Multi-factor Monitoring of Hybrid Laser-Arc Welding Applications

First Time Quality Welding Processes

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NASSCO | NSWCCD | EWI | Ingalls |

Outline

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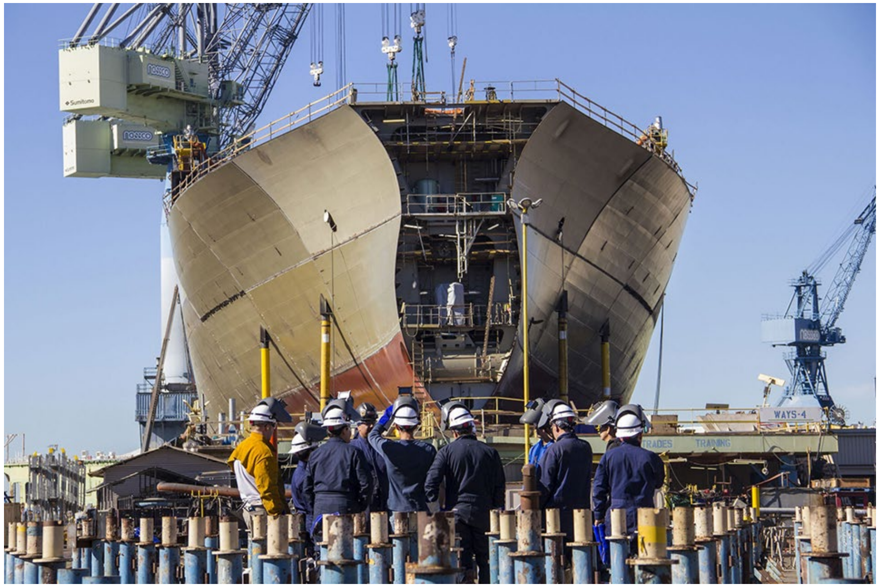
Introduction

- NASSCO has expressed issues with intermittent weld defect formation in their hull panel welds, that require re-work to be fit-for-service
- Introduction of in-process monitoring is proposed to alleviate these issues and provide first-time quality welds

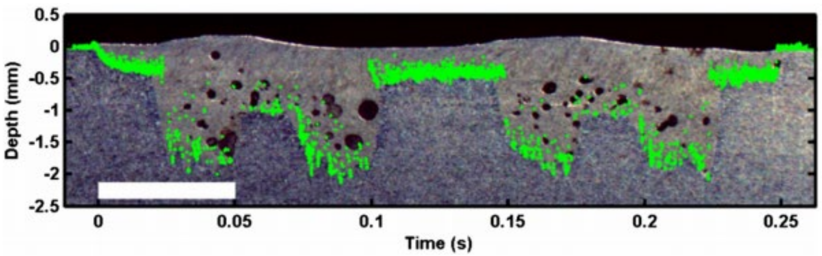


Background

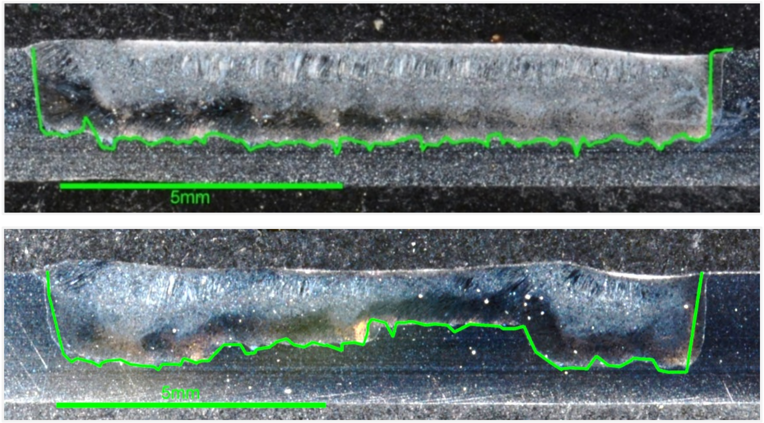
- The shipbuilding industry is seeking to adopt real-time weld sensor technology to meet increasing productivity and quality demands.
- This project will investigate the monitoring performance, operating characteristics, and implementation requirements of the monitoring technology known as Laser Depth Dynamics (LDD).

Motivation

- Develop first time quality capability using off the shelf technology
  - Real-time weld measurements
  - Immediate correction of quality issues
- Provide a platform for future partial penetration hybrid welding applications
  - Fillet welding stiffener panels
  - Improves accuracy control and ship structure performance



ICIT depth measurement of cross-section containing porosity defects [1]



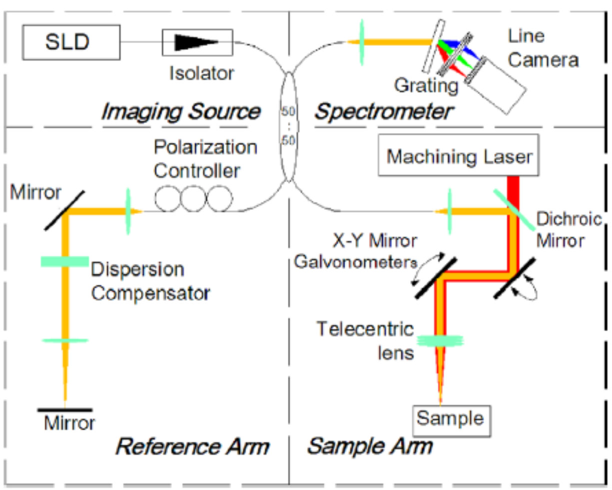
Constant vs. varied laser power, illustrating depth tracking capability of ICIT system

