Development of Signal-to-Process Relationships In Laser Beam Welding Of Stainless Steel

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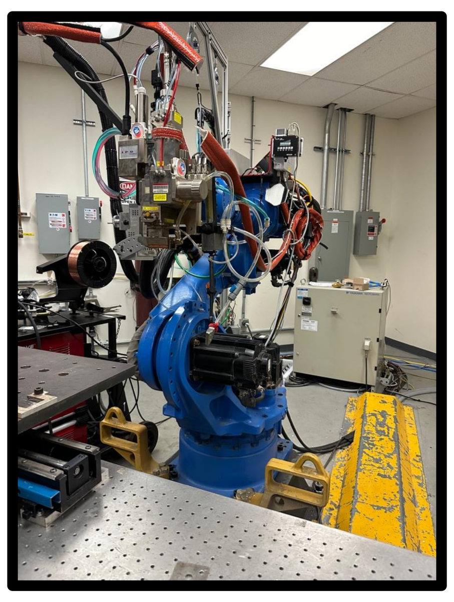
Background and Motivation

- **Laser beam welding** is an advanced process characterized by high penetration, high travel speeds, and low heat input welds.
- Numerous **welding defects** stem from beam parameters, component machining and fit up, and beam-material interactions.
- **Standard weld procedure development** can be **prohibitively costly** or can have **exceedingly long timelines** with certain material types and applications.
- Attempts have been made to study beam-material interactions but **lack proper process characterization and monitoring data**.
- Development of a **signal-process relationship** for LBW is required to streamline weld qualification and quality control of welds.

Experimental Approach & Results



- *IPG Photonics YLS-6000 Laser System*

IPG Photonics YLS-6000 Laser System

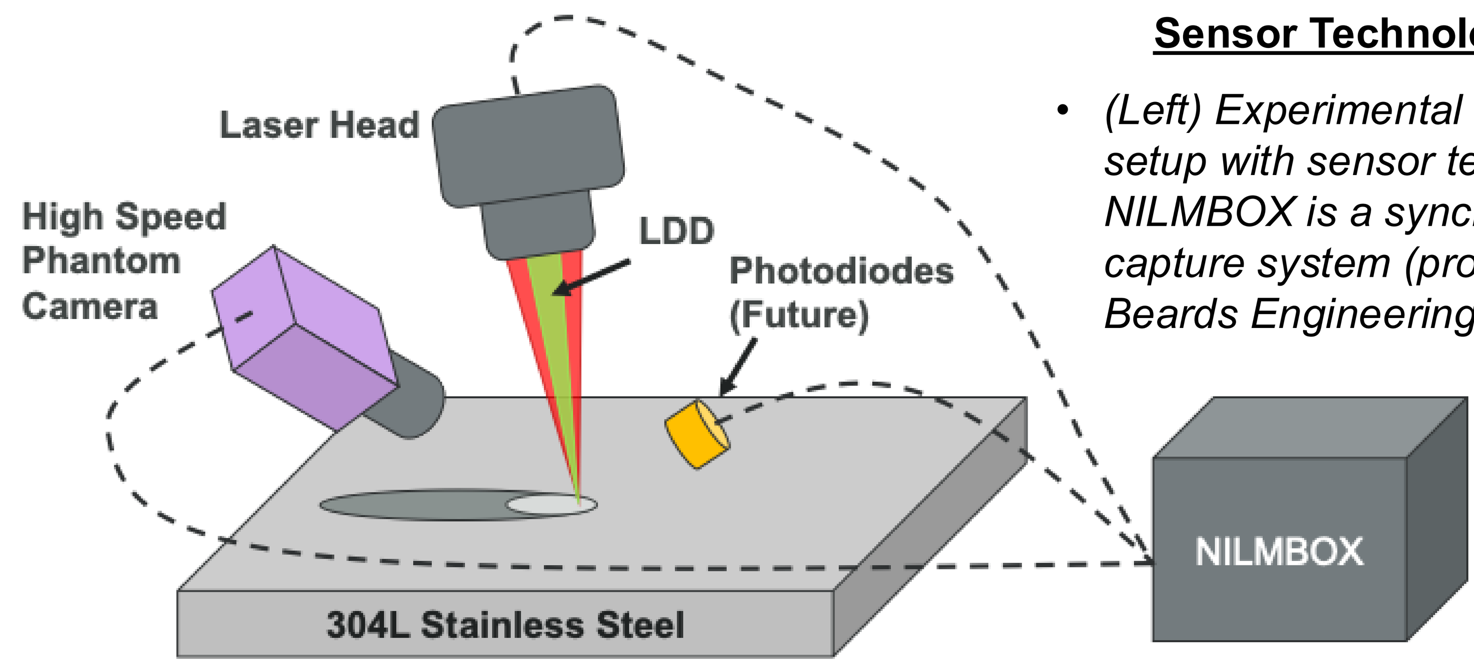
Power: 6kW
Type: Fiber
Wavelength: 1070 μm
Fiber diameter: 300 μm
Collimating lens: 150 mm
Focusing Lens: 300 mm
Spot Size: 600 um

