# Effect of Materials on Weld Residual Stress of Ship Structures

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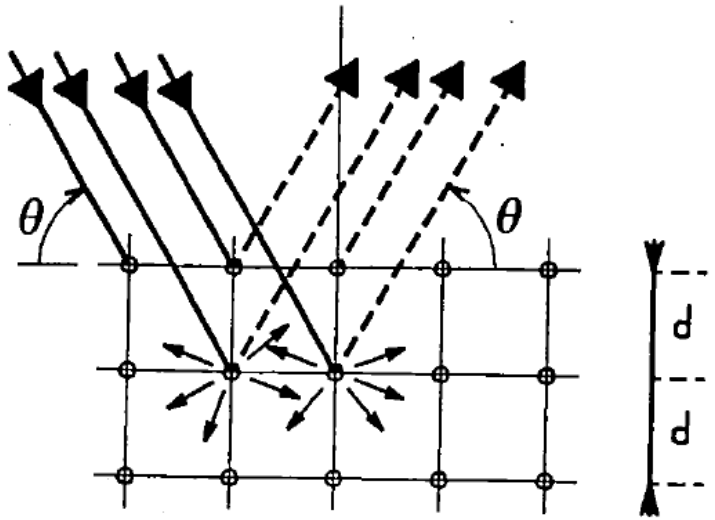
# Presentation Outline

- Introduction
- Residual Stress Measurement Methods
- Laboratory Residual Stress Measurements
- Shipyard Residual Stress Measurements
- Finite Element Analysis Study
- Conclusions

# Introduction

- Weld residual stress plays an important role in the production and operating performance of ship structures.
- Materials including DH36, HSLA-65, HSLA-80, HSLA-100, HY-80, and HY-100 have been widely used to build ship structures.
- The effect of materials on weld residual stress was studied by making measurements and performing finite element simulations.

# Residual Stress Measurement Method: X-Ray Diffraction

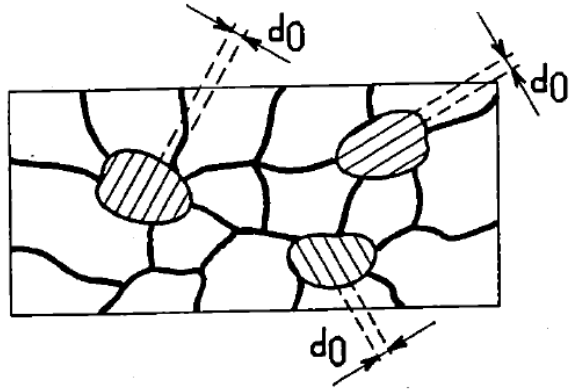



Bragg's law – X-ray diffraction can be observed in θ-direction if

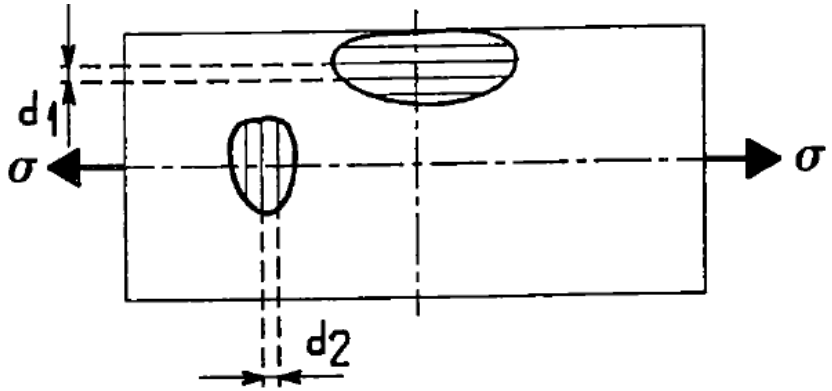
$$n\lambda = 2d\sin\theta$$

$$\varepsilon = \frac{d - d_0}{d_0}$$

*Ref. Lu, Handbook of measurement of residual stresses*

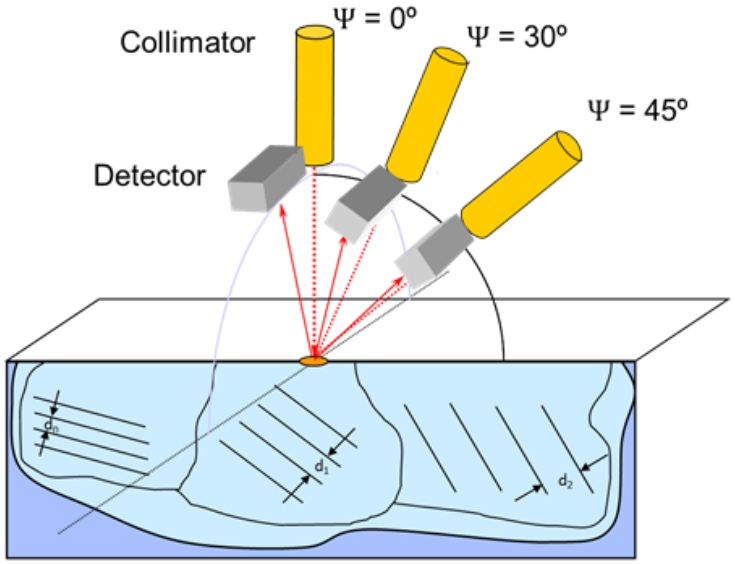



The interplanar distance $d_0$ is the same for all family planes, in every direction, when there is no stress in material.



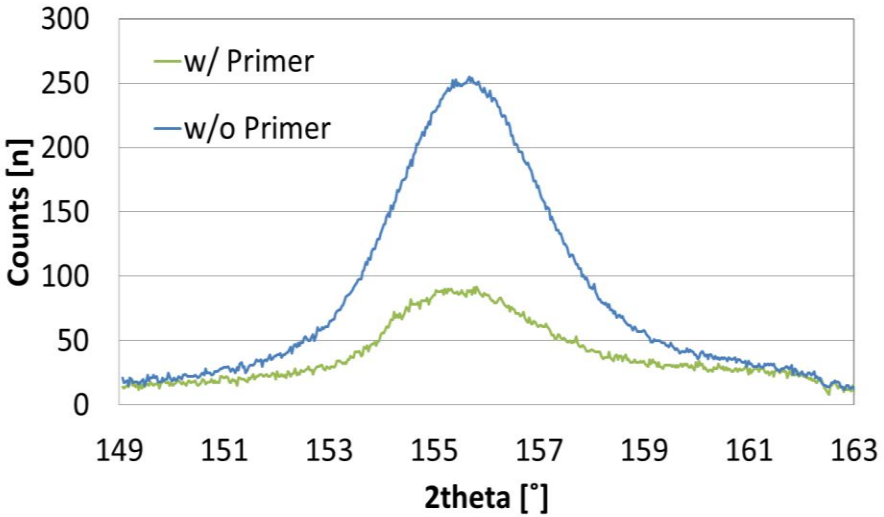

This distance varies in every direction, in presence of stresses.