Approach

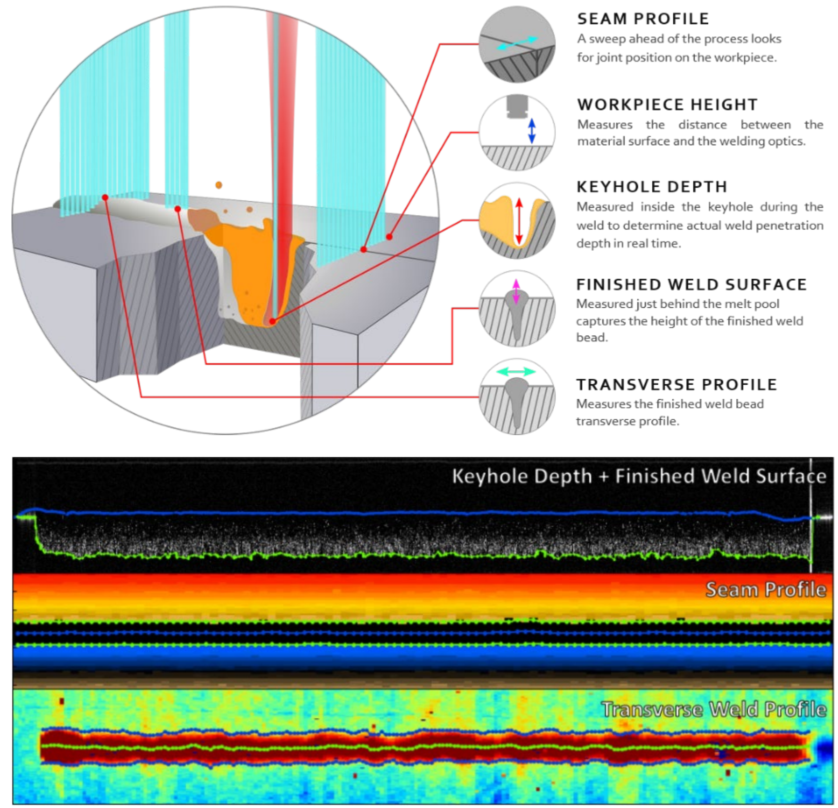
- Evaluate monitoring performance of five different process variables
  - Workpiece height, seam profile, keyhole depth, finished weld surface, and transverse profile
- Evaluate discontinuity / defect detection and process monitoring capability
- Determine measurement sensitivity, reproducibility, and repeatability
- Assess performance for quality monitoring of pre-weld, in-weld, and post-weld conditions
- Assess implementation impact and requirements.

Real-Time Weld Monitoring

- Inline Coherent Imaging Technology (ICIT)
  - Laser Depth Dynamics (LDD) 700 System
    - Form of Michaelson interferometer
    - 800-900nm wavelength laser
    - 1200x1200μm scan region
    - 6mm field of fiew (FOV)



Schematic of an ICIT system [2]



Pre-, in-, and post-weld ICIT scan schematic with keyhole, seam, and transverse profiles

LDD Video

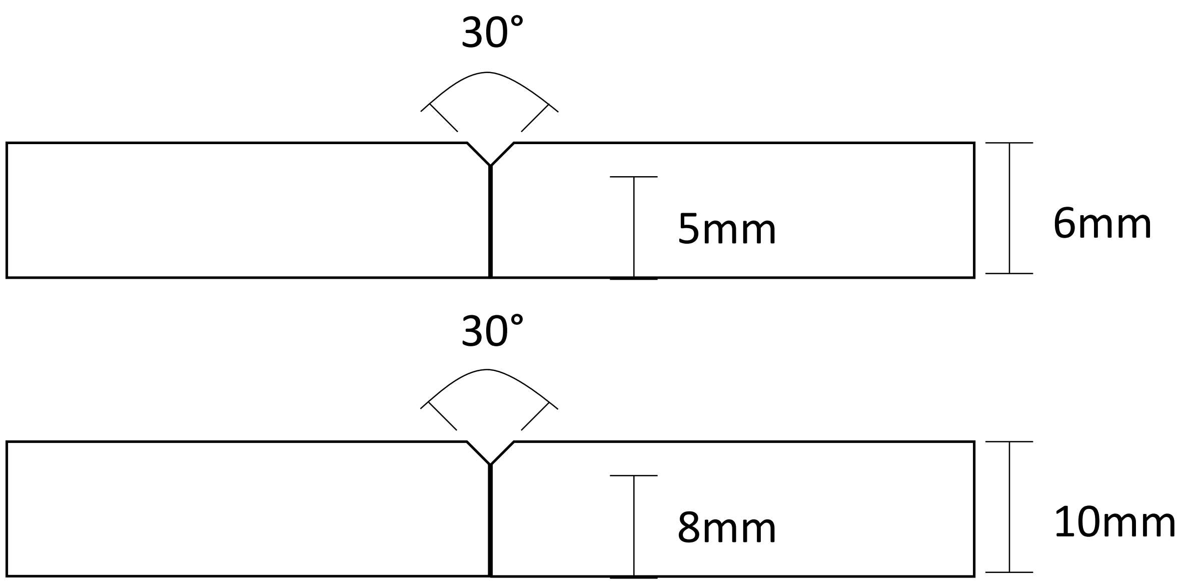
Deliverables

- Test matrices and procedures for developing weld defects during quality scenarios
- LDD data of hybrid laser-arc welds
    - Quality scenario tests with defects
        - Defects should preferably match issues that occur during production
    - Ideal welds without defects
- Additional quality scenario test data to evaluate the LDD for sensitivity, reproducibility, and repeatability
    - Data will be compared to ultrasonic and x-ray NDE test methods
- Evaluation of sensor for pre-weld, in-weld, and post-weld capability
- Cost analysis for implementation of LDD into NASSCO production line