Material System

Material: 304/304L Stainless Steel
Thickness: 3/16 inch

Weld Parameters

Travel Speed: 10-40 mm/s
Power: 600-5000W
Angle: 5 degrees (push)
Shielding Gas: 100Ar

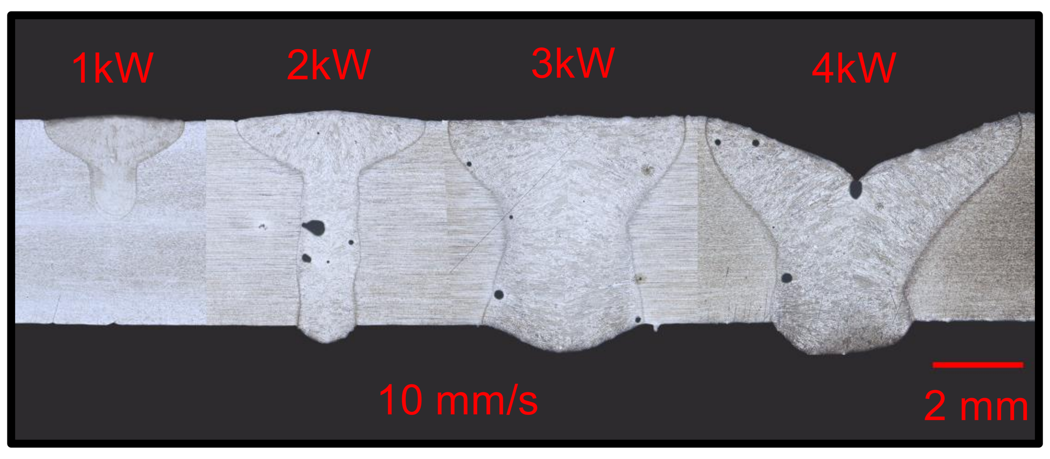


Sensor Technologies

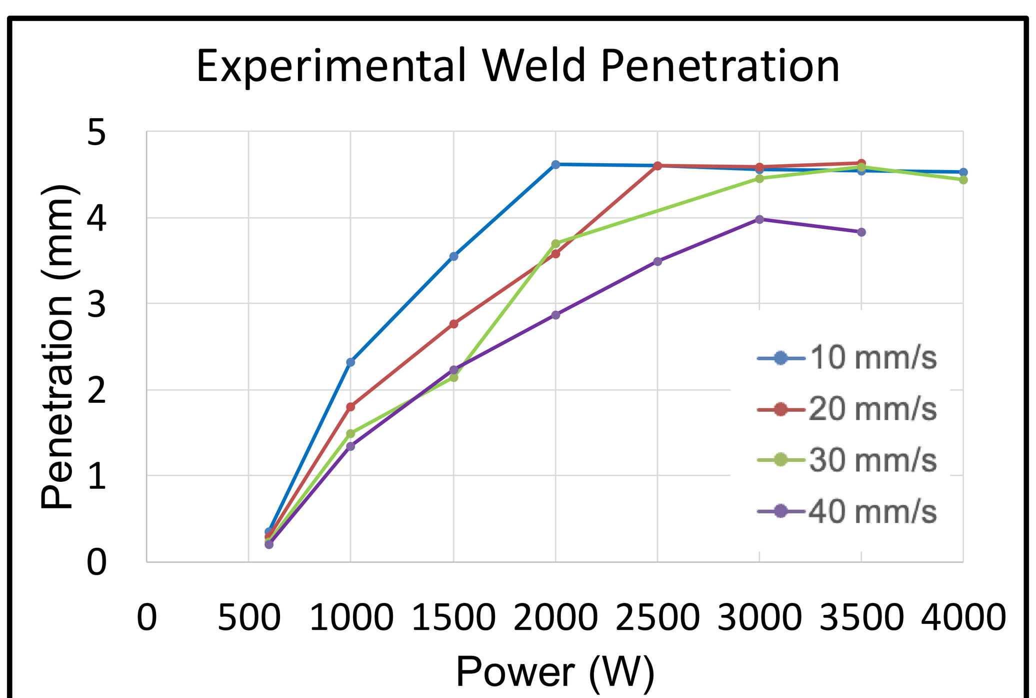
- *(Left) Experimental laser welding setup with sensor technologies. NILMBOX is a synchronous capture system (provided by Gray Beards Engineering)*