# Residual Stress Measurement Method: Portable Equipment



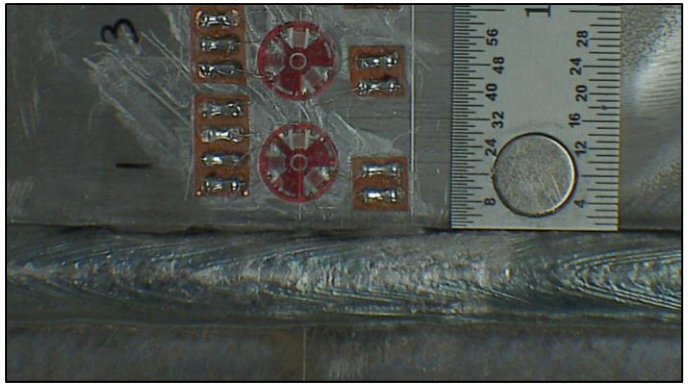

Portable equipment

Comparison of returned X-ray beam with and without primer on plate

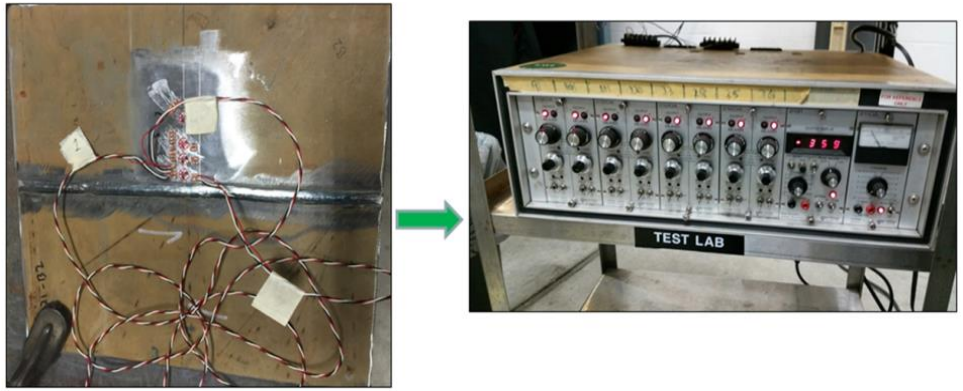



For measurement at each point, the measurement head (collimator and detector) rotates to scan the grain structures in the material. When Bragg's law is fulfilled, the detector can receive the peak of returned X-ray.

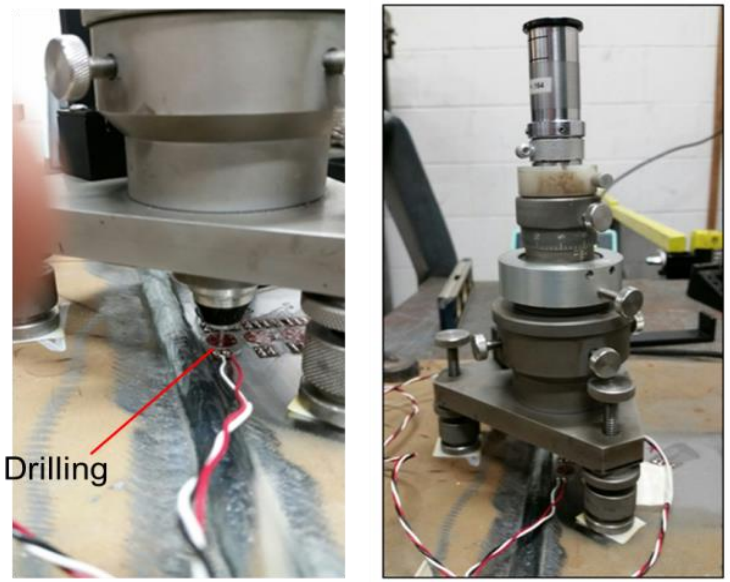
# Residual Stress Measurement Method: Hole Drilling Method



Rosettes



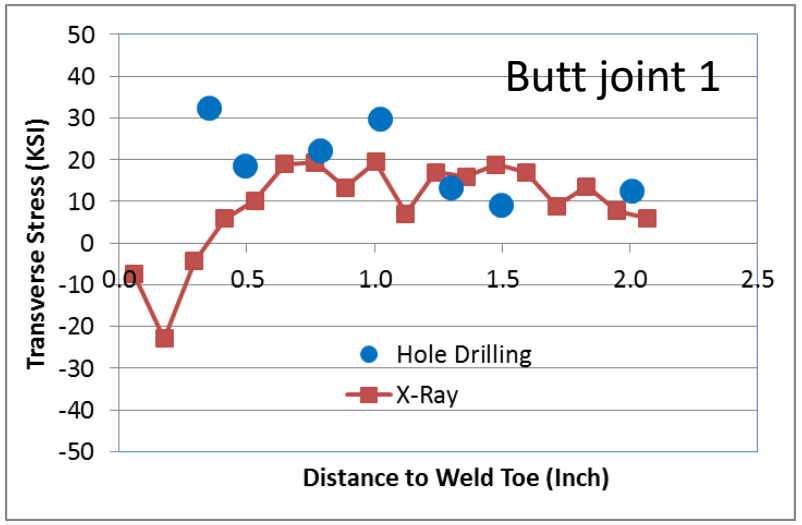

A data acquisition system connected to rosettes for recording strain




Hole drilling and an optical microscope

Measurements were conducted according to the ASTM standard test method for determining residual stresses by the hole drilling strain gage method (E837-13a).

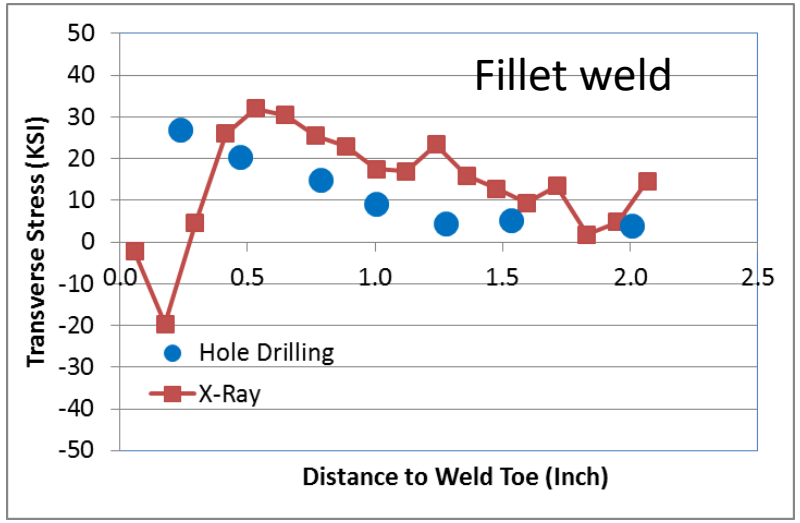
# Laboratory Residual Stress Measurement: Butt Joint

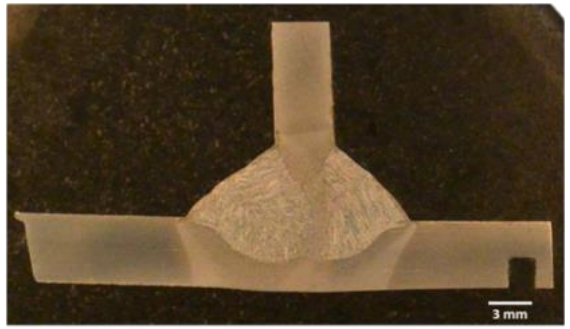


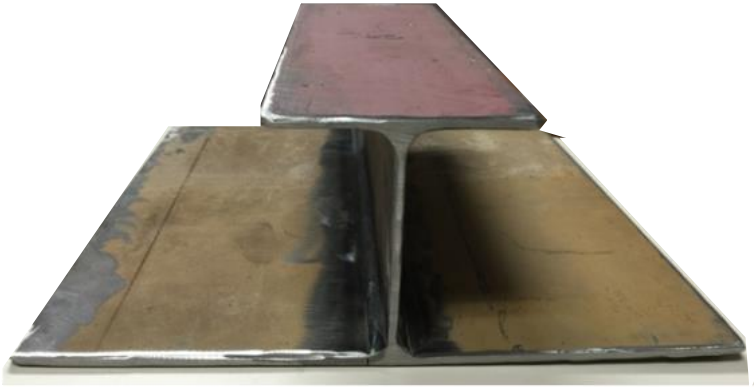



- Difference:
  - Hole drilling: diameter = 2mm and depth = 2mm
  - X-Ray: surface measurement
- Discussion
  - Overall trends were the same between two methods.
- Difference near the weld
  - X-Ray measured compressive stress induced by surface grinding
  - Hole drilling measured stresses were inside the plate.

