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Constitutive Properties of Dissimilar Metal Laser Welds

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Introduction

- Constitutive properties of weldments is needed for analysis of mechanical performance
- For larger welds, conventional, subsize, or miniature samples can be extracted, but must assume homogeneous behavior across sample
- Testing of weldments under a variety of loading conditions can be used, but do not provide constitutive properties
- Analysis of complex tests by finite element methods can be used to extract intrinsic properties, but usually results in non-unique solutions
- Recently, digital image correlation (DIC) methods have been applied to spot welds, friction stir welds, and 304L laser welds (reported on previously)

- In this study we evaluated the potential of the DIC technique for use in determining constitutive properties of sub mm sized dissimilar laser welds

Welding Procedures

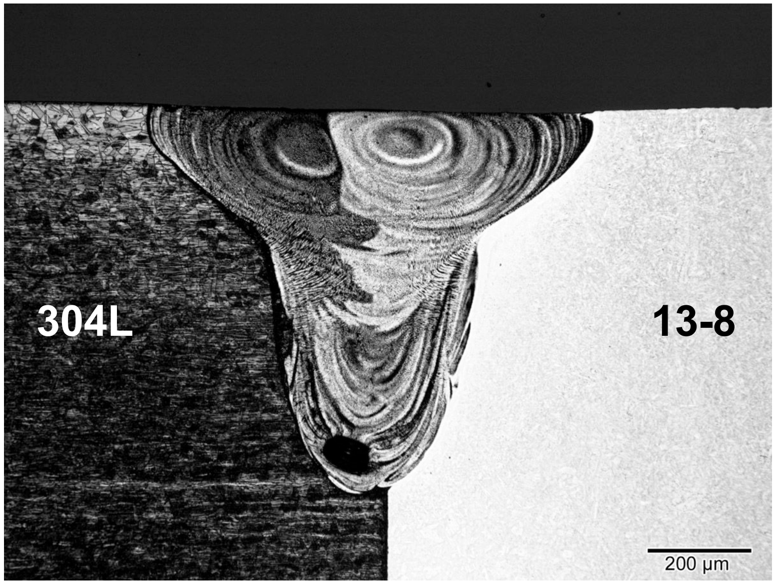
- Seam welds in 1.6 mm thick PH-13-8 Mo 304L sheet
- Rofin-Sinar CW 015 HQ Nd:YAG

- Matrix includes:

  13-8(H1100) to 304L
  13-8(H950) to 304L
  13-8(H1100) to 13-8(H1100)
  13-8(H950) to 13-8(H950)

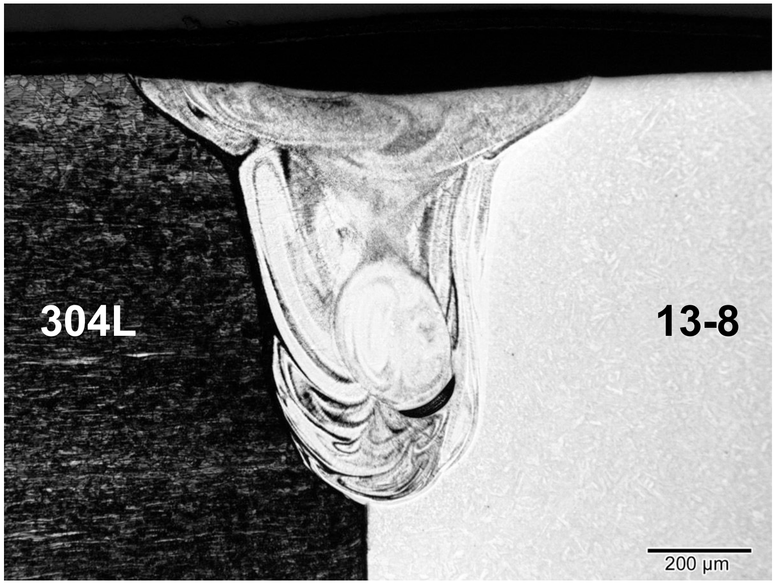
Continuous Wave

Butt Joint, 75 μm gap
195 W
25.4 mm/sec
0.5 mm penetration

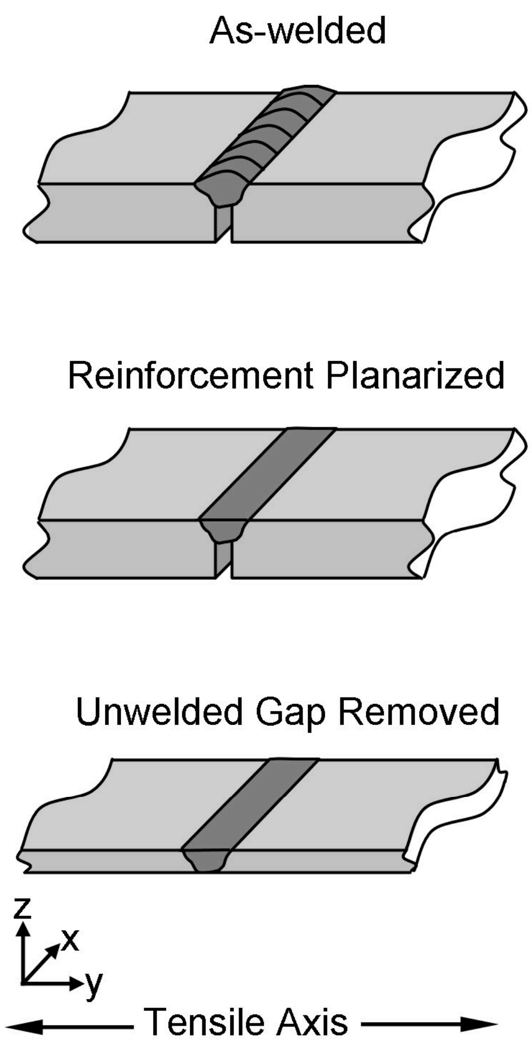


Pulsed

Butt Joint, 75 μm gap
45 W average power, 20 Hz
3.8 mm/sec
0.5 mm penetration, 75-80% overlap