Materials

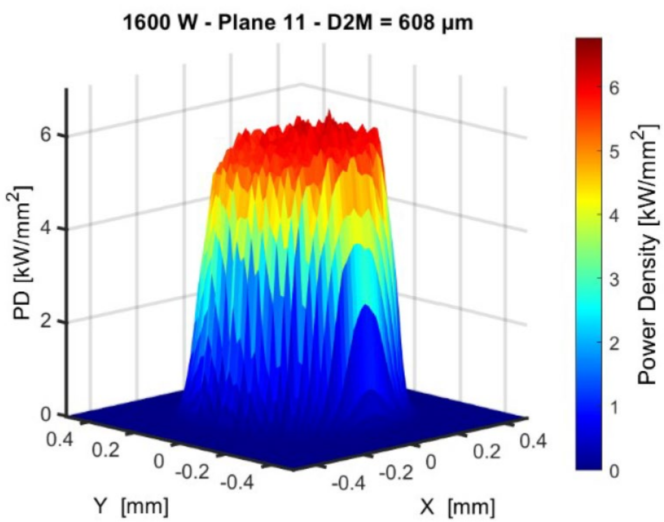
- AH36 steel in 6mm and 10mm thicknesses
- Edges milled into a y-groove configuration

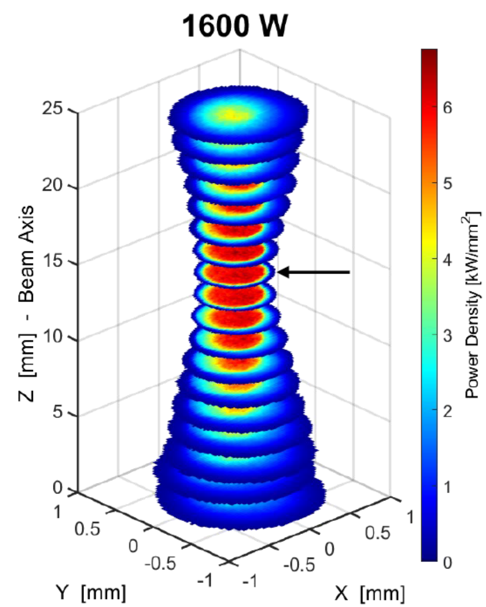
Alloy	C	Mn	Al	Si	P	S
AH36	≤0.18	0.70-1.60	≥0.015	0.10-0.50	≤0.04	≤0.04

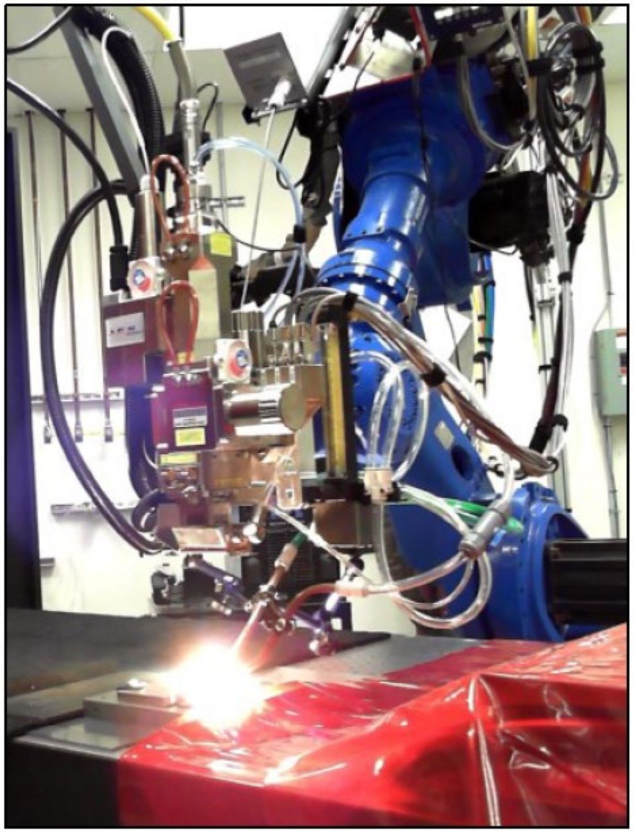


Weld Parameters

- Laser
  - IGP YLS-6000
  - 600µm beam diameter (D2M) with "tophat" distribution
  - 6kW power
  - 0mm defocus
  - 0° beam angle
  - 59.1ipm travel speed
- Arc
  - Lincoln S-350
  - GMAW
  - 335ipm wire feed speed
  - 1.05 trim
  - 0.5" wire stick-out
  - 2mm beam to wire distance
  - Lincoln RapidArc Waveform

