SAND2016-11463C

Porosity Analysis and Mechanical Characterization of Laser Welds

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iDICs 2016/SEM Fall Conference

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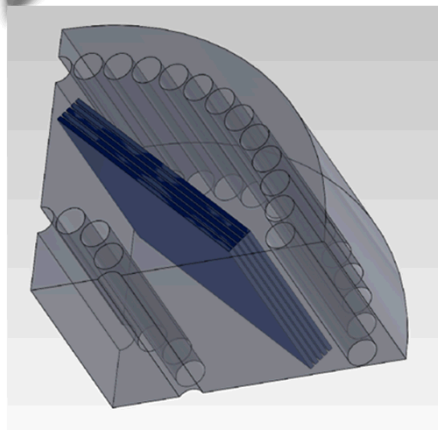
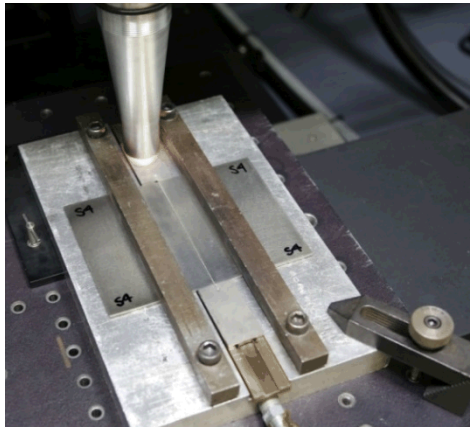
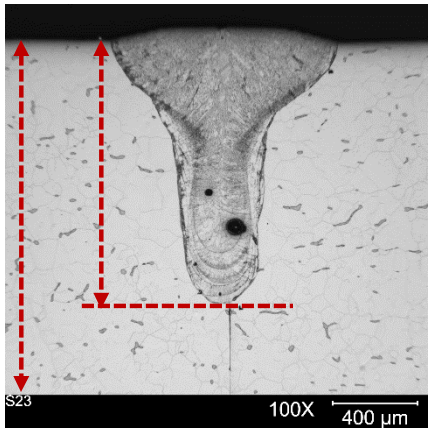
Background and Motivations



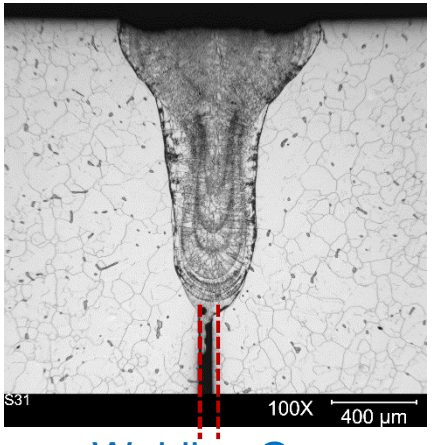
304L Plate



Laser welding



Laser Welds with Partial Penetration of 0.050”



Welding Gap

- **Materials:** 304L VAR from 16” bar;
- **Weld schedules:** Two weld schedules A and B;
- **Partial penetration depths:** 0.030 in (0.76mm), 0.040 in (1.02mm), 0.050 in (1.25mm) and 0.060 in (1.50mm);
- **Welding gaps:** 0 in, 0.004 in (0.1mm), 0.008 in (0.2mm) for welds with 0.030” and 0.050” depth;

- Laser welding generates narrow welds;
- Porosity in the laser welds is of great concern;
- How welding schedules and gaps affect the porosity and mechanical properties of the laser welds?

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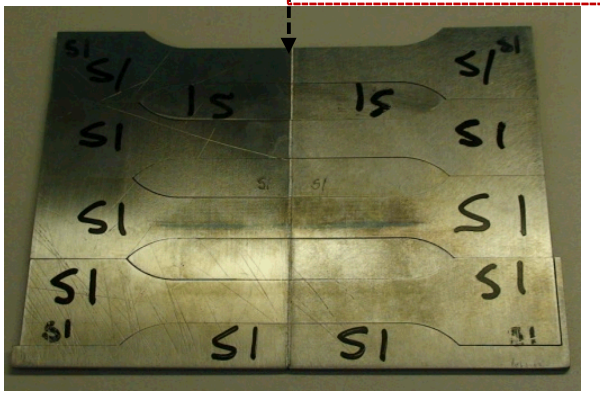
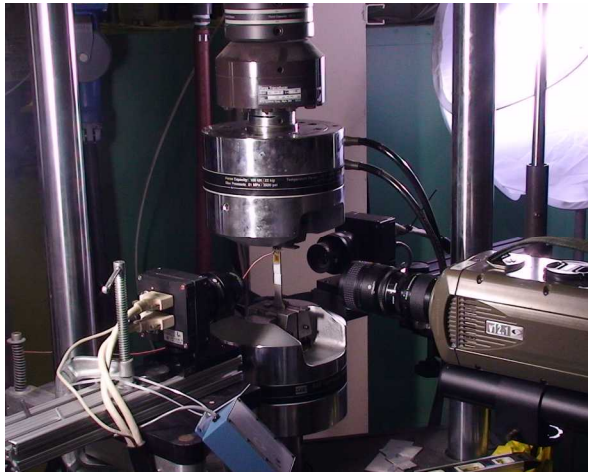
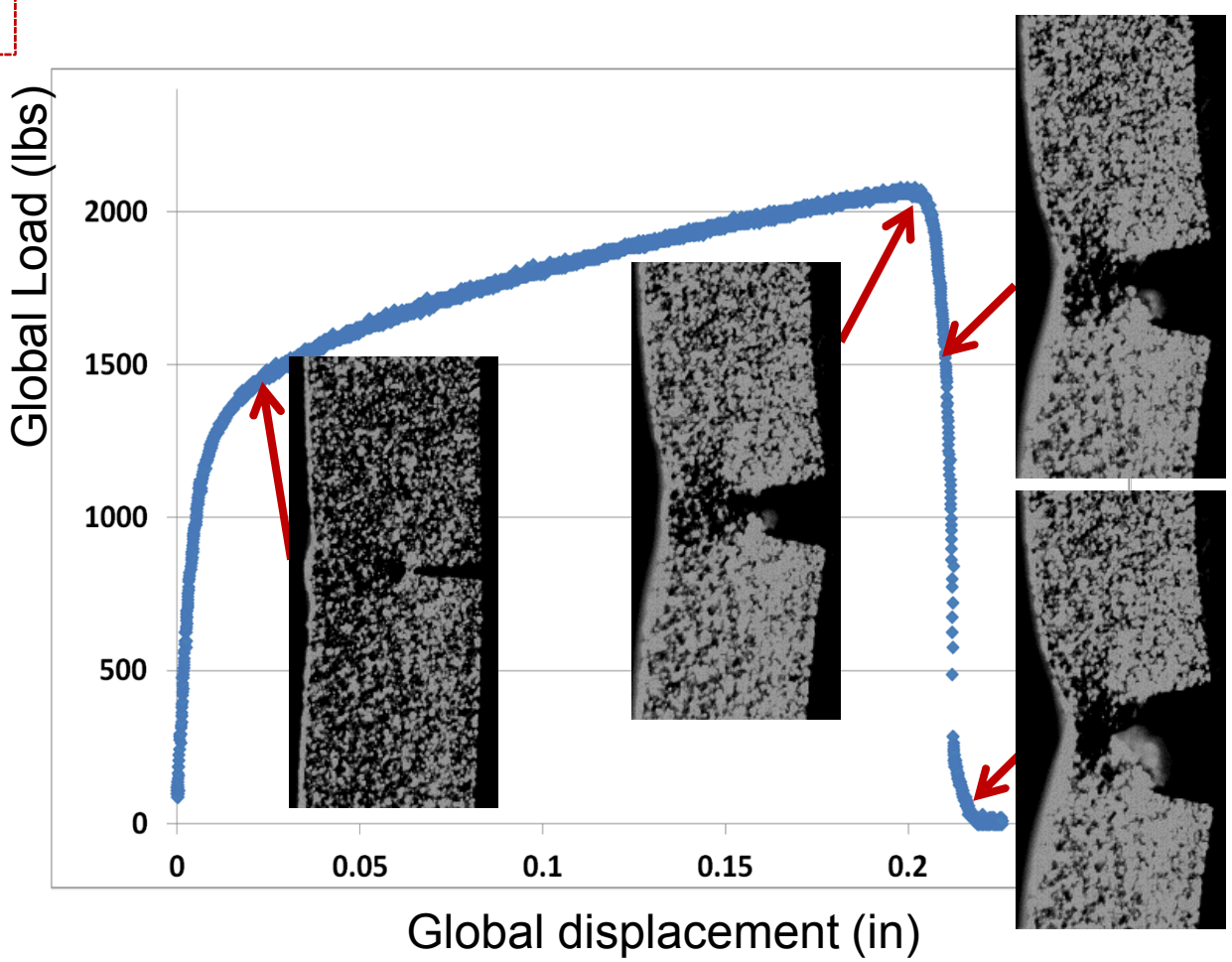
Mechanical Characterization of Laser Welds







