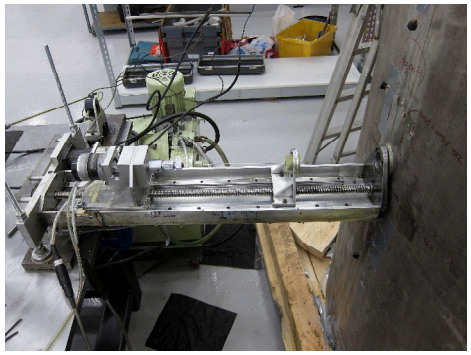
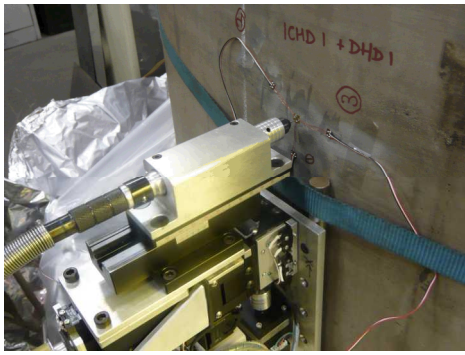
Exceptional service in the national interest

SAND2016-10860C

Sandia National Laboratories



Understanding the Risk of Chloride Induced Stress Corrosion Cracking of Interim Storage Containers for the Dry Storage of Spent Nuclear Fuel: Residual stresses in typical welded containers

D.G. Enos and C.R. Bryan
Sandia National Laboratories
Albuquerque, NM

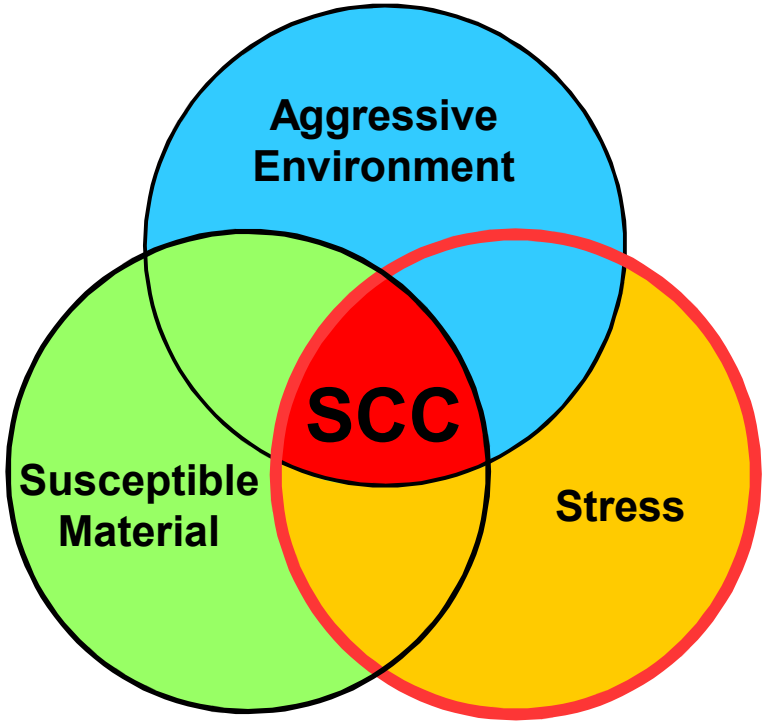
Materials Science and Technology, 2016
October 27th, 2016

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND NO. 2016-1939C

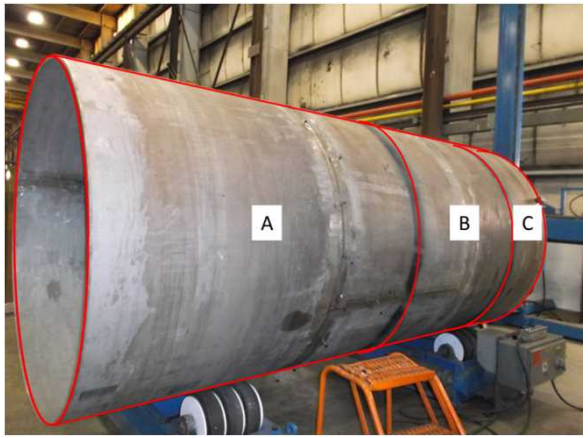
Degradation Mechanism of Concern: Stress Corrosion Cracking (SCC)

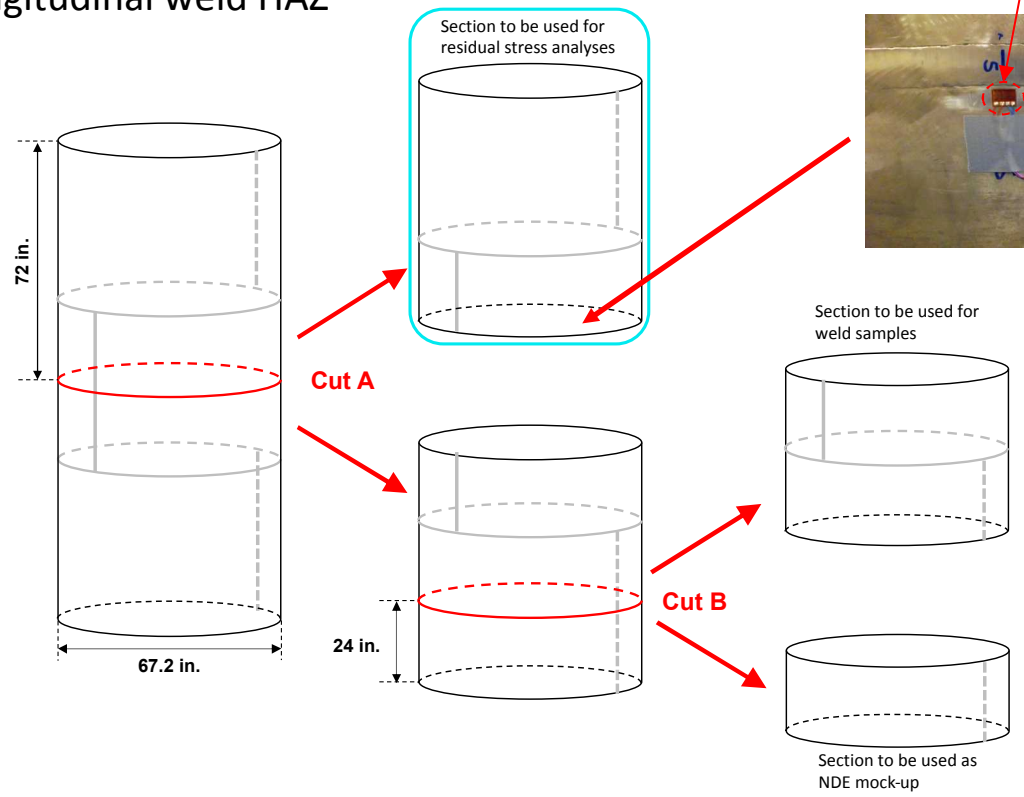


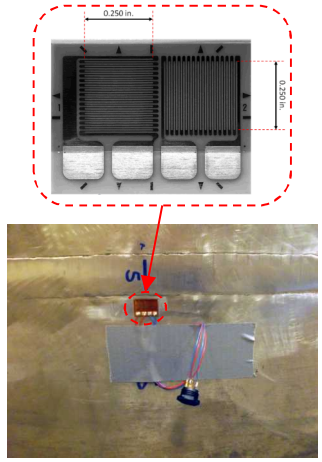
Goal: Determine the nature of the residual stress state associated with the container and associated welds for a representative interim storage container.