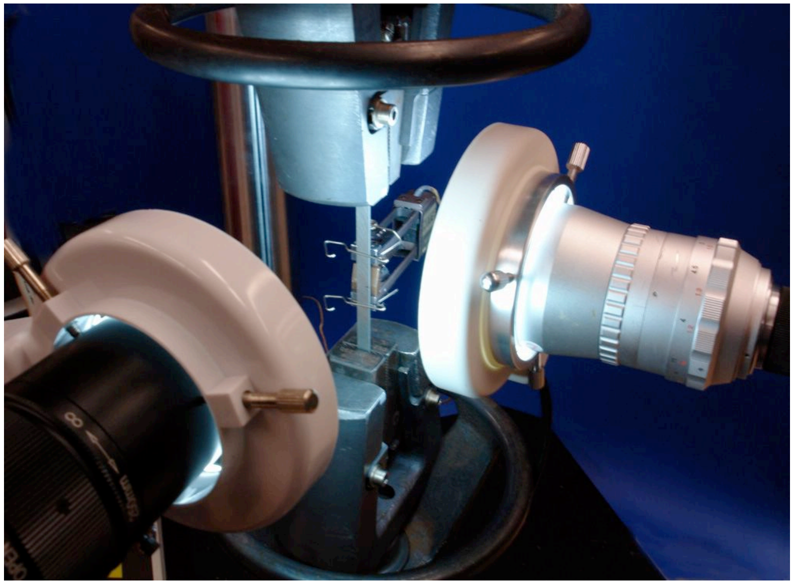


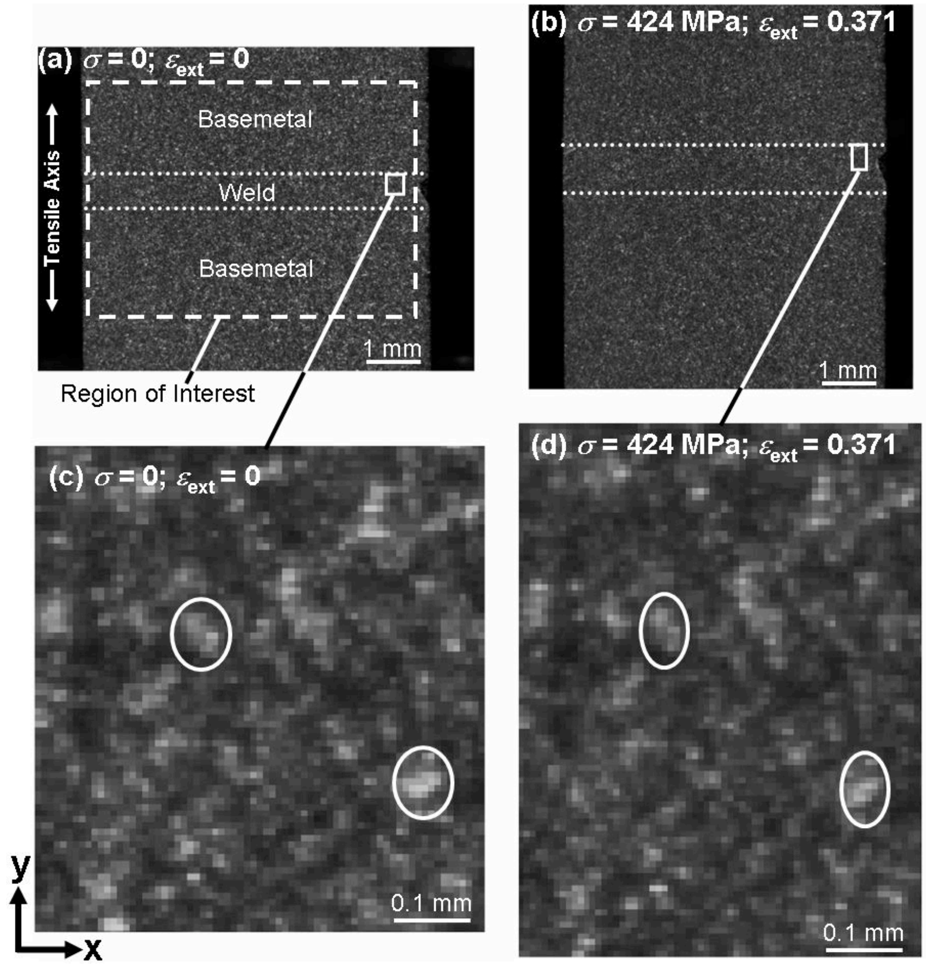
Sample Preparation



- Rectangular transverse tensile samples 100 × 6.35 × 1.6 mm EDM'ed from weldments
- Samples planarized by lapping to 0.5 mm thickness
- Lightly bead blasted with 27 μm alumina to provide speckling

Digital Image Correlation (DIC)





Strain resolution dependent on:

- **Speckle distribution**
- **Imaging optics**
- **Correlation algorithm**
- **Out of plane displacements**

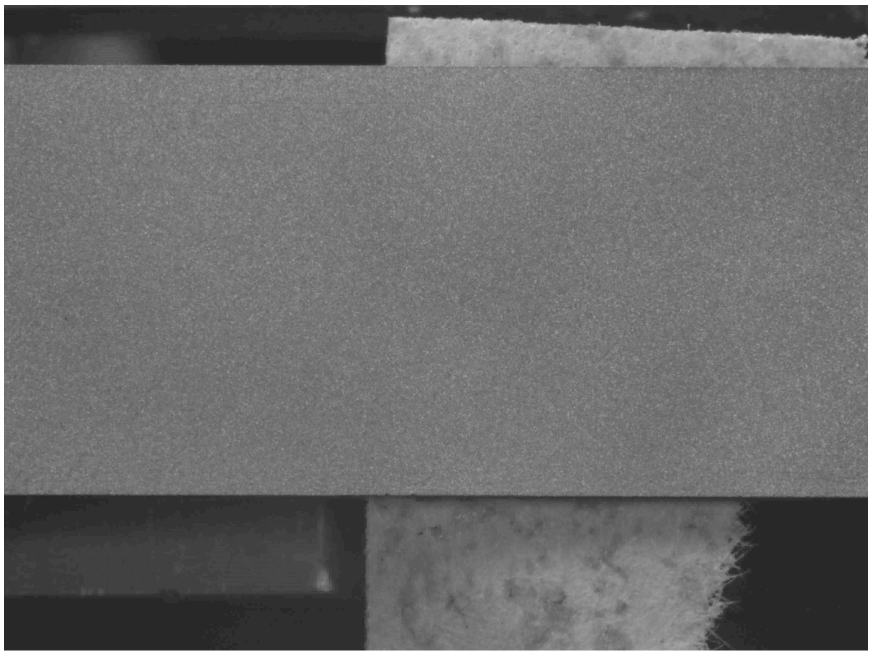
Strain error empirically estimated for current conditions as <0.002 mm/mm

