Multi-factor Monitoring of Hybrid Laser-Arc Welding Applications

First Time Quality Welding Processes

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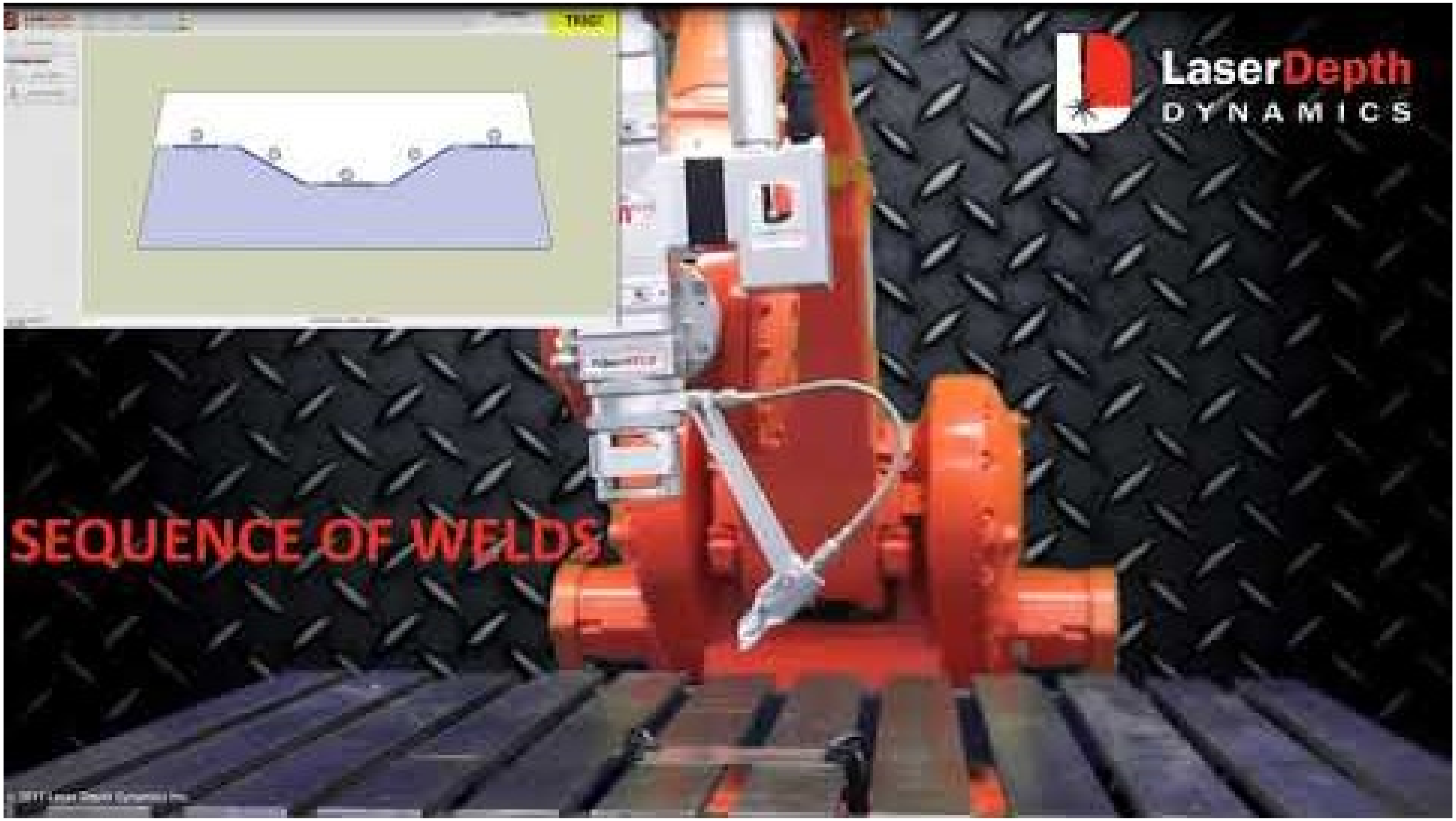
Problem Statement

- Shipbuilders need real-time weld sensor technology to achieve first time quality of hybrid laser-arc welding (HLAW) applications.
- This project will investigate the monitoring performance, operating characteristics, and implementation requirements of the monitoring technology known as Laser Depth Dynamics (LDD), a form of inline coherent imaging technology (ICIT).