Residual Stress Measurement

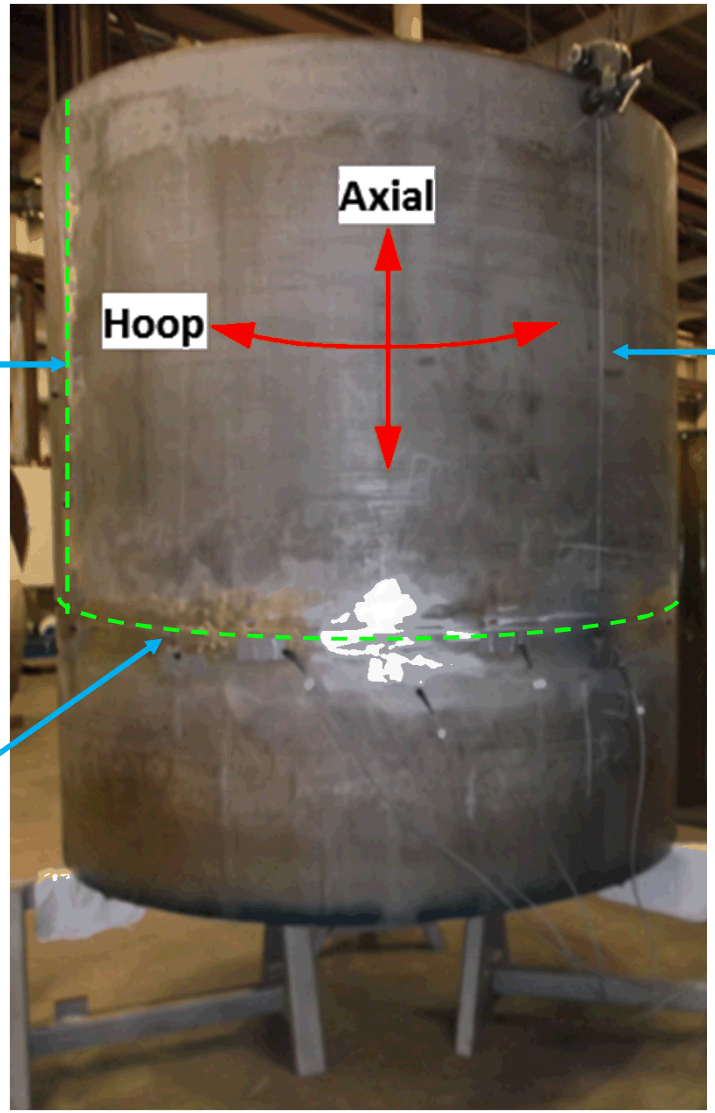
- Full-scale mockup container simulating a NUHOMS 24P container (produced at Ranor using procedures established for containers at Calvert Cliffs ISFSI)
- 304L with 308L filler material, SAW welding method
- Several key areas will be discussed here
  - Base metal (far from welds)
  - Circumferential and Longitudinal weld HAZ
  - Weld Repair