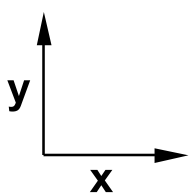
Apparent strain rate: 7×10^{-4} s^{-1}

Testing

13-8(H1100) to 304L CW Weld

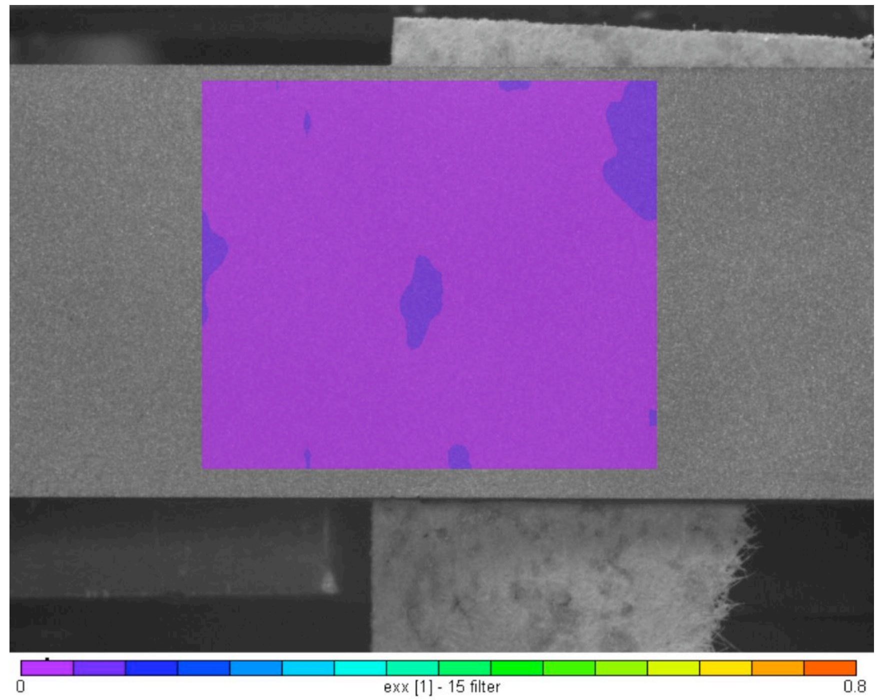
13-8 **304L**





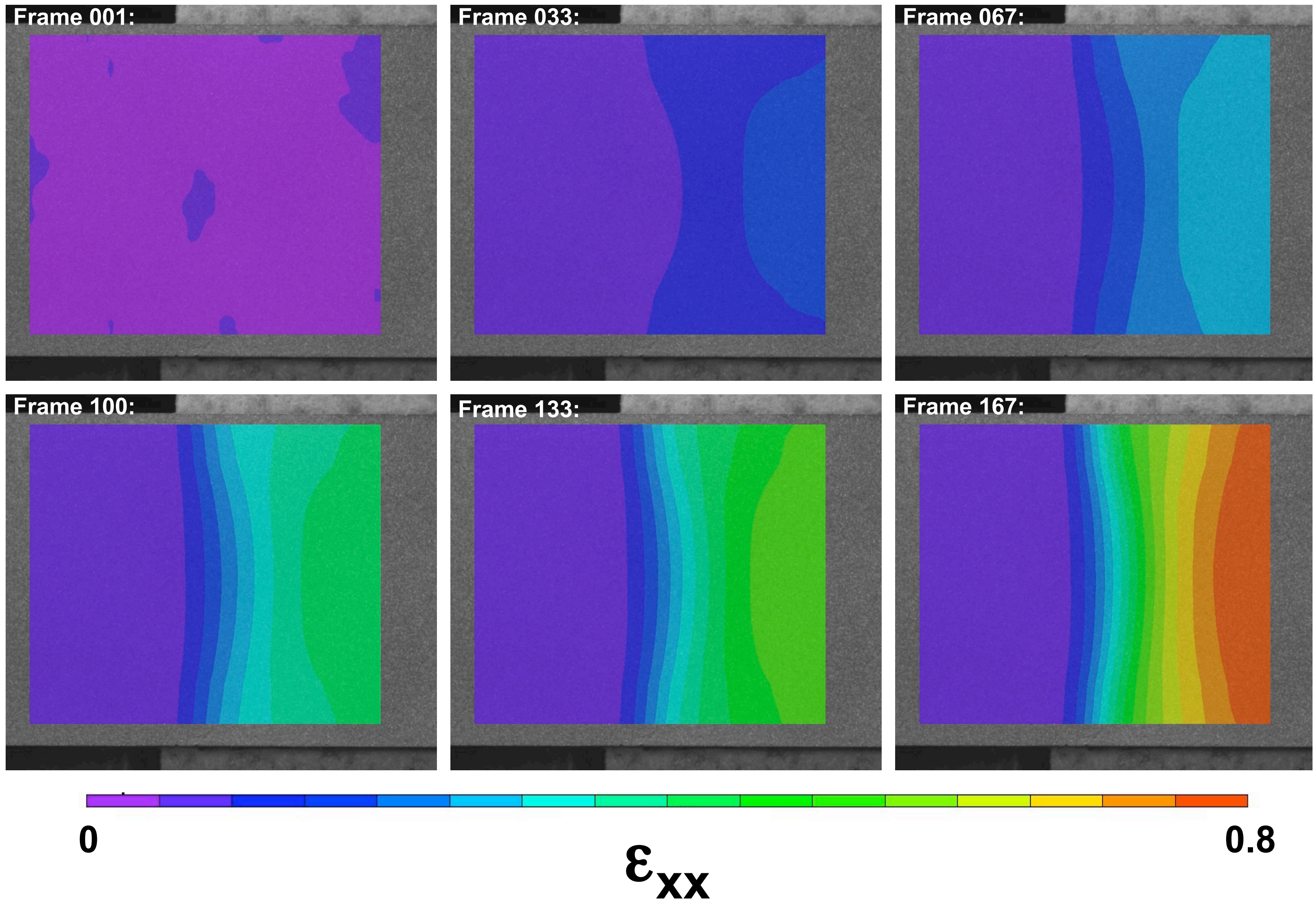
ε_{xx} Strain Contours

13-8 **304L**

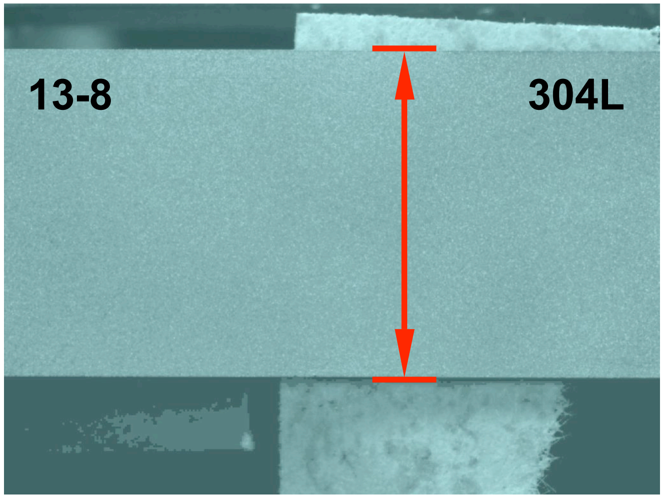


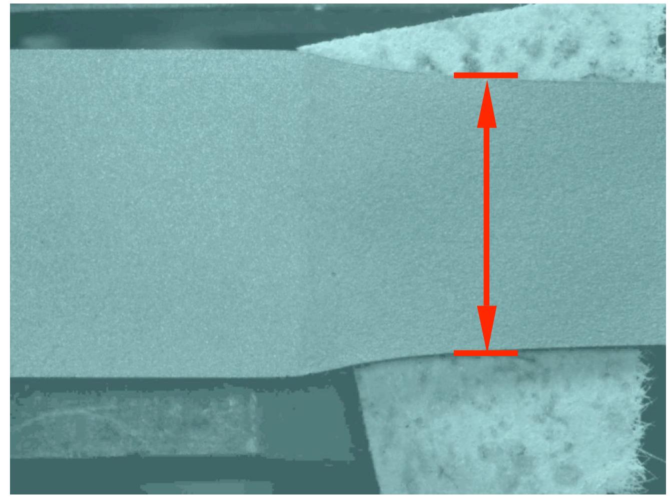
0 **ε_{xx}** **0.8**

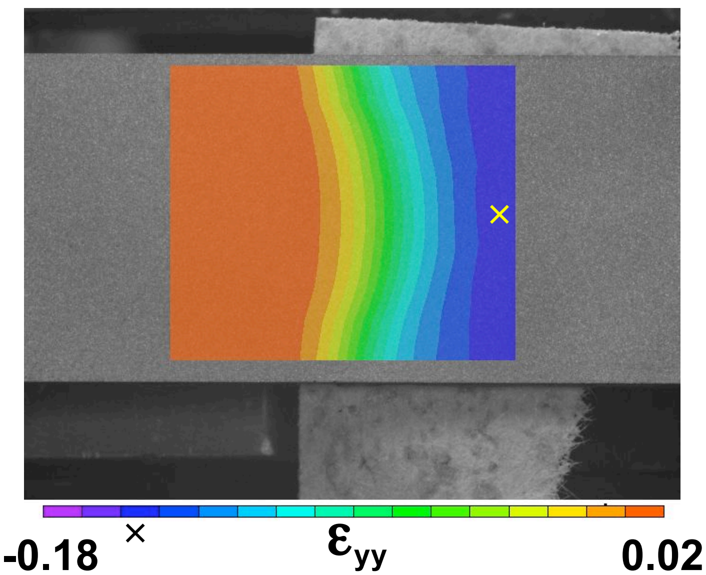