- Global load versus displacement from the whole gage;
- The side camera observe the crack opening of the welds;

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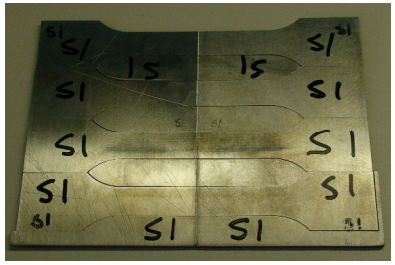
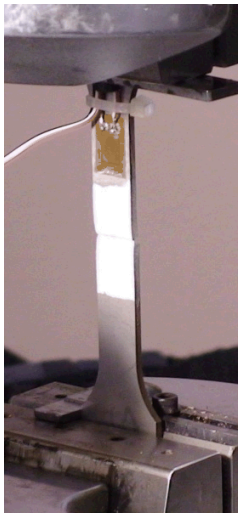
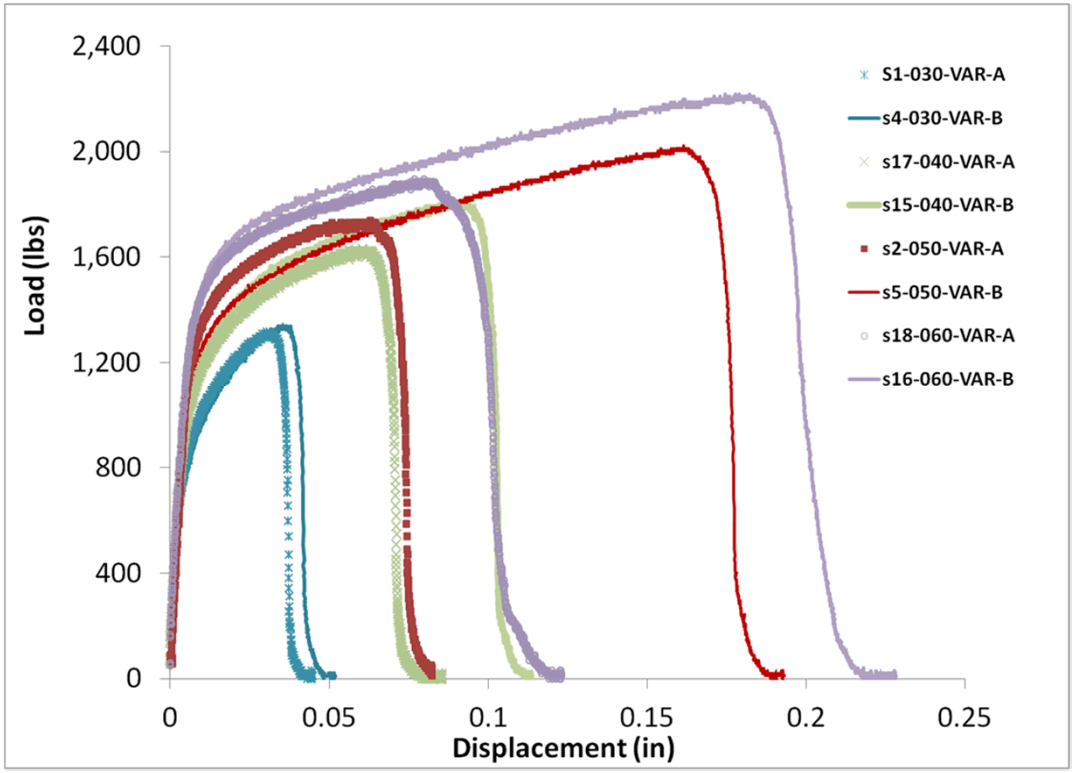
The Mechanical Performance of Laser Welds with Different Welding Schedules and Penetration Depths





Large tensile specimens



Mechanical tension tests conducted for *VAR.*

Weld schedules are *A & B*

Depths of penetration:

-030- = 0.030 in.
-040- = 0.040 in.
-050- = 0.050 in.
-060- = 0.060 in.

S18-060-VAR-A

This is specimen 18 with a depth of penetration of 0.060 in. The material is VAR and the weld schedule is A.

- **The specimens from schedule B has higher strength and larger displacement than those from schedule A.**

