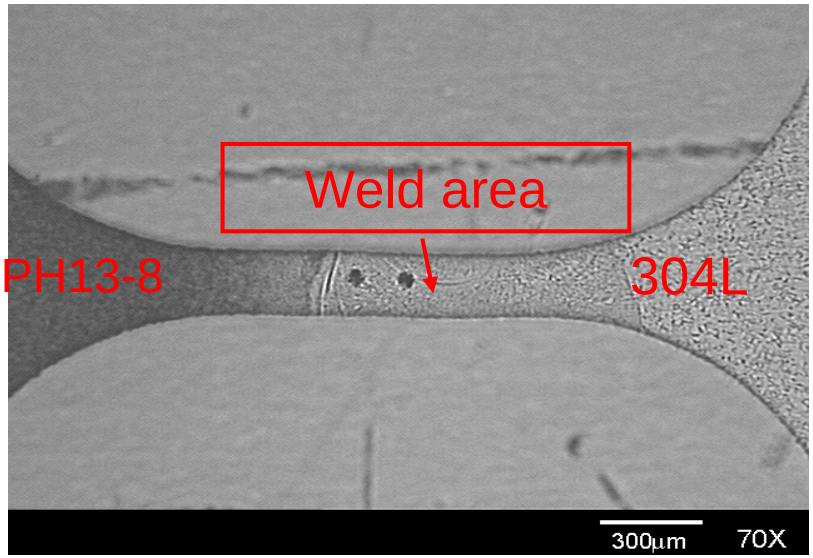
SAND2008-3518C




# Study of Laser Welded Material using Laser Interferometry

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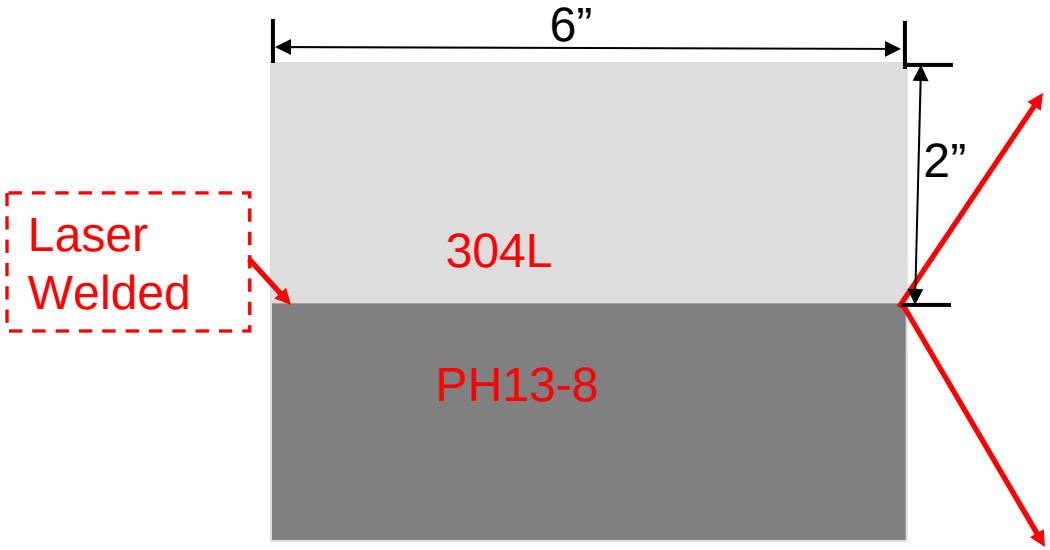
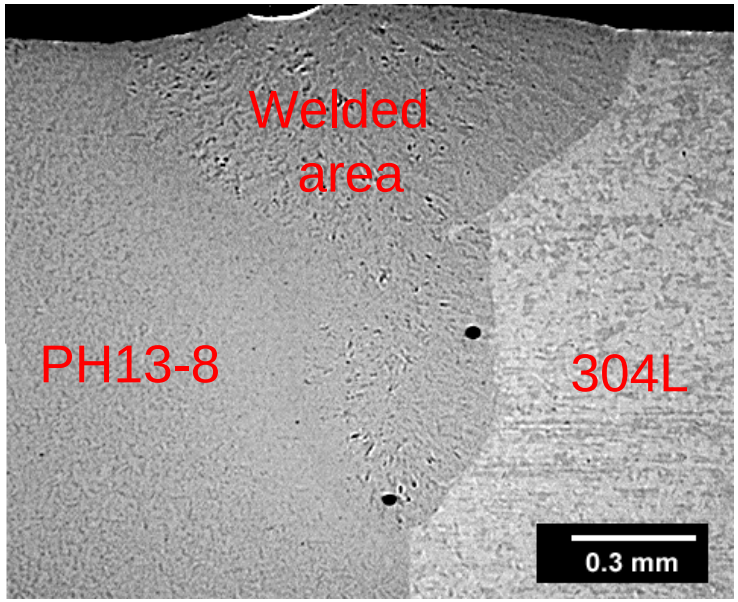
# Laser Welded Material




Sketch of laser weld coupons




Cross section of weld material

- 304L is laser welded to PH13-8
- Base material is 0.09” (2.28mm) thick, 2” wide and 6” long
- Partial penetration weld 0.060” (1.52 mm)
- The welded area is less than 1mm wide with various width through depth

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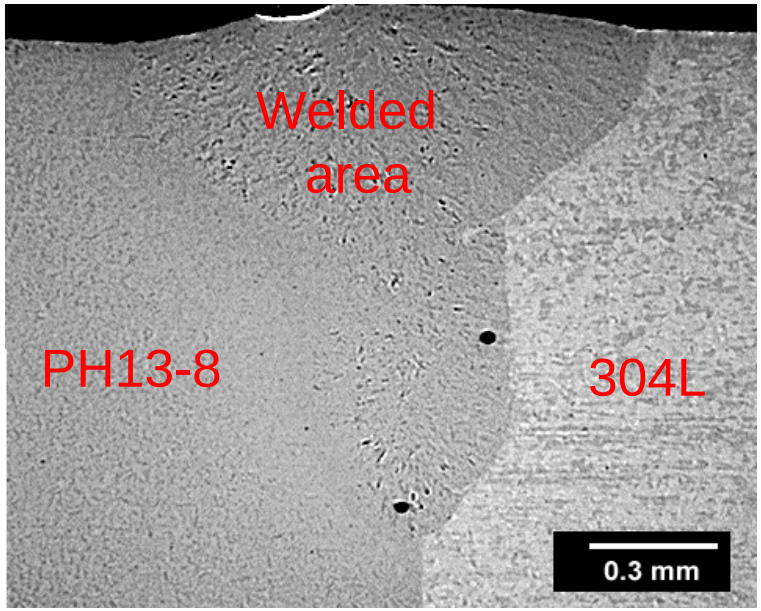
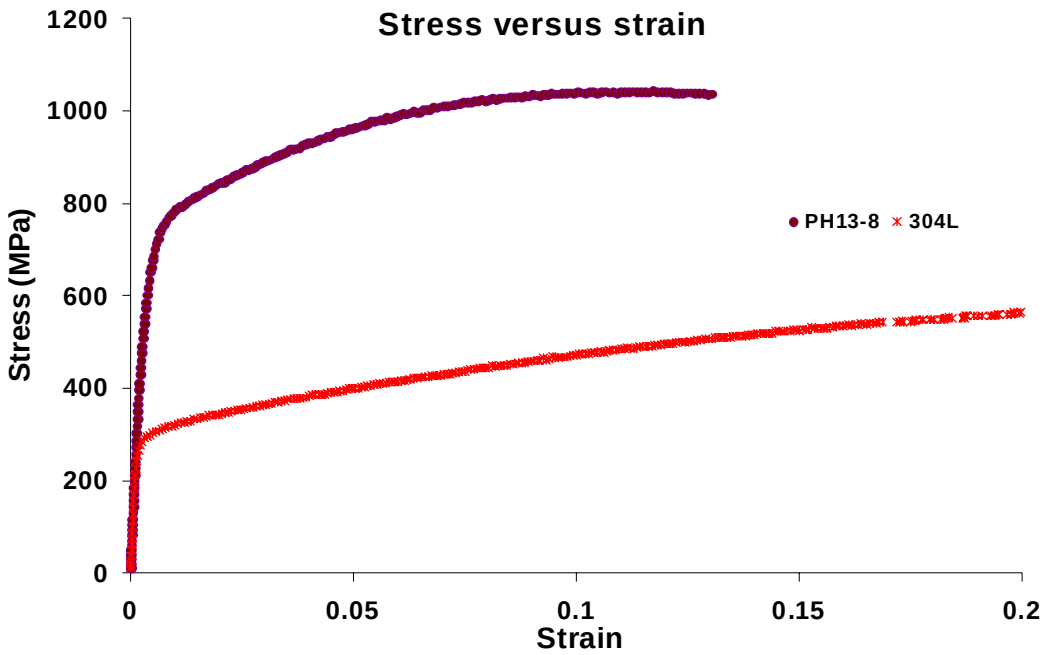
# How will the mechanical properties of welded area differ from the base material?




Cross section of weld material




Mechanical properties for 304L and Ph13-8

**Property of welded area?**

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# There are two sources of laser welded materials


304L and PH13-8 is laser welded;
Laser welded materials from two welding source: Kansas city plant and laserfusion welding company;

KC series:

- Laser: Lumonics, Nd:YAG, CW
- Power: 600W, 100Hz sine wave
- Feed Rate: 50 IPM
- Gas: Argon
- Focus: 100mm focal length

LF series:

- Laser: Lumonics, Nd:YAG, Pulsed, 9.0PPS, 10.5ms pulse width
- Power: 207 W
- Feed Rate: 50 IPM
- Gas: Argon
- Focus: 100mm focal length

