyses

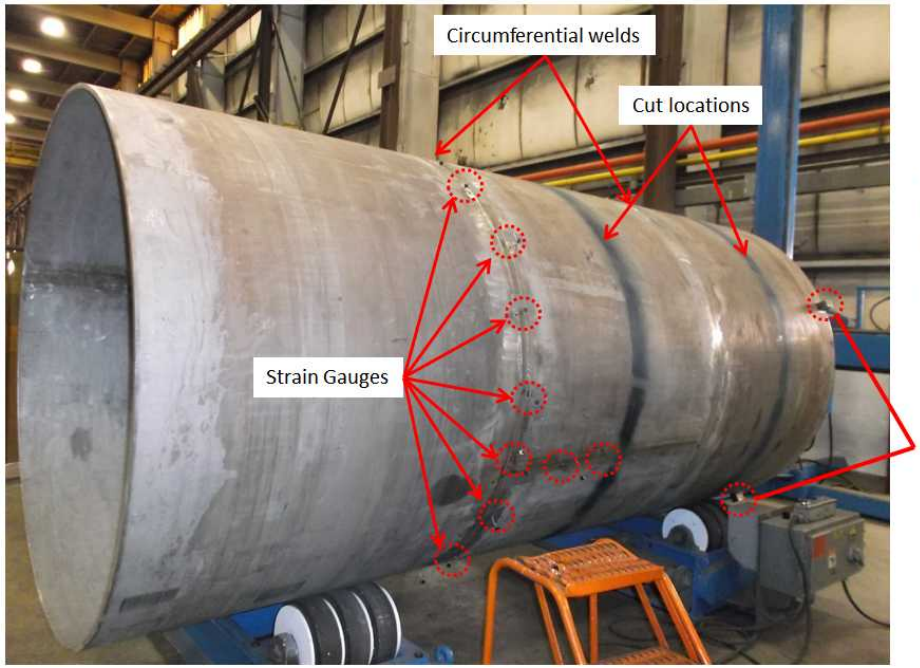
- **Container sectioned for residual stress measurements and sample fabrication**
  - Impact of cutting process assessed via surface mount strain gauges





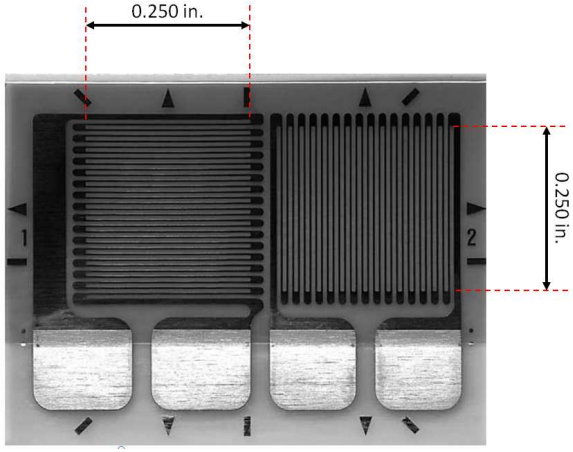
Container Preparation for Cutting

- **Surface mount strain gauges positioned to monitor circumferential and longitudinal welds**



Side view of container – strain gauges visible along circumferential weld and longitudinal weld. Temporary mounting blocks visible on far end of container.

Temporary mounting blocks



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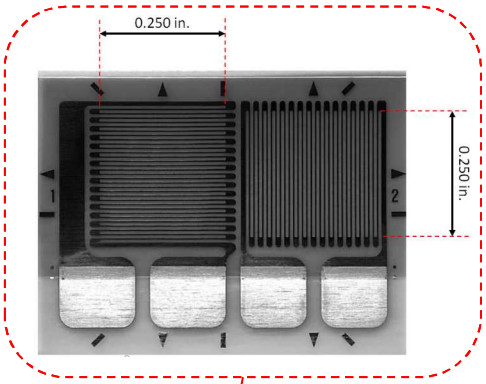
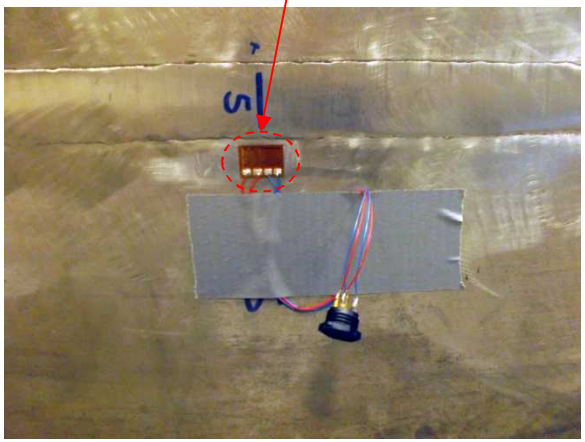
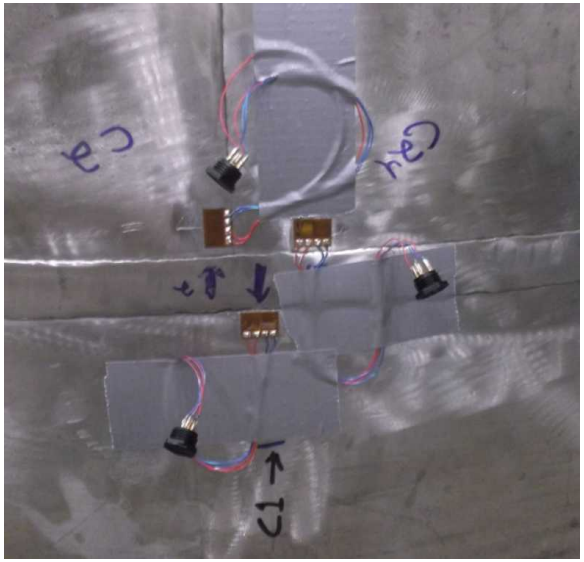
Strain Gauge Positioning

- Gauges positioned such that one grid was parallel and one perpendicular to the weld
- Positioning required that a region with no heterogeneities be identified