# Laboratory Residual Stress Measurement: Fillet Weld



- Difference:
  - Hole drilling: diameter = 2mm and depth = 2mm
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  - X-Ray measured compressive stress induced by surface grinding
  - Hole drilling measured stresses are inside the plate.

# Laboratory Residual Stress Measurement: Discussion

- X-Ray can go through the primer on the plates to provide a reasonable residual stress measurement.
- The trends and magnitudes of X-ray measured residual stress are similar to the ones measured by hole drilling.

# Shipyard Residual Stress Measurement: Three Materials

- DH36 and HSLA-65 have similar compositions and mechanical strengths.
- HSLA-80 has higher strength than DH36 and HSLA-65.

Chemical Composition of Tested Materials

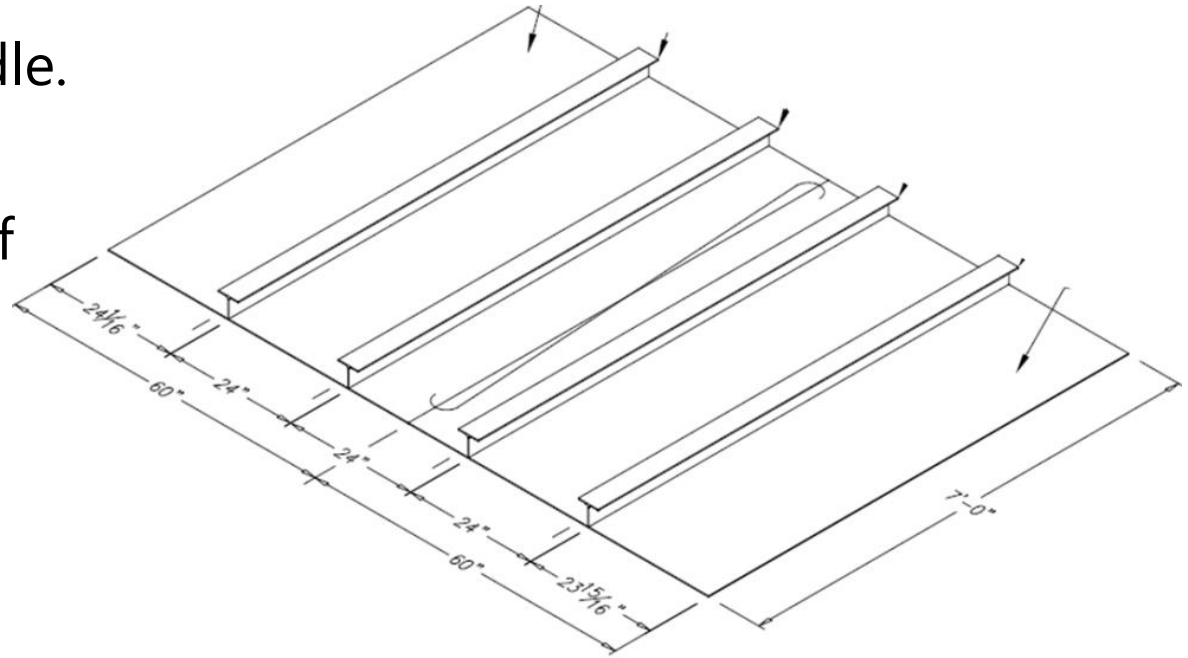
| | Composition, Weight (%) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Material** | C | Si | Mn | P | S | Al | Ti | Cu | Cr | Ni | Mo | V |
| **DH36** | 0.07 | 0.24 | 1.31 | 0.01 | 0.004 | 0.03 | 0.014 | 0.03 | 0.04 | 0.01 | 0.01 | 0.044 |
| **HSLA-65** | 0.08 | 0.28 | 1.49 | 0.01 | 0.001 | 0.03 | 0.013 | 0.01 | 0.03 | 0.01 | 0.01 | 0.073 |
| **HSLA-80** | 0.04 | 0.26 | 0.57 | 0.01 | 0.004 | 0.03 | 0.001 | 1.16 | 0.70 | 0.86 | 0.20 | 0.002 |

Strength of Tested Materials

| Grade | Yield Strength MPa (ksi) | Tensile Strength MPa (ksi) | Elongation, % 50mm (2-in) gauge |
|---|---|---|---|
| **ABS Grade DH36** | 534 (77.5) | 580 (84.1) | 40 |
| **HSLA-65** | 519.5 (75.4) | 615 (89.2) | 40 |
| **HSLA-80** | 638.5 (92.6) | 689.5 (100) | 26 |

# Panel Design

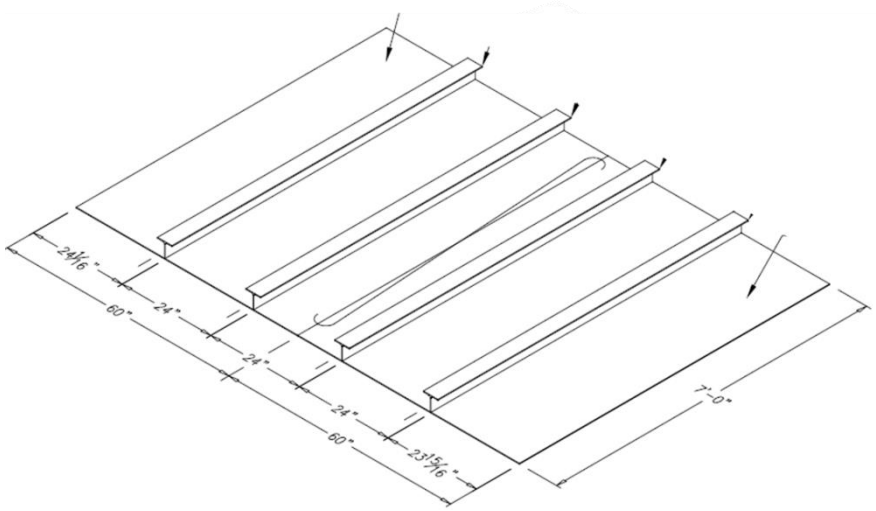
- Four stiffeners and a butt joint in the middle.
- Measurements were conducted on the smooth side (back) of the panel.