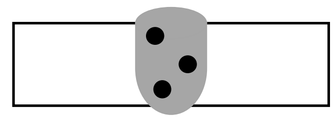


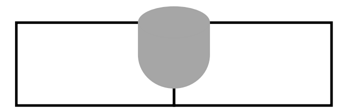


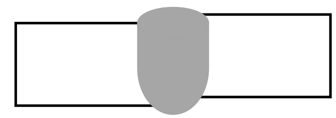


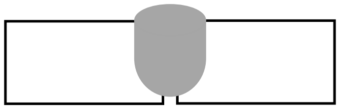
Defects – Weld Quality Scenarios

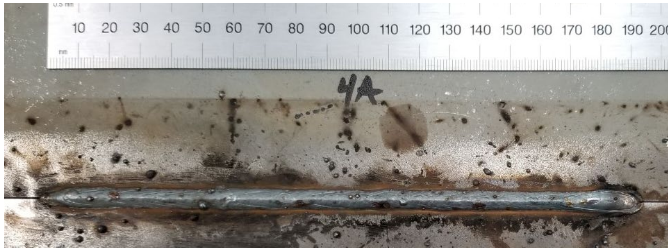
- Hybrid laser-arc test welds were performed by the student at EWI to develop test procedures and test matrices for quality scenarios that have defects representative of what occurs in manufacturing
- Quality scenarios with defects such as:
  - Joint gap
  - Joint mismatch
  - Porosity
  - Lack of penetration

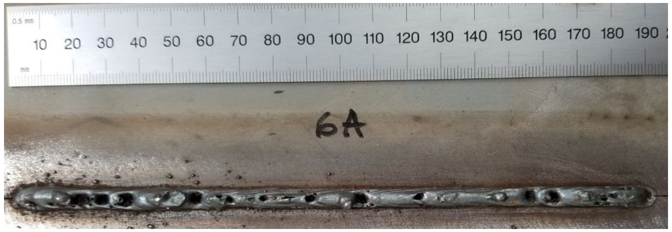

Porosity


Lack of Penetration


Joint Mismatch

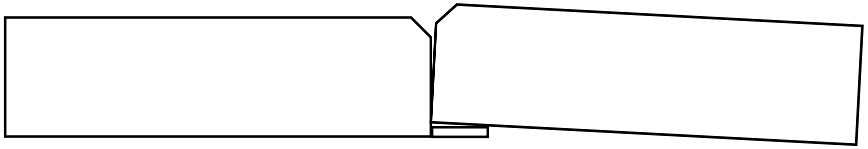

Joint Gap



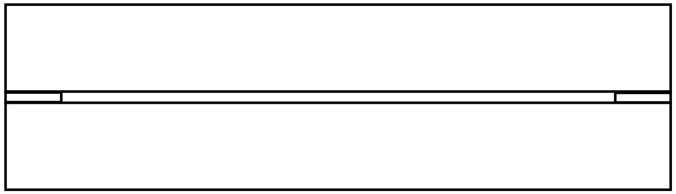


Joint Gap/Mismatch

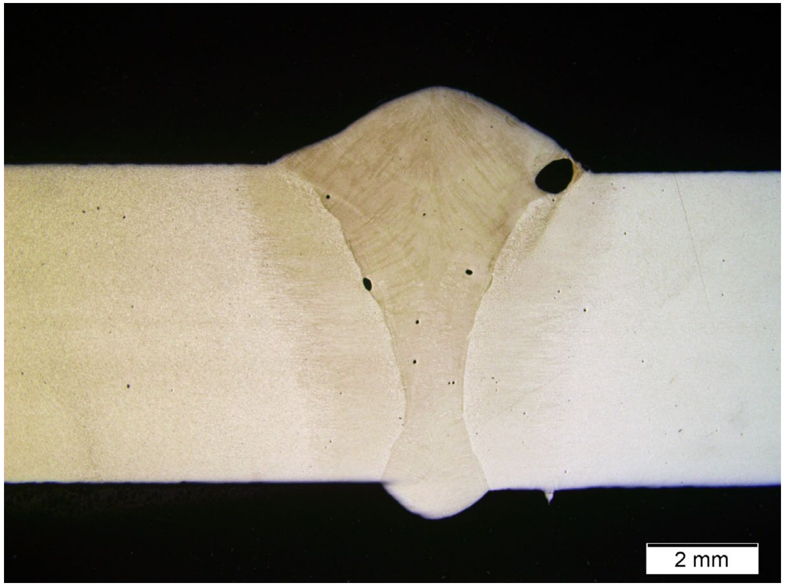
- To form the gap/mismatch 0.01" shims were placed at both ends of the weld joint either in between both or under one of the weld coupons
  - Subsequent welds were then performed using the regular weld parameters