Mock-Up Container

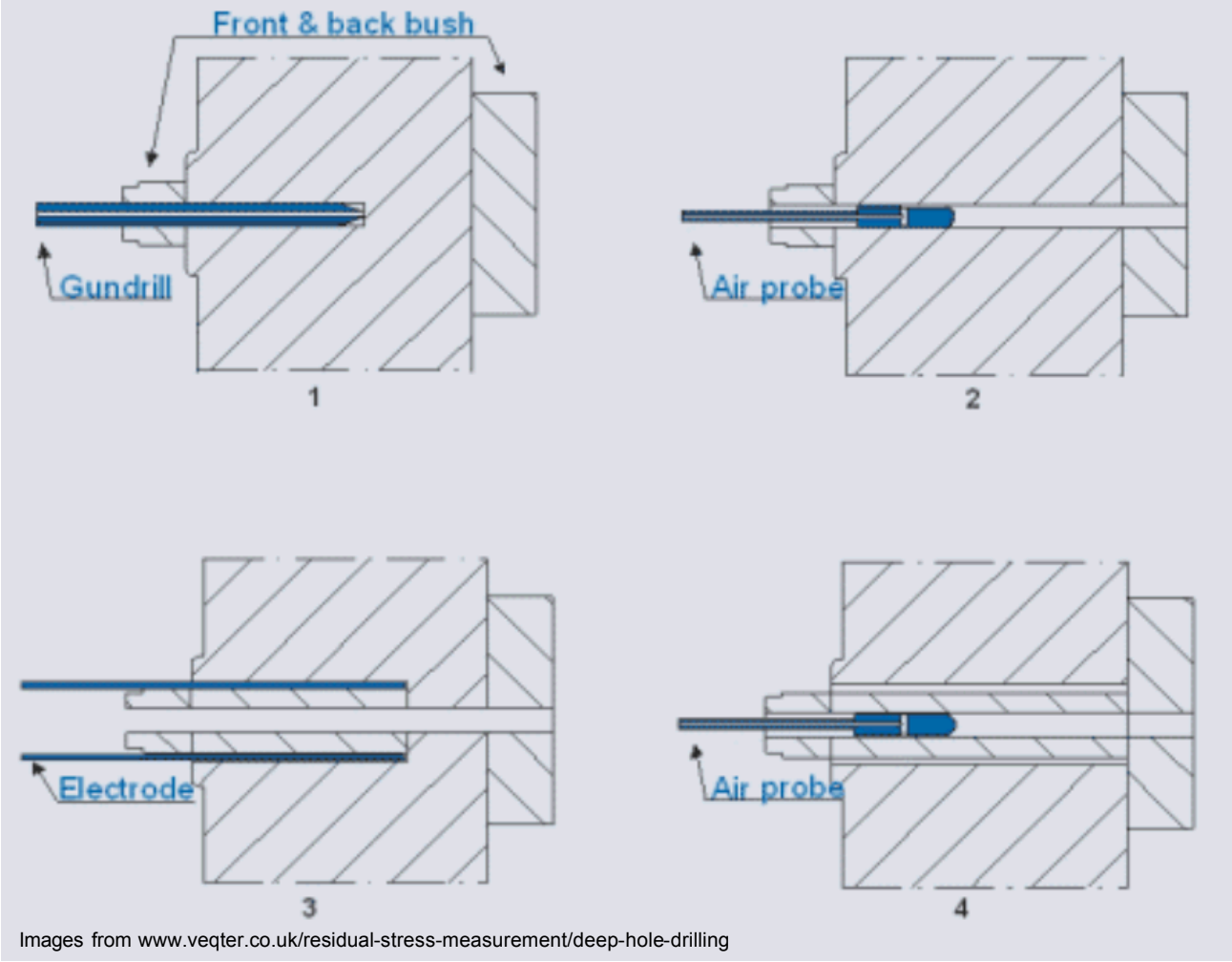


Longitudinal Weld

Stress Nomenclature

Circumferential Weld

Deep Hole Drilling

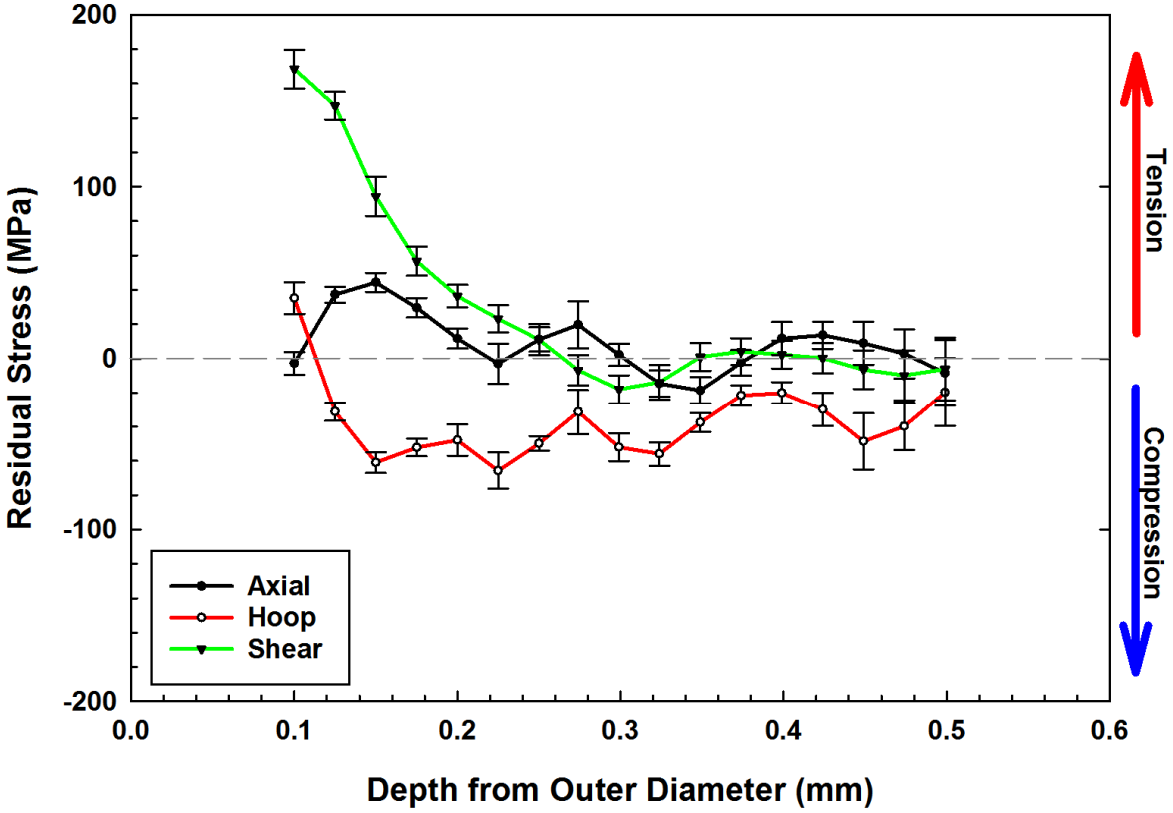


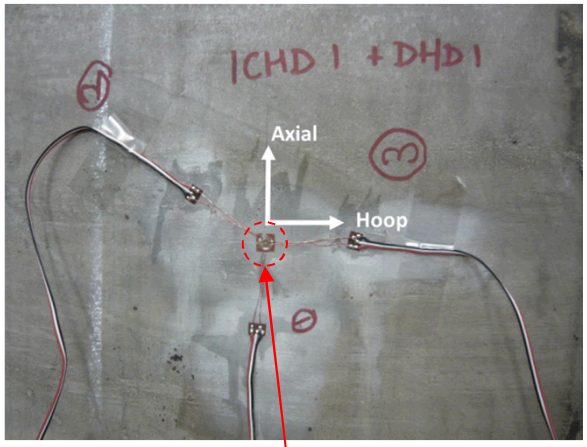
Images from www.veqter.co.uk/residual-stress-measurement/deep-hole-drilling

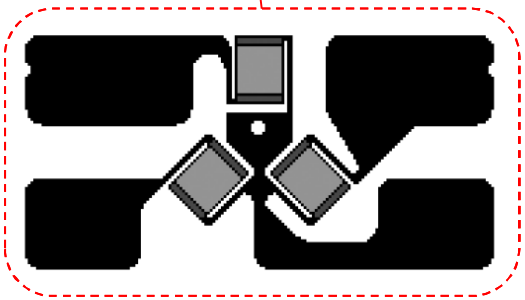
- Provides a one dimensional map of initial stress state without cutting up structure
- Semi-destructive, labor intensive ($)

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

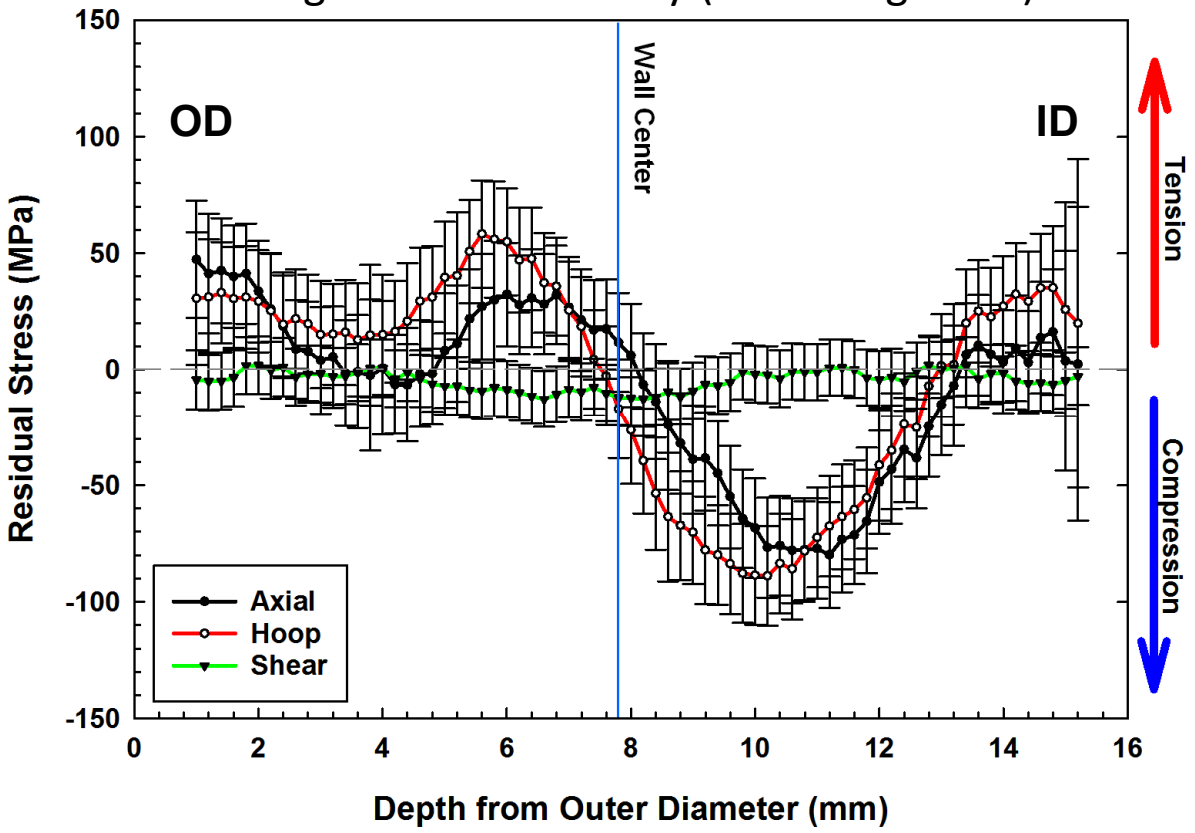


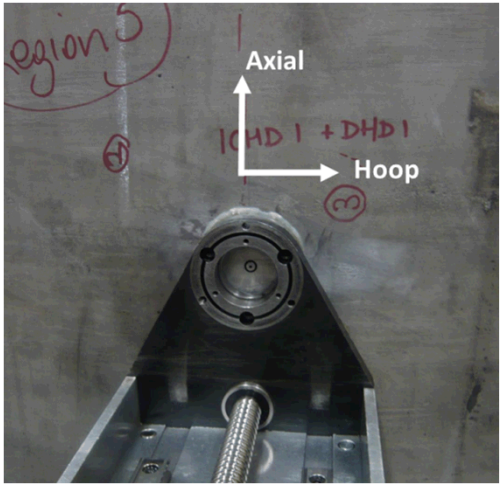




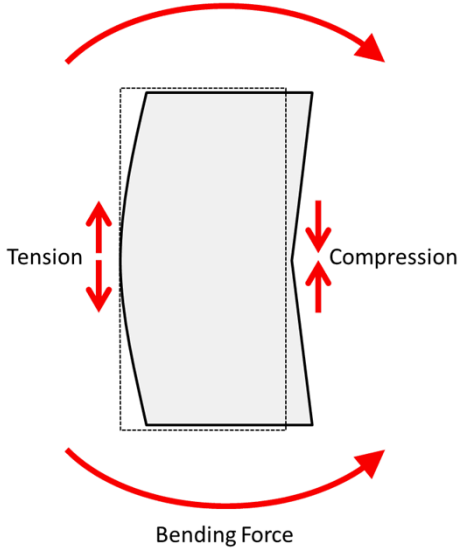
Residual Stresses in the Base Metal Far from Welds

- Stress state consistent with forming process
  - Stresses on OD tensile
  - Stresses in ID compressive
  - Through wall SCC unlikely (no driving force)