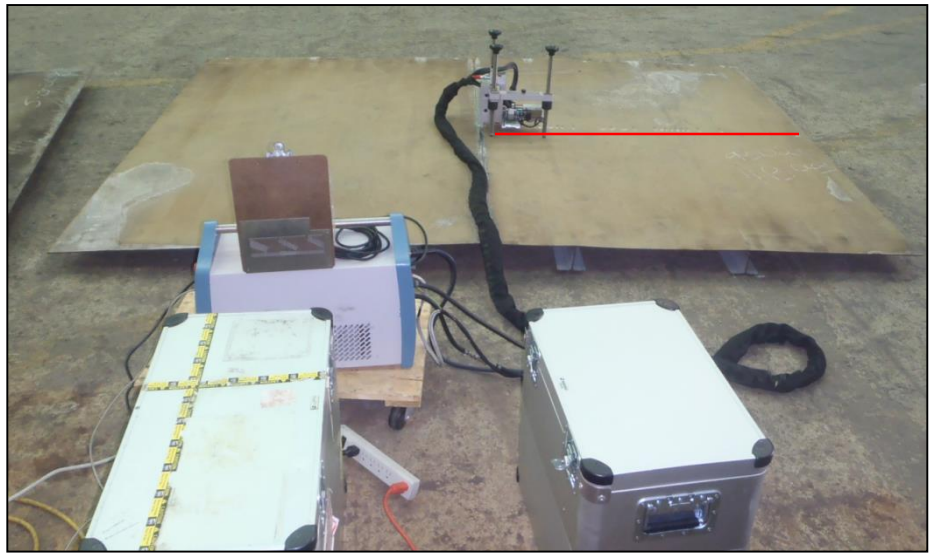



| INDEX OF TEST PANELS SUBASSEMBLY AND FAB SCHEDULE | | | | | | |
|---|---|---|---|---|---|---|
| PANEL ID # | FIXTURING | STRONGBACK/ CLAMPING | LONGITUDINAL SEAM | REPLICATES | SUMMARY | * FAB SCHEDULE |
| 4B | FLOOR | YES | YES | 1 | DH36 | 7/18/16 7/22/16 |
| 5A | FLOOR | YES | YES | 1 | HSLA-65 MATERIAL | 8/29/16 9/02/16 |
| 5B | FLOOR | YES | YES | 1 | HSLA-80 MATERIAL | 8/22/16 8/26/16 |

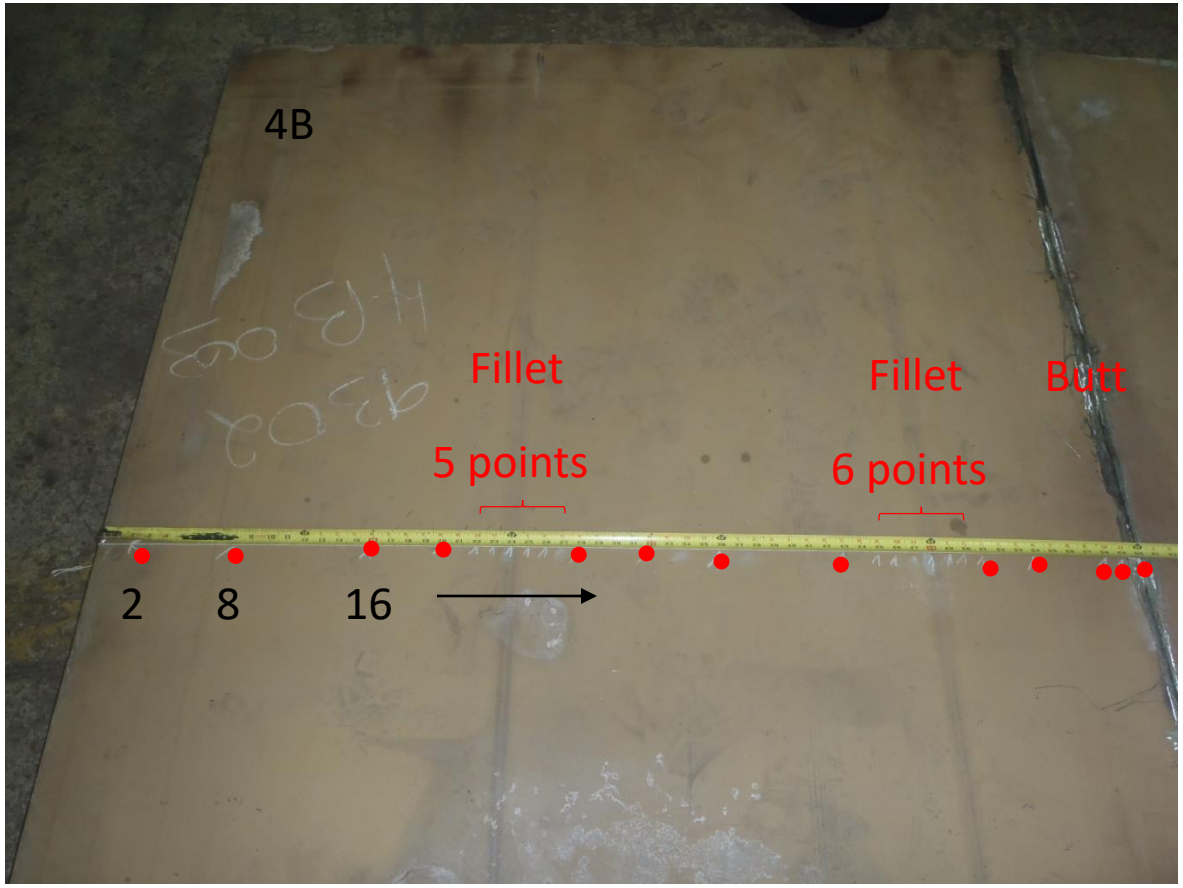
# Measurement of Test Panels

- Measurements were conducted using the x-ray diffraction method.
- Measurements were focused on the study of material effect on residual stress:
  - DH36
  - HSLA-65
  - HSLA-80