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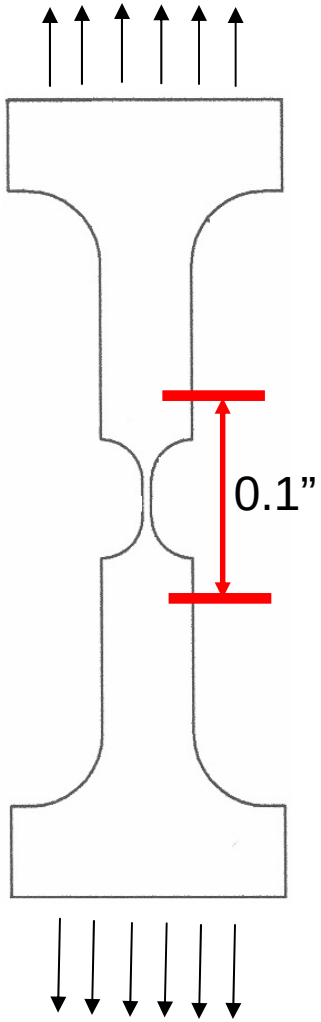
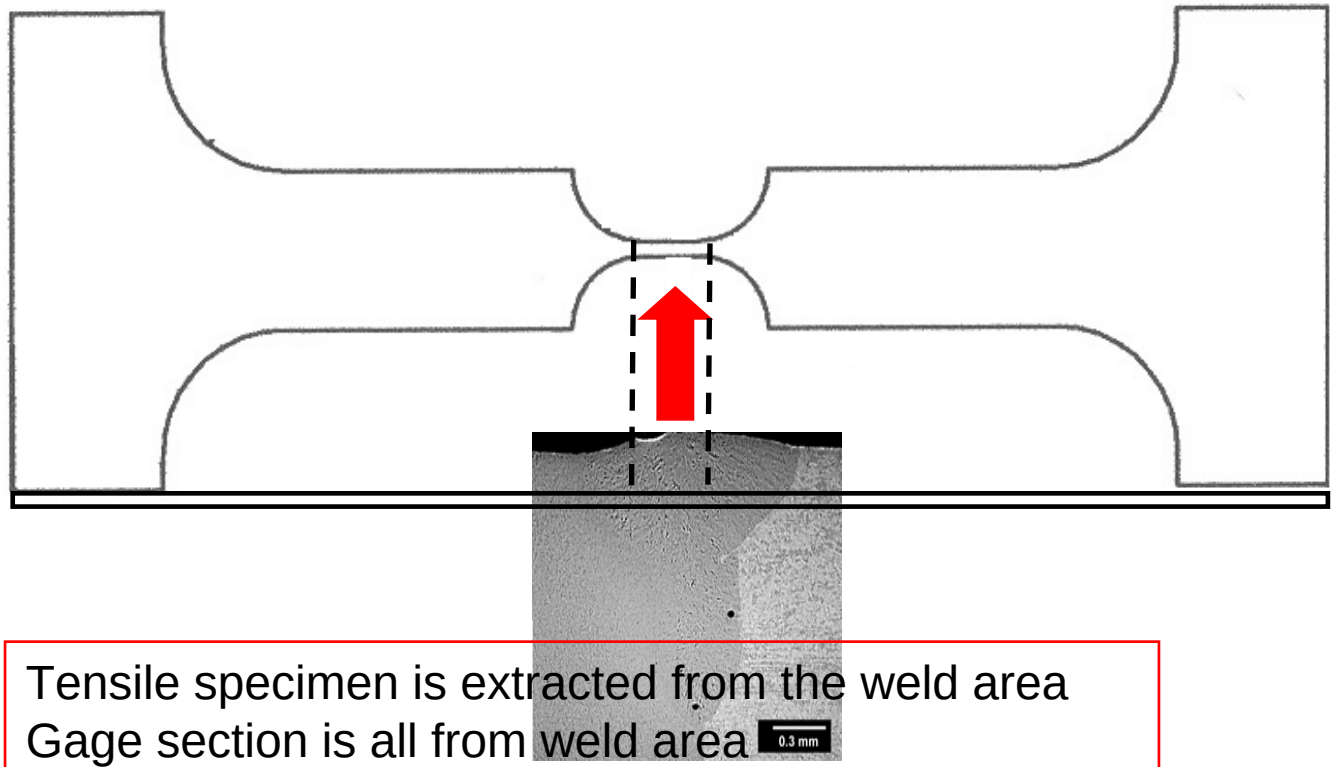
# First approach is to use conventional tensile test




- Tensile specimens were loaded from MTS machine
- Extensometer is used to record the displacement




Tensile specimen is extracted from the weld area
Gage section is all from weld area

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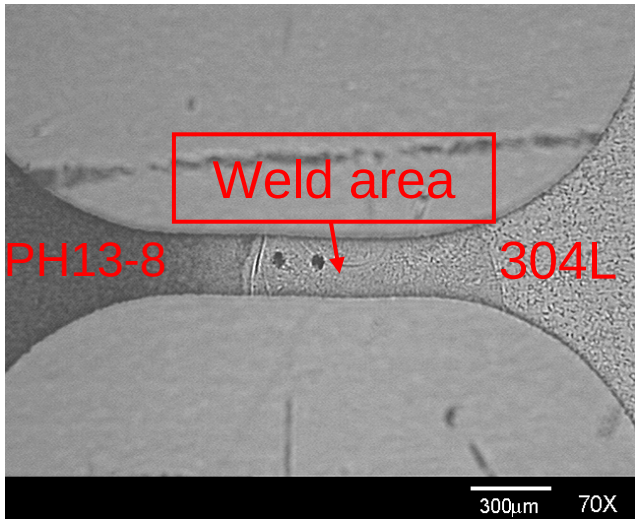
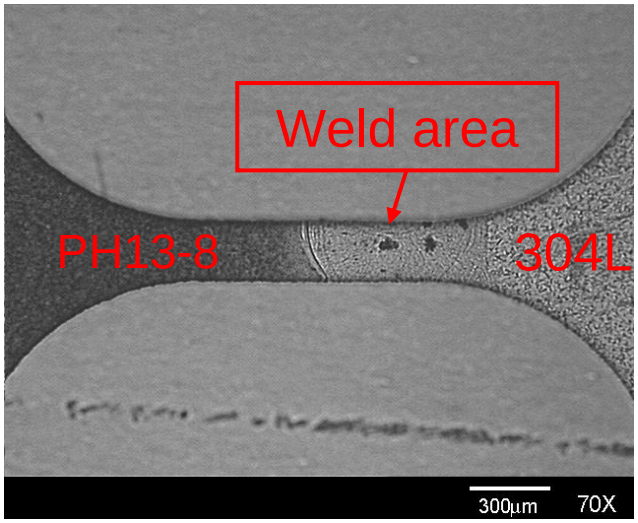
# Gage section of tensile specimens cover different portion of welded area




- Micro-tensile specimens were extracted using EDM method
- EDM has error in locating the specimen to the welded material
- Gage section of the specimens cover different portion of welded specimen

Direct displacement/strain measurement from gage section

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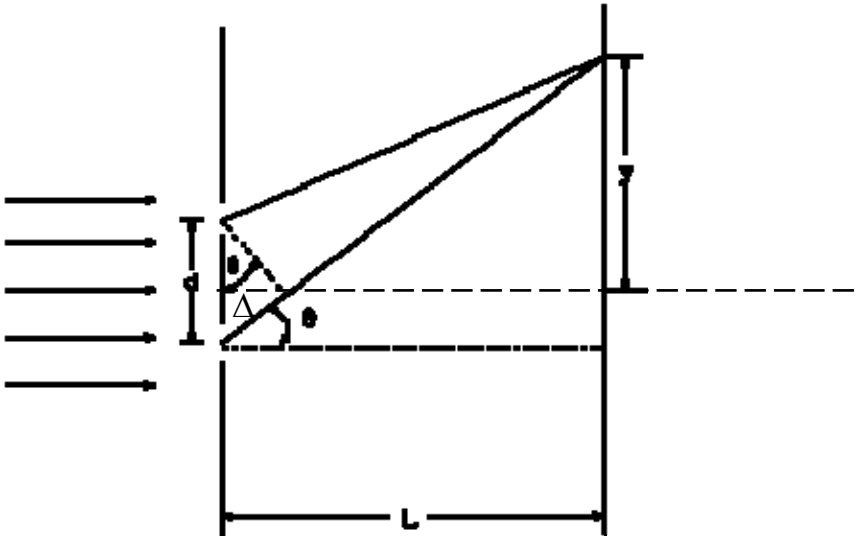
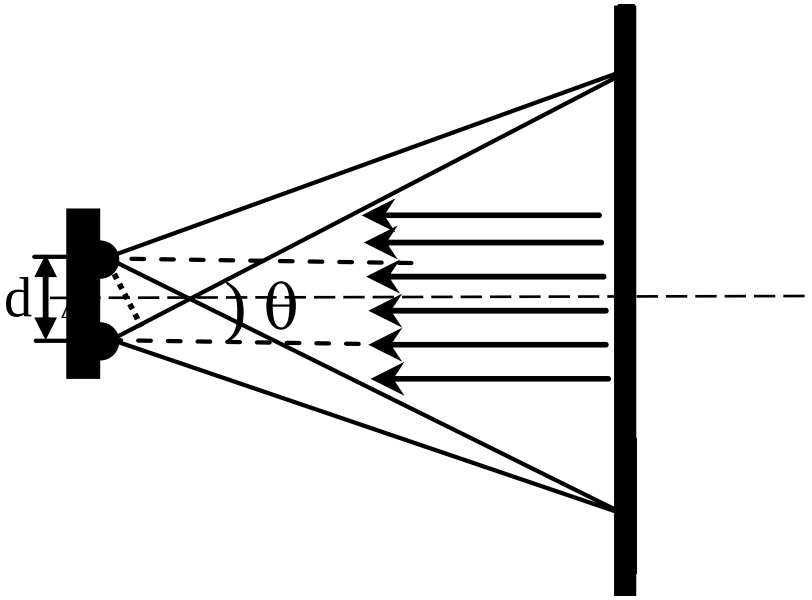
# The optical basics of laser interferometry technique is similar to young's double slit

Young's double slit




Transmitted coherent light

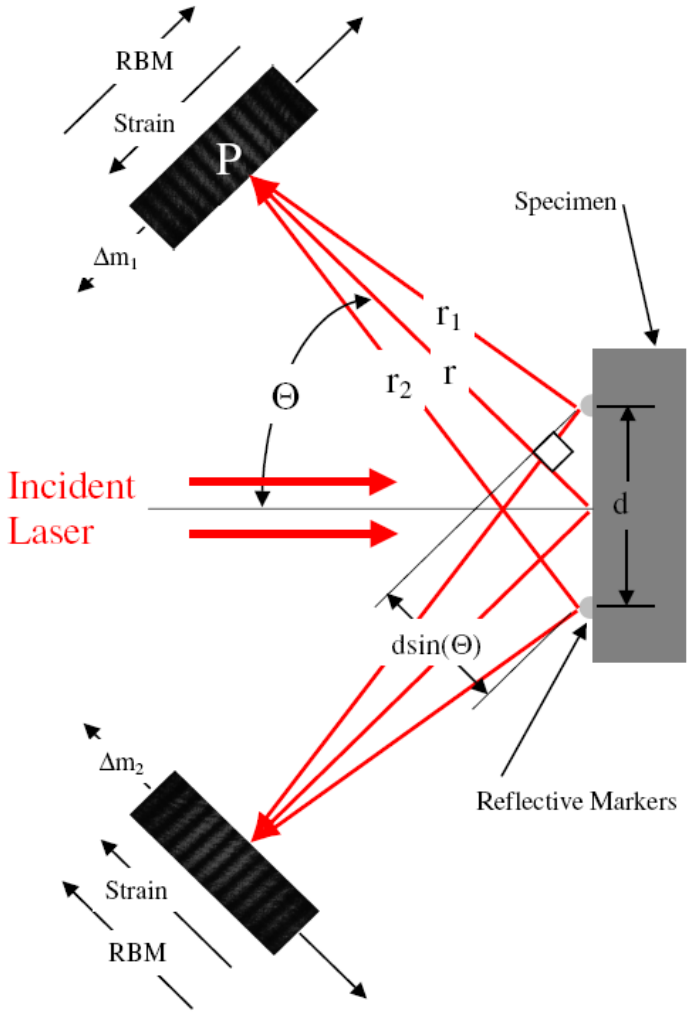
Modified Young's double slit




Reflected coherent light

$$m\lambda = d \sin \theta_m = \Delta \quad \Rightarrow \quad \delta \mathrm{d} = \frac{\delta m \lambda}{\sin \theta}$$

# Strain can be tracked from the phase shift of fringe patterns




$$\delta m = \frac{\delta\Phi}{2\pi}$$

$$\delta\ \mathrm{d} = \frac{\delta m\ \lambda}{\sin\ \theta} = \frac{\frac{\delta\Phi}{2\pi}\lambda}{\sin\ \theta}$$

$$\delta\Phi = \delta\Phi_1 - \delta\Phi_2$$

$$= \delta\Phi_{1\mathrm{RBM}} + \delta\Phi_{1\mathrm{strain}} - (\delta\Phi_{2RBM} + \delta\Phi_{2\mathrm{strain}})$$

$$\varepsilon = \frac{\delta\,\mathrm{d}}{d_0} = \frac{\frac{\delta\Phi}{2\pi}\lambda}{d_0 \sin\theta}$$

The strain is proportional to the phase shift.