Bending Force

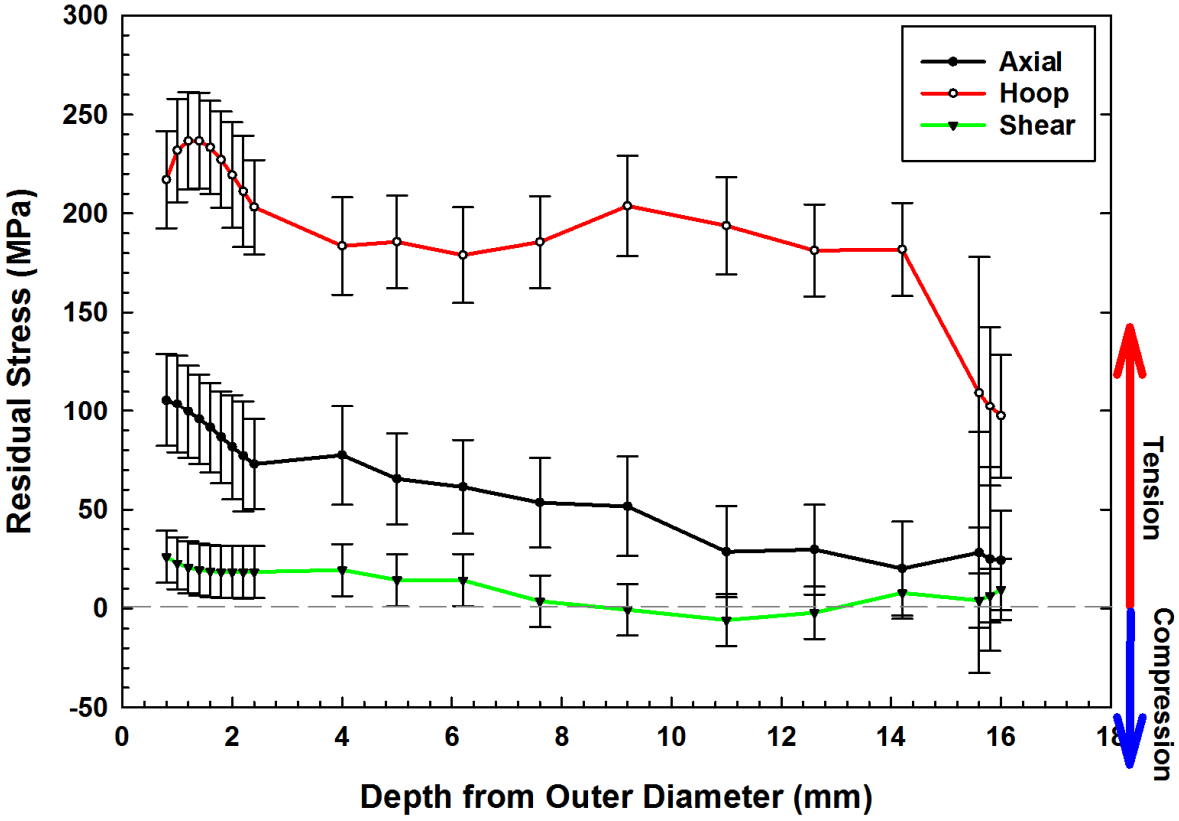


Bending Force

Note – locations where temporary supports have been welded and removed will be different…

Residual Stresses in Circumferential Weld (HAZ)

- HAZ is region where sensitization is likely, rendering the material more susceptible to localized corrosion and intergranular attack

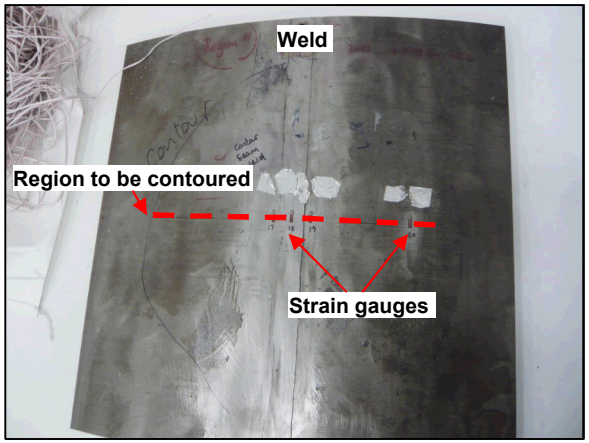


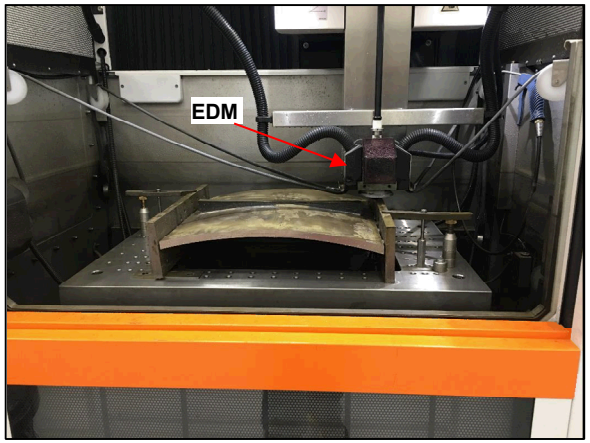
- 4mm from OD weld toe
- Hoop stress strongly tensile through wall
- Axial stress lower in magnitude, but tensile through thickness
- Single measurement location

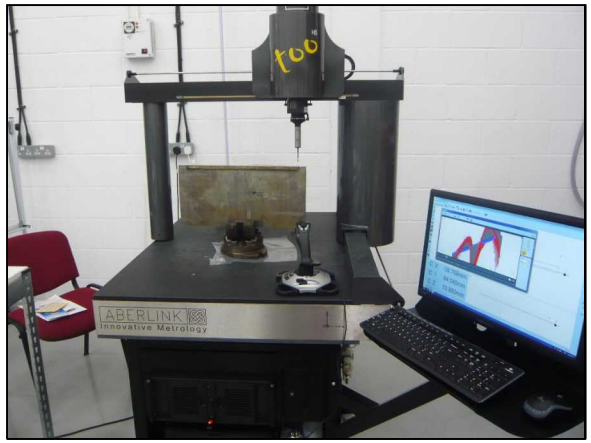
- ***Strongly tensile residual stress through thickness of the container wall***

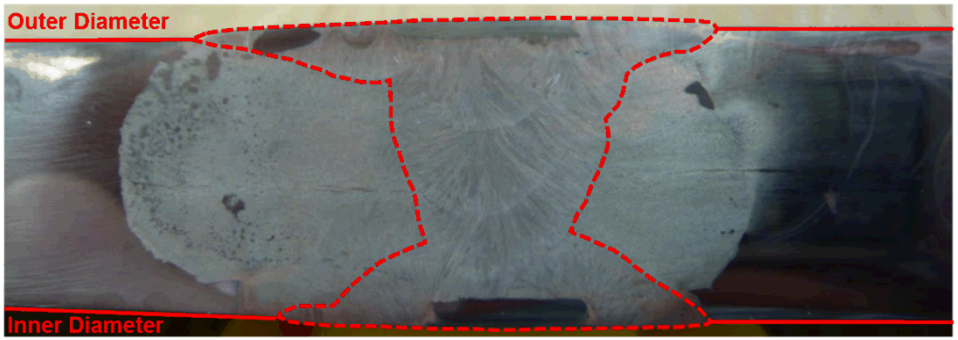
Contour Method

- Region is removed and cut
- Stress relaxation results in displacement of the cut face
  - Deviations from “flat” used to calculate pre-existing residual stress
- Provides a surface map of the residual stress