Strain Contours at Selected Times



Correlation Checks

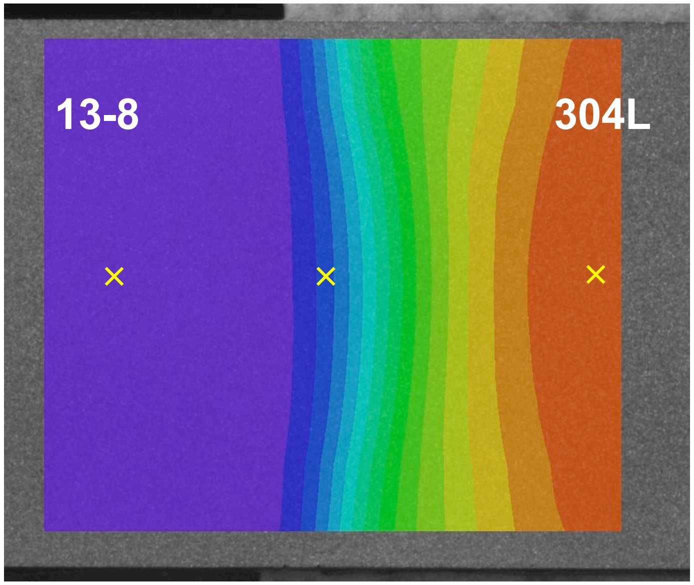


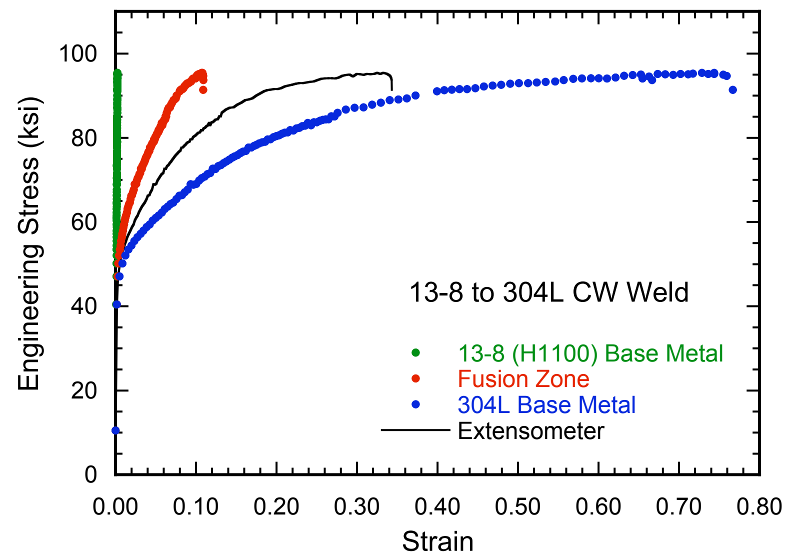


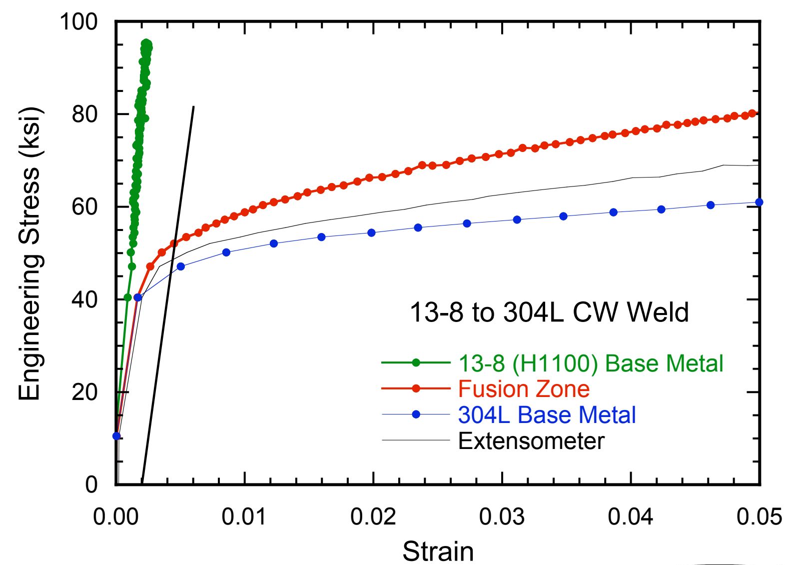


- Macroscopic checks can be applied to validate strain estimates
- In this case, Poisson contraction (ε_{xx}) can be validated against specimen width
- Other visible features can be also used