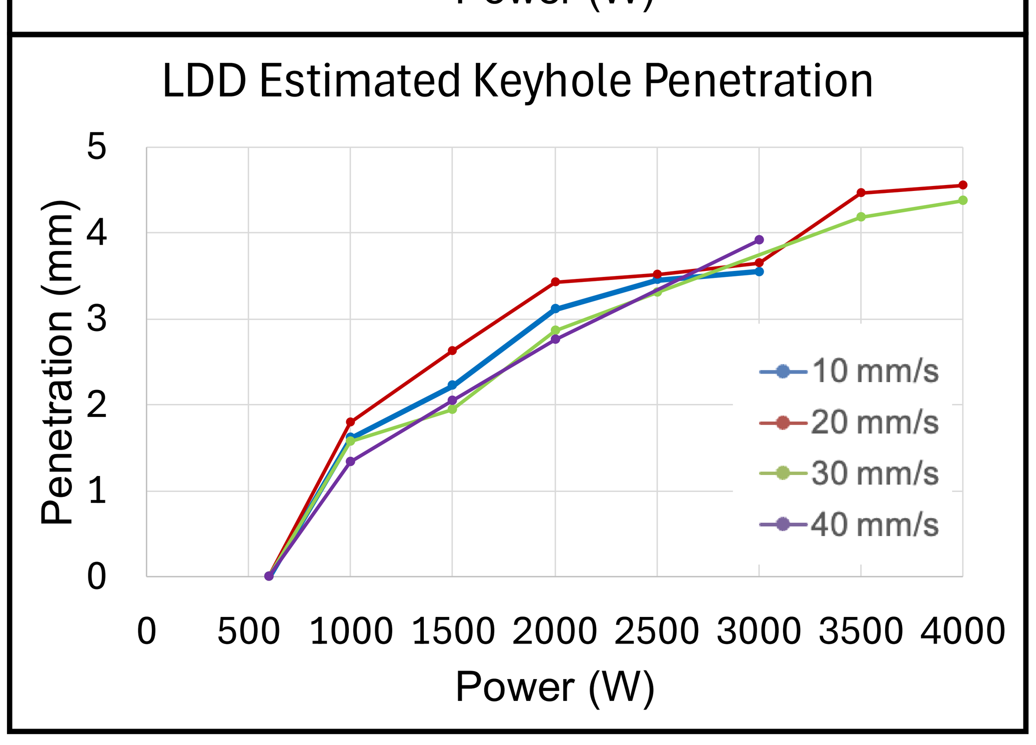
Phase 1

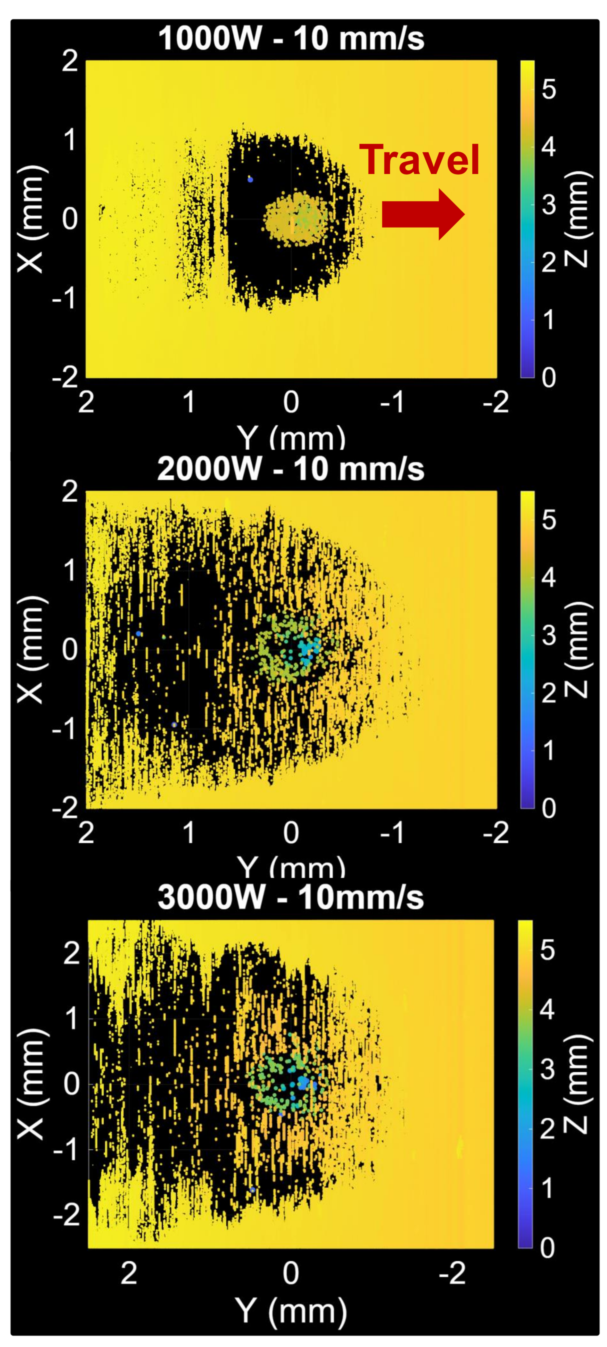
- Develop initial process window for 304L stainless steel laser welds
- Varying travel speed and laser power