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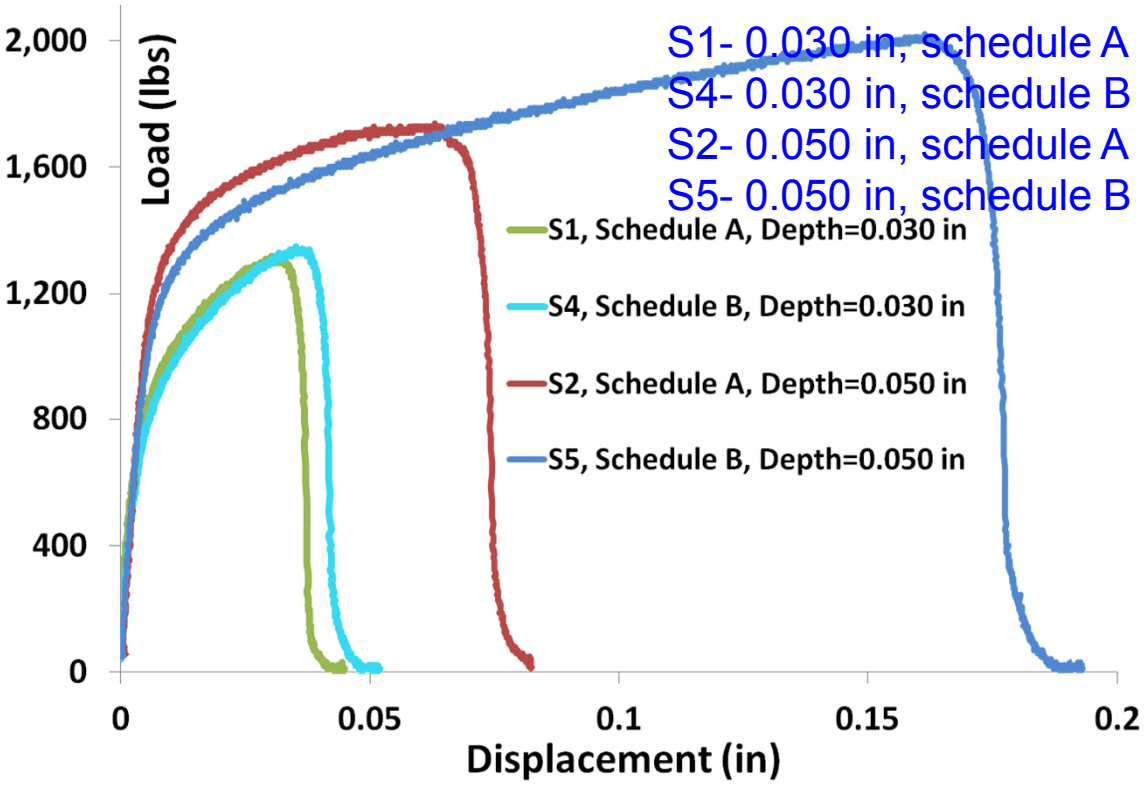
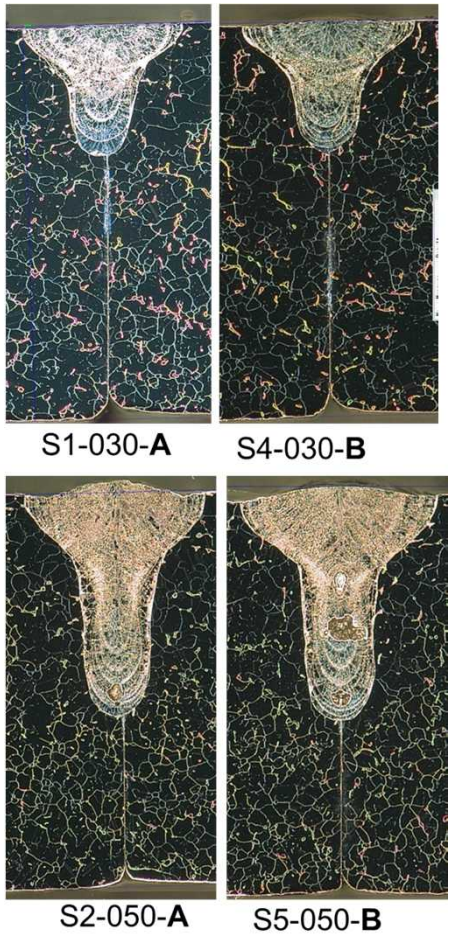
The Effect of Welding Schedule on the Mechanical Performance of Laser Welds





The specimens from schedule B has higher strength than those from schedule A.

Weld schedule impacts mechanical performance.

- No apparent difference of the weld depth and width between the two welding schedules.

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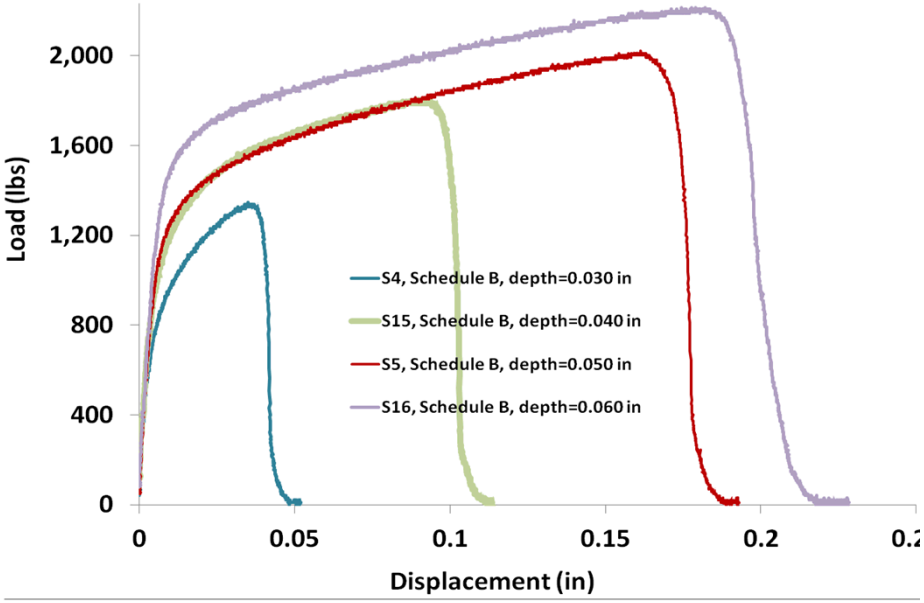
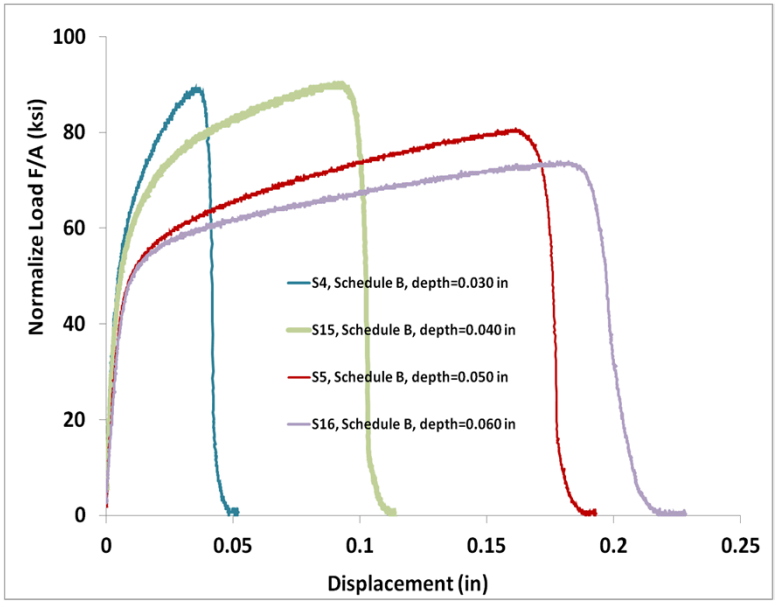
The Effect of Penetration Depth on Mechanical Performance of Laser Welds

S4 - 0.030 in, schedule B
S15- 0.040 in, schedule B
S5 - 0.050 in, schedule B
S16- 0.060 in, schedule B





The maximum load increases as the penetration depth increases. However, the normalized load decreases as the penetration depth increases.