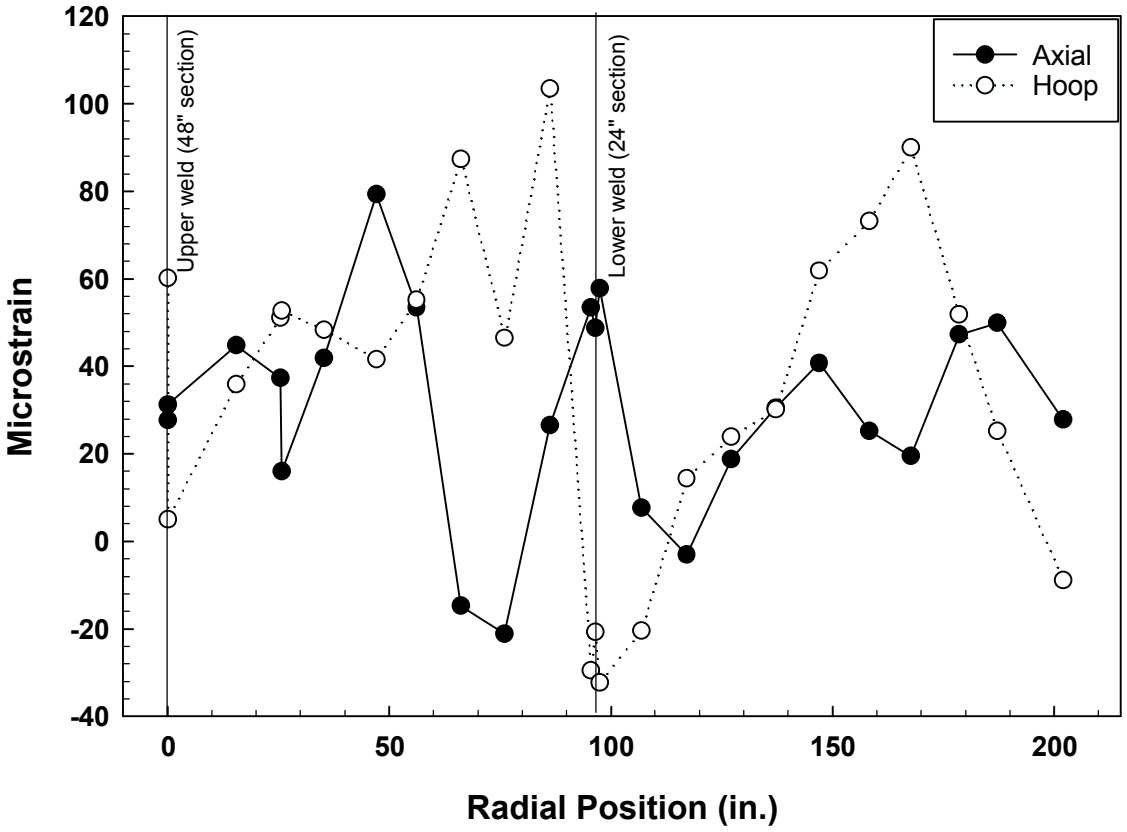


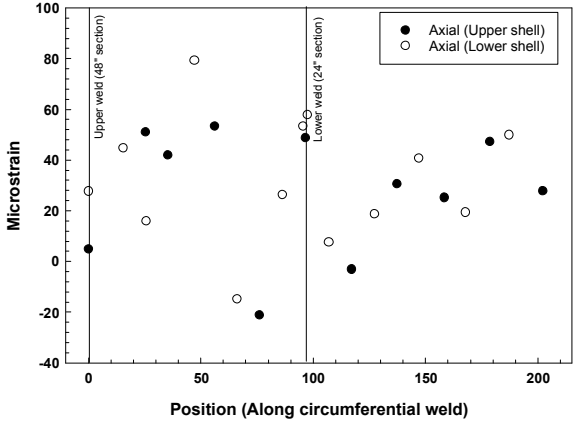


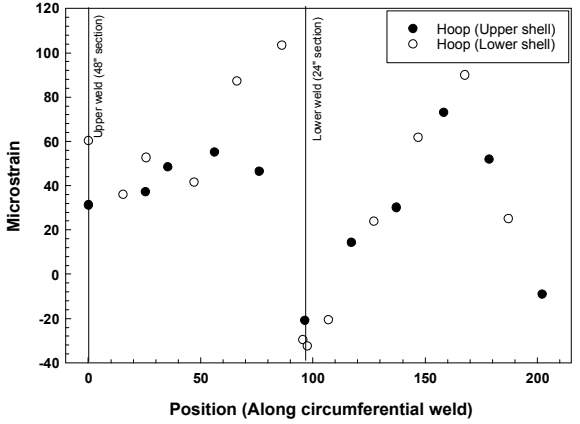


Surface Strain Gauge Data Circumferential Welds

- **Minimal impact of cutting operation on the circumferential weld**
  - Also assessed if measurements made on the upper vs. lower shell mattered (cut was on the lower shell)