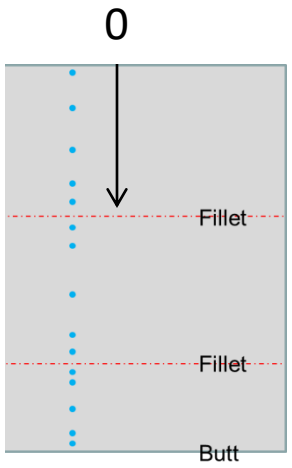


# Measured Locations on Test Panels

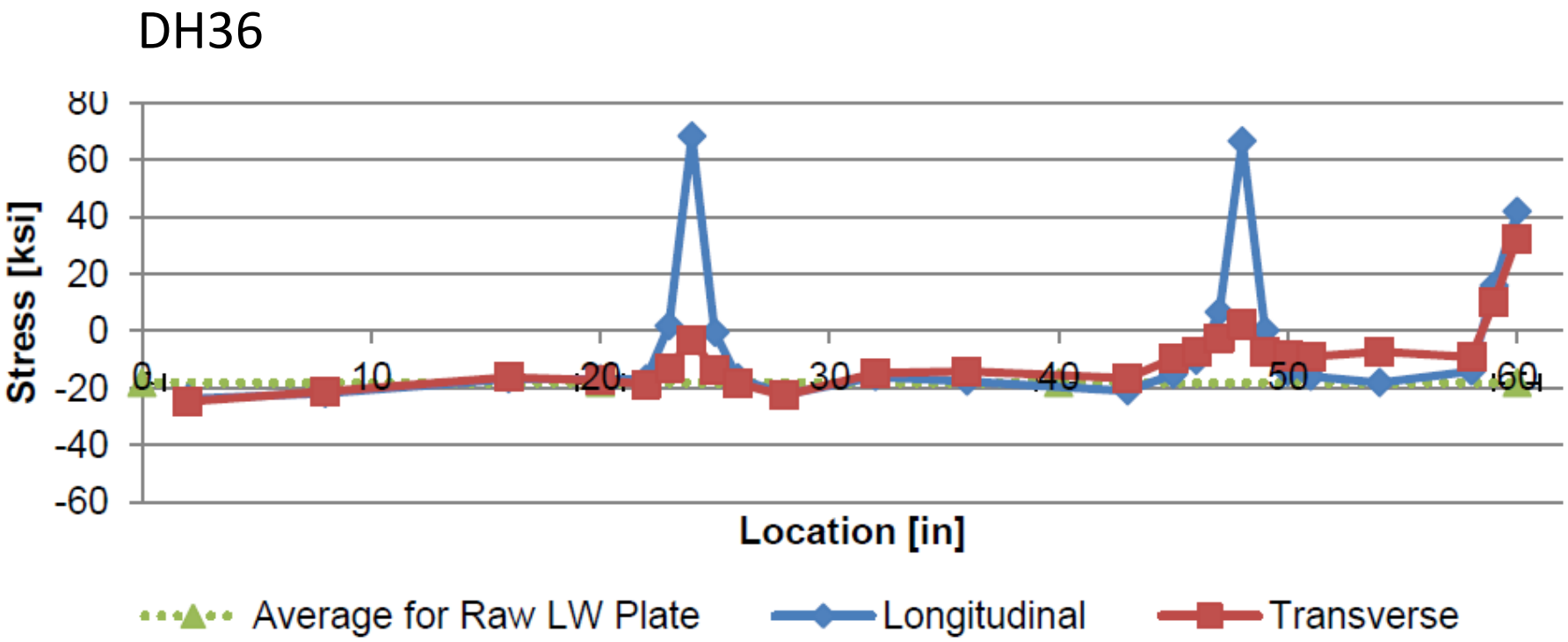



| Point | Distance to the Plate Edge (in.) |
|---|---|
| 1 | 2 |
| 2 | 8 |
| 3 | 16 |
| 4 | 20 |
| 5 | 22 |
| 6 | 23 |
| 7 | 24 |
| 8 | 25 |
| 9 | 26 |
| 10 | 28 |
| 11 | 32 |
| 12 | 36 |
| 13 | 43 |
| 14 | 45 |
| 15 | 46 |
| 16 | 47 |
| 17 | 48 |
| 18 | 49 |
| 19 | 50 |
| 20 | 51 |
| 21 | 54 |
| 22 | 58 |
| 23 | 59 |
| 24 | 60 |