- Quantify weld geometry and keyhole geometry experimentally and verify against LDD data



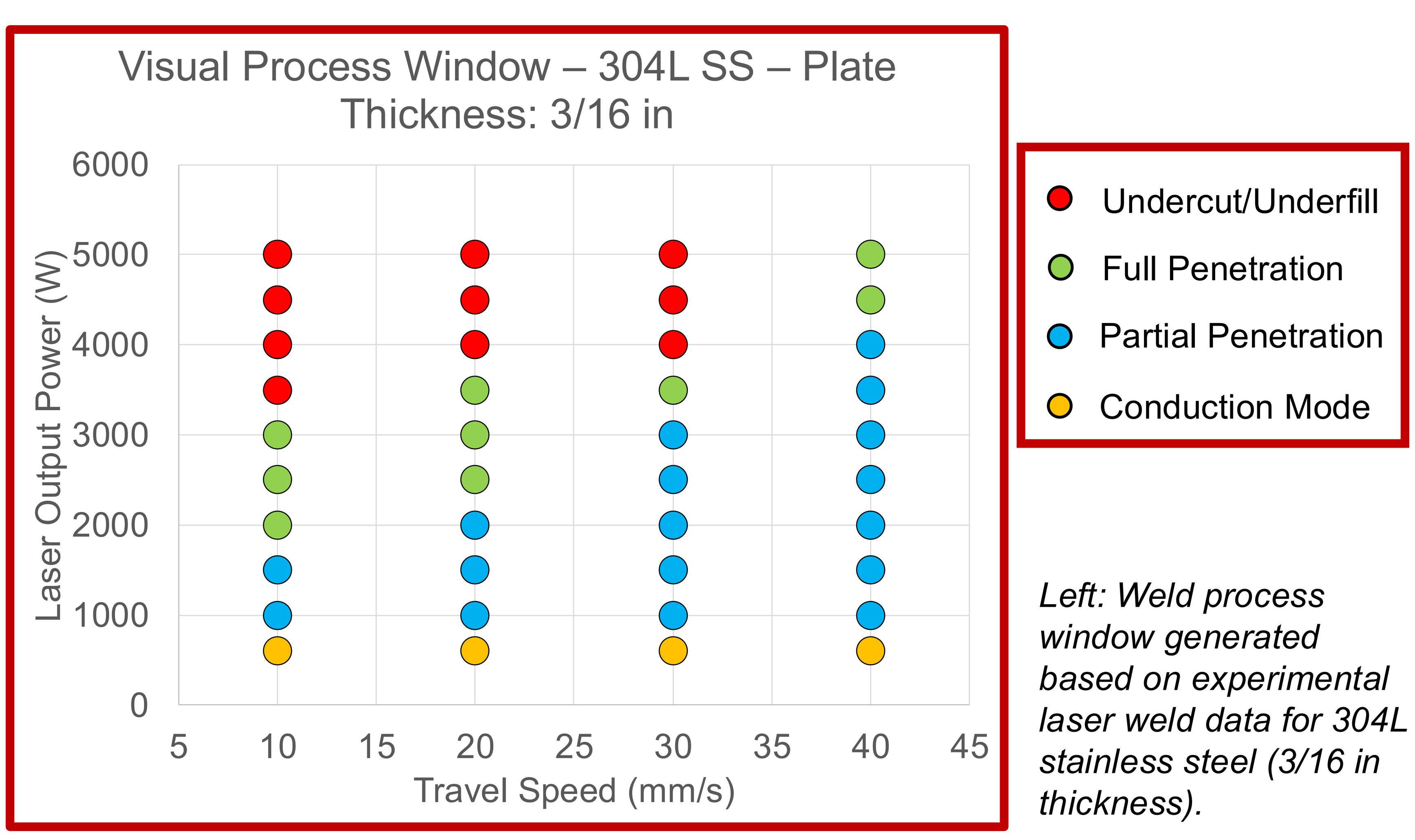
- *Transverse cross sections of 10 mm/s laser welds at powers 1000-4000W*