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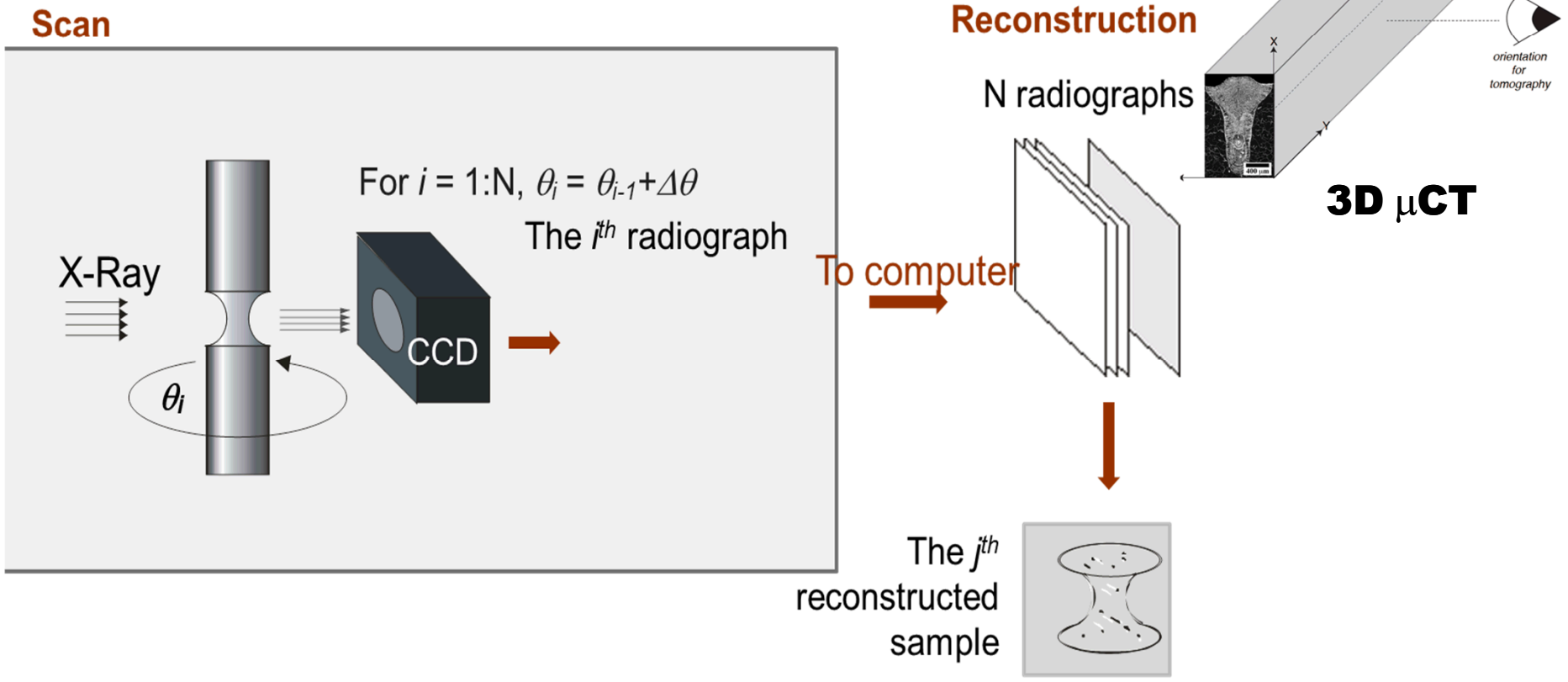
X-ray Computed Tomography Imaging



XCT imaging is used to study the porosity inside the laser welds.

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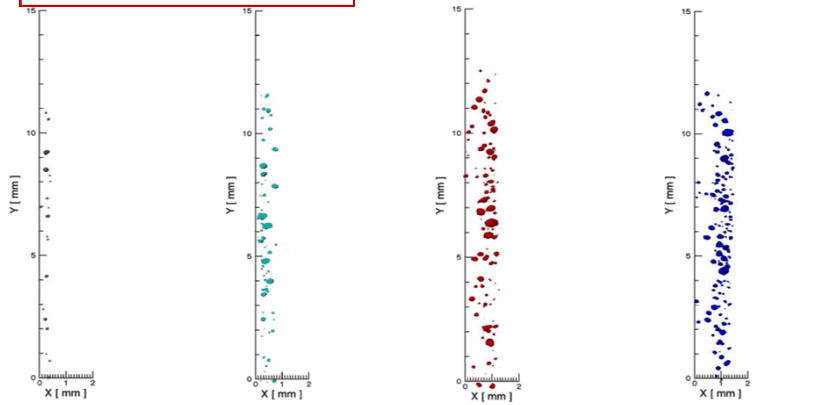
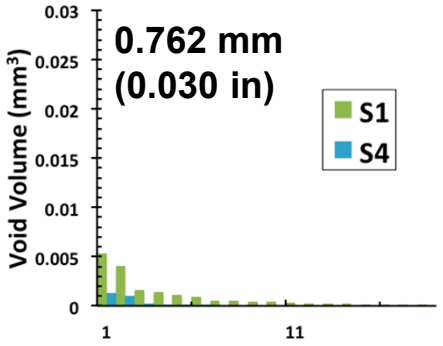
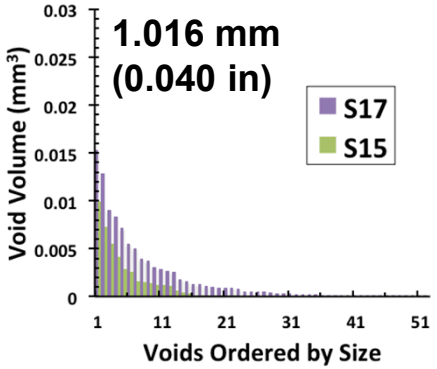
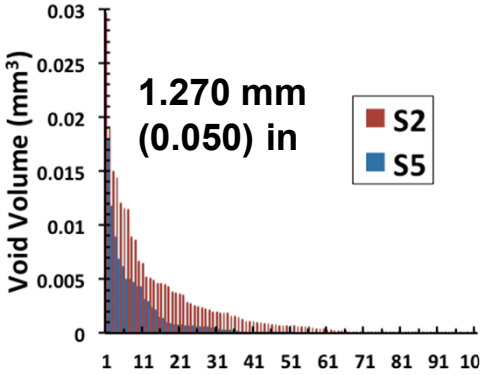
The Effect of Weld Schedule and Penetration Depth on Porosity of Welds

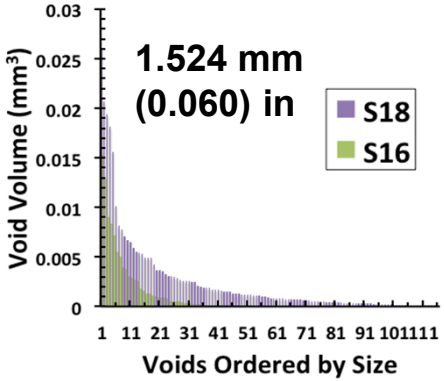
Schedule A











Schedule B

- Welds with schedule B have less porosity and smaller void volume fraction than those from schedule A.
- Deeper penetration welds have higher volume fraction and larger voids.

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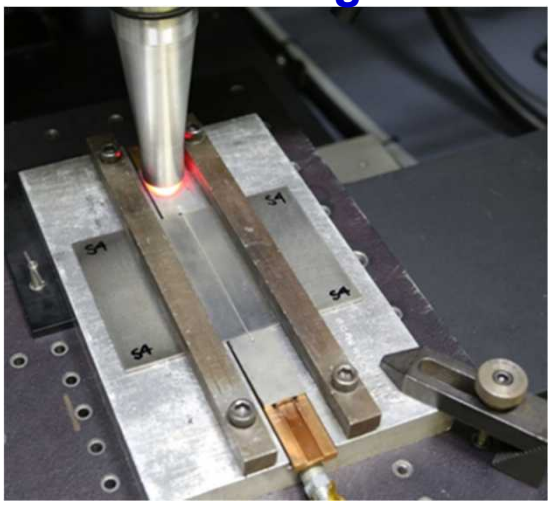
Welding Gaps in the Laser Welds With 0.050 in Penetration Depth

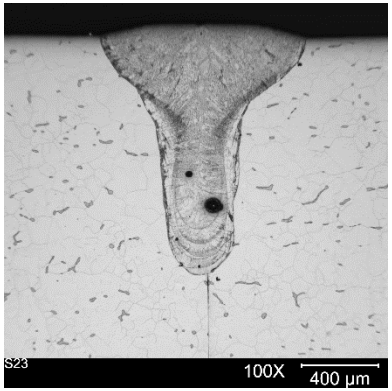
Laser Welding



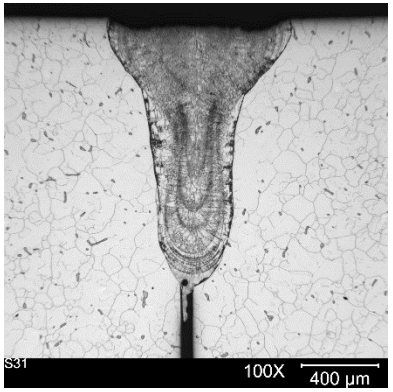
Welding gap-
(a) 0.0 (b) 0.04 in (0.1016 mm),
(c) 0.2032

Welding gaps are inevitable in the production. How do the gaps affect the mechanical performance and porosity of the welds?