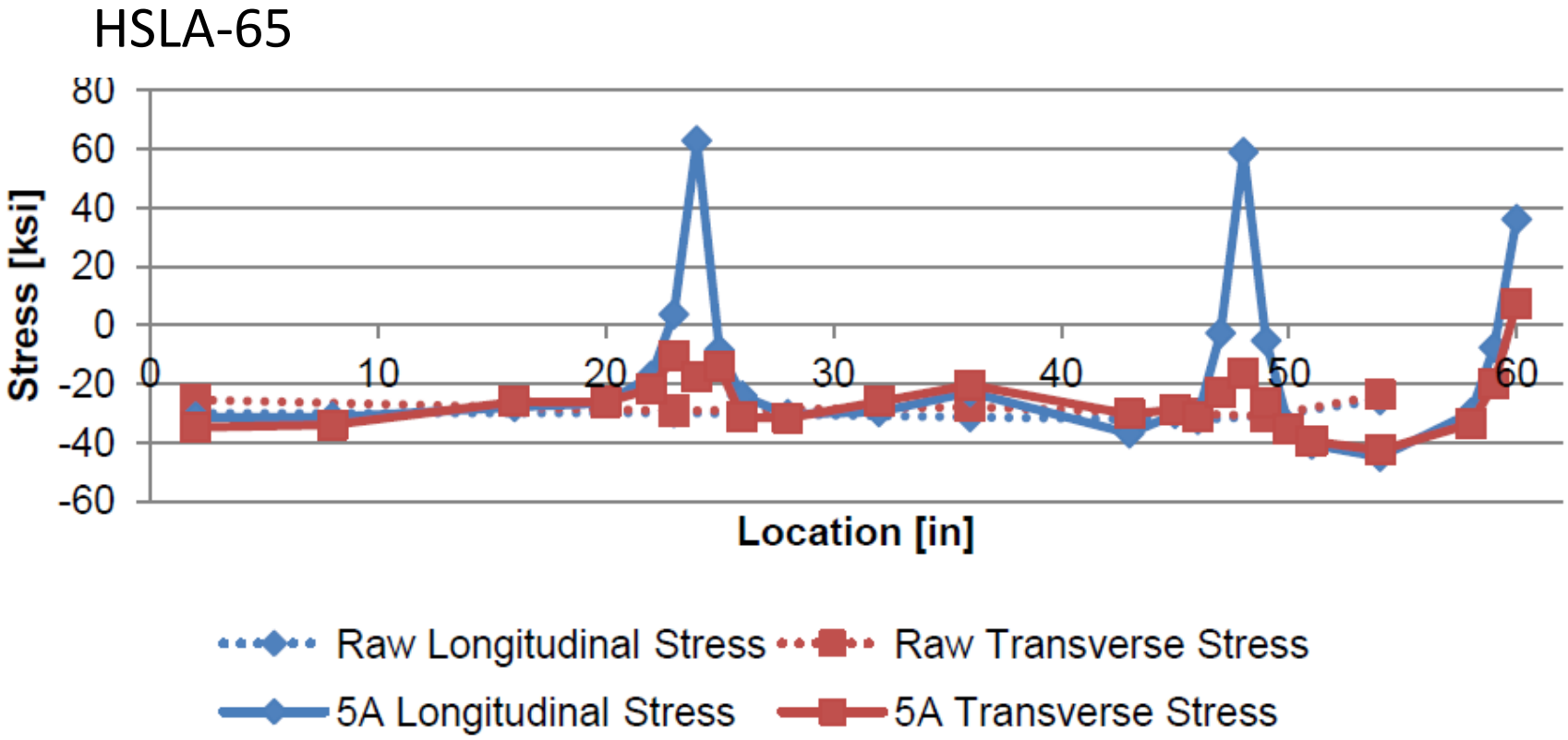

Distributions of Measured Locations: more points near the welds

# Results of Residual Stress Measurement: DH36



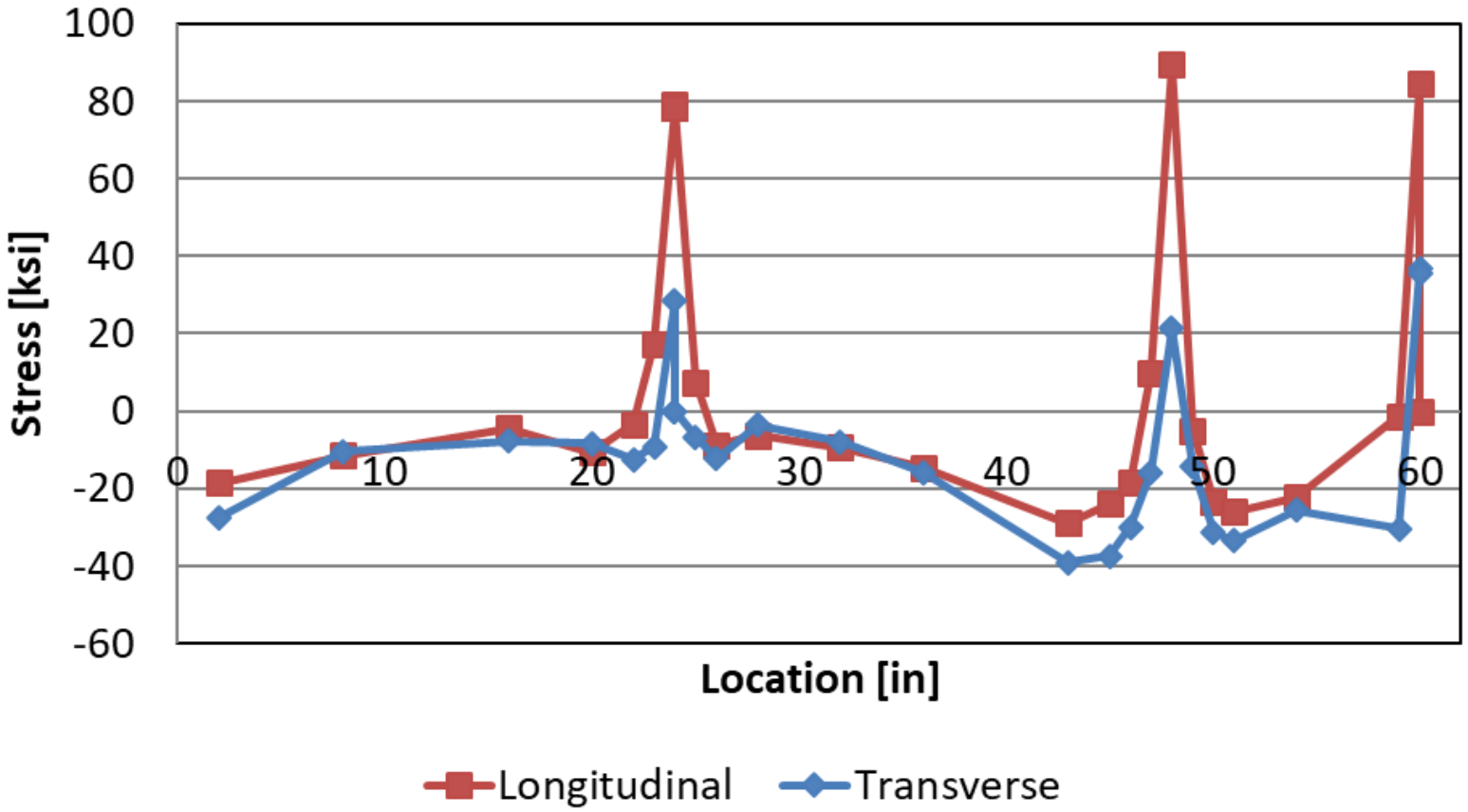

- **Tension near the weld**
- **Compression away from the weld**

# Results of Residual Stress Measurement: HSLA-65




- **Tension near the weld**
- **Compression away from the weld**

# Results of Residual Stress Measurement: HSLA-80



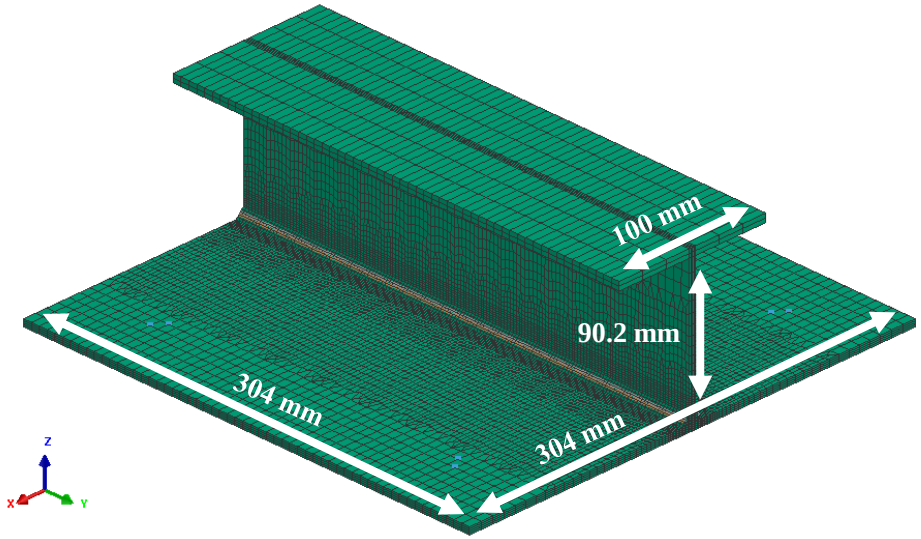

- **Tension near the weld**
- **Compression away from the weld**

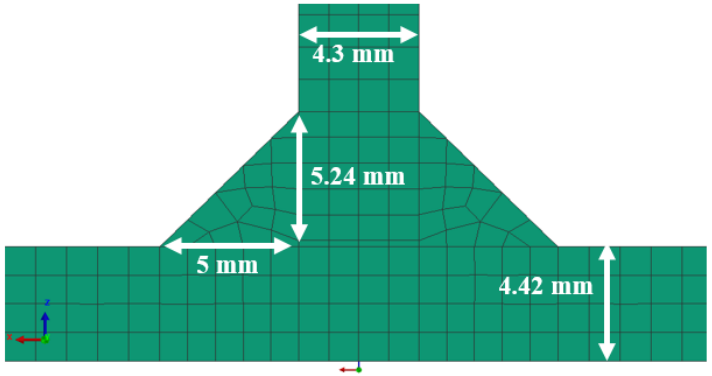
# Observations

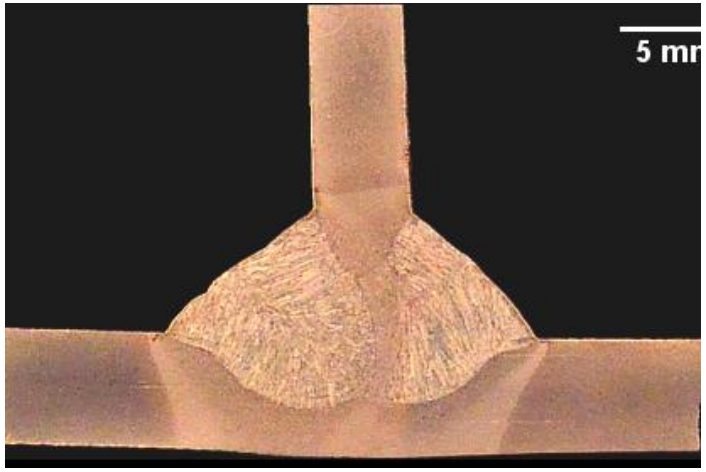
- Similar stress distributions were observed on three materials.
- Residual stress range for DH36 is 89 KSI:
  - Low = −21 KSI
  - High = 68 KSI.
- Residual stress range for HSLA-65 is 95 KSI:
  - Low = −35 KSI
  - High = 63 KSI.
- Measured residual stresses on HSLA-80 were highest among three materials.