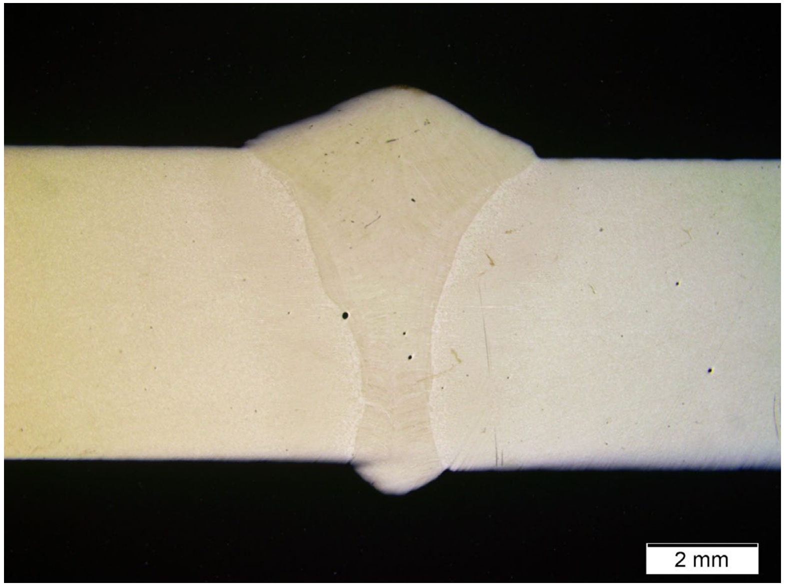
Vertical Mismatch



Joint Gap

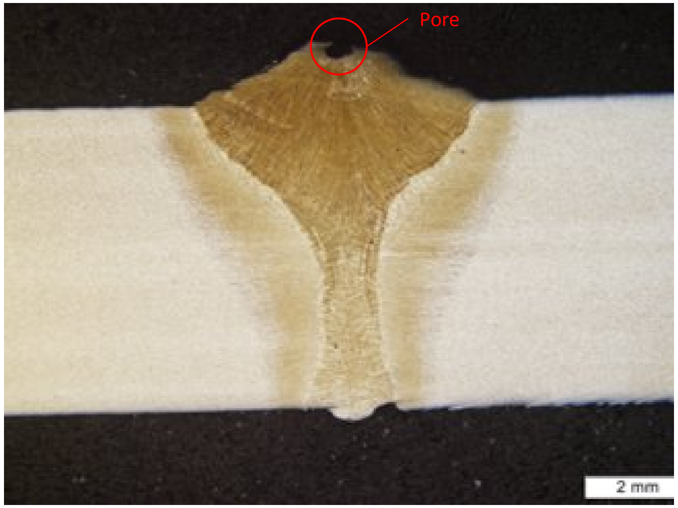


Weld with 0.01” Joint gap

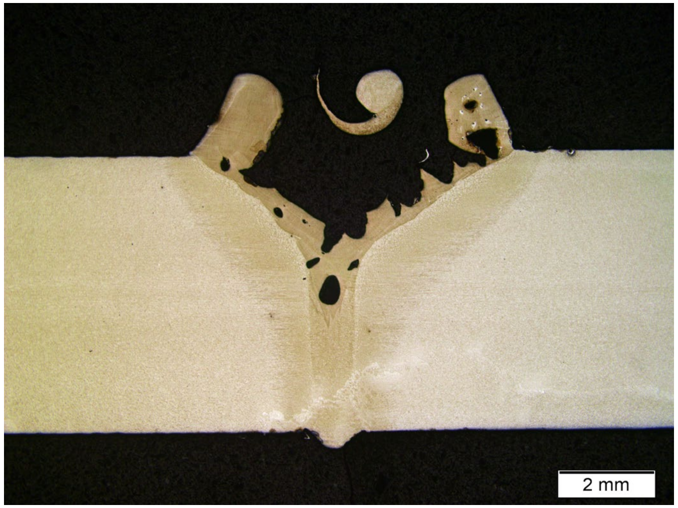


Porosity

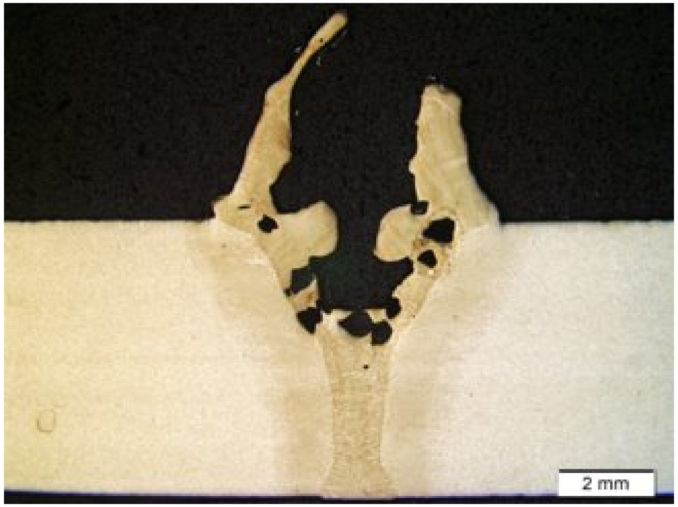
- To form porosity, welds were made using a few different approaches, including:
  - Oil in joint
  - No shield gas out of arc nozzle
  - Excessive wire stick-out
  - Salt water in joint