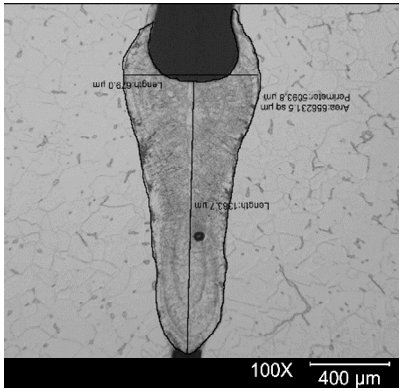
Schedule A



Gap = 0.0 in

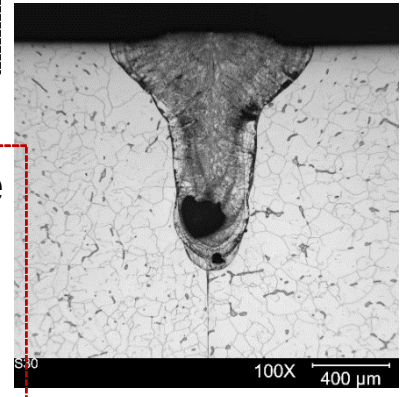


Gap = 0.004 in

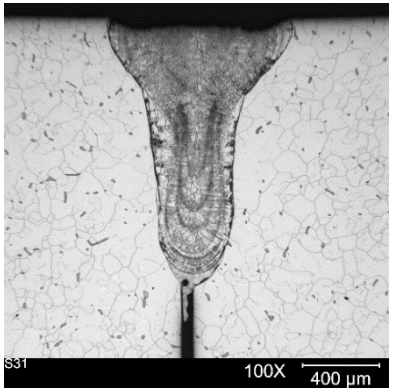


Gap = 0.008 in

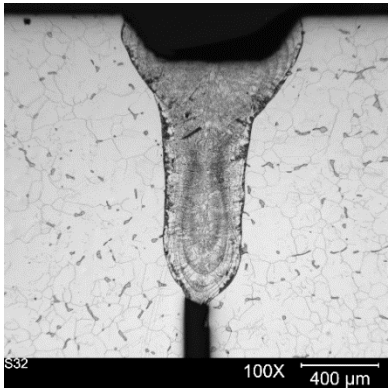
Schedule B



Gap = 0.0 in



Gap = 0.004 in



Gap = 0.008 in

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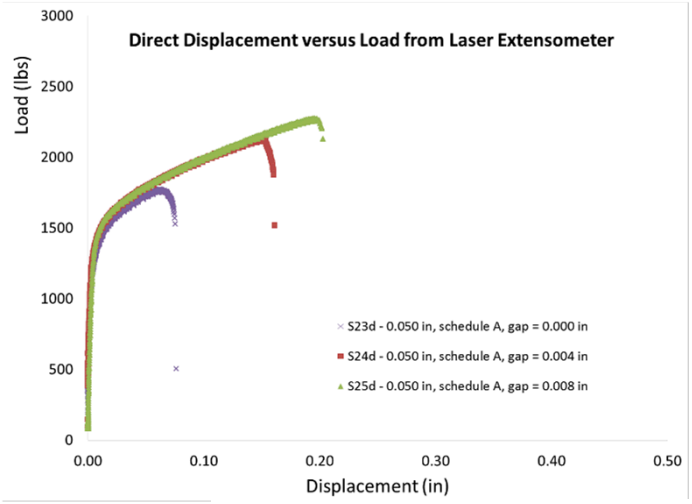
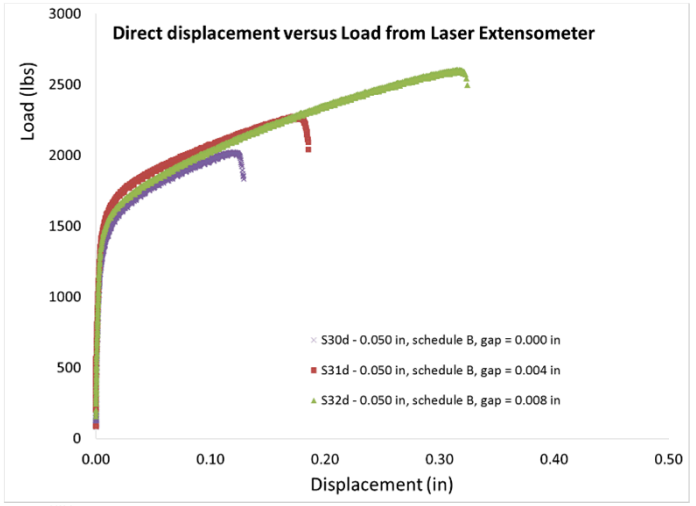
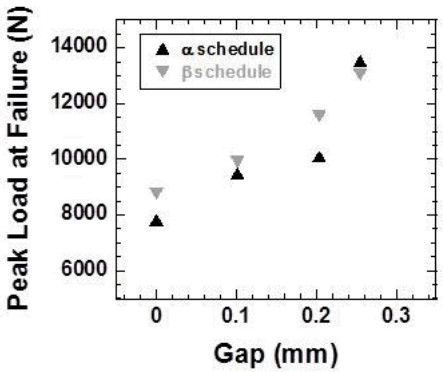
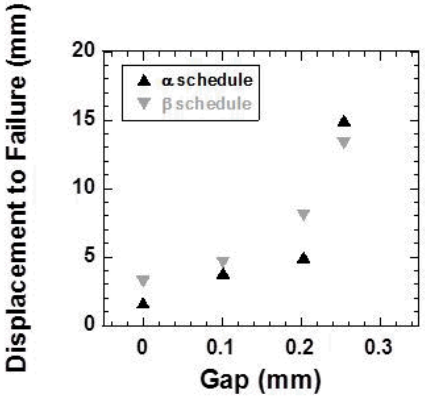
The Effects of Welding Gaps on the Mechanical Performances of the Welds with 0.050 in Penetration Depth





Schedule A





Schedule B

The welding gap greatly affect the mechanical performance of the laser welds with both schedule A and B. The failure load of both welds increases with the increasing welding gap.

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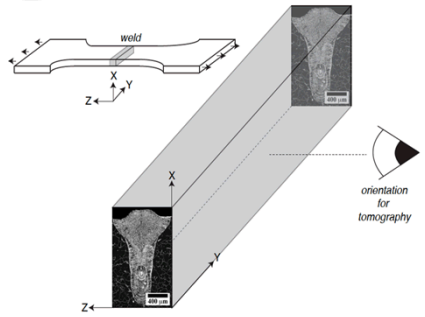
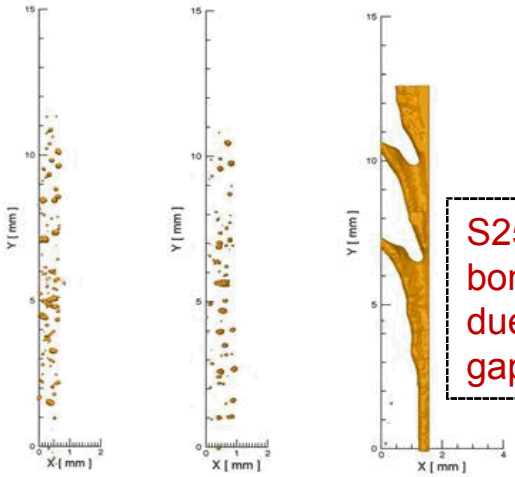
The Effects of Welding Gaps on the Porosity of Deeper Welds