# Finite Element Analysis Study

- ESI Visual-Weld “SYSWELD” used



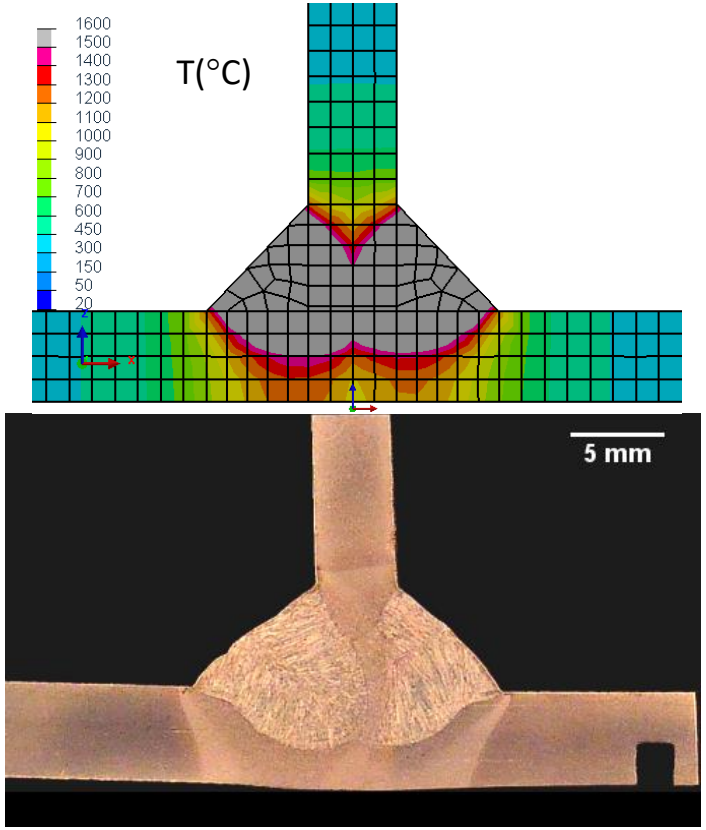




*Jennifer Semple, Pedigreed Material Property Data for Residual Stress and Distortion Modeling of Naval Steel Weldments, The Ohio State University, August, 2018.*

# Predicted Temperature

- A heat convection coefficient of $1x10^{-4}$ was found to produce the best thermal gradient
- Thermal gradient in the HAZ matched well with etched macrograph

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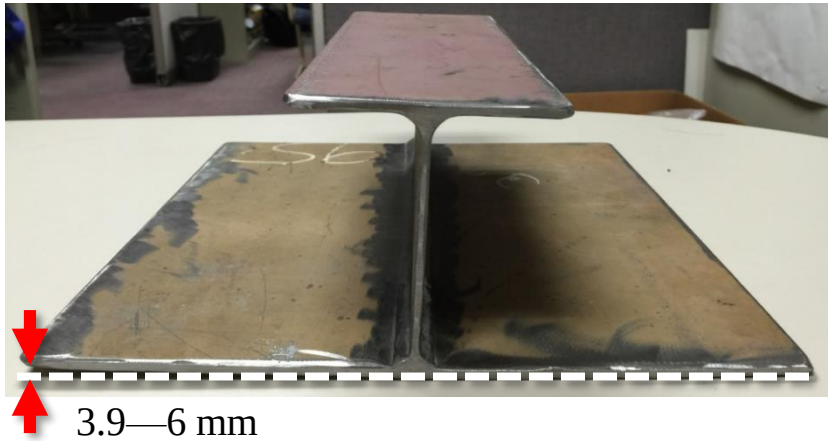
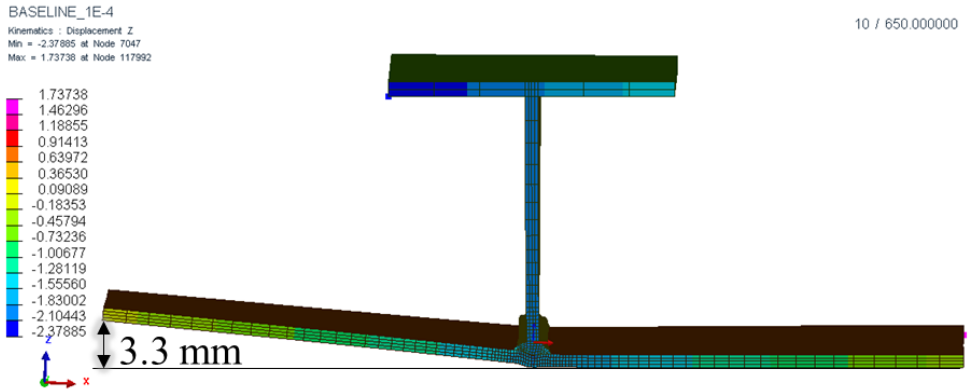
# Predicted Angular Distortion

Deformation on the welded sample




Modeled predicted deformation




- Predicted angular distortion agreed with the experimental measurement.

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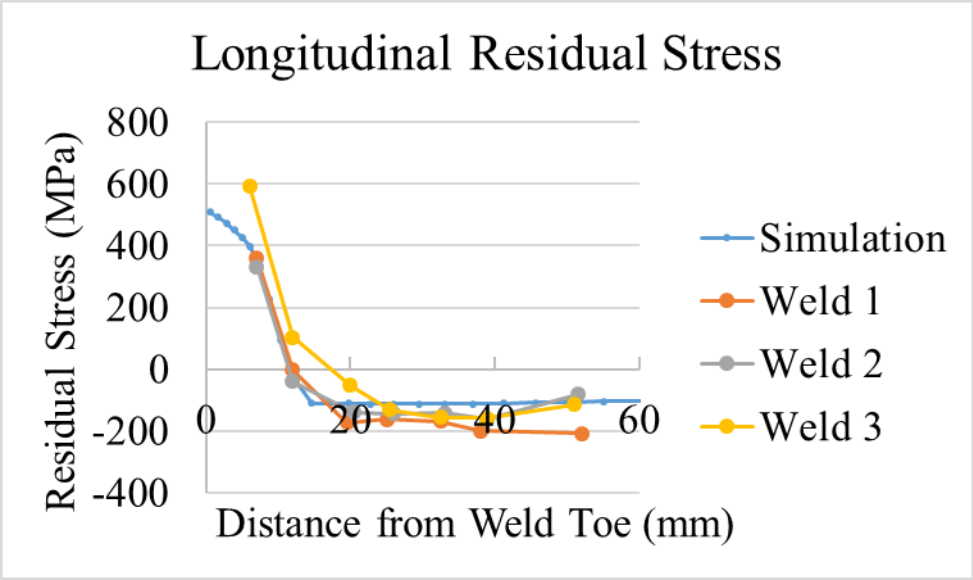
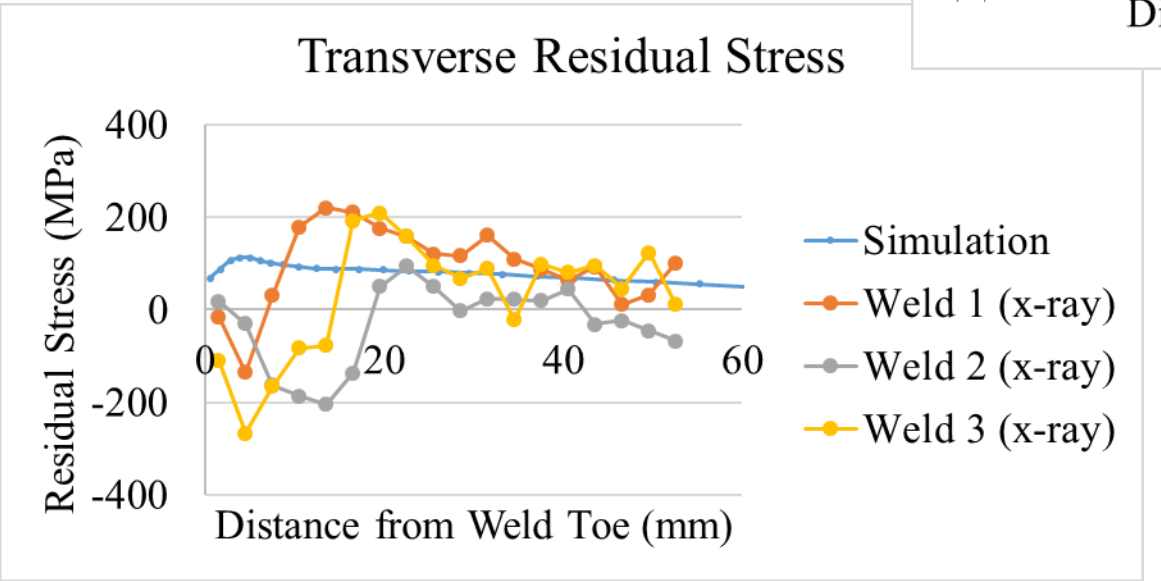
# Predicted Residual Stress

- Experimental and predicted residual stress values matched fairly well for the baseline case.