M. Zupan, K.J.Hemkler, *Experimental Mechanics,* Vol. 42, 2, 214-20

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# *Background:* ISDG

*ISDG (Sharpe, W.N.Jr.)*[1]

- Linear photodiode arrays (1x512 pixels) were used to capture the fringe pattern
  - One-dimension signal only captures very small portion of the fringe
  - Larger noise to signal ratio
- Fringe pattern minima is tracked to measure the fringe motion

In this work, CCD cameras are used to capture two-dimension information of fringe pattern.

[1.] Sharpe, *W.N., Jr., Experimental Mechanics 8(4), 164, 1968; Optical Engineering, 21(3), 483, 1982*

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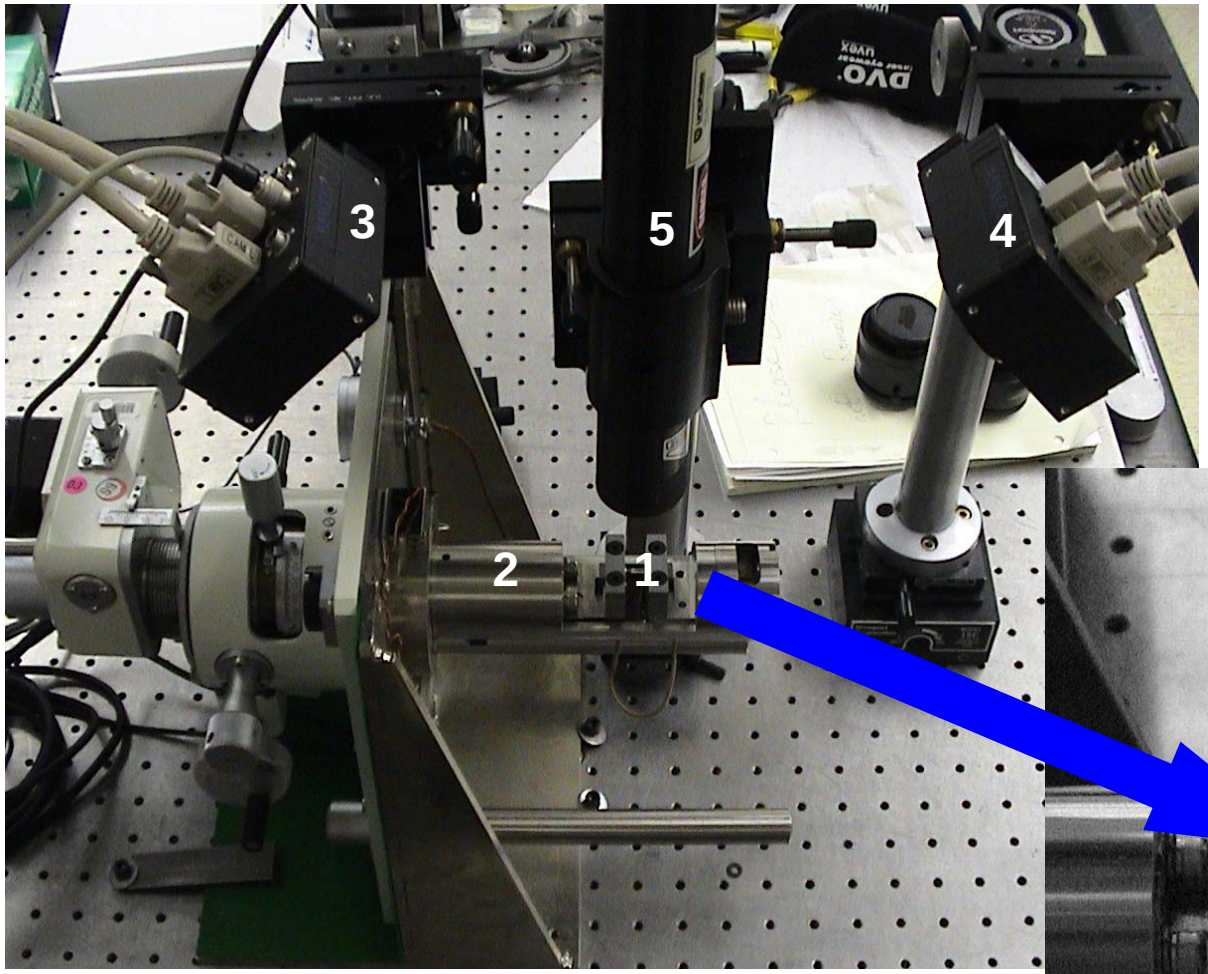
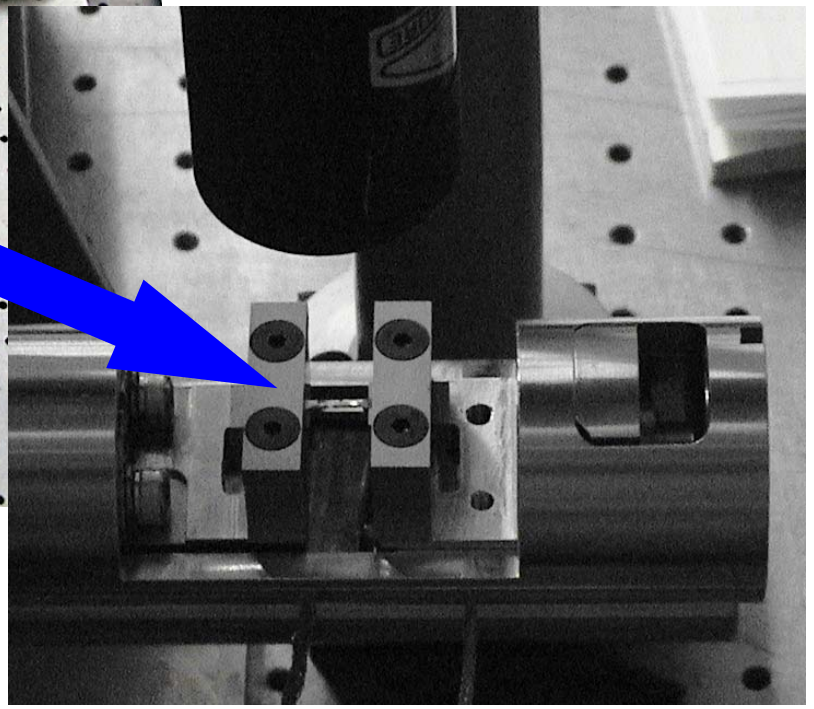
# Uniaxial strain measurement configuration



1 — Specimen  2 — Loading Stage

3,4 — CCD Cameras  5 — HeNe Laser

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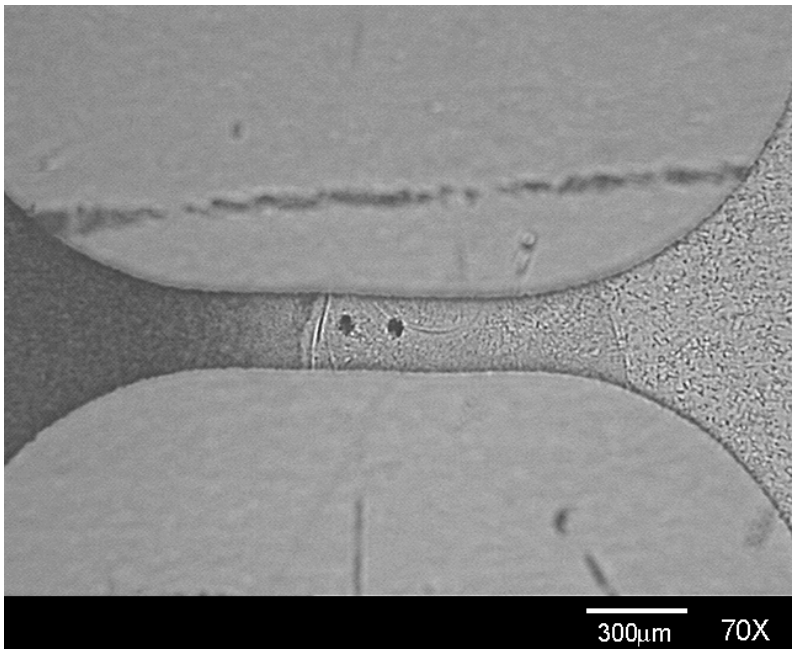
# Application of laser interferometry technique for testing laser welded material




- Vickers indents were used as laser reflection markers
- Indents are located in the welded material
- Displacement/strain are measured directly using the reflection markers as the gage section

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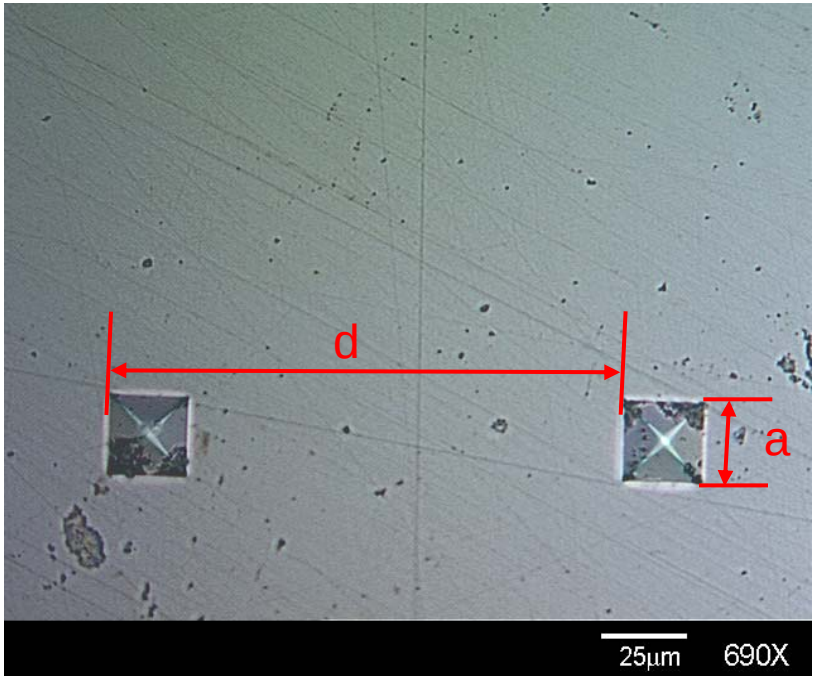
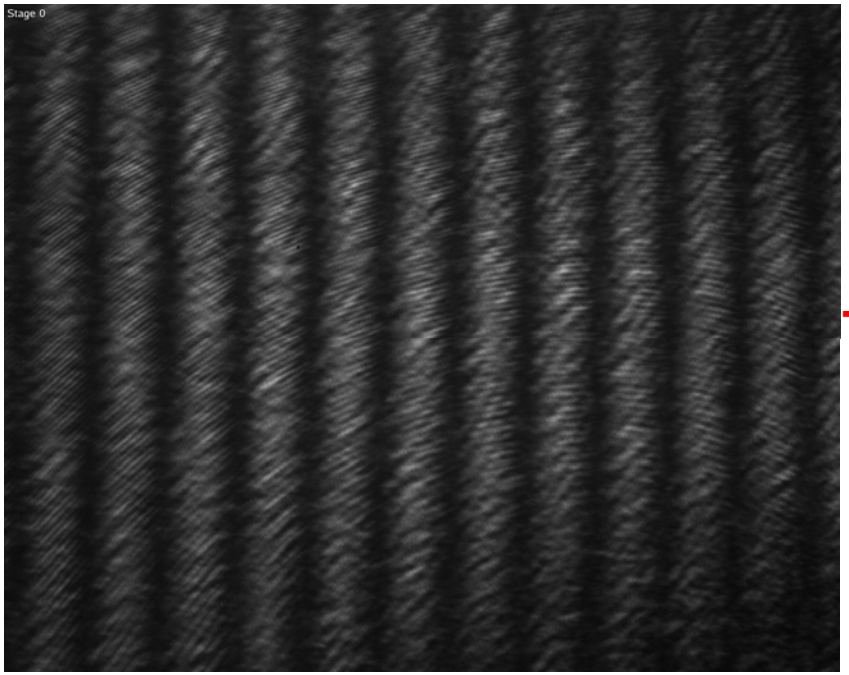
# Reflection Markers and Fringes