Stress-Strain Response

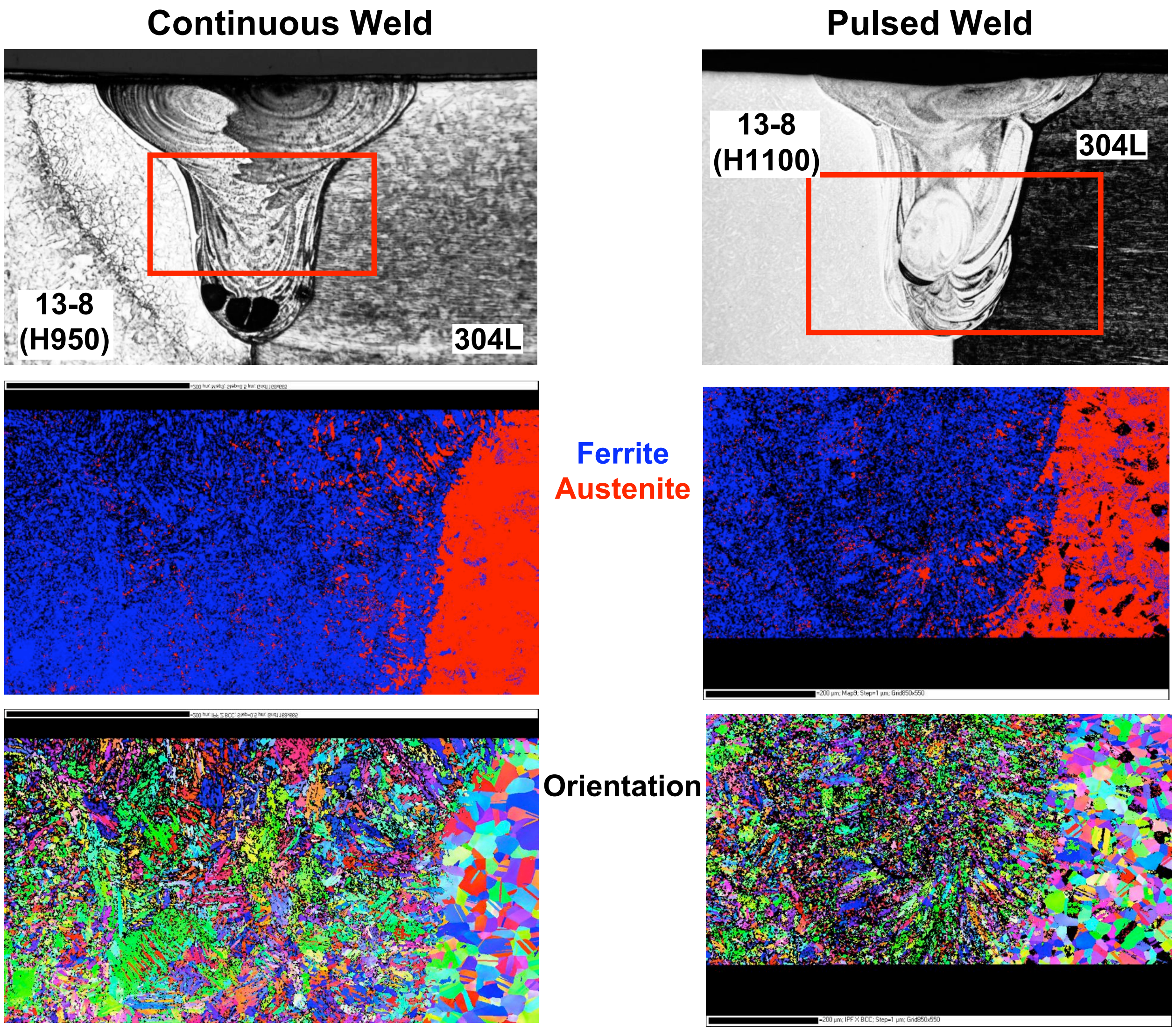






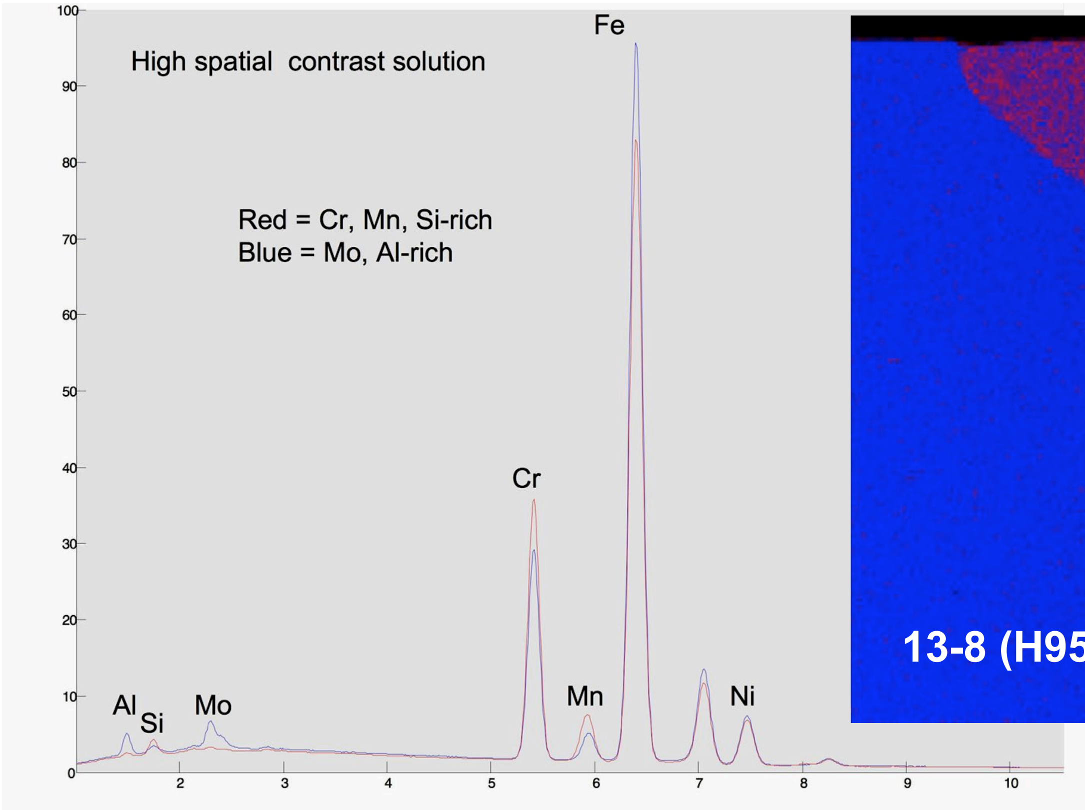
- Stress assumed to be continuum engineering stress at all locations
- Conventional cross weld test is incapable of discerning differences
- Method is capable of determining response in individual regions