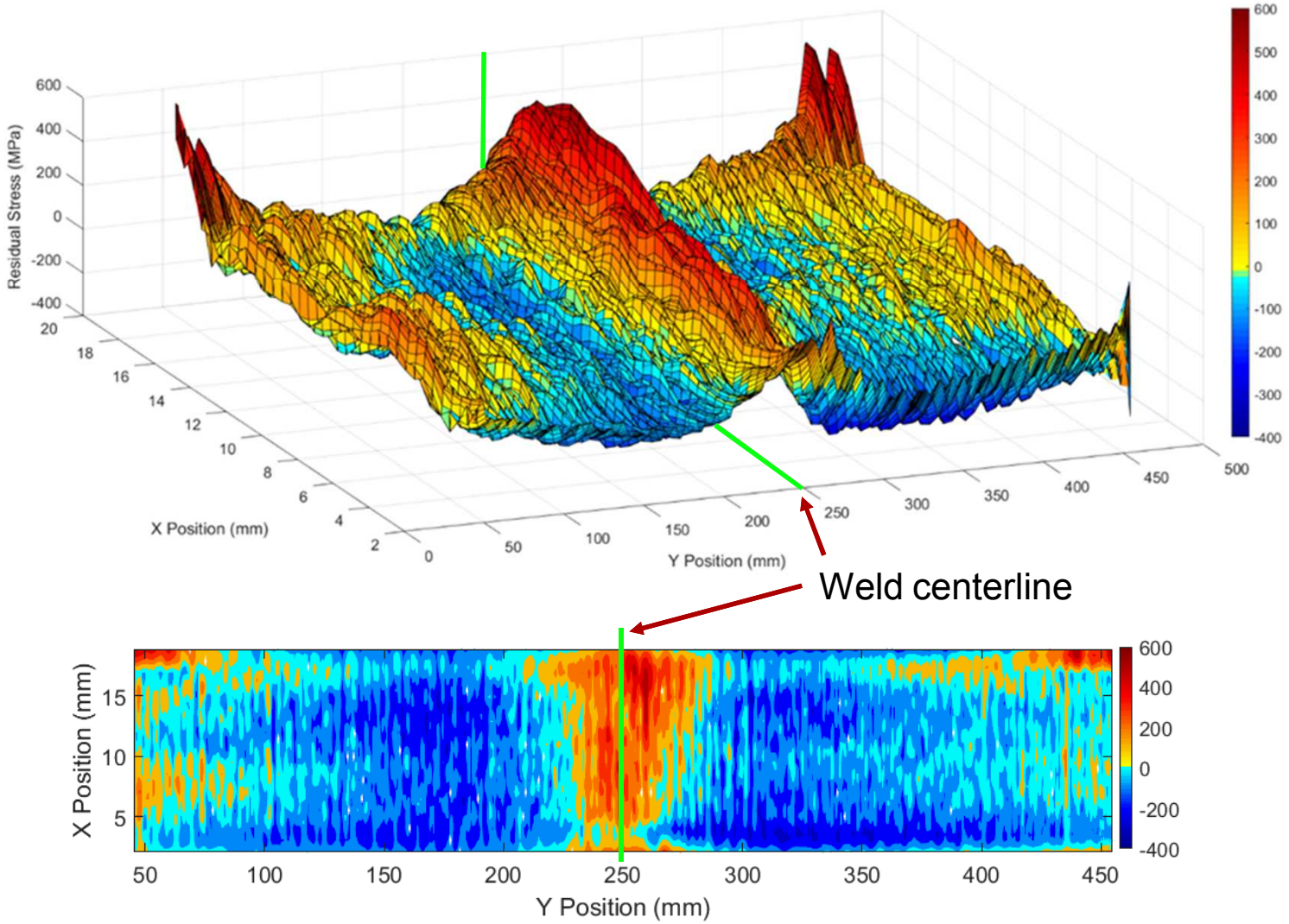






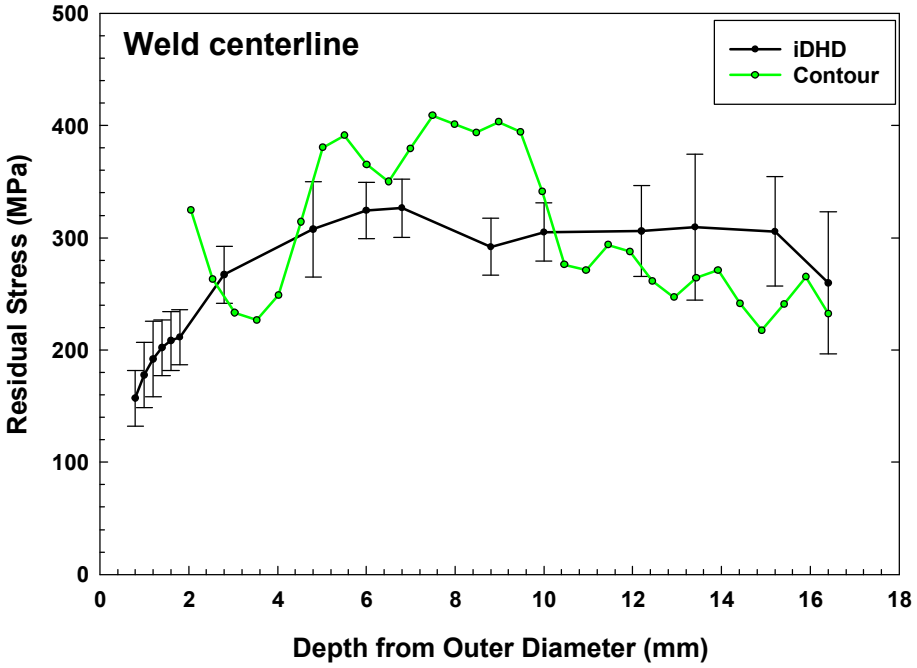


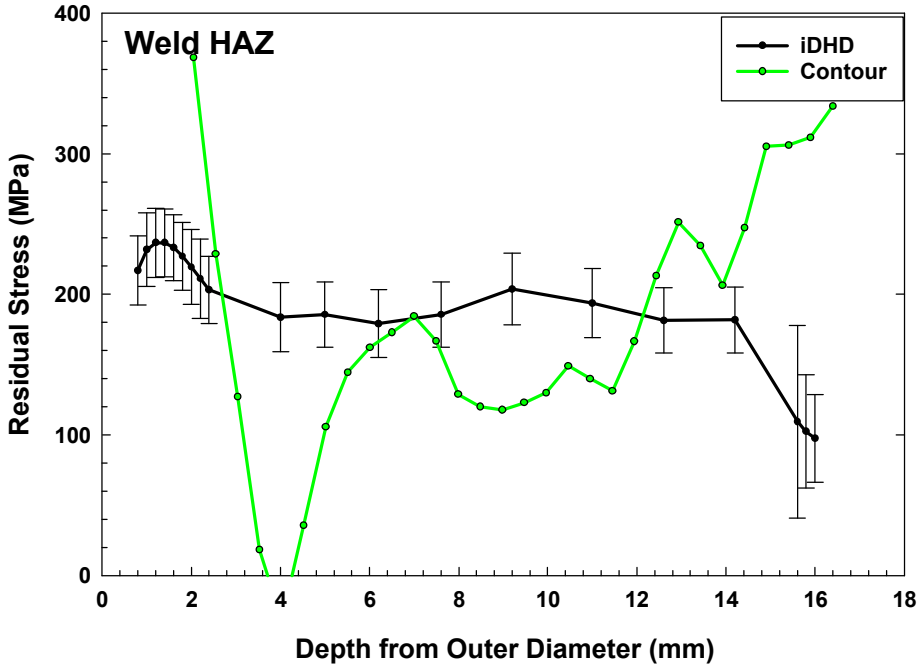
Residual Stresses in Circumferential Weld via Contour Method



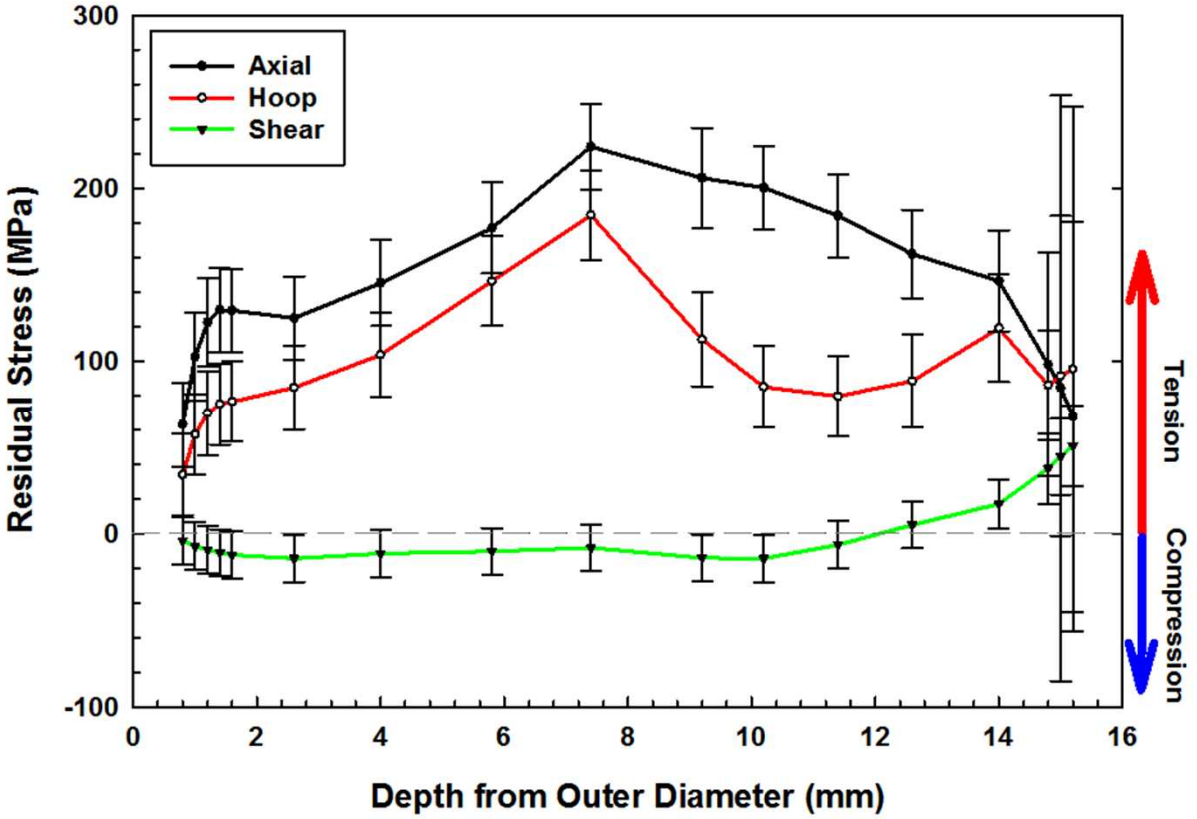
Comparison of iDHD and Contour Measurements for Circumferential Weld