Oil in joint



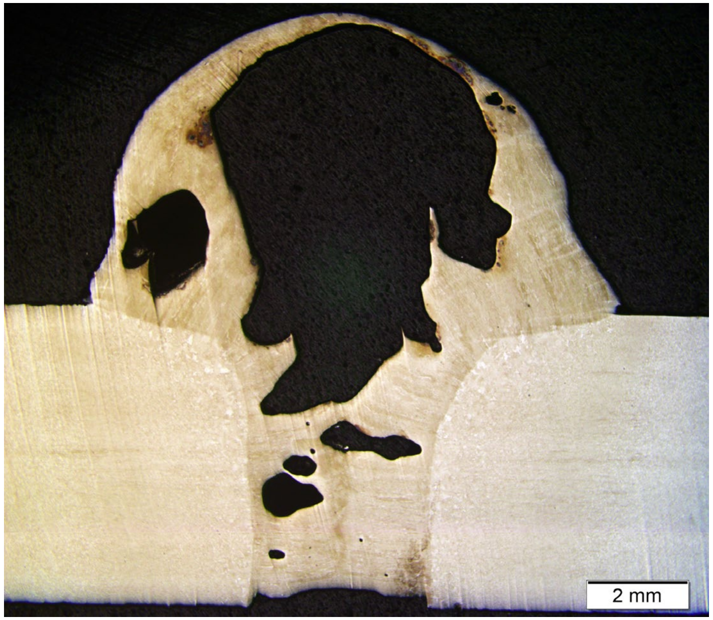
Excessive wire stick-out

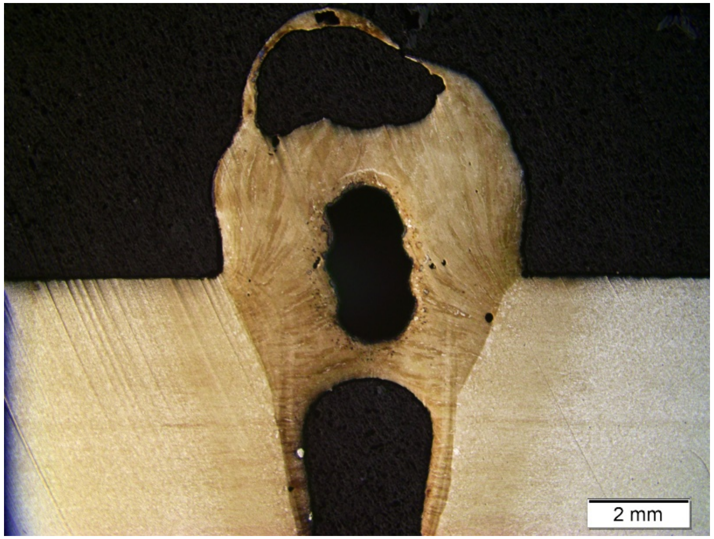


No shield gas

Lack of Penetration

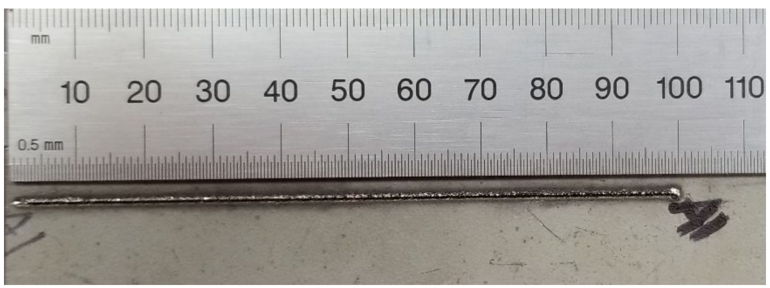
- To form lack of penetration the travel speed was slowed down to cause the filler metal to build up in the weld and reduce the effect of the laser on the weld root
  - Travel speed: 25ipm
- This approach also proved to be good for forming porosity
- Increasing the travel speed or decreasing laser power will also be used in future in-process monitoring trials

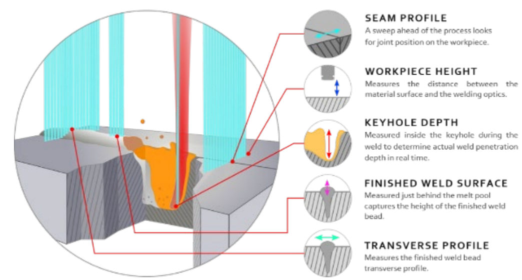


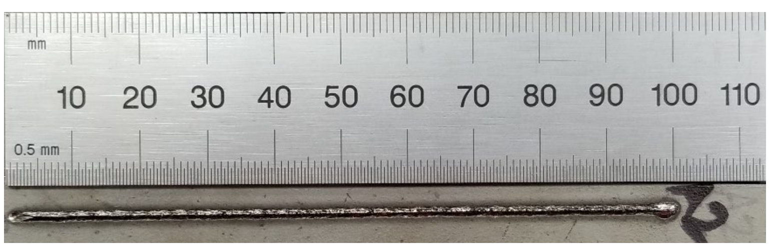


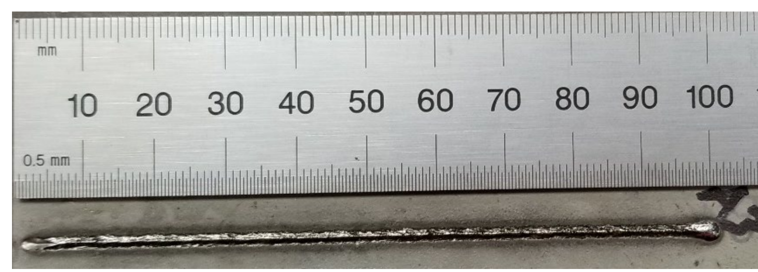
Laser Depth Dynamics (LDD)

- The LDD sensitivity at various penetrations and joint configurations was tested on
  - Autogenous laser welds
  - Y-Groove butt joint laser welds
- We have completed trials for understanding the sensor limits