Reflection markers are from Vickers microindentation:

$$d = 150\ \mu m, a \approx 20\ \mu m$$




Indents on laser welded specimen




**1280 pixels**

Selected Fringe Window

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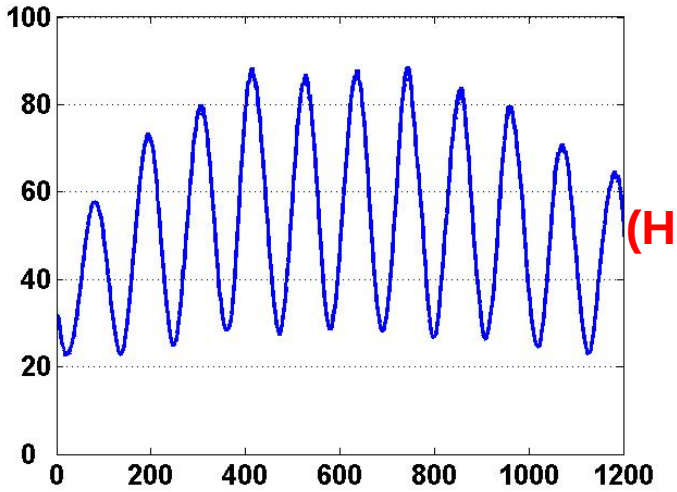
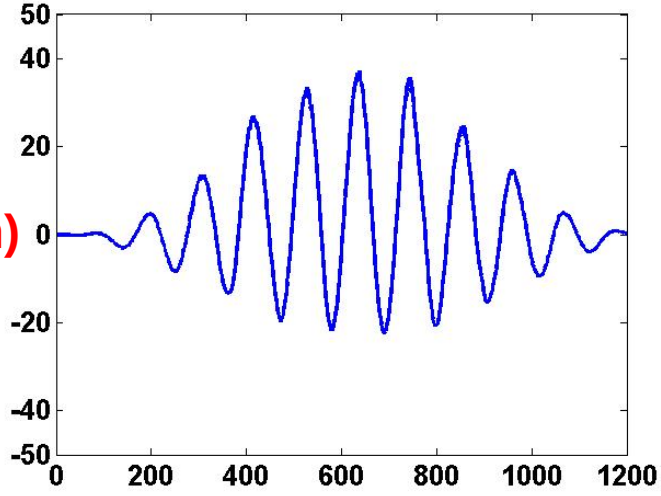
# Fourier Analysis of Fringes

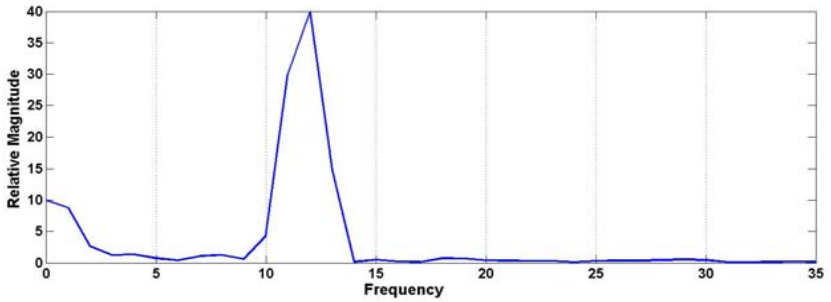



Intensity (Raw fringe pattern)

**(Hanning function)**




Intensity (Hanning windowed fringe pattern)




Frequency

$$\text{Phase } \Phi = \arctan\left(\frac{\text{Im}}{\text{Re}}\right)$$

$$\varepsilon = \frac{\delta \text{ d}}{d_0} = \frac{\frac{\delta \Phi}{2\pi}\lambda}{d_0 \sin \theta}$$

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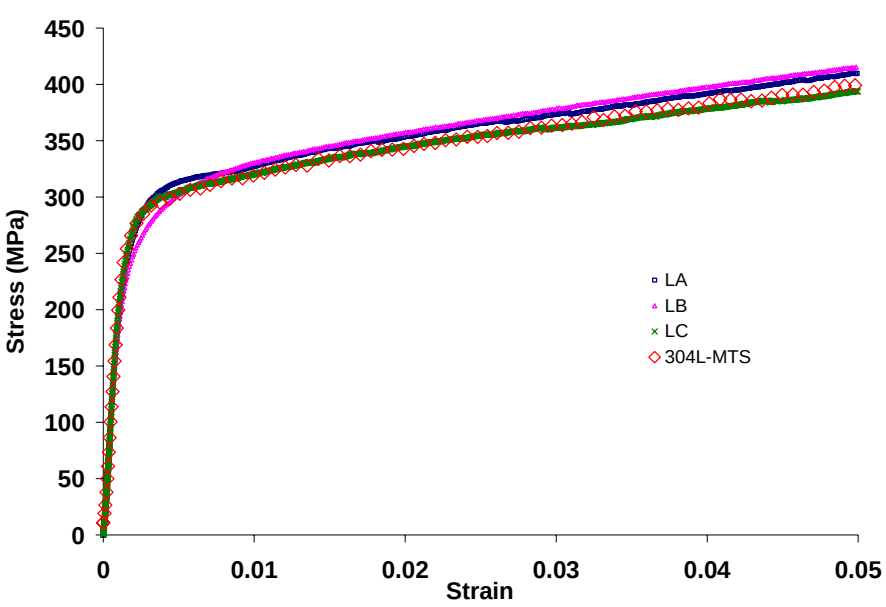
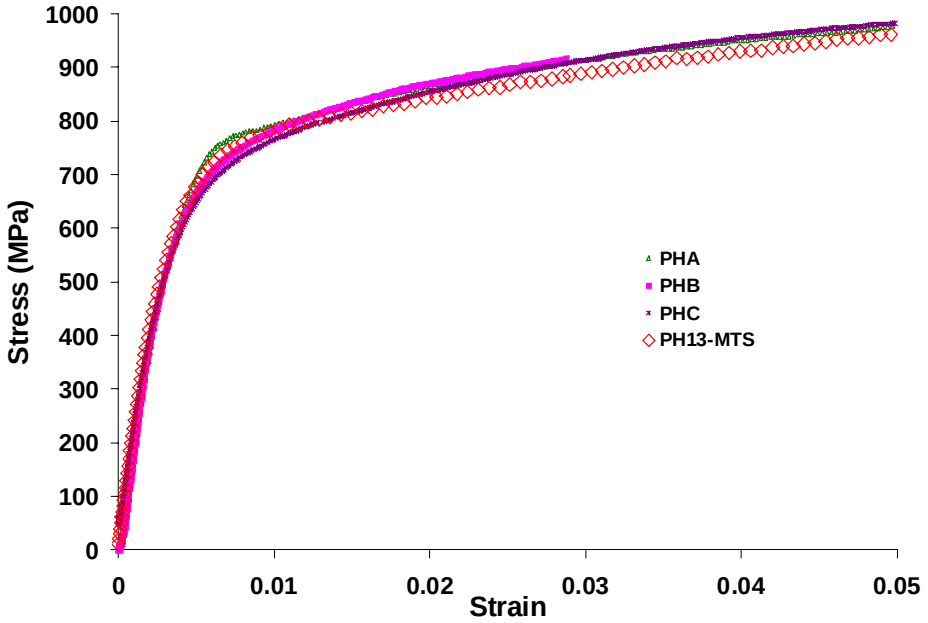
# Base material properties using laser interferometry and conventional technique




Stress versus strain for 304L




Stress versus strain for PH13-8

The mechanical properties of base materials are consistent using laser interferometry and conventional methods, which approves that the technique is providing accurate results.