- Hoop stress assessed via contour method compares well with similar measurements from iDHD





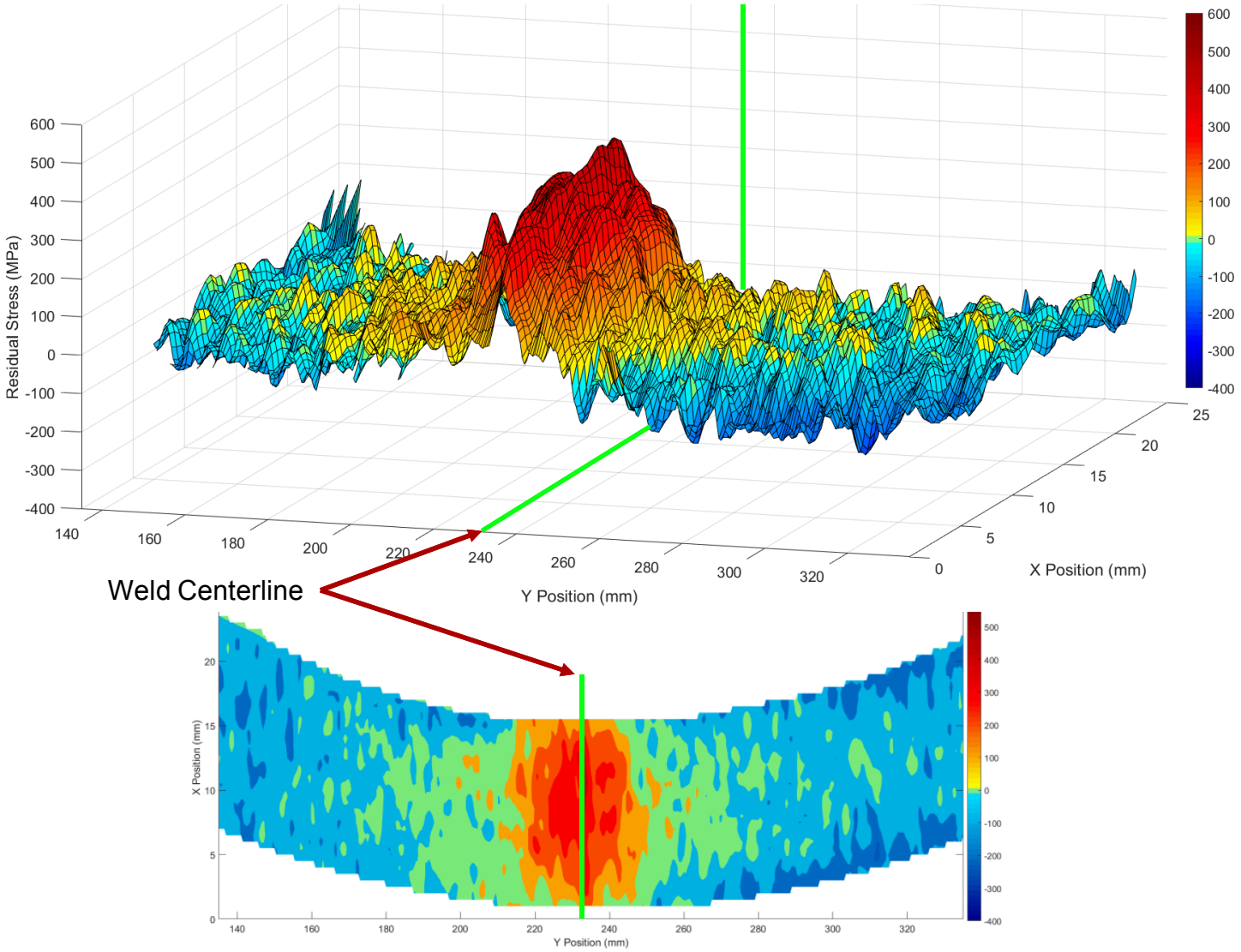
Residual Stresses in Longitudinal Weld (HAZ)



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

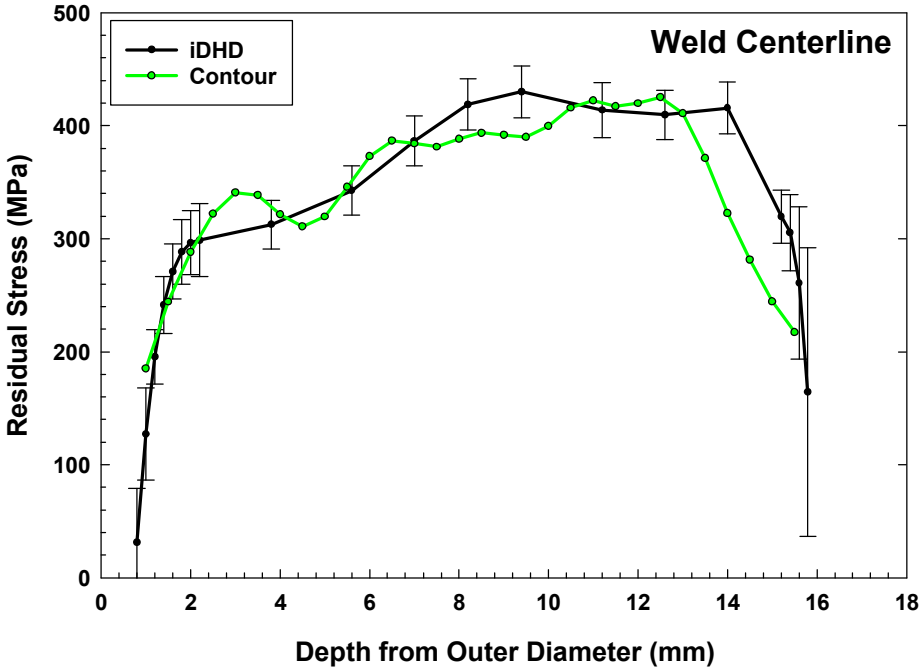
- ***Strongly tensile residual stress through thickness of the container wall***