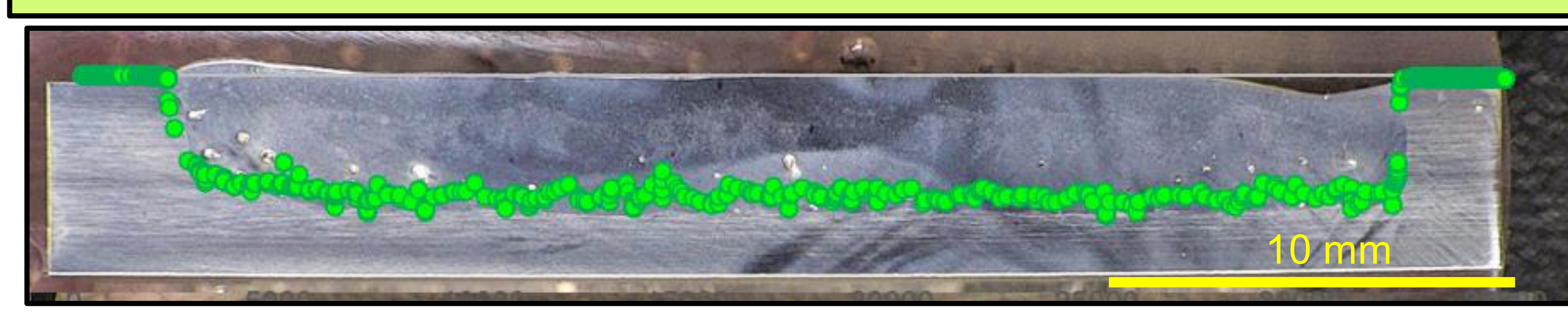
- *Top: Keyhole and melt pool captured via IPG LDD-700 at 10 mm/s from 1000-3000W. Note the increase in keyhole width and depth at increasing laser power. Travel is from left to right.*
- *Left: Weld penetration as a function of travel speed (10-40 mm/s) and power (600-4000W). Obtained via a) experimentally, and b) LDD signal data.*