- Failure occurred well away from weld in 304L

Phase Mapping

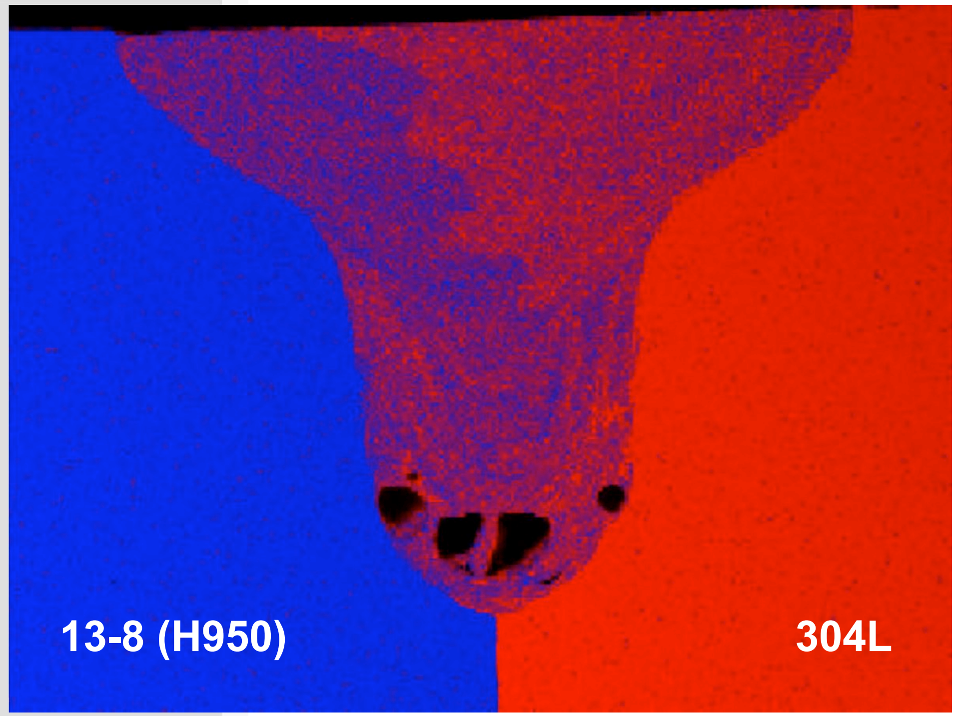


- Fusion Zone is predominantly ferrite (or martensite) in both welds
- Incomplete mixing evident and retained austenite on 304L side of FZ
- Apparently greater mixing in pulsed weld