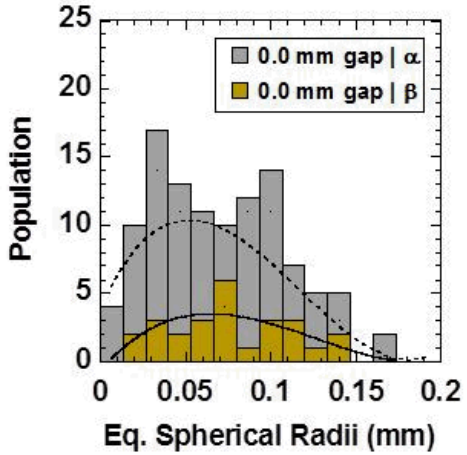




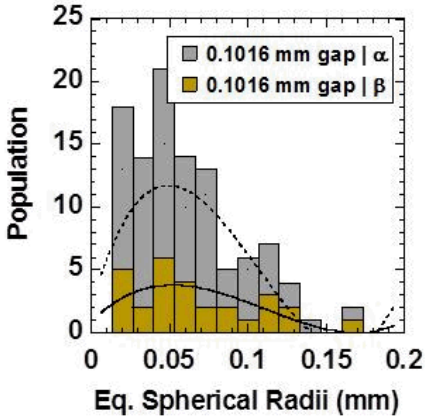
schedule α: (a) (b) (c)

S25 is not bonded well due to large gap

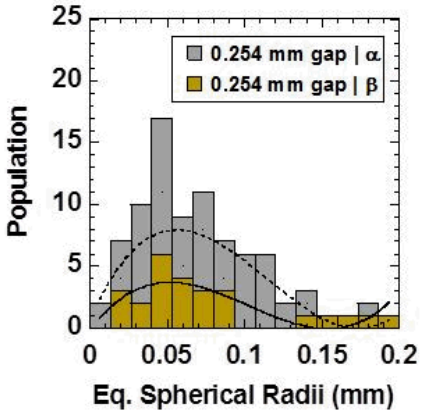
schedule β: (a) (b) (c)



(a) 0.0 mm



(b) 0.1016 mm



(c) 0.254 mm

The welding gaps affect the porosity of the laser welds of both schedules. The porosity decreases with the increase of the welding gap.

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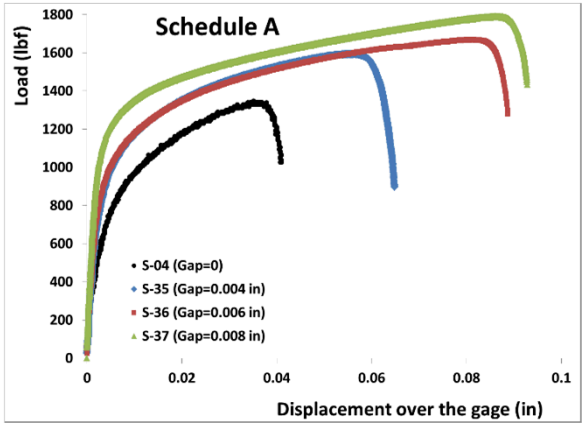
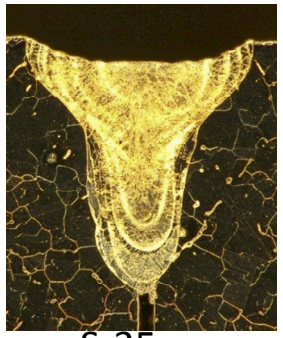
Effect of Welding Gaps on Mechanical Properties of Shallow Laser Welds

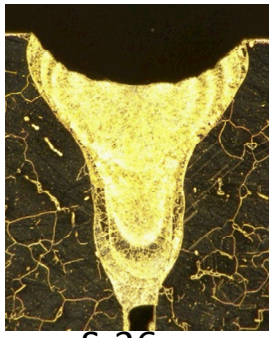


Schedule A

S-01
Gap=0

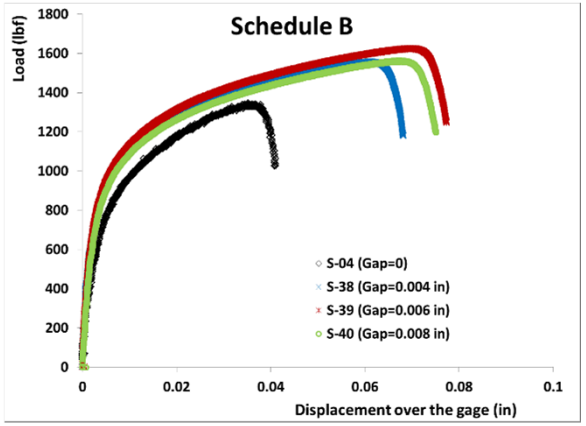


S-35
Gap=0.004in

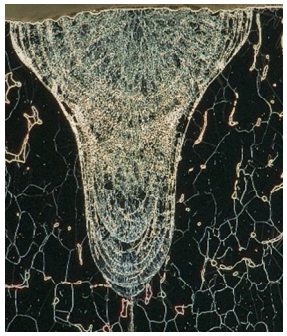


S-36
Gap=0.006in

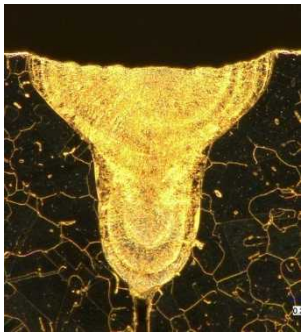
S-37
Gap=0.008in



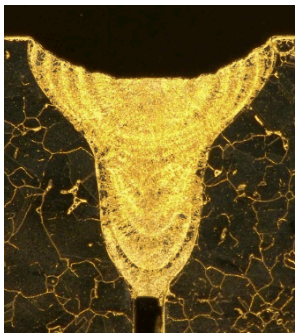
Schedule B



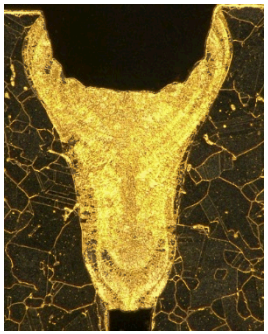
S-04
Gap=0



S-38
Gap=0.004in



S-39
Gap=0.006in



S-40
Gap=0.008in

The global load versus displacement over the whole gage section obtained from the mechanical testing of the large welded specimens are summarized above.