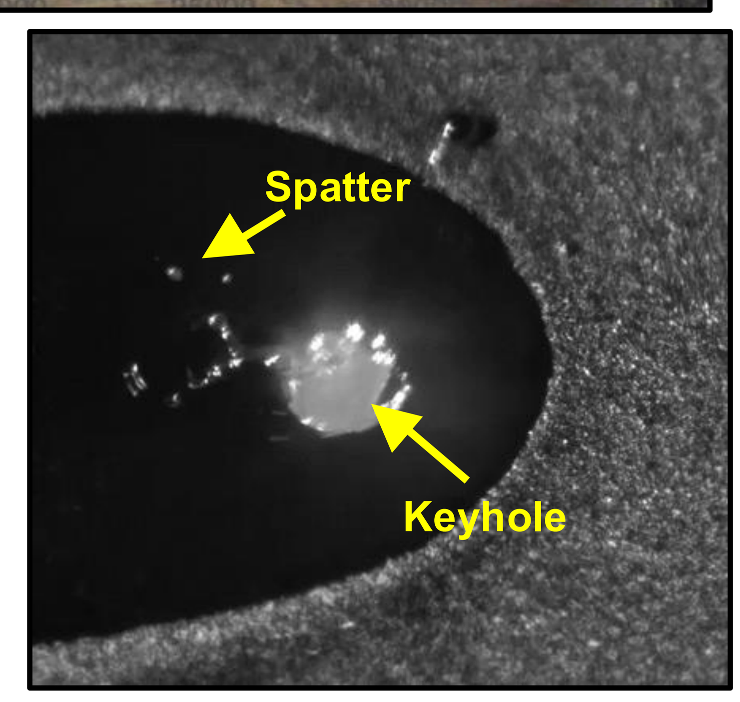
Left: Weld process window generated based on experimental laser weld data for 304L stainless steel (3/16 in thickness).

Phase 2

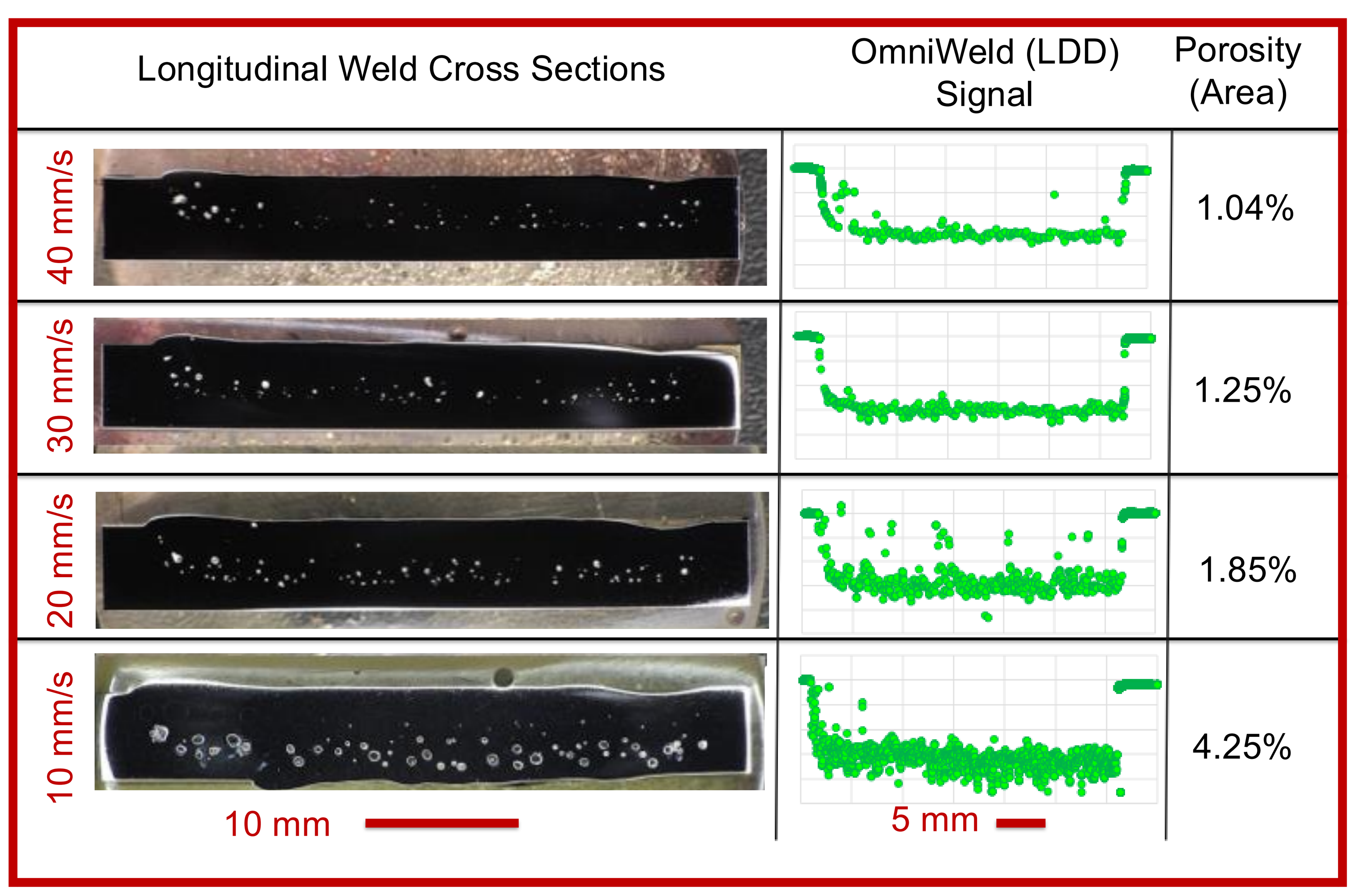
- Integration of multi-sensor analysis including high speed cameras, LDD, photodiodes, spectrometers
- Collect and quantify weld signals across various travel speeds and laser powers. Correlate signal characteristics to defect formation.
- Building keyhole stability index based on sensor diagnostics