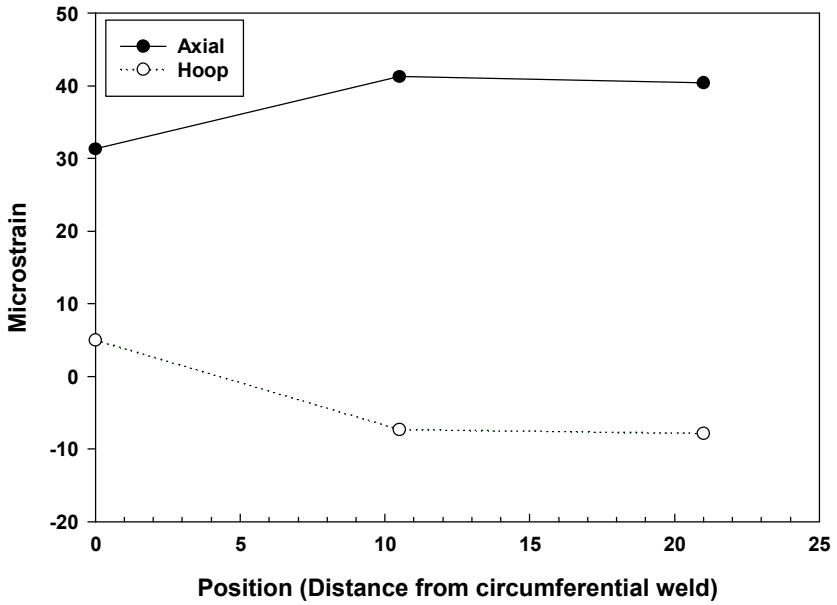


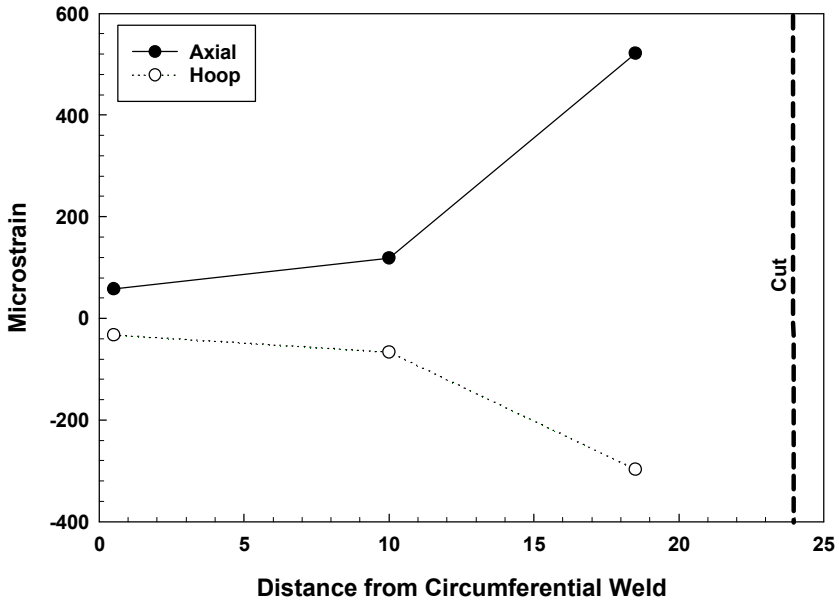




Surface Strain Gauge Data Longitudinal Welds

- **Upper weld (shell which was not cut) not disturbed by the cutting operation**
- **Lower weld (shell which was not cut) impacted by cut**
  - Some deformation of the cylinder occurred near the cut, despite the high wall thickness



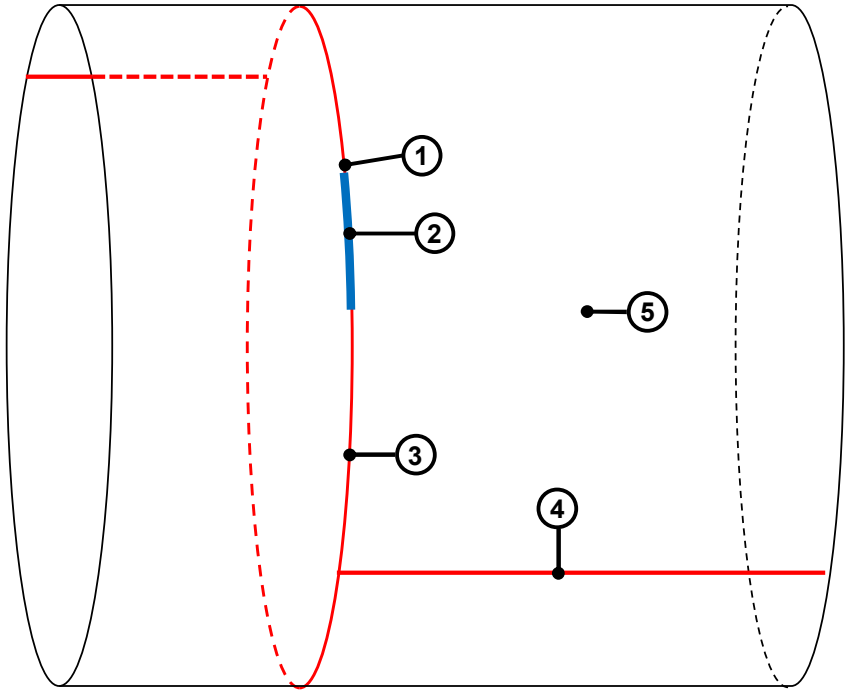


Residual Stress Measurement

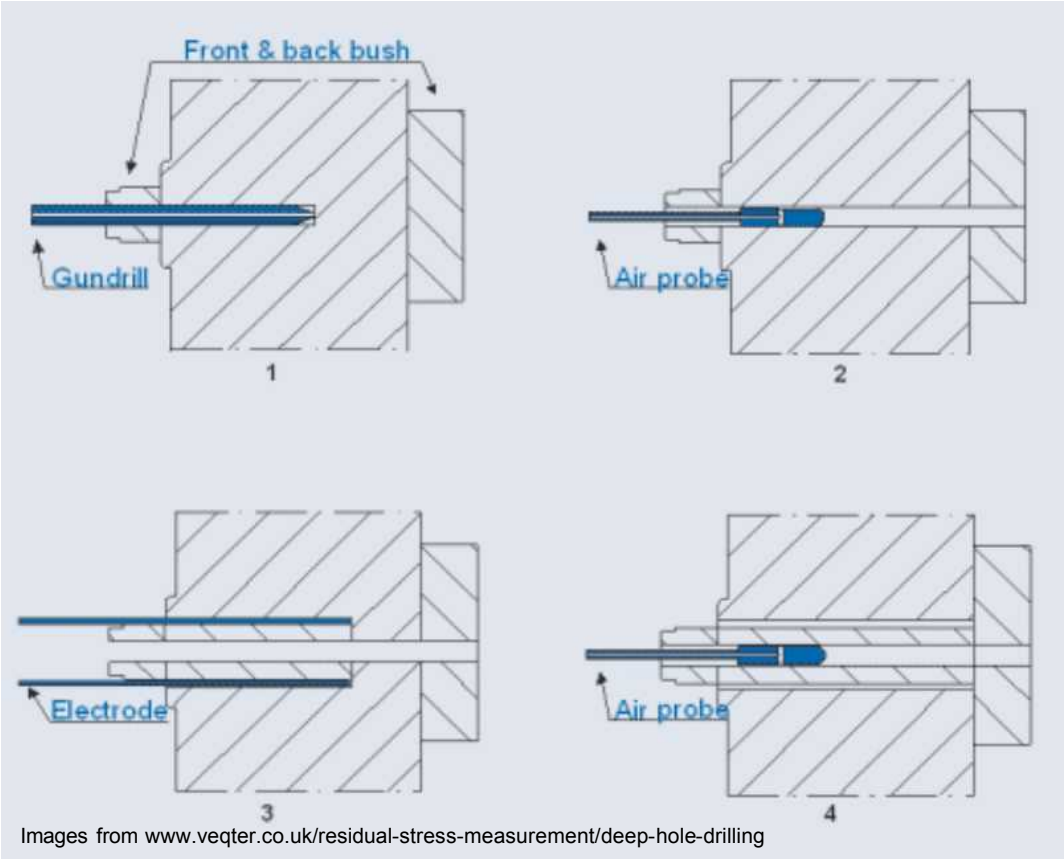
- **Residual stress state will be high in the weld due to the constraint imposed by the cylindrical geometry of the mock-up**
- **Removal of the mechanical constraint (i.e., cutting up the container) will relax the residual stress state at the weld**
  - Want to make measurements in the undisturbed state (or have a way to reference back to that state)
- **Variety of techniques are available and being considered for the analysis of the container**
  - Deep hole drilling
  - Contour measurement
- **There are advantages and disadvantages for each method**
  - Most require the material to be sectioned (stress relaxation can be monitored)
  - A combination of techniques is needed to assess the stress state