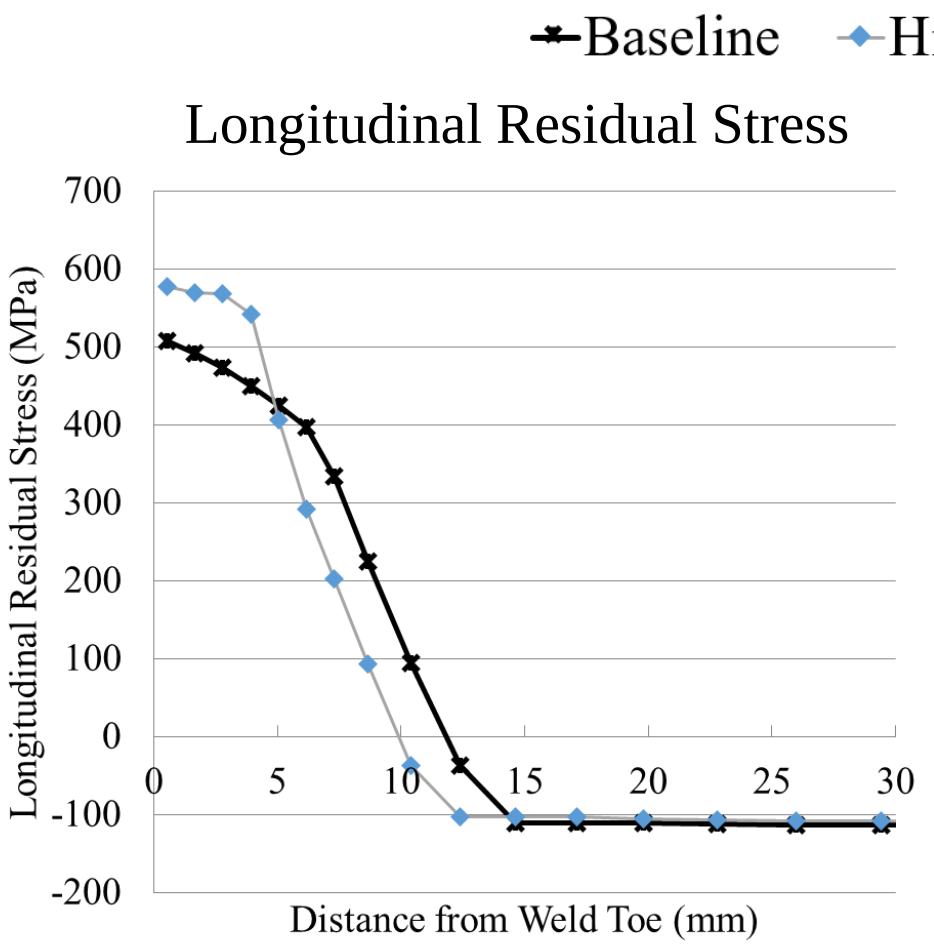

*Jennifer Semple, Pedigreed Material Property Data for Residual Stress and Distortion Modeling of Naval Steel Weldments, The Ohio State University, August, 2018.*

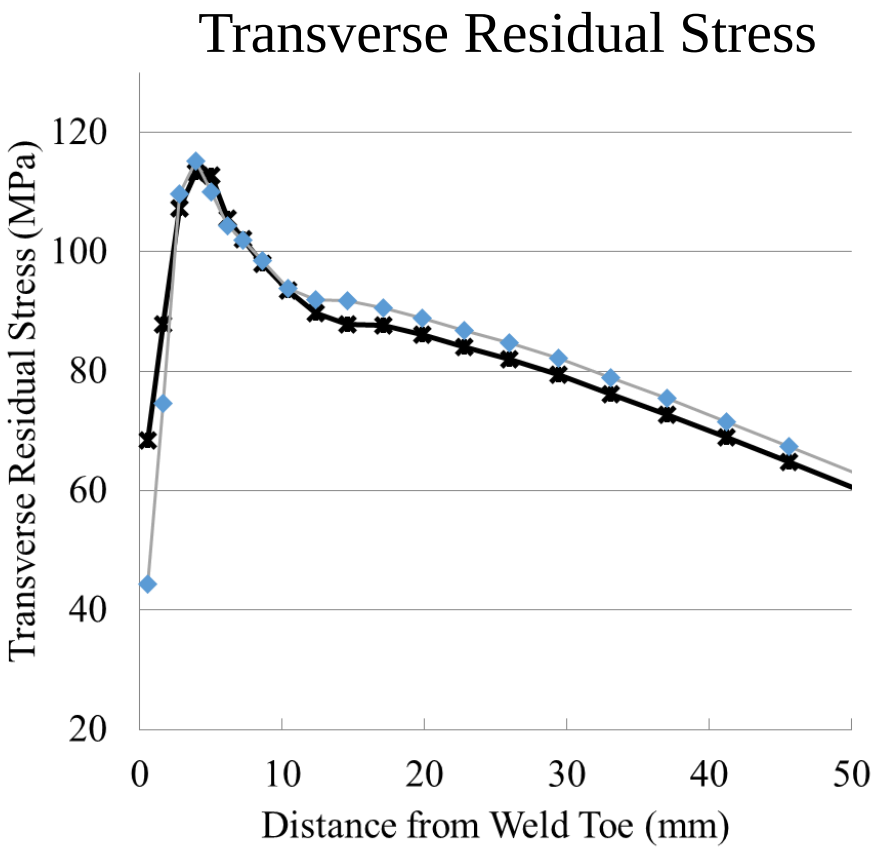
# Effect of Yield Strength on Distortion

- Yield strength was increased by 25% for all temperatures
- Increase in displacement was relatively small: 5.08% and 4.0% on the weld start and finish sides, respectively

| Yield Strength | Angular Distortion (°) | | Z Displacement (mm) | |
|---|---|---|---|---|
| | Start | Finish | Start | Finish |
| 25% Higher | 178.819 | 178.715 | 3.133 | 3.409 |
| Baseline | 178.879 | 178.766 | 2.974 | 3.273 |

# Effect of Yield Strength on Residual Stress



# Conclusions

- Similar distributions of residual stresses were obtained on DH36, HSLA-65, and HSLA-80 panels.
- The residual stresses on DH36 and HSLA-65 panels have similar magnitude.
- Measured residual stresses on HSLA-80 were highest among the three materials.
- As material yield strength increases, longitudinal residual stress increases, while transverse residual stress is similar based on the limited FEA study.