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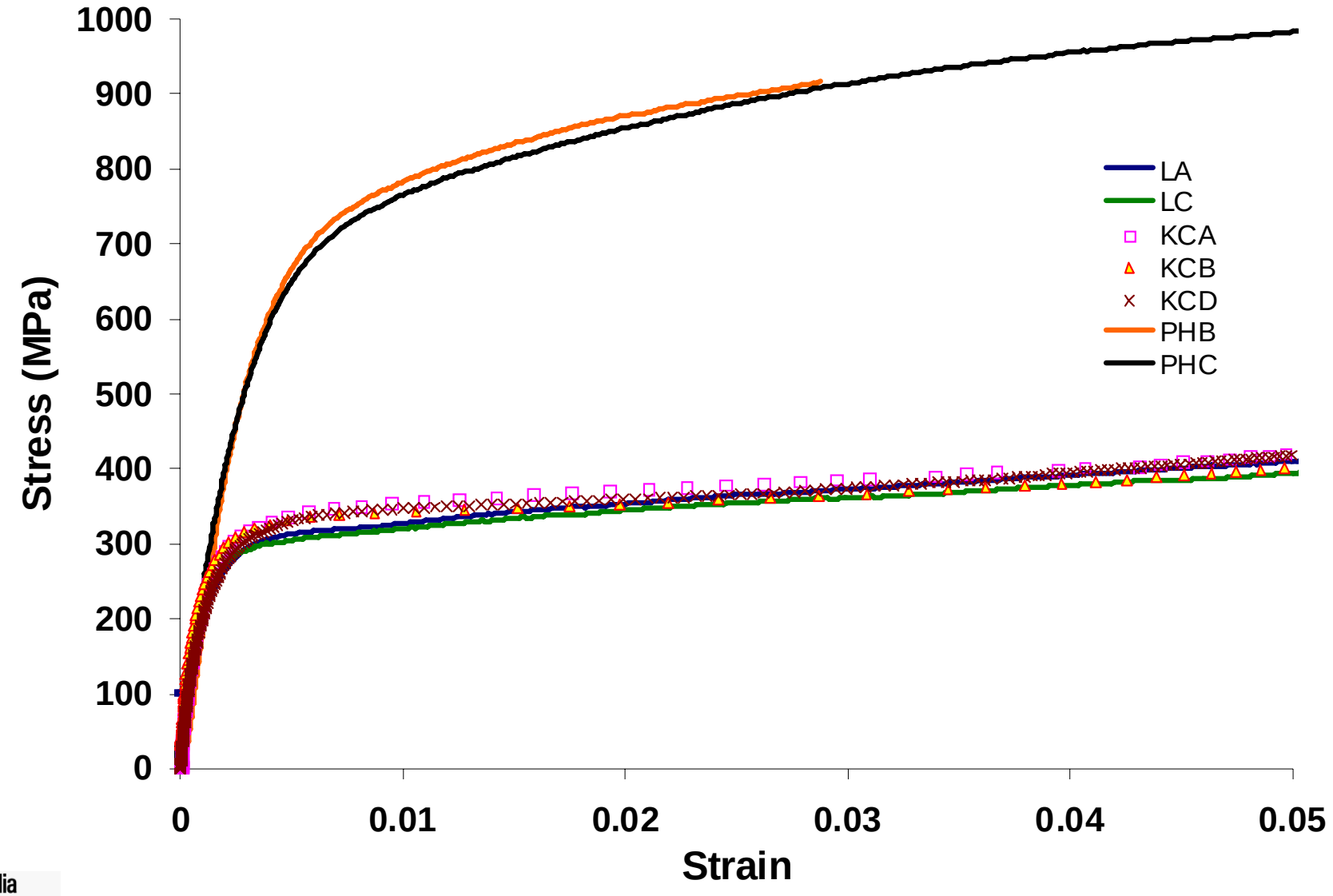
# Mechanical properties of KC series is close to 304L

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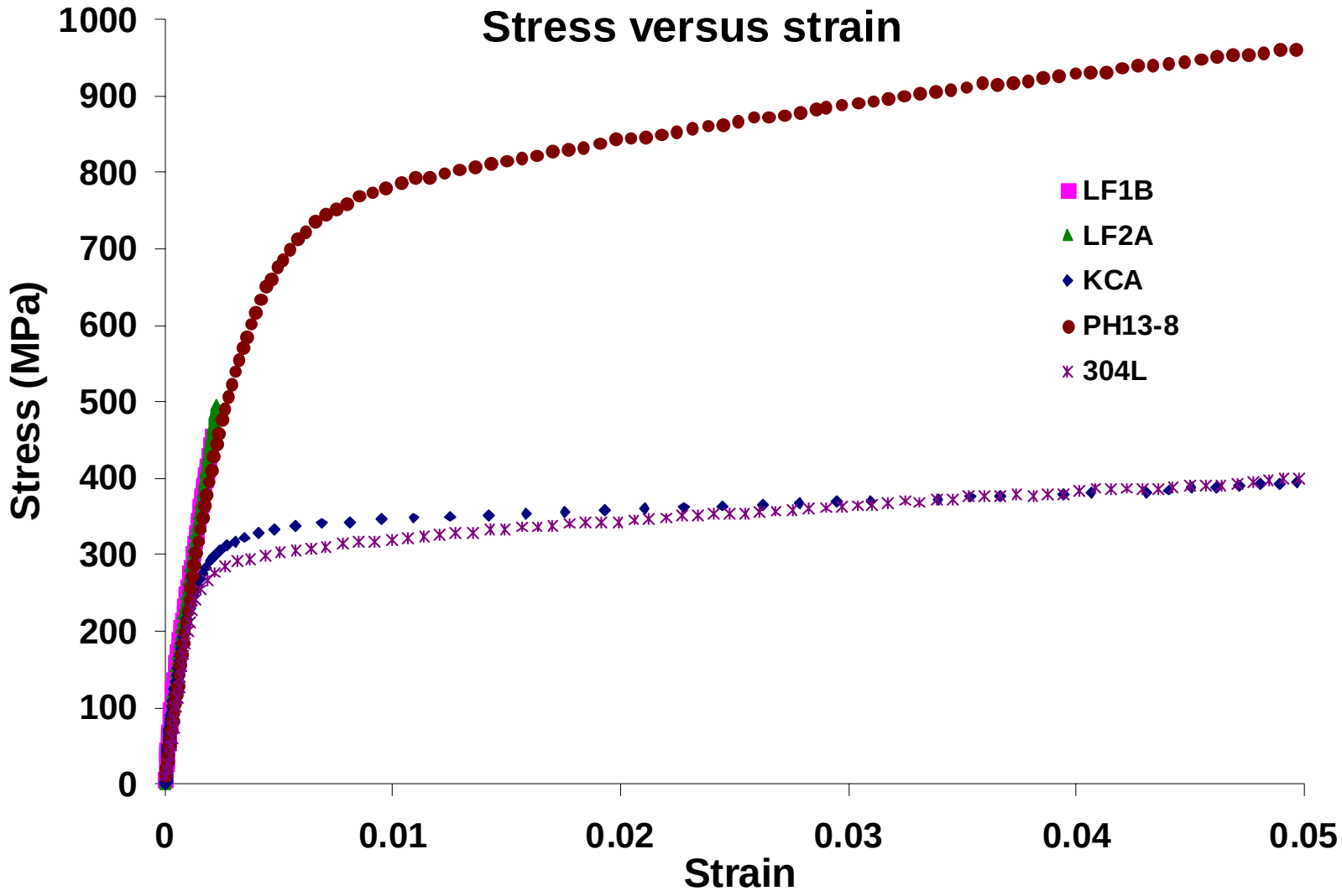
# But, the mechanical properties of LF series is close to Ph13-8

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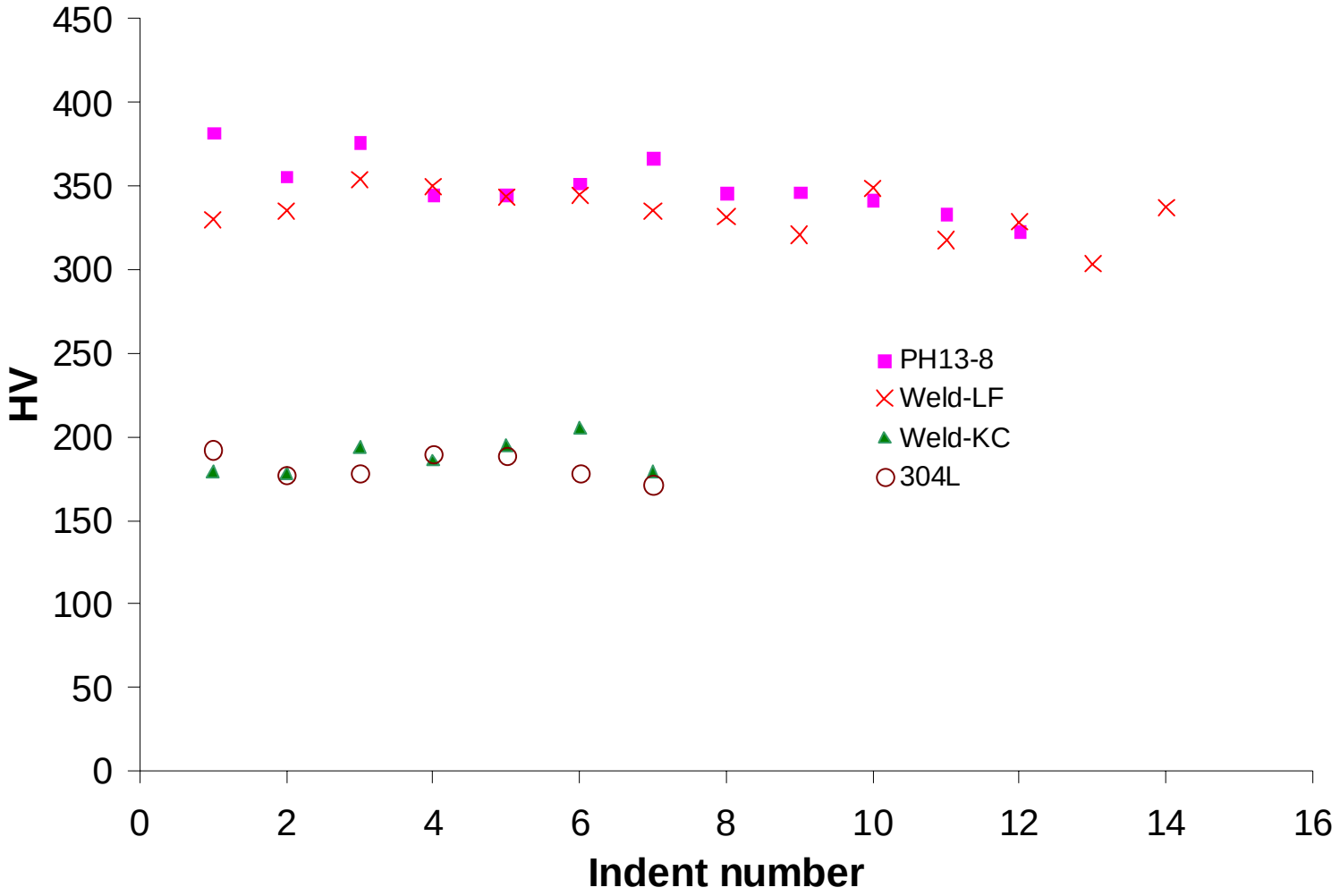
# Hardness value is consistent with stress~strain curve from laser interferometry