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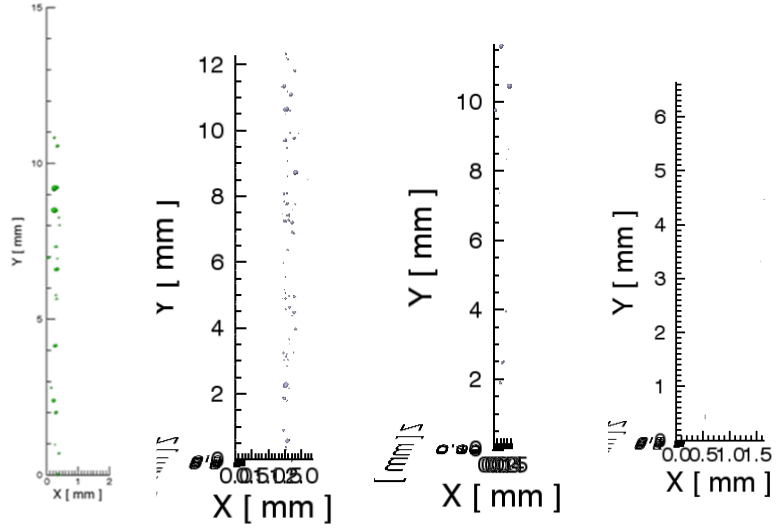
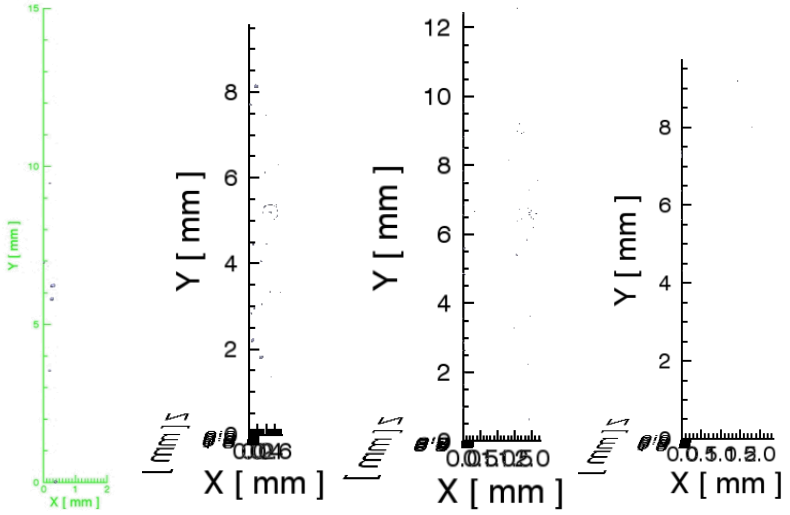
The Effect of Welding Gaps on the Porosity of Shallow Welds

Schedule A



S-01 Gap=0 | S-35 Gap=0.004in | S-36 Gap=0.006in | S-37 Gap=0.008in

Schedule B



S-04 Gap=0 | S-38 Gap=0.004in | S-39 Gap=0.006in | S-40 Gap=0.008in

- Spatial resolution of each voxel is 10µm. Specimen is scanned along the specimen width.
- Only voids with more than 5 voxels are considered.
- The porosity in the shallow penetration welds is very sparse. There are far fewer pores than what we have seen in the deep penetration welds.
- Welds from schedule A still shows more porosity than that of schedule B.

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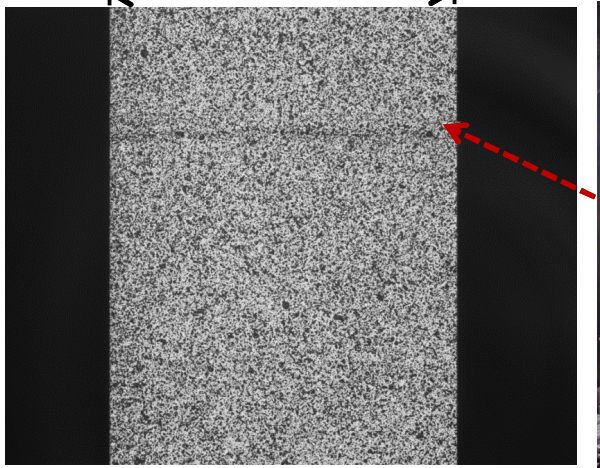
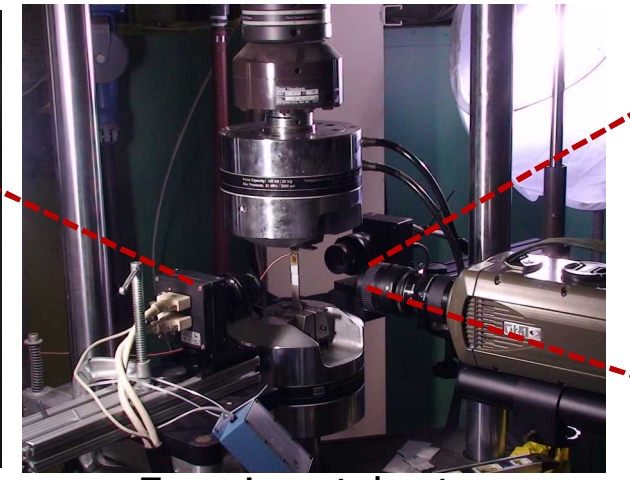
Local Deformation from the Welded Zone



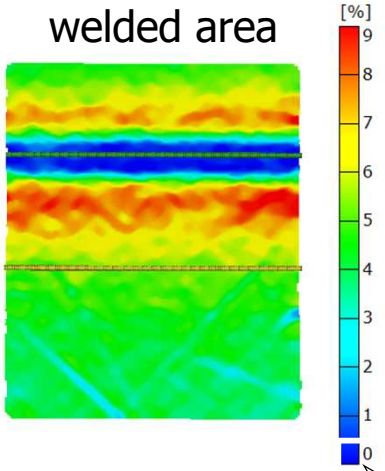
Front view of the specimen

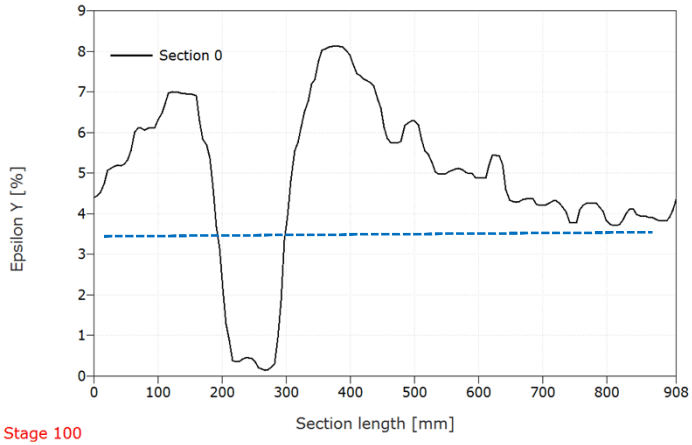


Experimental setup

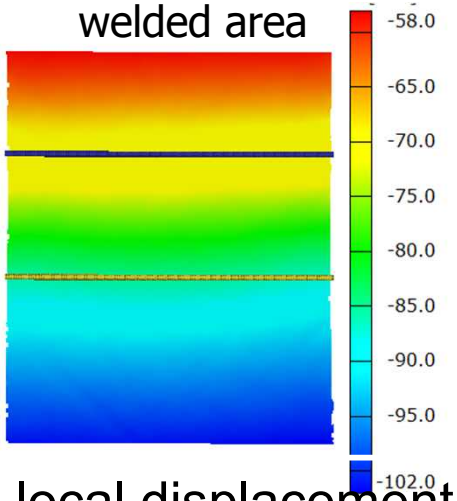
Side view of the etched specimen

Local strain at welded area





Displacement from welded area



- DIC results will enable us to measure local displacement and strain at the welded zone.