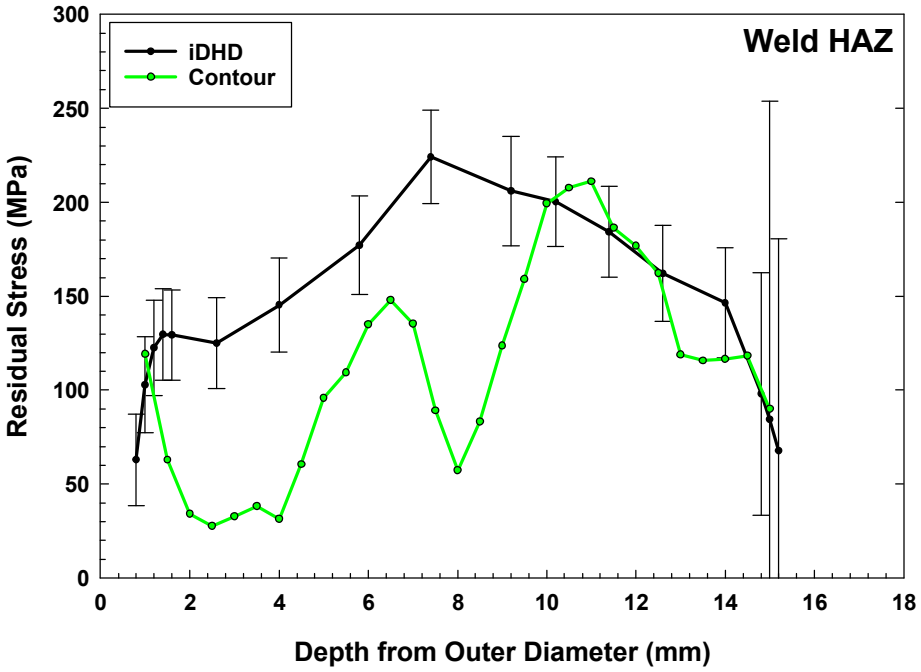
Residual Stresses in Longitudinal Weld via Contour Method



Comparison of iDHD and Contour Measurements for Circumferential Weld

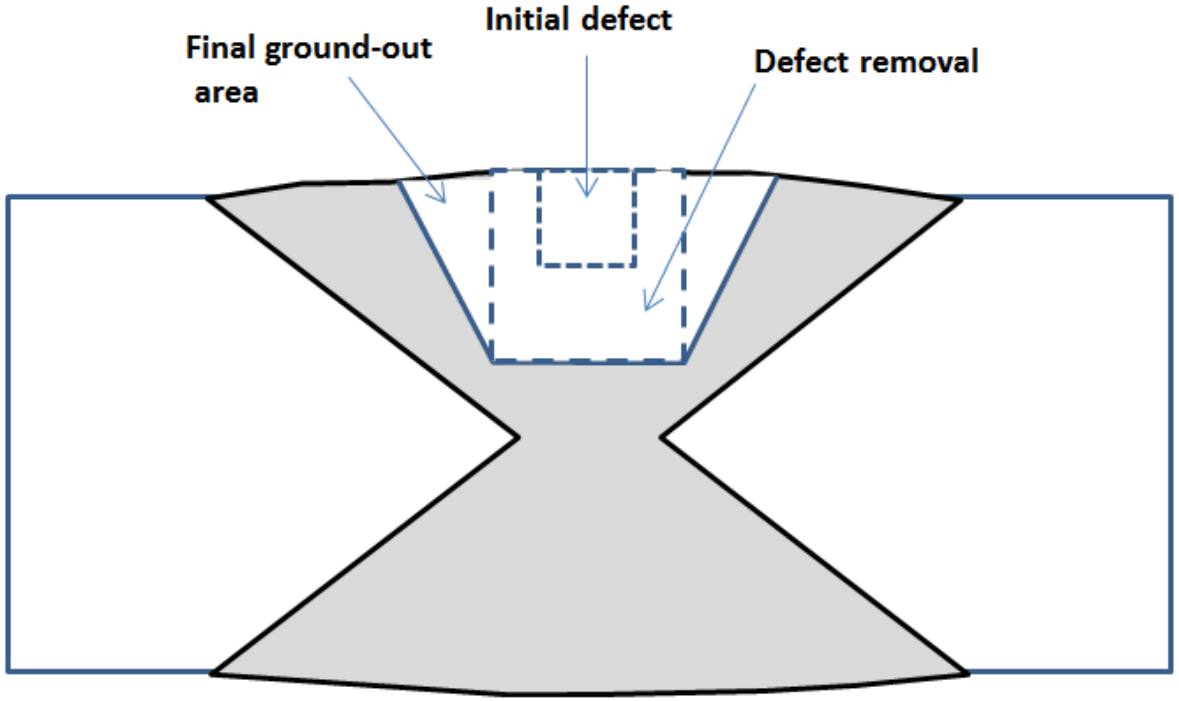
- Axial stress assessed via contour method compares well with similar measurements from iDHD





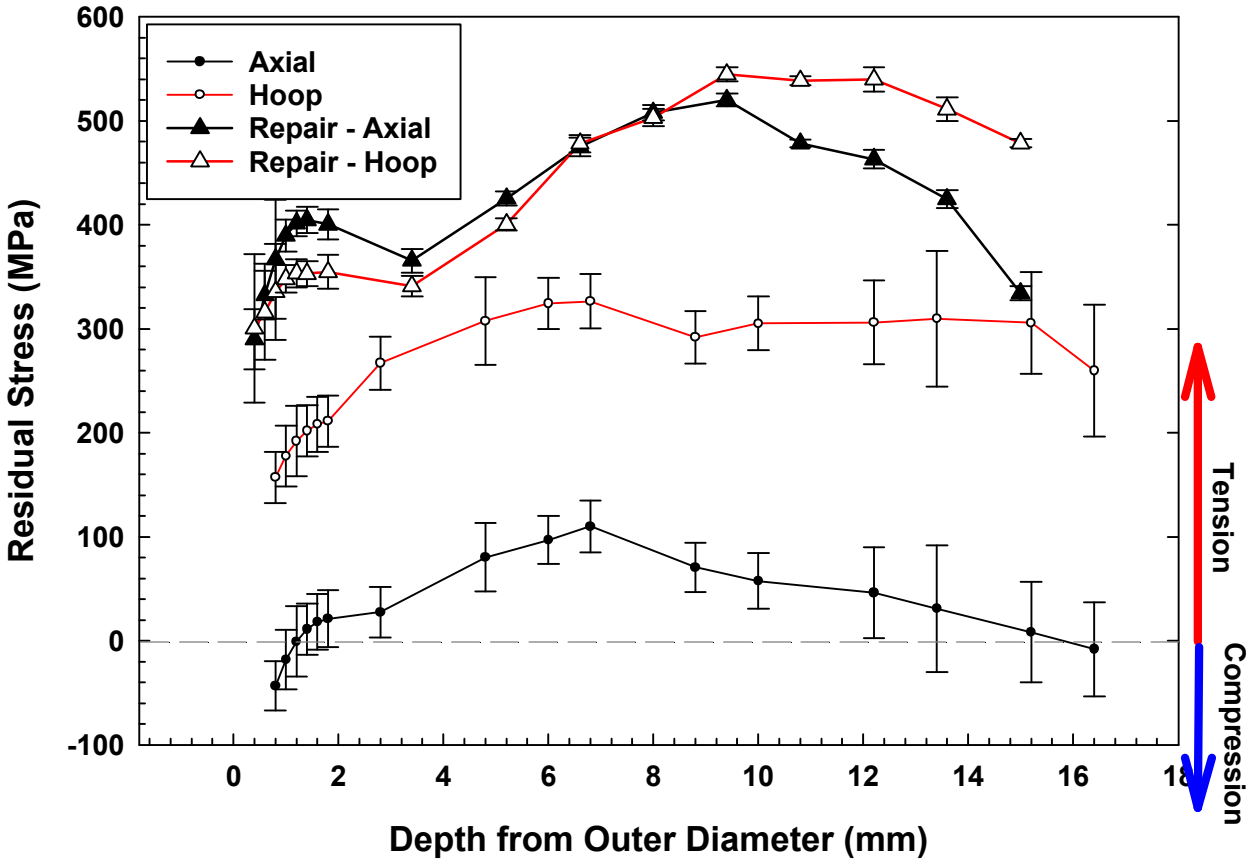
Weld Repairs on Circumferential Welds

- 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.