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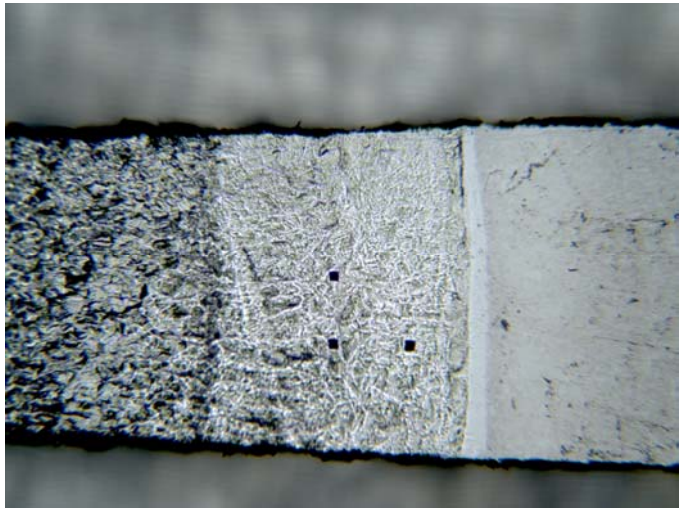
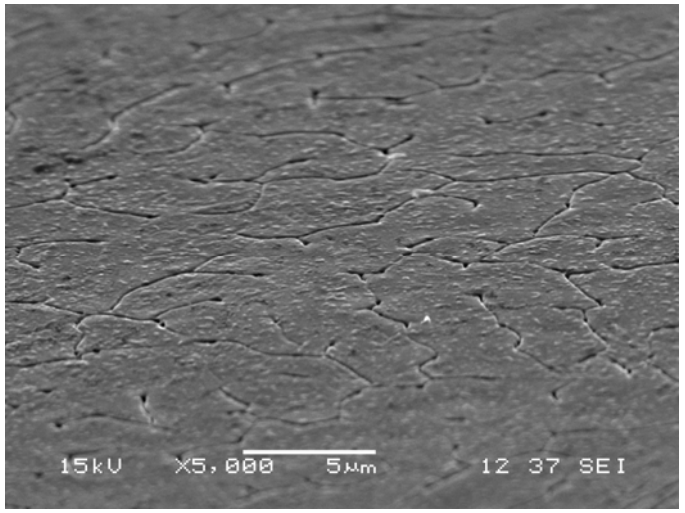
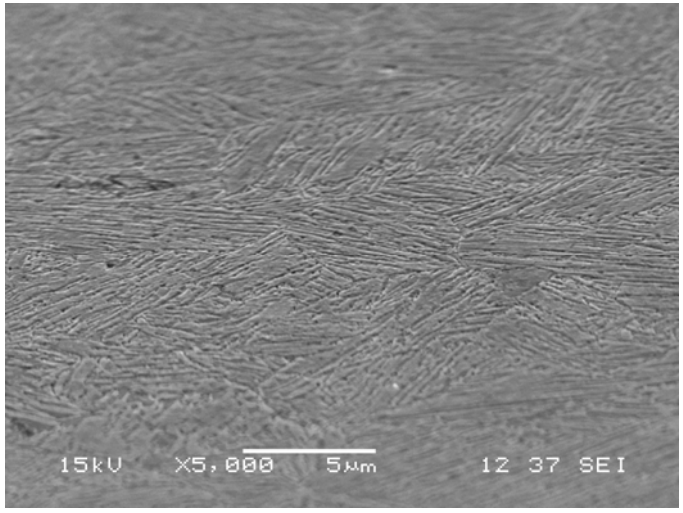
# Welded area of KC series show a lot of deformation



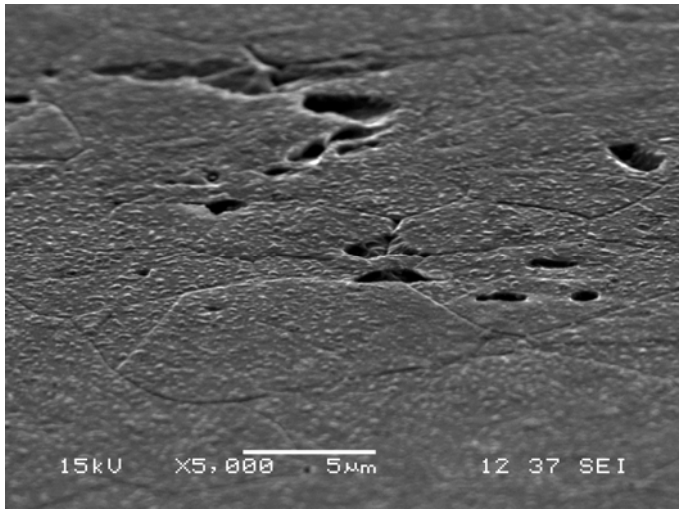
Specimen KCA1




Welded area (next to indents)




PH13-8




304L

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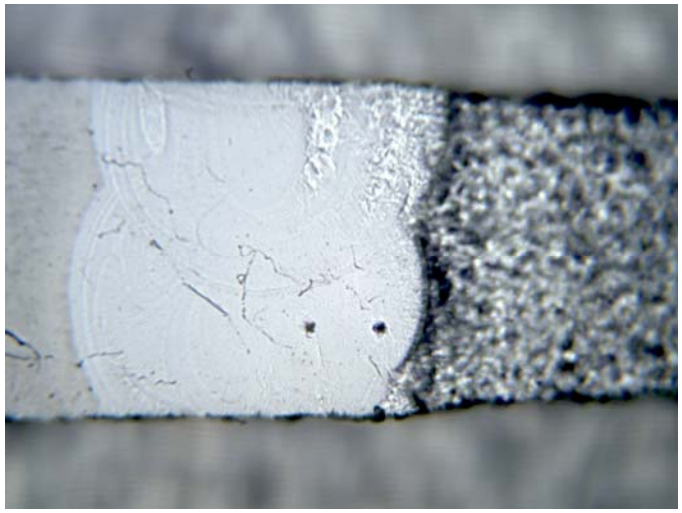
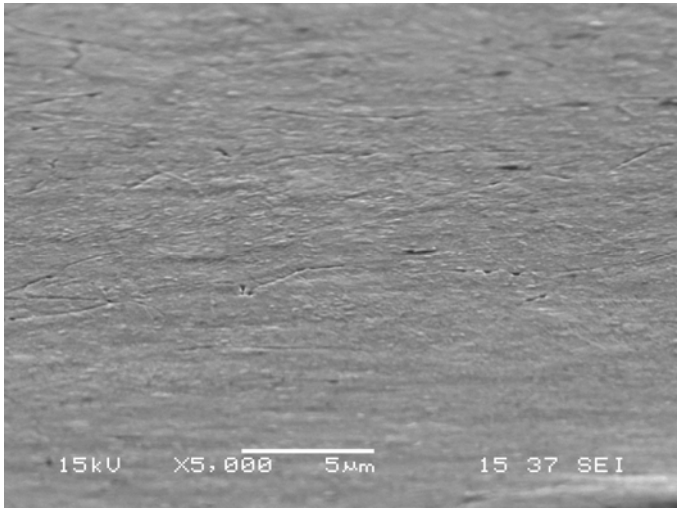
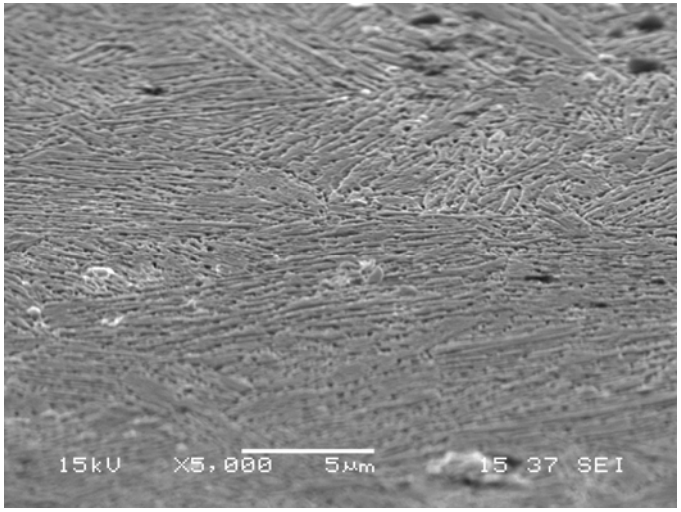
# But, welded area of LF series does not show deformation



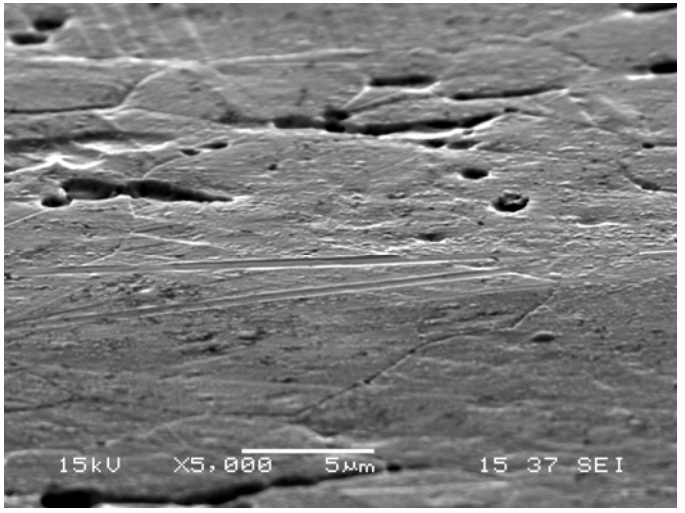
Specimen LF1A




Welded area (next to indents)




PH13-8




304L

Both KC and LF series show similar surface features.

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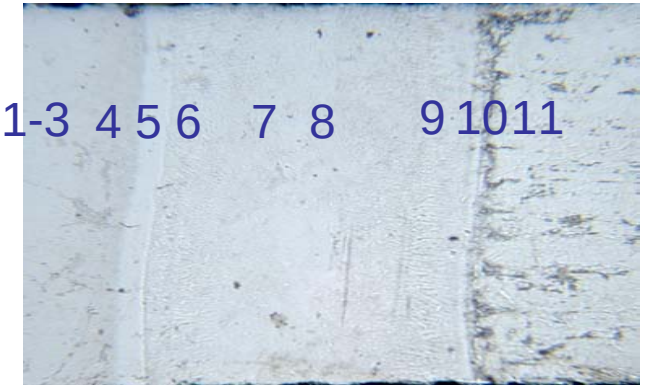
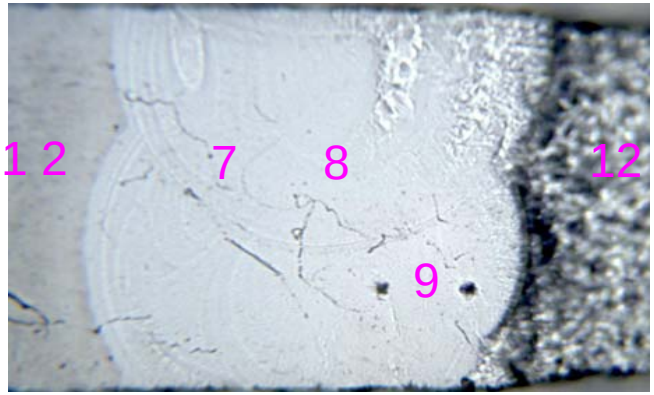
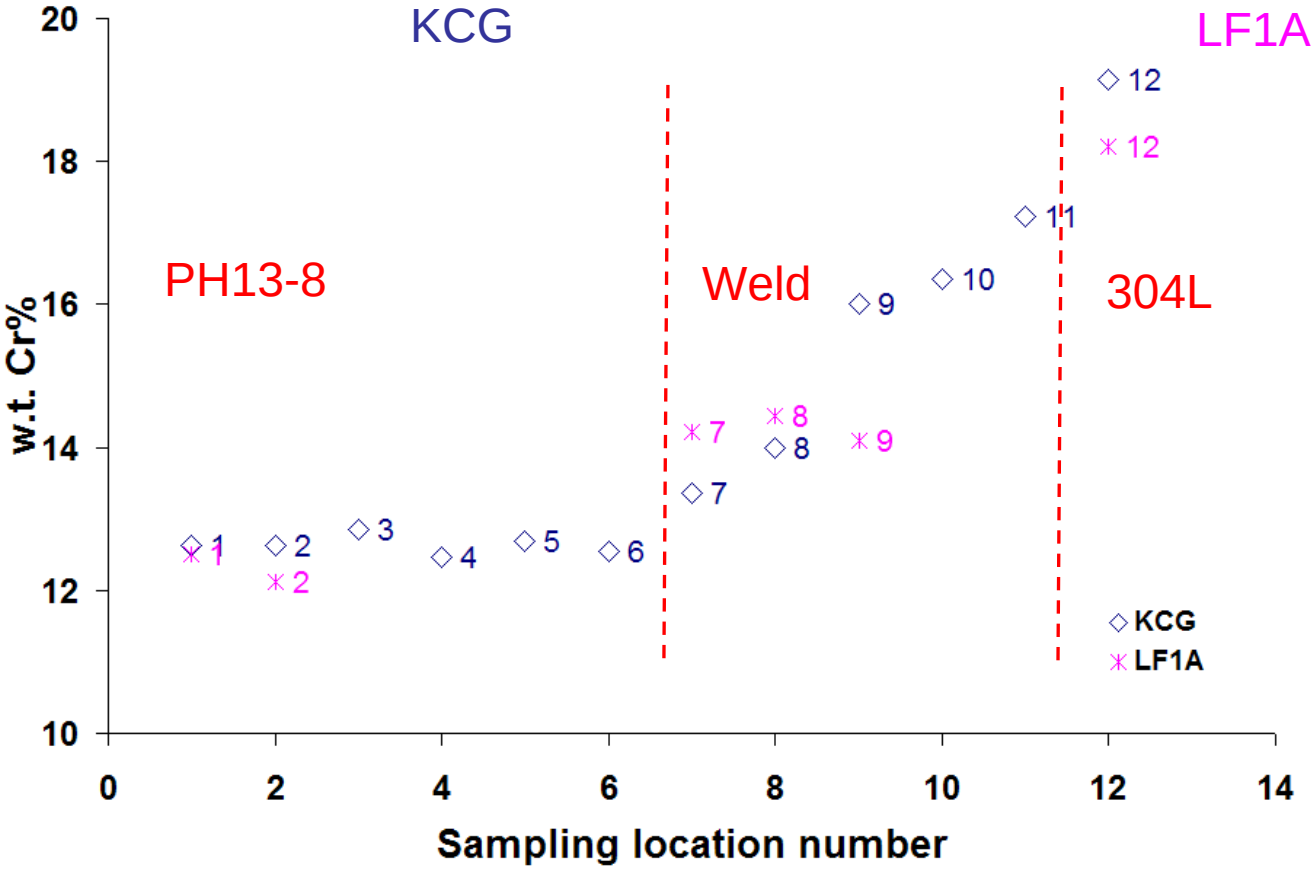
# Chemical Composition