Spectral Imaging

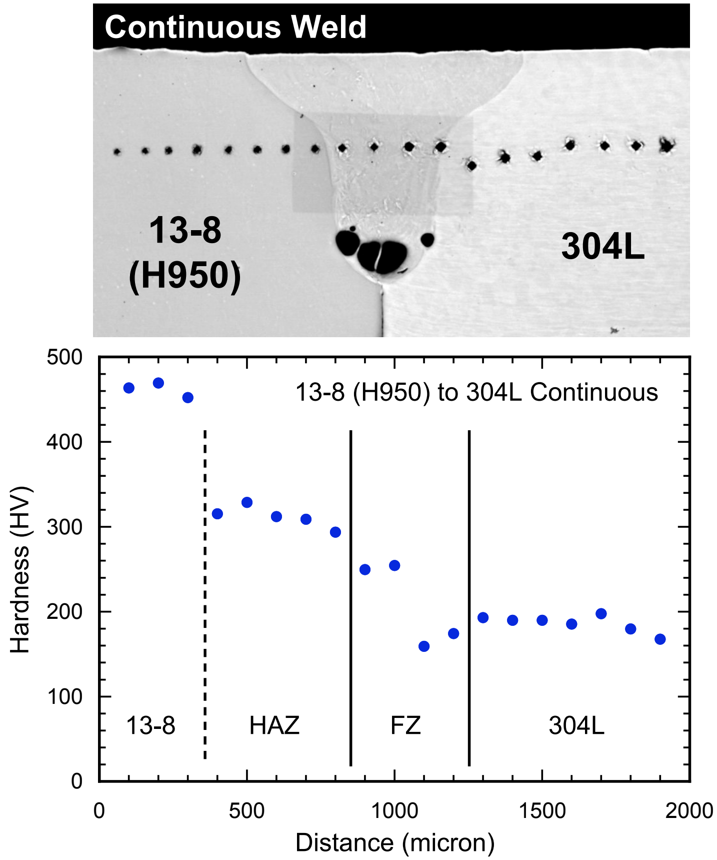


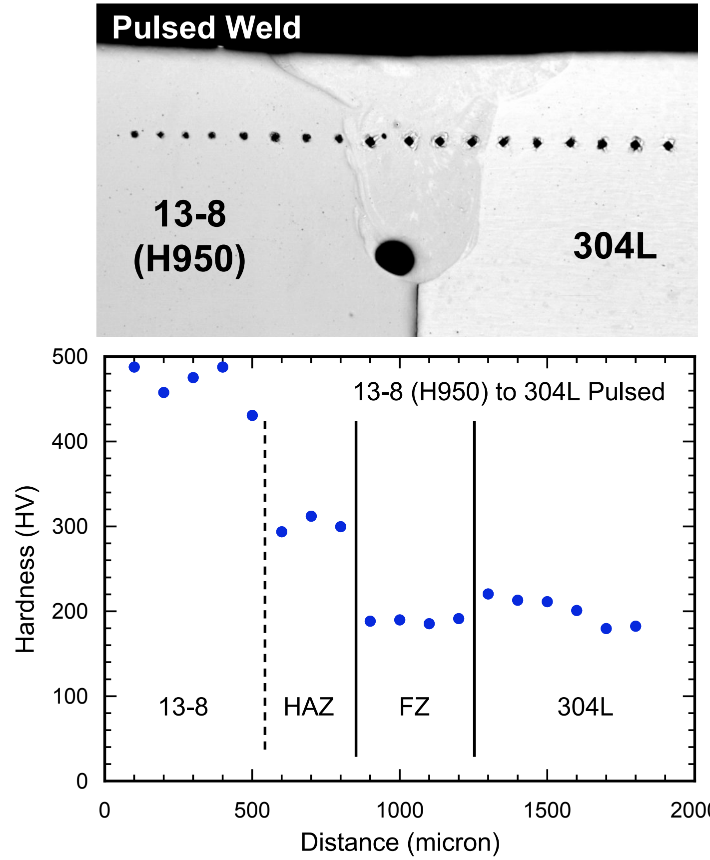
Continuous Weld



- Spectral imaging shows regions of incomplete mixing predominantly 13-8 (Al, Mo) versus predominantly 304L regions