Residual Stress Measurement Sites

- **Series of key areas are being assessed**
  - 1,2: Weld Repair
  - 3: Circumferential Weld (Centerline and HAZ)
  - 4: Longitudinal Weld (Centerline and HAZ)
  - 5: Base metal (far from welds)



Deep Hole Drilling



Images from www.veqter.co.uk/residual-stress-measurement/deep-hole-drilling

- **Hole precisely drilled through region to be characterized**
- **Air probe used to measure the inner diameter of the hole as a function of position**
- **EDM used to cut core around the hole, relaxing the constraint placed by the surrounding material**
- **Air probe used to measure the resulting distortion of the hole inner diameter**
- **Stress state calculated from displacements**
- **Complicated when stresses are high (requires modified technique)**

- Get one dimensional map of initial stress state without cutting up structure
- Semi-destructive, labor intensive ($)

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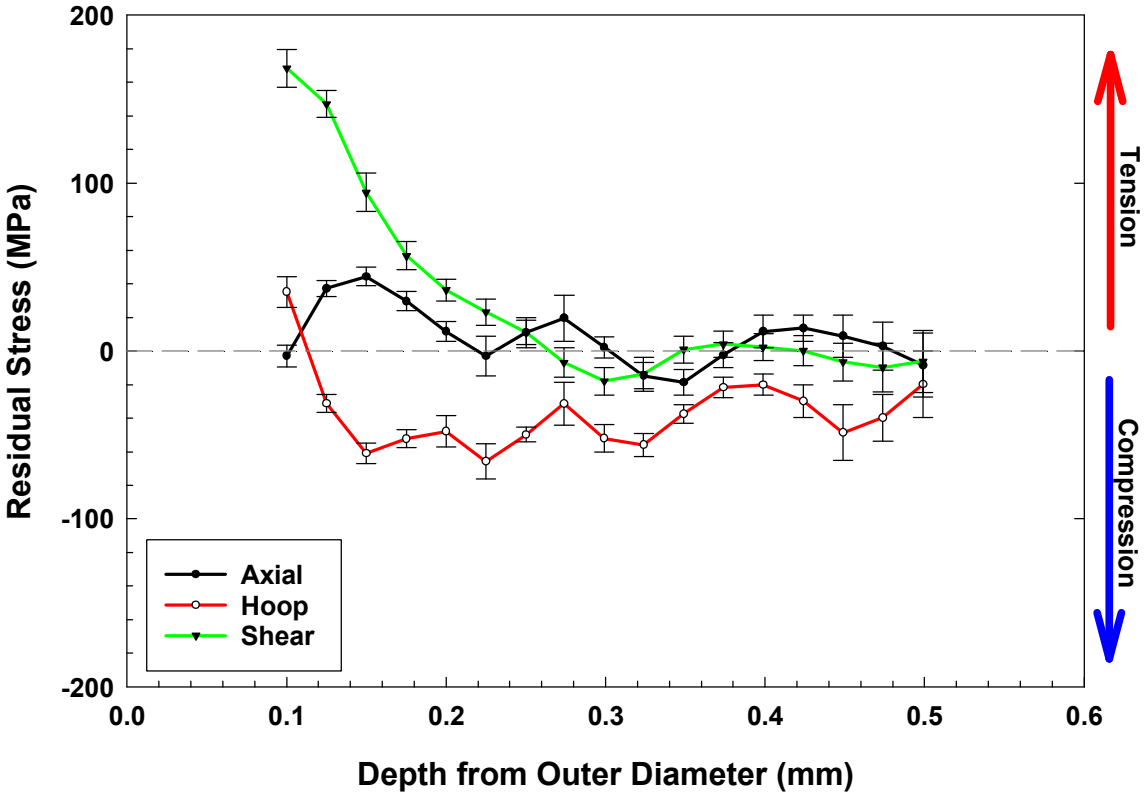
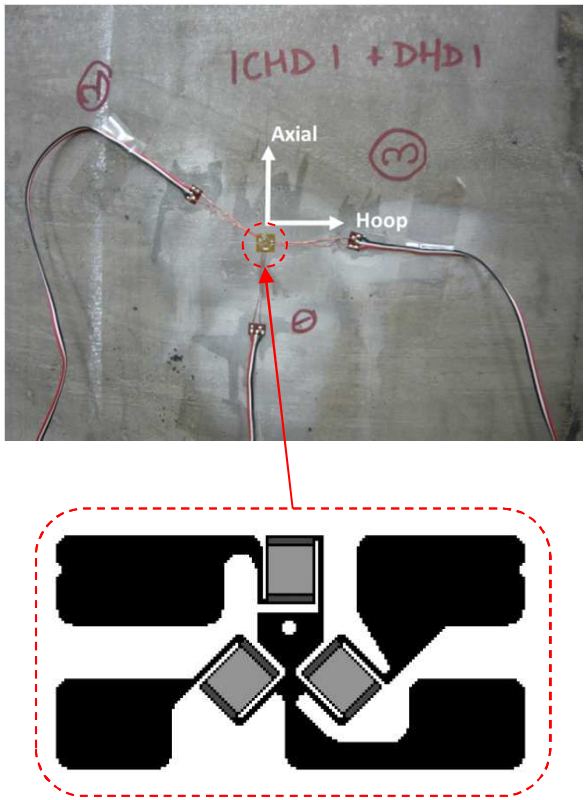
Near Surface Stresses Assessed Via Incremental Center Hole Drilling