KCG




LF1A

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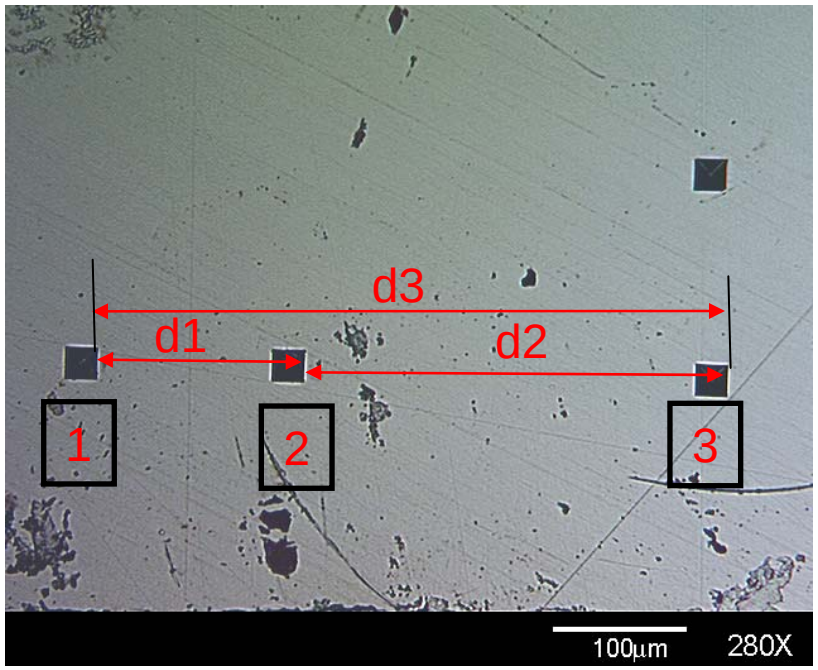
# Multi-Marker interference was developed to test the material property variation

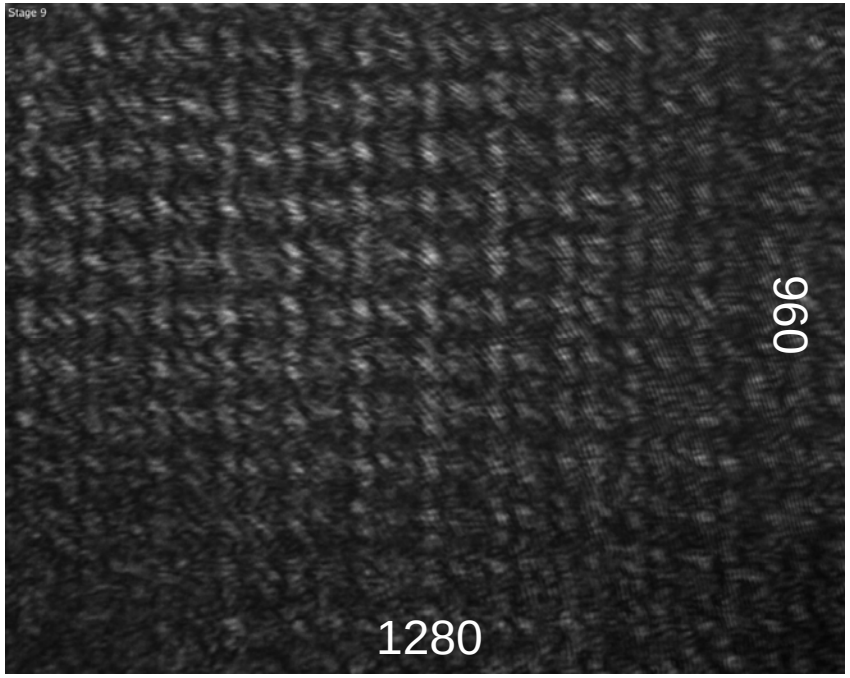
Multi indents with various spaces:

$$d_1 = 100\ \mu m, d_2 = 200\ \mu m, d_3 = 300\ \mu m$$

These indents generated fringes with various frequencies;




Indents




Fringes

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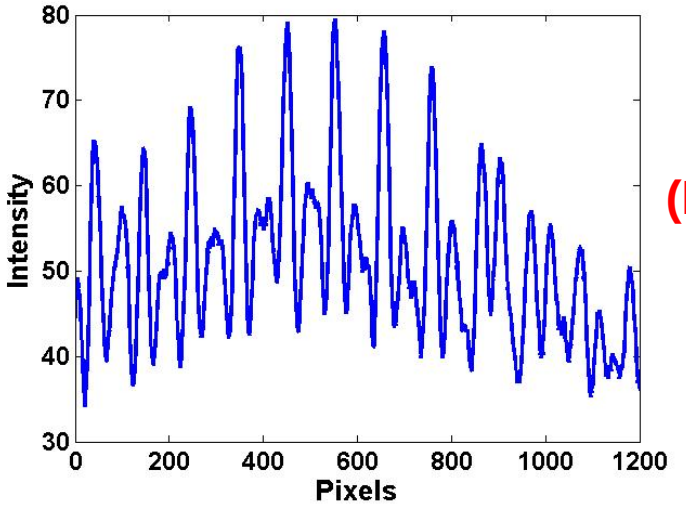
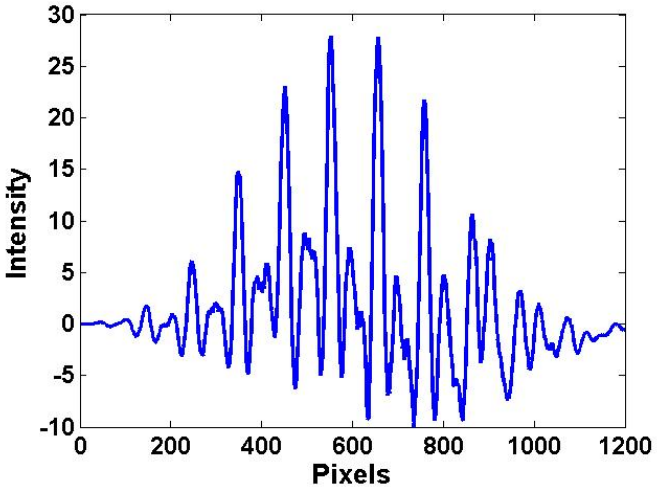
# Fourier Transfer of Fringes from Multi-marker Reflection

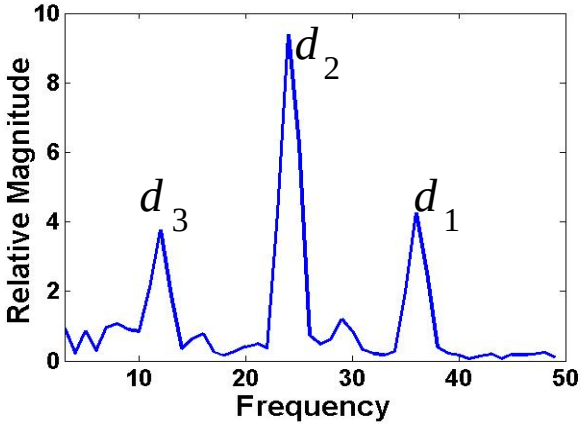



Intensity (Raw fringe pattern)

**(Hanning function)**




Intensity (Hanning windowed fringe pattern)