Microhardness

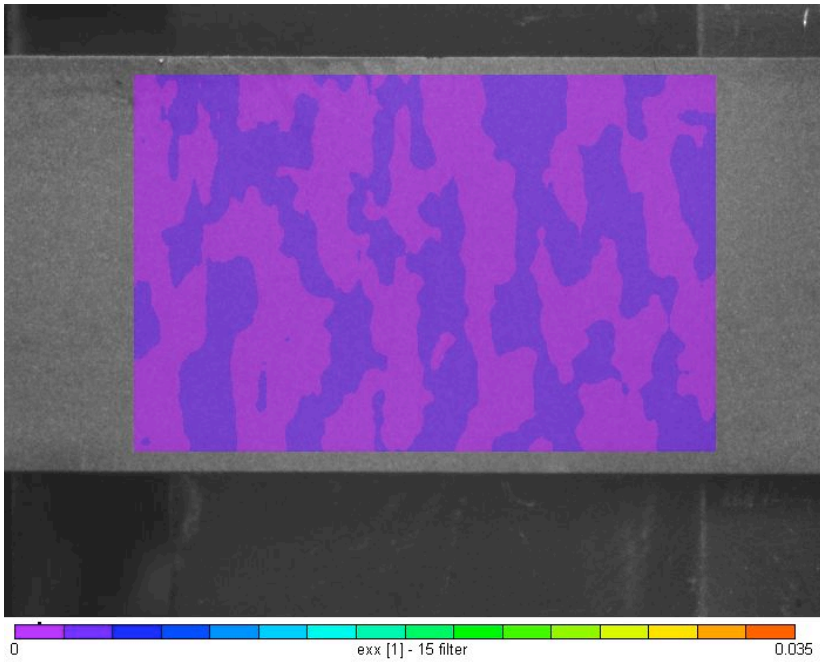


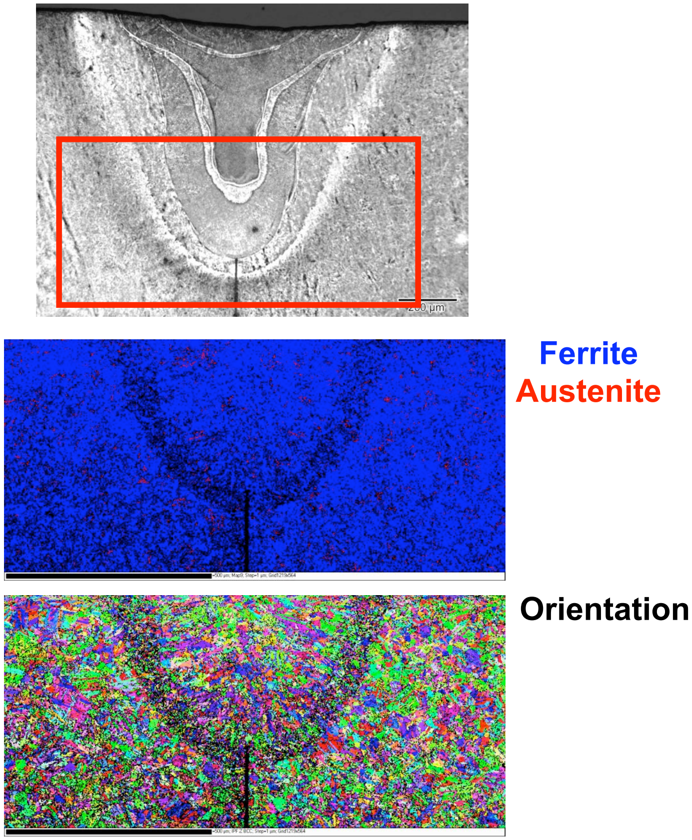


- **Extent of reaustenitized HAZ greater in CW weld**
- **Somewhat less homogeneity in CW fusion zone, likely unaged martensite (in predominantly 138 regions) versus ferrite (in predominantly 304L regions)**
- **Further refinement of DIC in weld regions desirable and underway**

13-8 to 13-8 welds

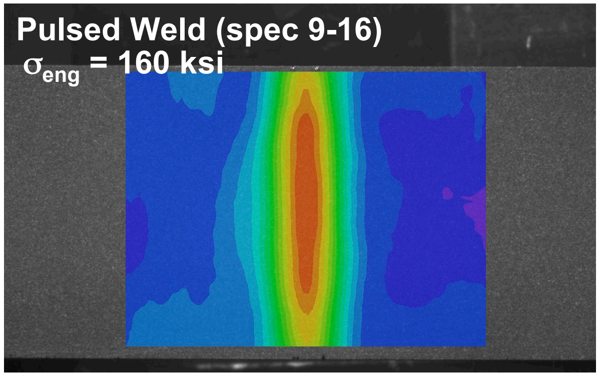
13-8(H1100) to 13-8(H1100)

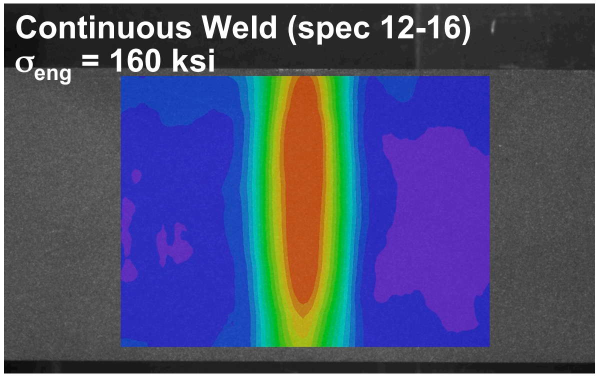


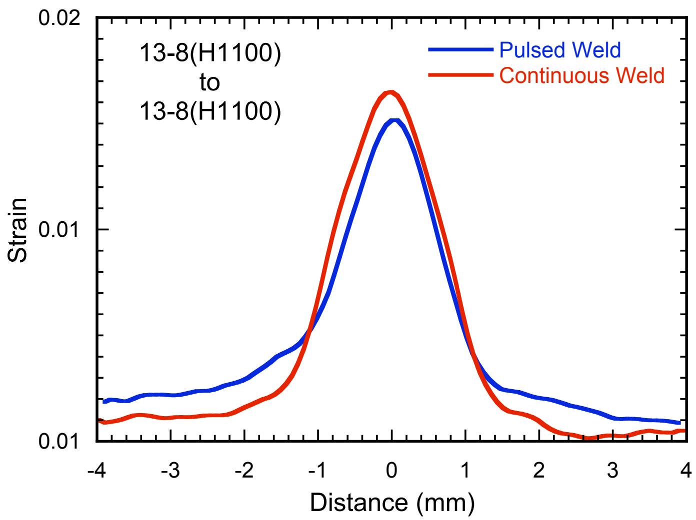


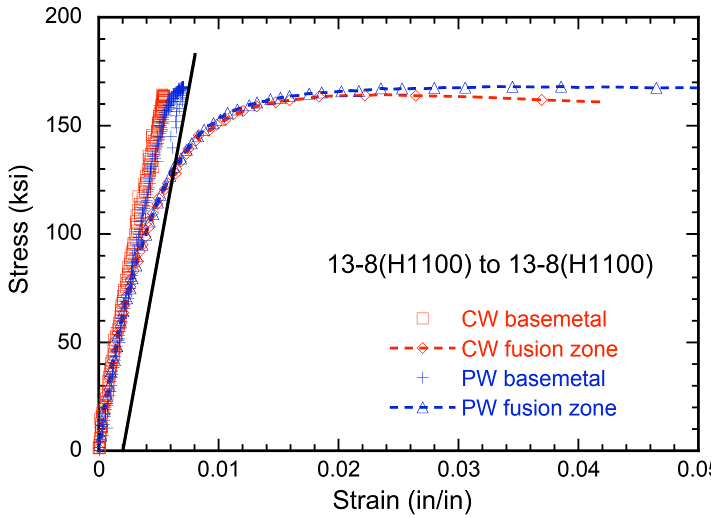
- Strains highly localized in weld region (unaged martensite)
- Strain rate also magnified appreciably in this region
- Weld zone is fully martensitic

13-8 Pulsed vs Continuous Welds









- Strains highly localized in weld region (unaged martensite)
- Weld zone $\sigma_{y(0.2\%)}$ = 130 ksi, commensurate with unaged martensite
- Minimal yielding in base metal

Conclusions

- Localized strain mapping technique successfully applied to small laser welds at static testing rates and can detect differences even welds with relatively small differences from the base metal
- Under the conditions used, strain resolution was less than 0.002 mm/mm
- The strain maps are useful for extracting local stress-strain response and verifying analytical predictions
- For the dissimilar welds, the fusion zone is predominantly ferritic (martensitic)
- Mixing in continuous weld appears less complete than in the pulsed weld, and the continuous weld likely contains both martensitic and ferritic regions
- Additional refinement of DIC analysis is underway
- For the 13-8 to 13-8 weld, the fusion zone strength is fully martensitic and the yield strength is commensurate with unaged martensite