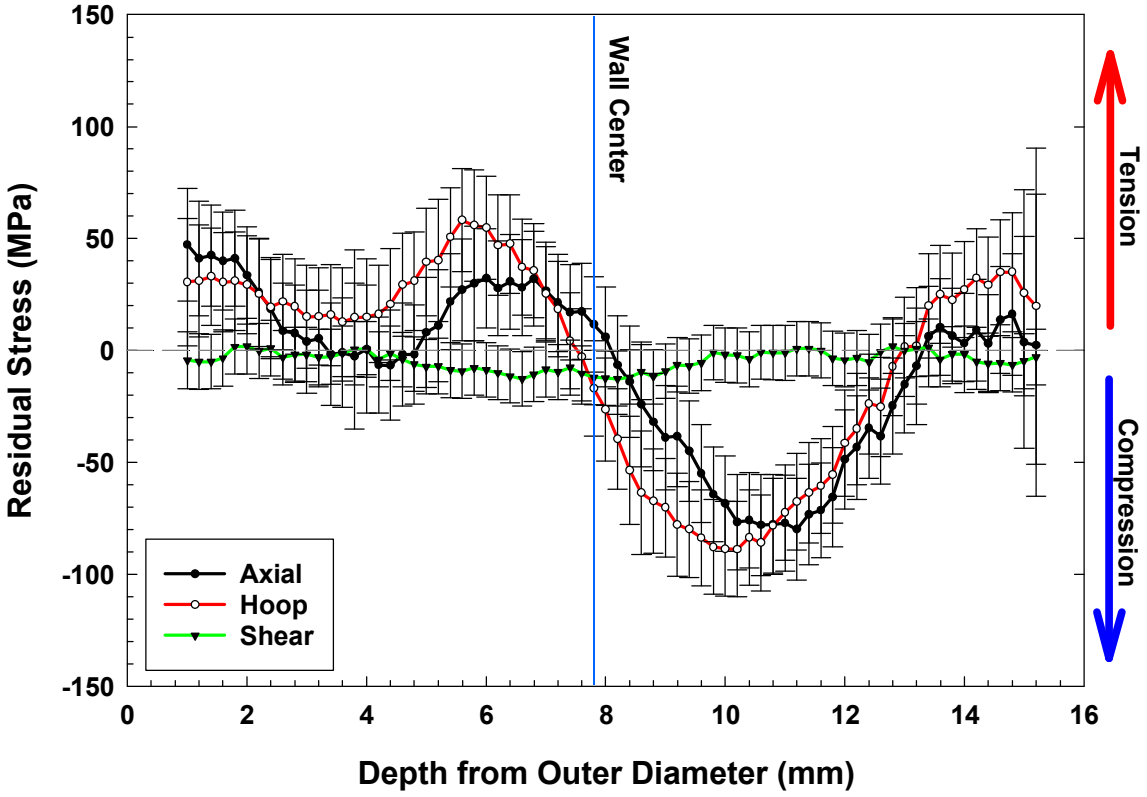
- DHD is not able to resolve strains accurately very near the metal surface (first 0.5mm or so)
- iCHD used to make these measurements

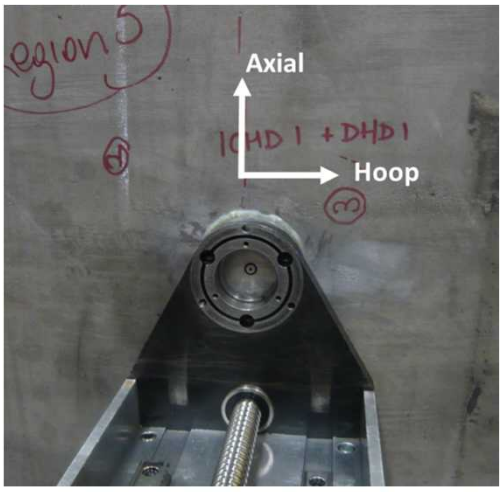


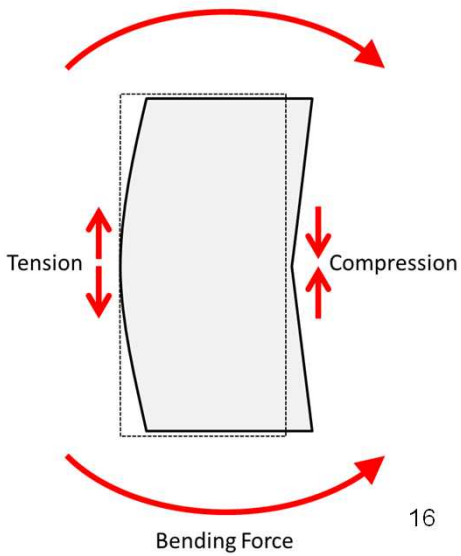


Residual Stresses in the Base Metal Far from Welds

- **Stress state consistent with forming process**
  - Stresses on OD tensile
  - Stresses in ID compressive