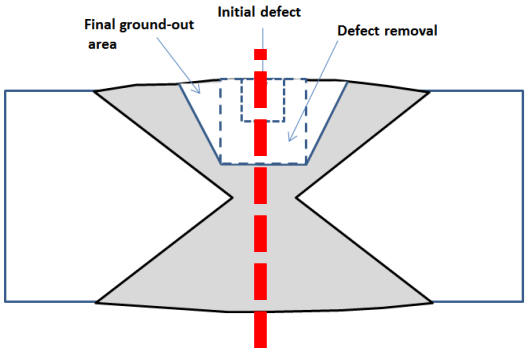


Residual Stresses in Repair: Circumferential Weld (Centerline)

- Dramatic increase in magnitude of stresses, particularly in the axial direction, when a repair is made

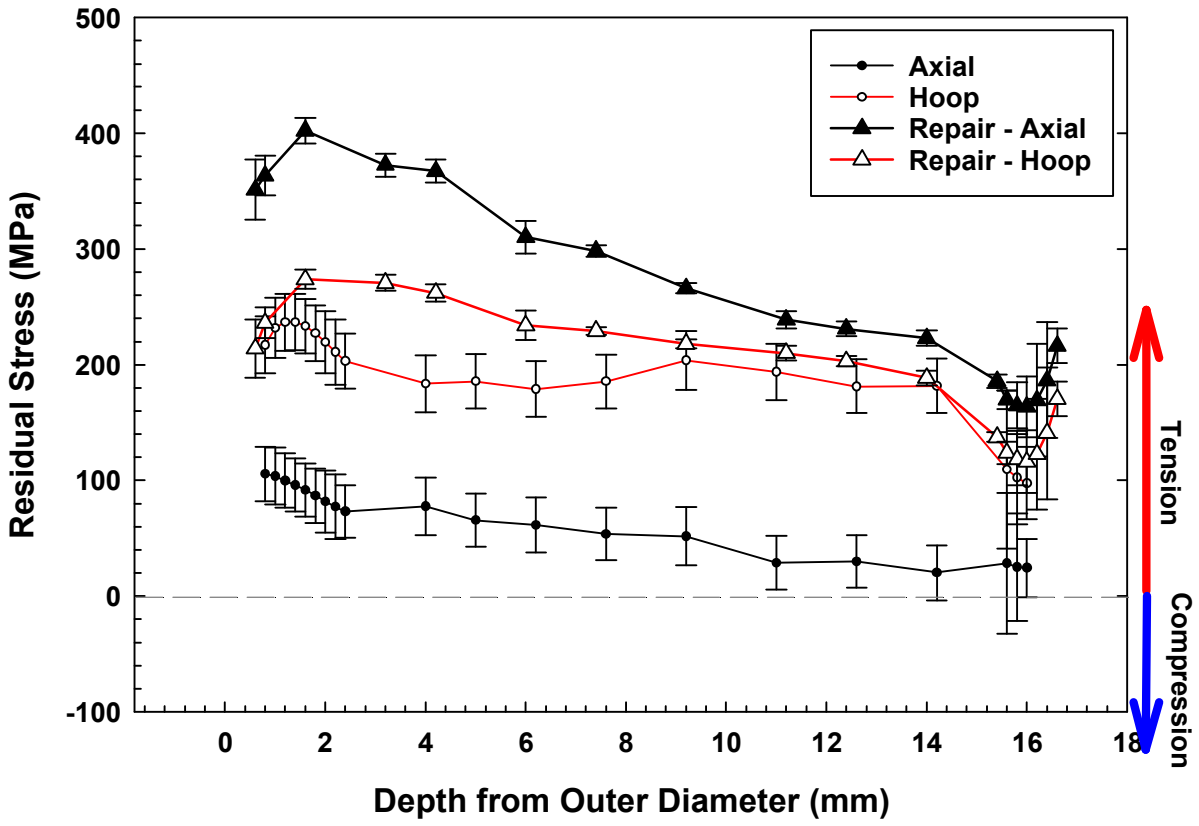


- DHD near surface, iDHD in bulk
- Both axial and hoop stresses dramatically increased in weld repair

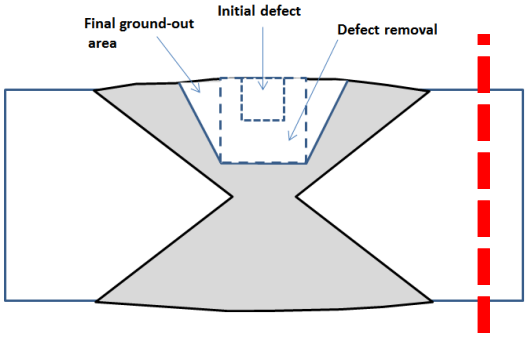


Residual Stresses in Repair: Circumferential Weld (HAZ)

- Dramatic increase in magnitude of stresses, particularly in the axial direction, when a repair is made

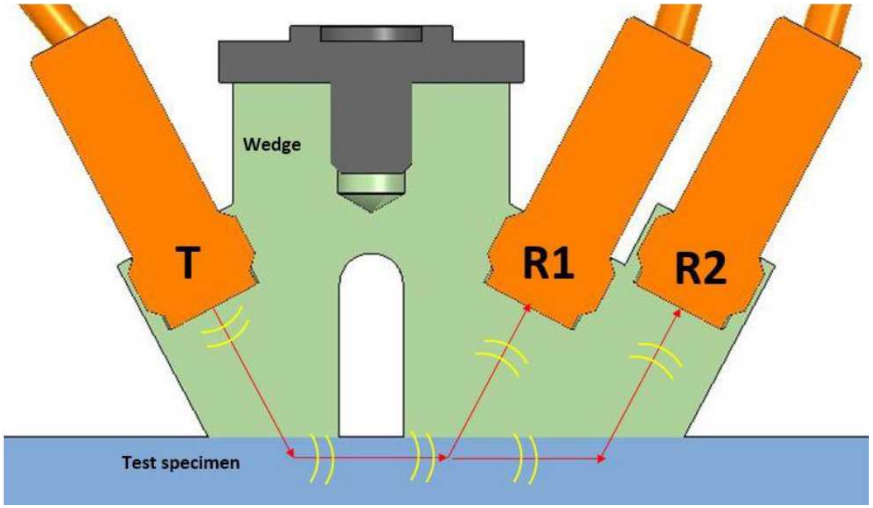


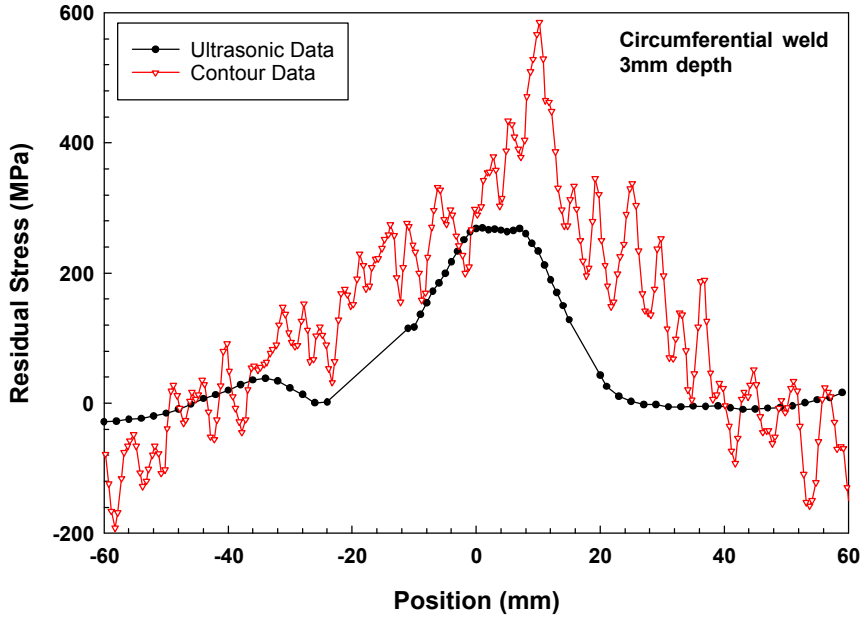
- 4mm from weld toe
- DHD near surface, iDHD in bulk
- Hoop stress increased in region of weld repair
- Axial stress dramatically increased in weld repair
- Larger impact at OD



Non-Destructive Measurement of Residual Stress via Ultrasonic Techniques

- Speed of sound through a material changes with stress
- Technique measures transit time of a sound wave through a well defined volume of material





- Insensitive to very localized variations in stress
- Ability to inspect structure for regions where stress is elevated (such as repair regions) without damaging structure

Conclusions

- Tensile stress exists through thickness for all welds evaluated
- Weld repairs exacerbate the stresses observed
- Contour measurements were consistent with the deep hole drilling measurements
  - 50mm for circumferential welds
  - 25mm for longitudinal welds
- Ultrasonic measurements offer a non-destructive technique through which a structure can be qualitatively assessed