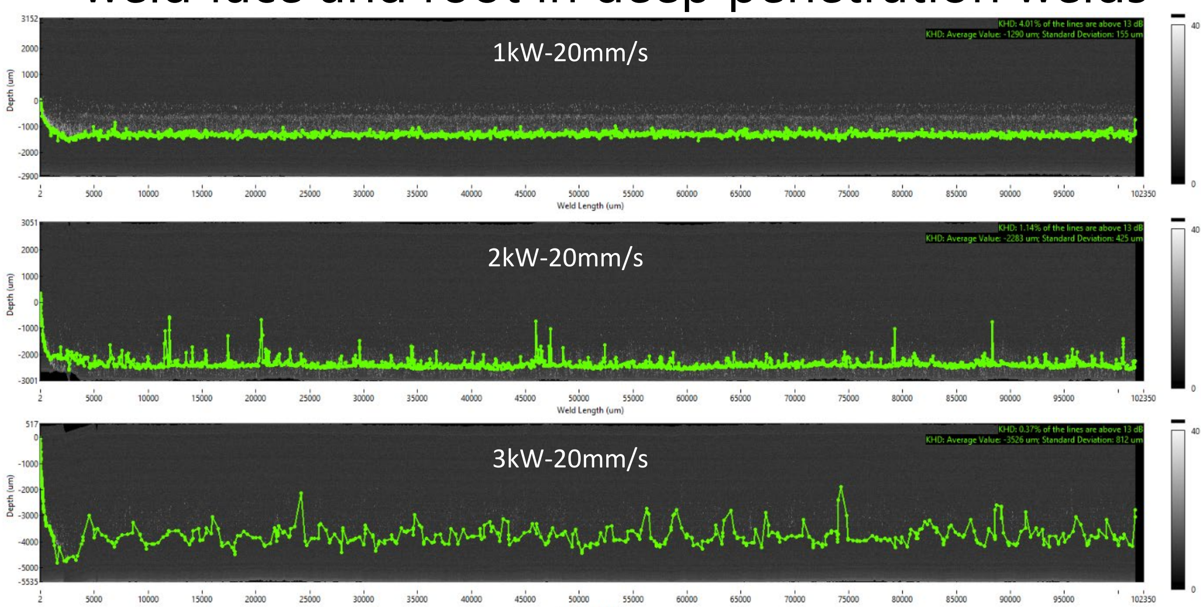


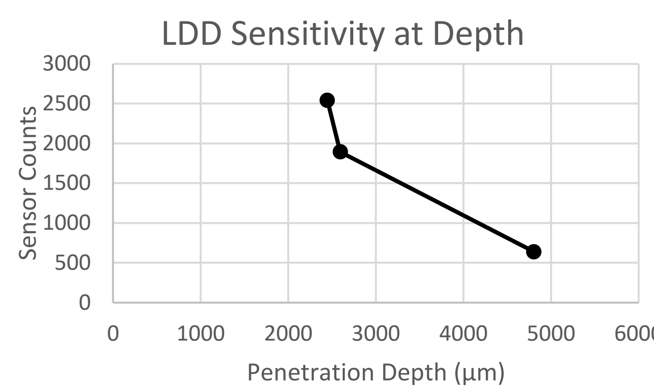




Laser Weld Analysis with LDD

- The LDD sensor is less sensitive near its maximum field of view
- In these initial trials the sensor was calibrated to the surface
  - As the penetration increased the accuracy of the penetration depth measurement decreased
  - Some of the signal spiking may be due to porosity in the weld [3]
- The LDD can be calibrated to a position below the surface of the part to accurately measure the depth of penetration
- LDD sensors with a larger depth of field are available to monitor the weld face and root in deep penetration welds

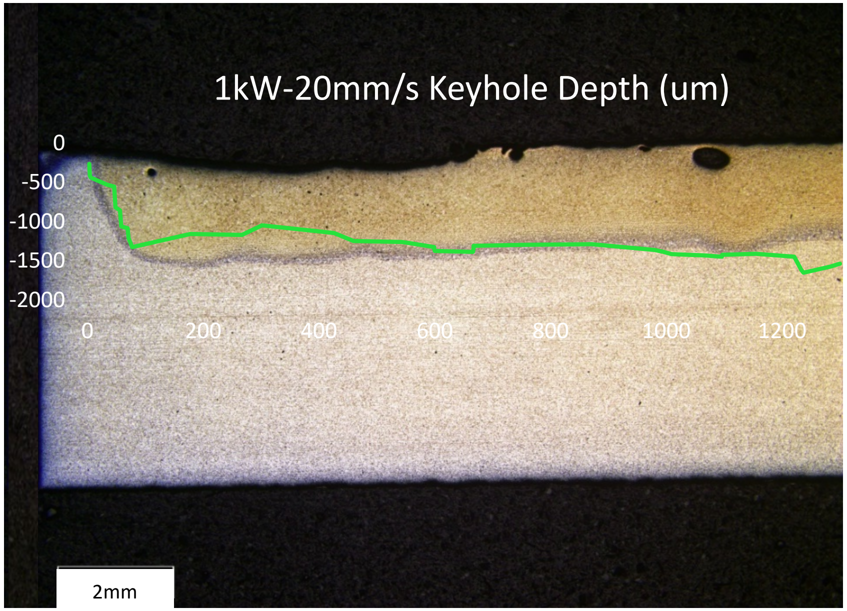




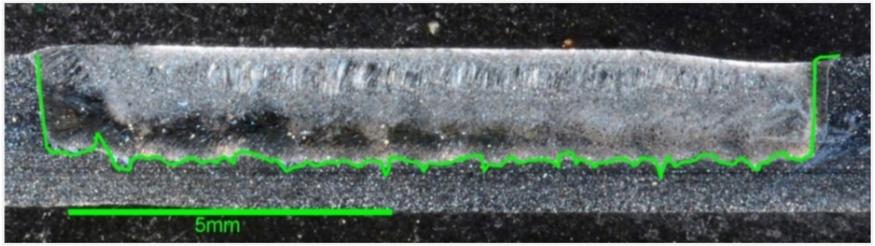
Laser Weld Analysis with LDD

Autogenous y-groove butt joint partial penetration welds with LDD

- At low penetration depths the un-calibrated LDD outputs approximate the weld seam geometry