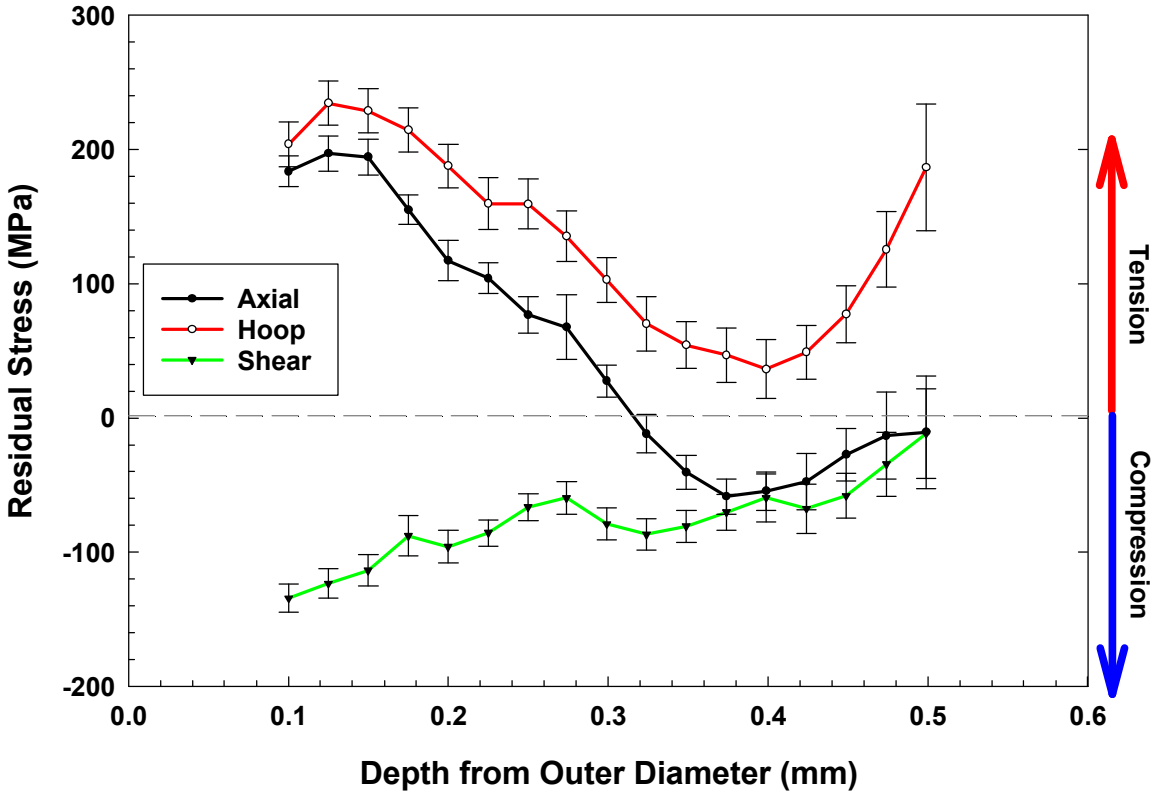






Residual Stresses in Circumferential Weld (Centerline)

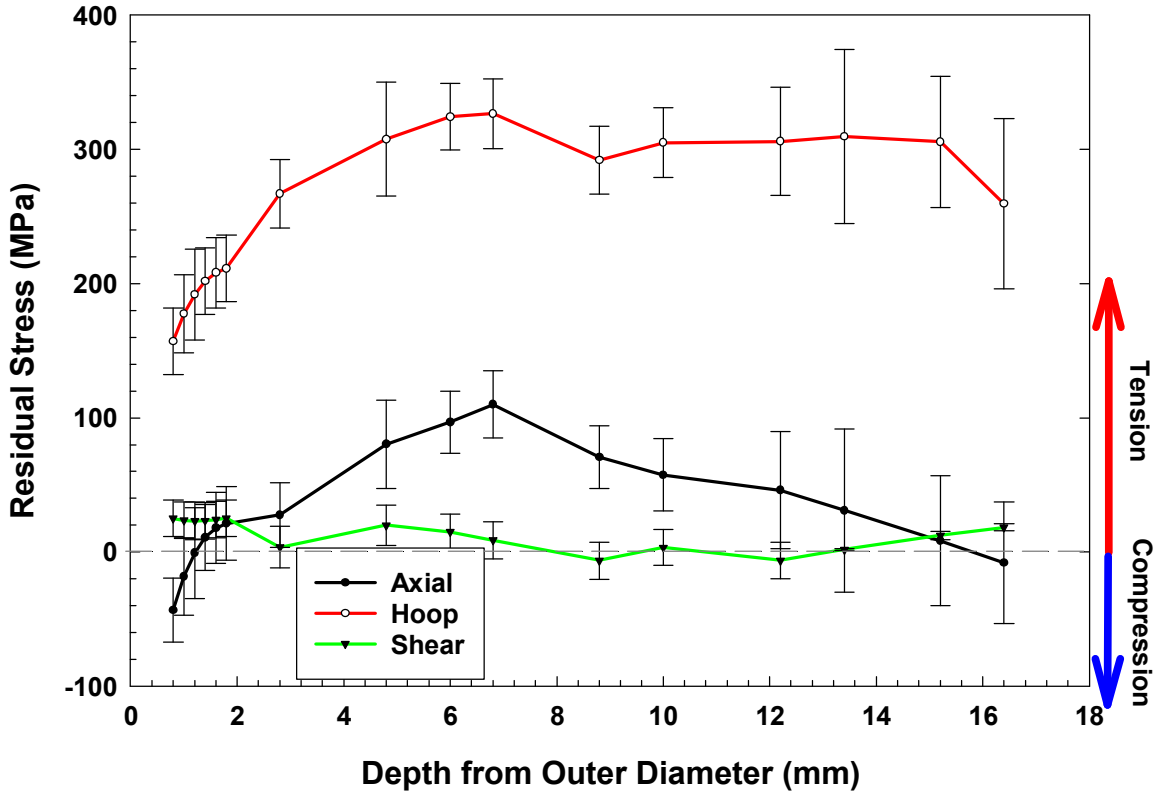
- iCHD used to assess stress state in region very close to the surface of the container (on the OD)



- Both axial and hoop stresses strongly tensile near surface
- iCHD measurements likely to exhibit some positional variability
  - Single test location
  - Consider qualitatively

Residual Stresses in Circumferential Weld (Centerline)