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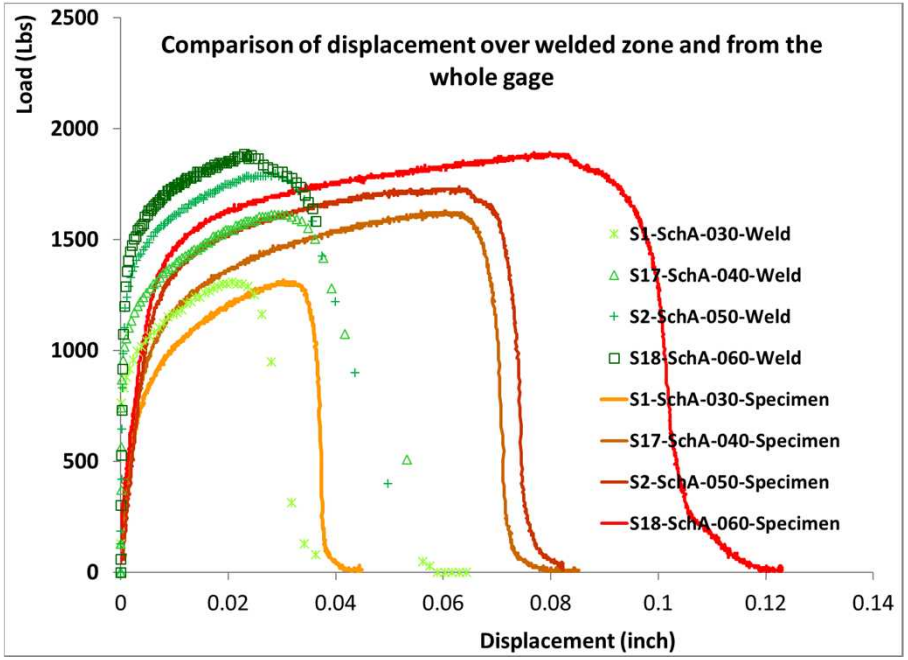
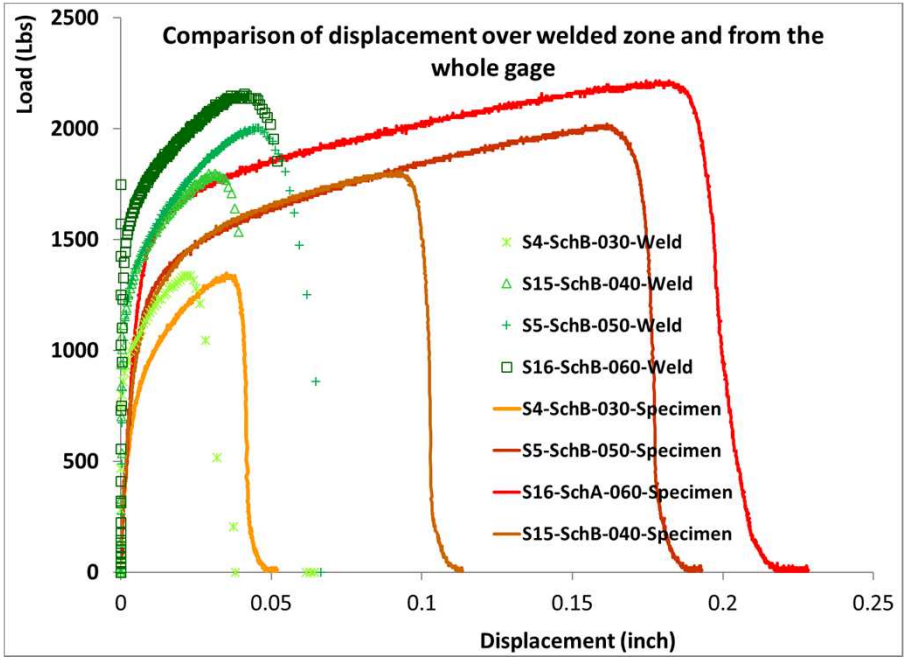
Comparison of Displacement from Welded Zone and the Whole Gage Session



Schedule A



Schedule B

- The DIC technique is able to measure the local deformation from the laser welded zone for specimens with different welding parameters.
- As the failure load increases, there is significant displacement from the base material on the gage. But the displacement from the welded zone has the same trend as the overall displacement from the whole specimen gage.

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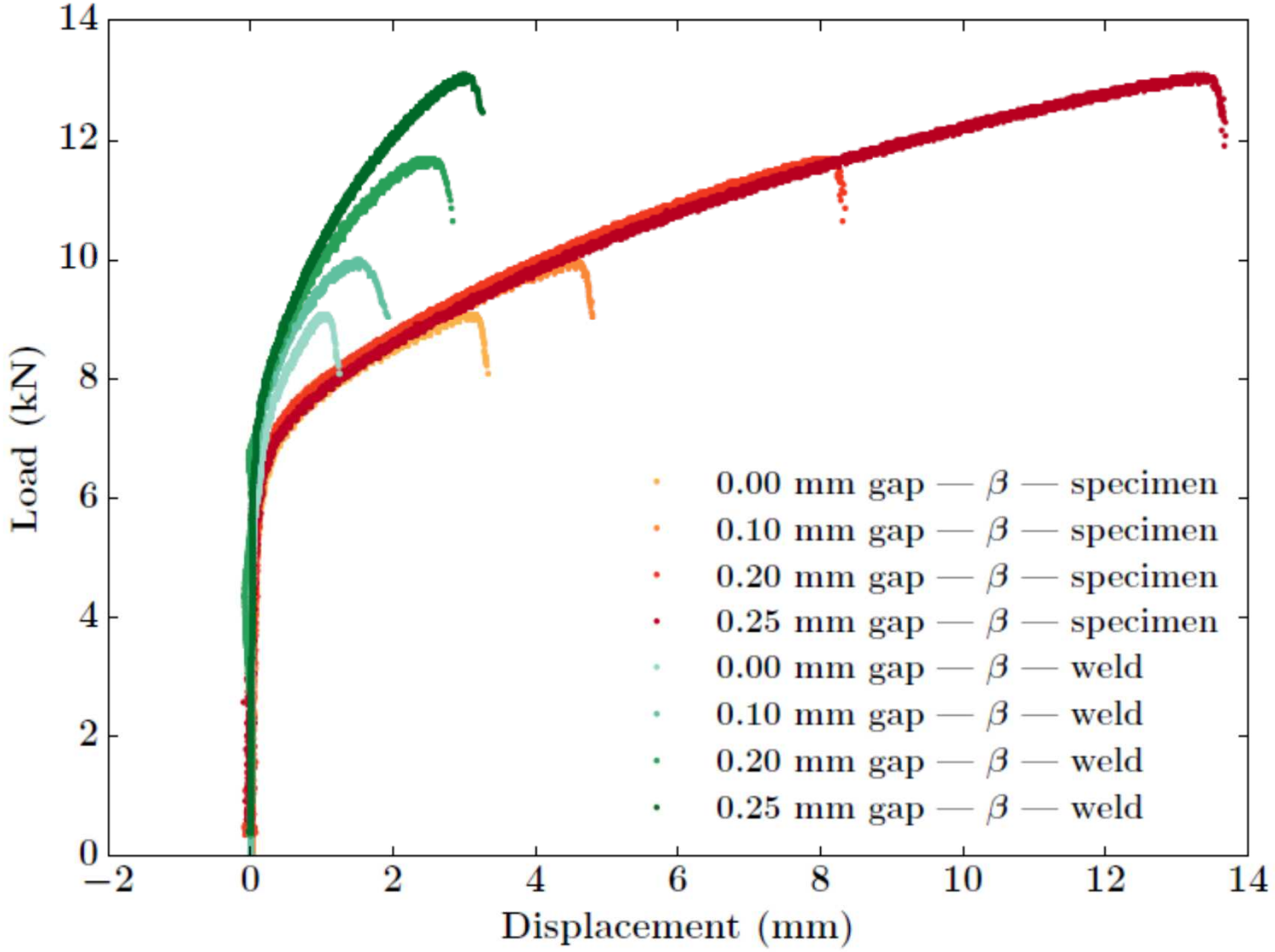
Load Versus Displacement for Gapped Specimens



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Summary

- XCT images are able to reveal the porosity in the welds with different welding parameters.
- Weld schedule affects porosity. Porosity affect mechanical performance.
  - Specimens from schedule B have smaller and fewer voids than schedule A;
  - Specimens from schedule B have higher strength than those from schedule A.
- Penetration depth affects porosity. Porosity impacts mechanical performance.
  - Deeper penetration welds have larger and more voids (higher void volume fraction) than those from shallow penetration depth.
- Welding gap affects the shape of welded zone and porosity, thus affects the mechanical performance of the welds.
- The DIC technique enables us to measure the local deformation from the laser welded zone for specimens with different welding parameters.