Frequency

$$\delta\Phi_{d_1}, \delta\Phi_{d_2}, \delta\Phi_{d_3}$$

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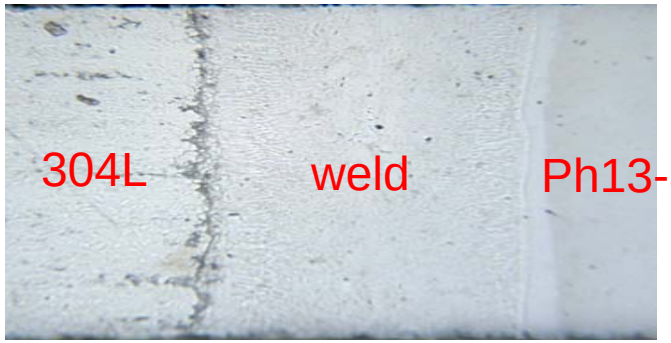
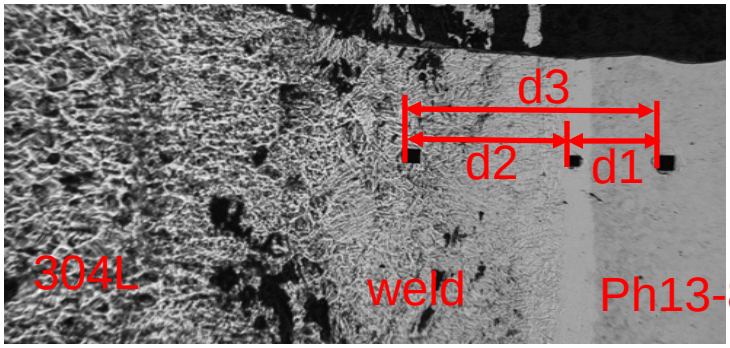
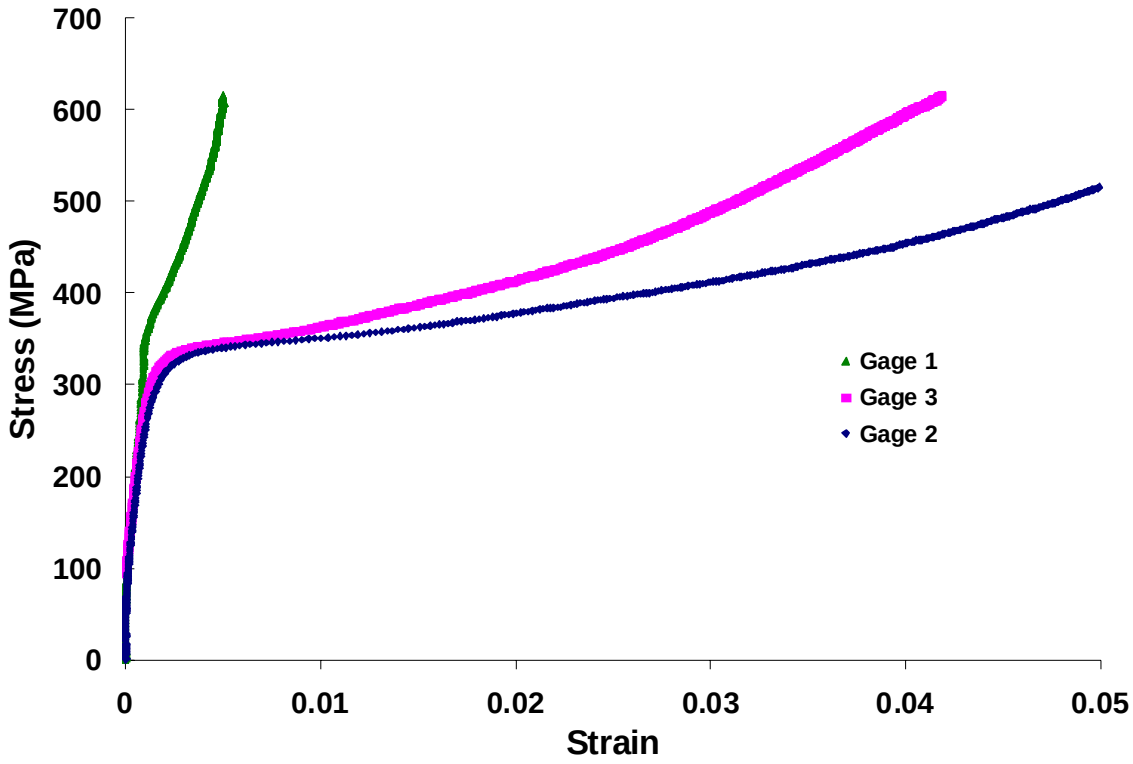
# Multi-marker test of KC series welded




Before test




After test

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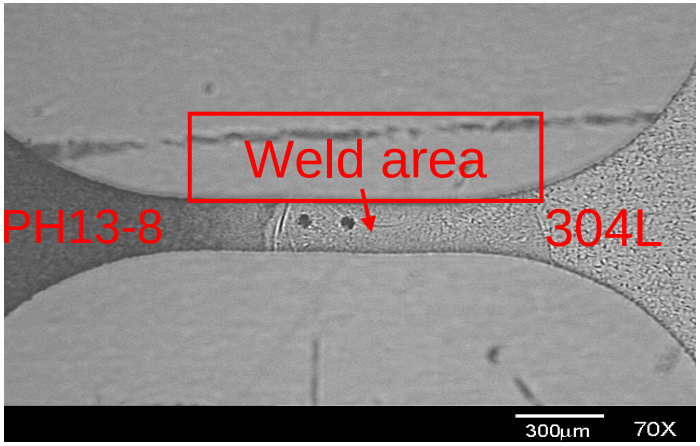
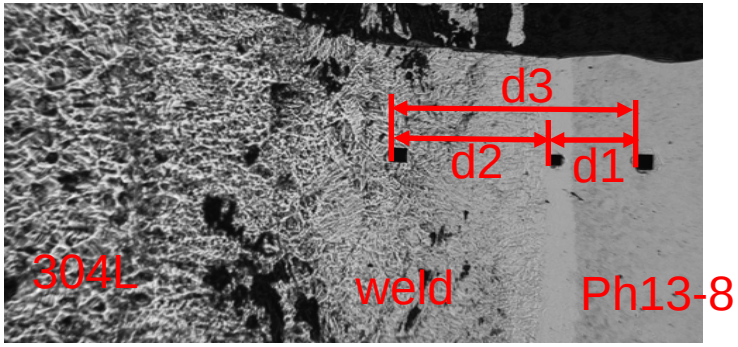
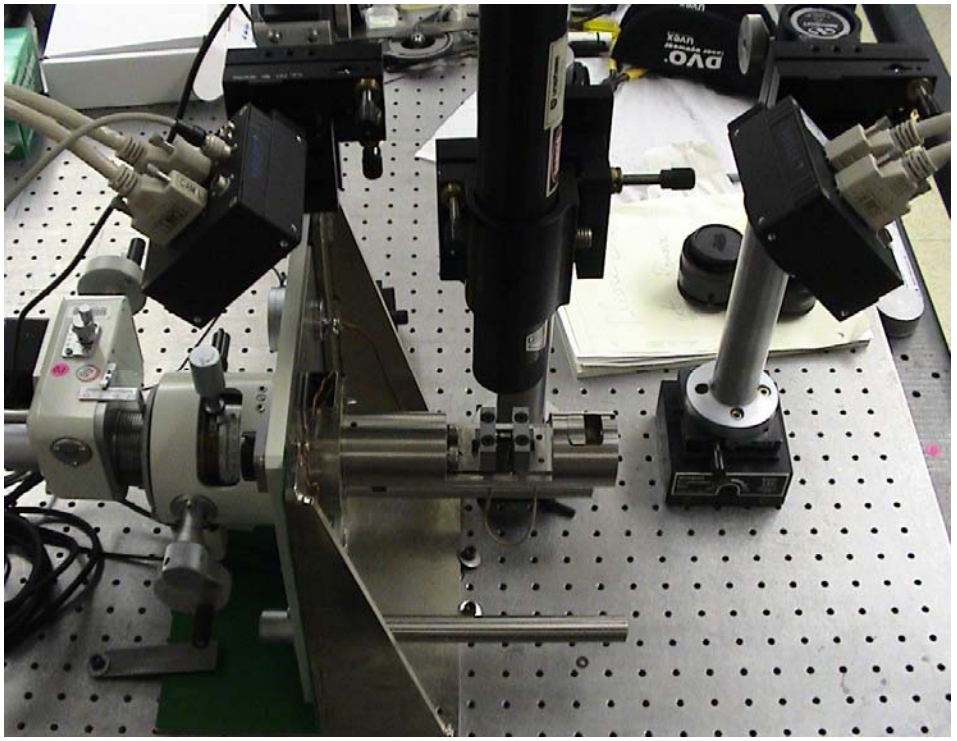
# Summary




Welded material specimen




Multi-marker interferometry



Laser interferometry strain measurement

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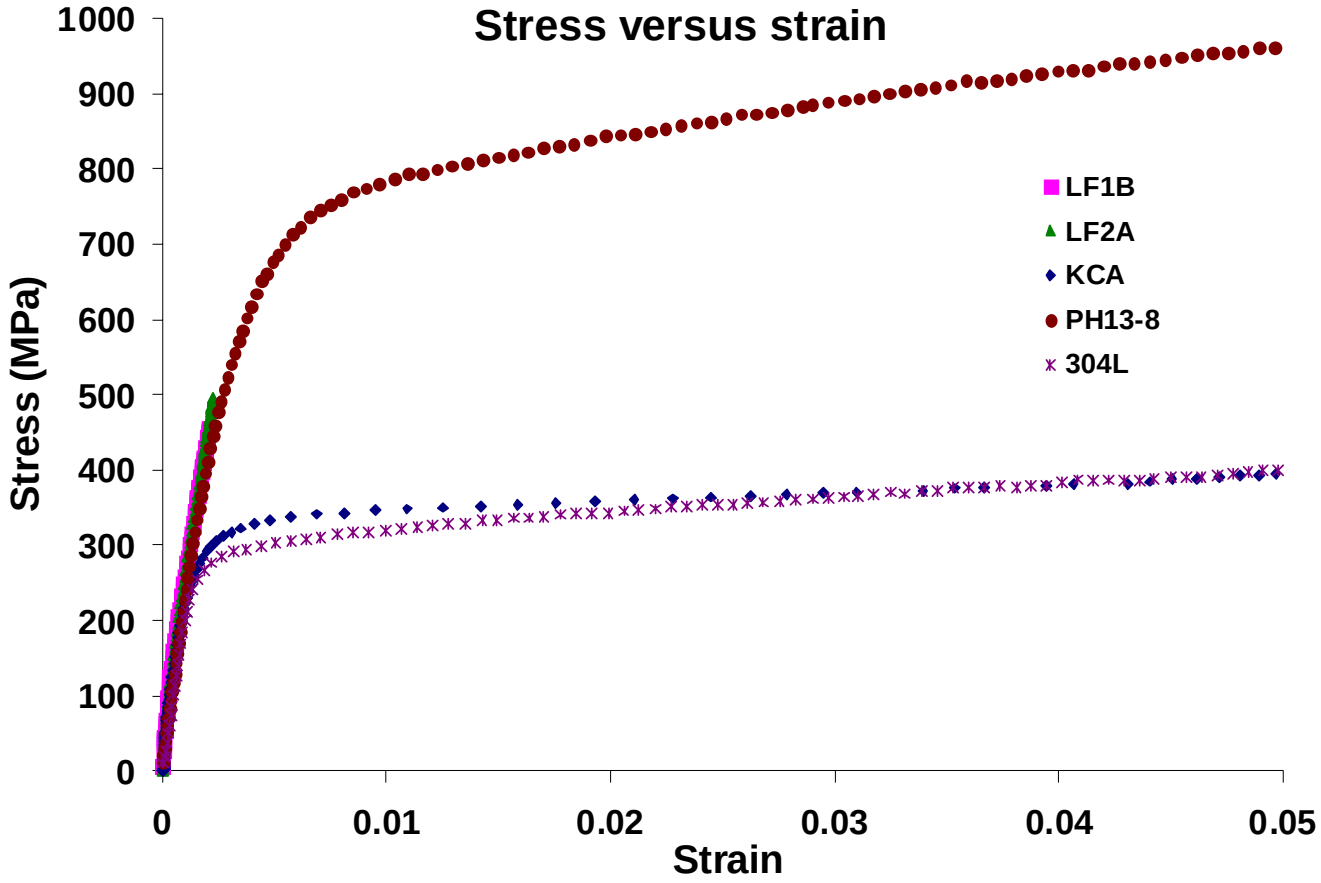
# Summary




What causes the difference of mechanical properties for welded area? Microstruture? Chemical Compositon?

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