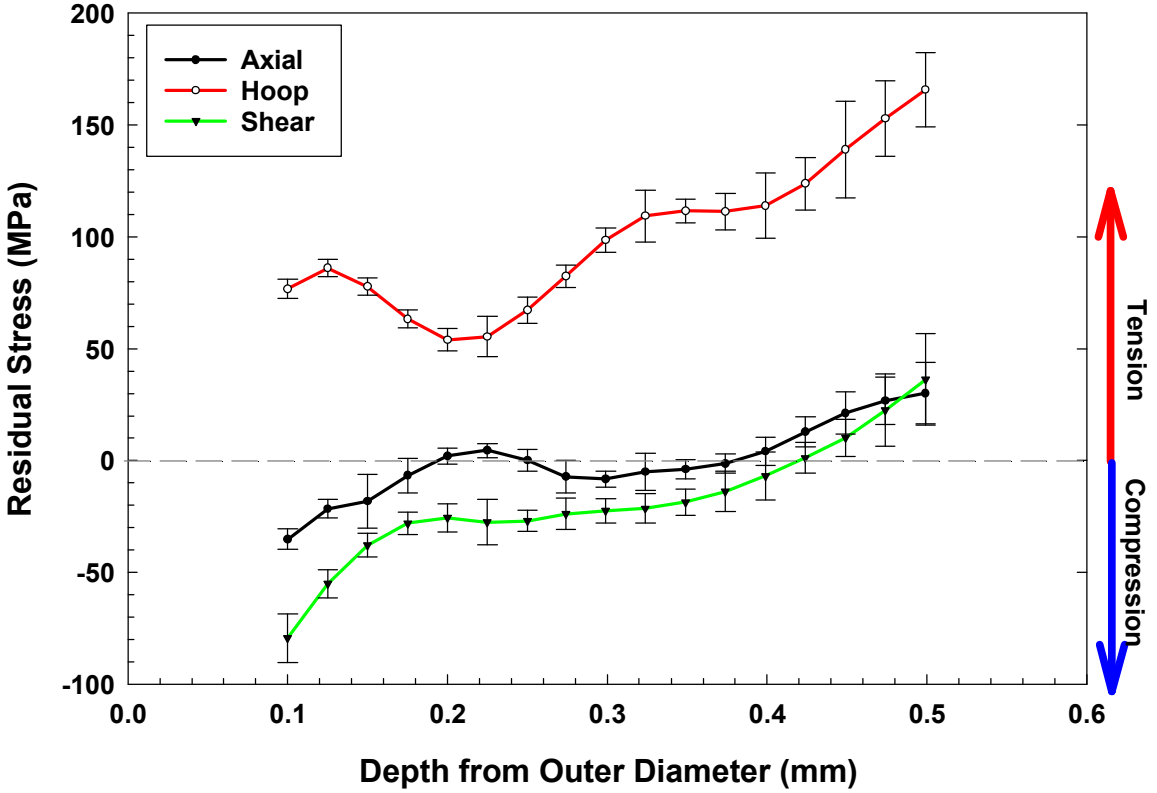
- Due to large stresses present in weld, material will yield as the core is cut for traditional DHD – as a result, incremental DHD measurements are made



- DHD near surface, iDHD in bulk
- Hoop stress strongly tensile through wall
- Axial stress compressive at surfaces, tensile through bulk
- Single measurement location

Residual Stresses in Circumferential Weld (HAZ)

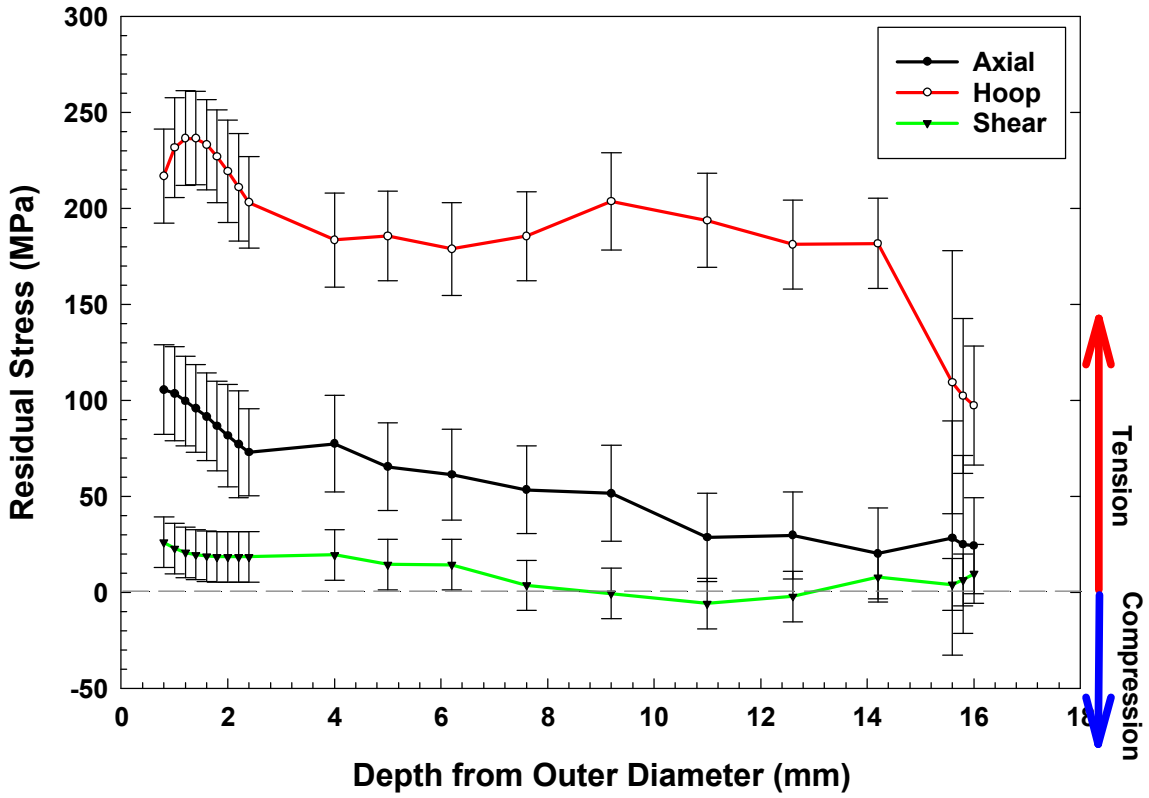
- iCHD used to assess stress state in region very close to the surface of the container (on the OD)



- Hoop stress tensile at surface, increasing with depth
- Axial stress low and slightly compressive, becoming tensile with depth
- iCHD measurements likely to exhibit some positional variability
  - Single test location
  - Consider qualitatively

Residual Stresses in Circumferential Weld (HAZ)