- *Top: Longitudinal cross section of a laser weld performed at 2000W 40 mm/s compared with in-situ penetration measurement via IPG LDD-700 tool. Note good agreement between experimental and measured penetration.*
- *Right: High speed videography of a laser weld performed at 2000W 10 mm/s. High speed videography was captured to correlate visual aspects of the weld to signal stability and weld quality.*



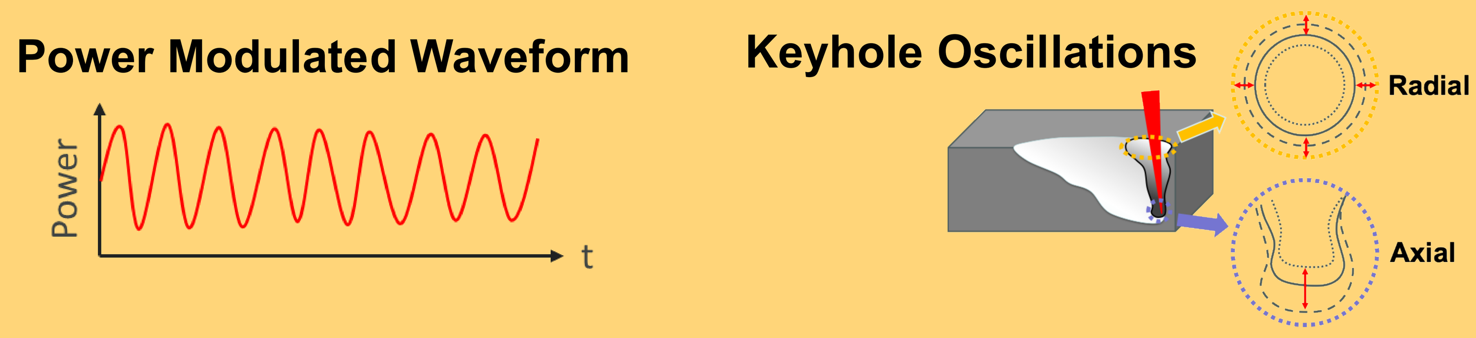
2000W OmniWeld (LDD) Evolution



Longitudinal cross sections of 2000W laser welds at varying travel speeds with correlating in-situ penetration measurements and porosity measurements. Note that as travel speed decreases, signal scatter and weld porosity increase.

Phase 3 & 4 (Future Work)

- The natural oscillations (radial and axial) of the keyhole will be studied and quantified using sensor-collected data. This will further fundamental understanding of laser and keyhole processes.
- Power modulation will be used to 'control' the keyhole and its stability



Current Progress & Future Work

- Near completion on a foundational weld process window to compare experimental data to signal process data of the keyhole (LDD)
- Next step: Implementation of a multi-sensor setup (LDD, photodiodes, spectrometers) to monitor laser welds in-situ
  - As signals are collected and quantified, a defect map based on signal data will be created
- Future works: Characterize fundamental keyhole fluctuations based on signal data, apply power modulation as a means to control the stability of the keyhole

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