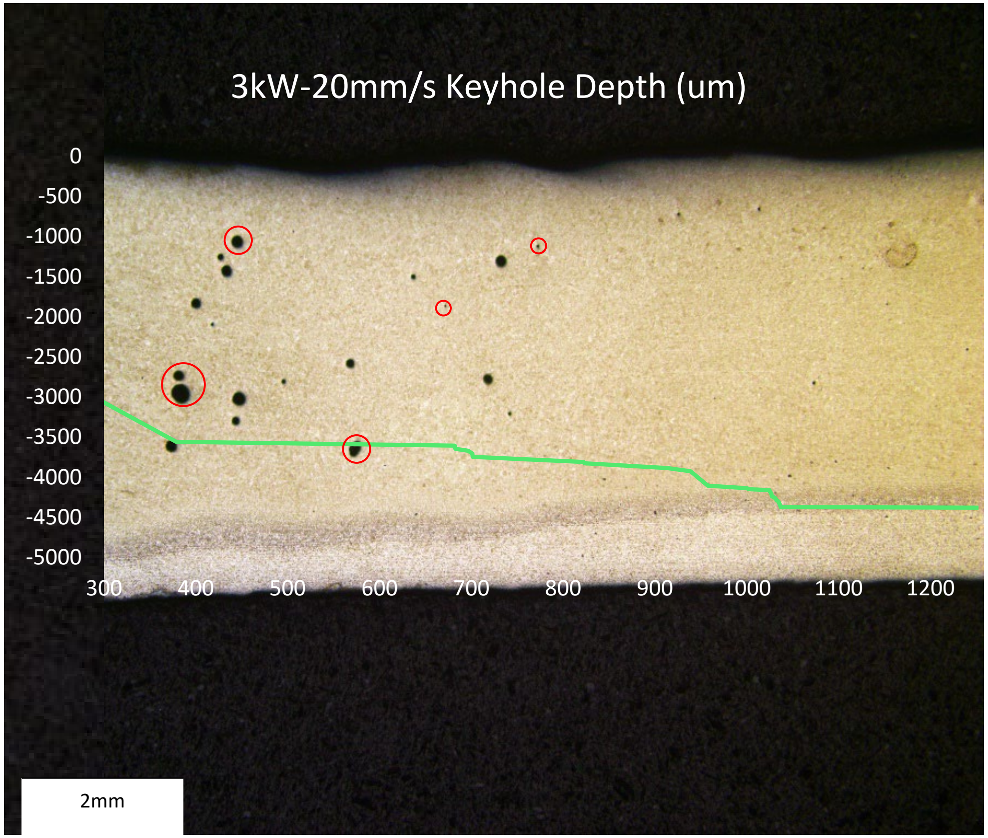


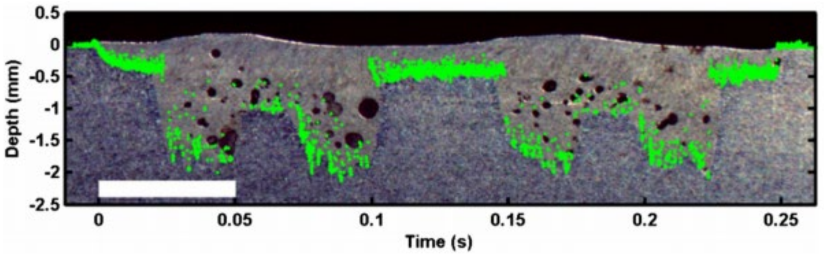
- Porosity close to weld surface was not visibly detectable in LDD output
- Small sudden shifts in penetration were not detected as well
- Calibration has been shown to significantly increase, an example is shown below



Porosity Detected in LDD Sensor

- In the areas with clusters of pores, lack of penetration was measured
- Regions without porosity very closely matched the penetration depth of the weld seam
- Calibration and high measuring rates will enable detection finer detection of defect location, an example is shown below with the spread of data points indicating the presence of porosity





Summary

- Test procedures for weld defect formation have been developed
- Procedures with the most consistent results have been identified for repeating with the LDD in-process monitoring
- Laser welds with the LDD are in-progress
- LDD sensitivity at penetrations close to the limit of the field of view has been found to have decreased
  - Calibrating the sensor to the weld depth will remove this issue
  - Changing to a sensor with a larger depth of field will remove this issue

Future Work

- Complete autogenous full penetration laser welds with LDD monitoring
- Complete hybrid laser-arc welds with the LDD monitoring
- Evaluate sensor sensitivity to weld defects in hybrid welds
  - Inspect the quality scenario test welds with non-destructive test methods and compare to LDD results
  - Evaluate sensor for pre-weld, in-weld, and post-weld detection capability
- Analyze cost for integrating sensor into production operation at NASSCO

Acknowledgements

GENERAL DYNAMICS
NASSCO

IPG PHOTONICS

EWI

YASKAWA
MOTOMAN ROBOTICS

NATIONAL SHIPBUILDING RESEARCH PROGRAM
NSRP

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Thank you.
Questions?