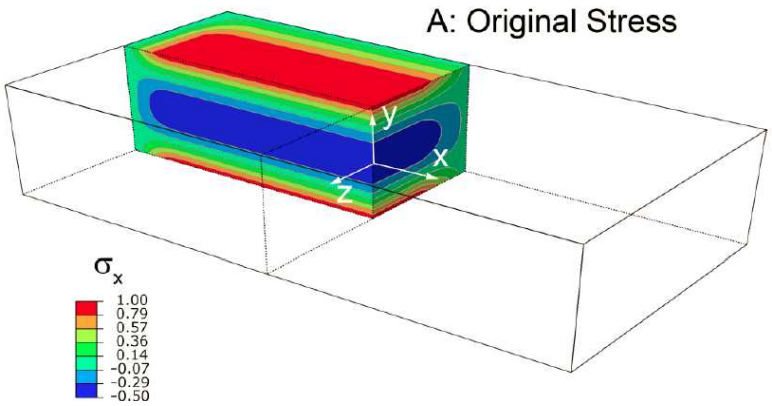
- Due to large stresses present in weld, material will yield as the core is cut for traditional DHD – as a result, incremental DHD measurements are made



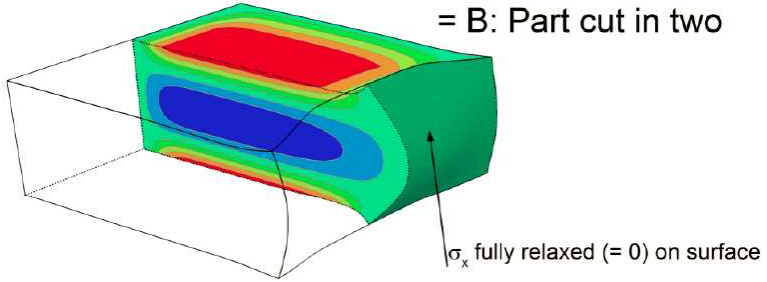
- DHD near surface, iDHD in bulk
- Hoop stress strongly tensile through wall
- Axial stress lower in magnitude, but tensile through thickness
- Single measurement location

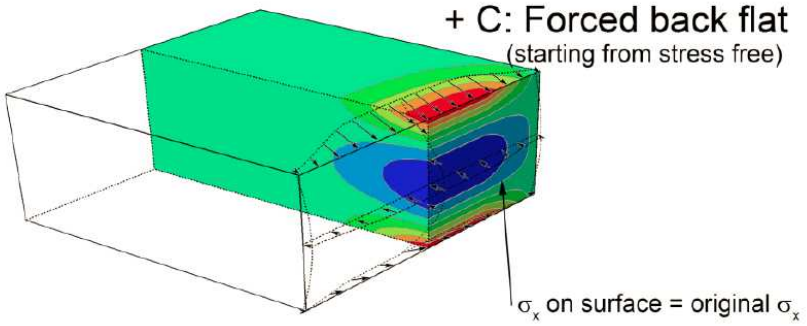
Additional Measurements Will Include Contour Measurements

Start with material containing a residual stress



Cut across region to be characterized – material distorts due to loss of constraint



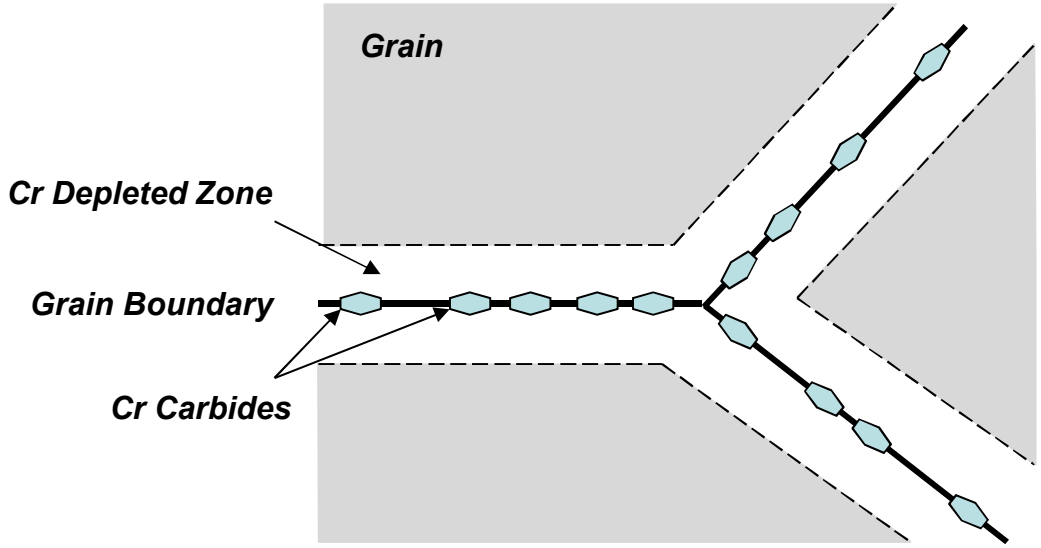


Based upon the distortion of the cut surface, the original stress state can be calculated

M. B. Prime and A.T. DeWald, 2013, "The Contour Method," Chapter 5 in Practical Residual Stress Measurement Methods, G. S. Schajer, (ed.), Wiley-Blackwell, pp. 109-138.

- Get two dimensional map of initial stress state (can combine with XRD for 3-D)
- Destructive, requires careful monitoring as the sample is sectioned
- Recent work by VEQTER has revealed these may be significantly impacted by yielding for high stress regions (e.g., a weld)

Moving Forward: What about sensitization in the weld HAZ?



- **Welding carbon bearing austenitic stainless steels such as 304 will result in sensitization**
- **Increased susceptibility to localized corrosion and SCC**
  - Active path along grain boundaries
- **Sensitization of HAZ will be mapped through thickness via double loop EPR**

Summary and Future Direction

- **Residual stress measurements in progress at VEQTER – anticipated to complete in early 2016**
  - Repair region
  - Contour measurements
  - Stress relaxation during sample cutting – how small can the coupons be?
- **Are there regions which we are not covering that should be covered?**
  - Now is the time to speak up if there is data you need!
- **Once stress analyses are complete, container will be subdivided and distributed**
  - Of considerable interest to UFD, NEUP, and EPRI
  - Information will be solicited from each group to identify where samples are needed and the data that they will yield
  - Prioritized list of coupons will be assembled, then material will be distributed