LaserDepth
DYNAMICS
SEQUENCE OF WELDS

Solution/ Approach

Characterize and evaluate ICIT for HLAW:

- Evaluate monitoring performance of five different process variables
- 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 requirements

Task Outline

- Task 1 - Develop “Quality Scenario Test” Procedures for ICIT (LDD) System Assessment (OSU, EWI)
- Task 2 – ICIT Measurements of Preferred Quality Scenario Test Procedures (OSU, EWI, NASSCO)
- Task 3 – ICIT Sensitivity, Reproducibility, and Repeatability (OSU, EWI)
- Task 4 – Assessment of ICIT for Pre-Weld, In-Weld, and Post-Weld Measurements for Shipbuilding (OSU, NASSCO)
- Task 5 – Assessment of ICIT Implementation Impact and Requirements (OSU, NASSCO)

Task 1 - Develop "Quality Scenario Test" Procedures for ICIT (LDD) System Assessment (OSU, EWI)

- Setup OSU HLAW station with 6KW laser
  - Initial focus: square groove testing on 5 mm AH36
- Develop one or more test procedures to assess monitoring performance for workpiece height, seam profile, keyhole depth, finished weld surface, and transverse profile of full penetration butt joints.
- Test matrix designed to include both square and Y-groove, both partial and full penetration keyhole modes, and effects of joint gap and mismatch
  - **Fit-up test conditions based on expected worst case conditions using NASSCO's laser hybrid panel station.**
  - Record monitor data pre-weld, in-weld and post-weld
  - Repeat quality scenario tests on thicker Y-groove butt joint samples; ~10 mm

Task 2 – ICIT Measurements of Preferred Quality Scenario Test Procedures (OSU, EWI, NASSCO)

- Evaluate adverse laser parameters with quality scenario tests matrix from Task 1 (groove configuration, fit-up conditions, and keyhole penetration matrix).
  - Vary NASCCO's procedure parameters and joint conditions to evaluate beam misalignment, out-of-focus, and low / high power conditions.
  - Compare to preferred welding conditions for each joint condition.
- Purpose: induce discontinuities and defects that could occur in production, and evaluate ICIT LDD system's ability to measure changes that can be correlated to the respective discontinuity and / or defect.
  - Potential defects: porosity, lack of fusion, lack of penetration, undercut, and underfill
  - Explore process window relationships.
- Select preferred "quality scenario tests" from the Task 2 for sensitivity study in Task 3.

Task 3 – ICIT Sensitivity, Reproducibility, and Repeatability (OSU, EWI)

- Subset of the quality scenario test matrix
  - Two different plate thicknesses (for example 5 mm square groove and 10 mm Y-groove) to provide a range of representative production panel welding configurations.
- Make series of welds using adverse laser parameters to provide a range of good welds and flawed welds.
  - Determine monitor's ability to flag the type quality variation (porosity, lack of fusion, lack of penetration, undercut, and underfill).
- Compared ICIT data to visual and volumetric (ultrasonic and/or radiographic analysis) nondestructive inspection.
  - Based on NDE a number of macro sections will be removed to further characterize the morphology of the discontinuities.
- Perform statistical analysis to determine the sensitivity, reproducibility, and repeatability of the ICIT system.

Task 4 – Assessment of ICIT for Pre-Weld, In-Weld, and Post-Weld Measurements for Shipbuilding (OSU, NASSCO)

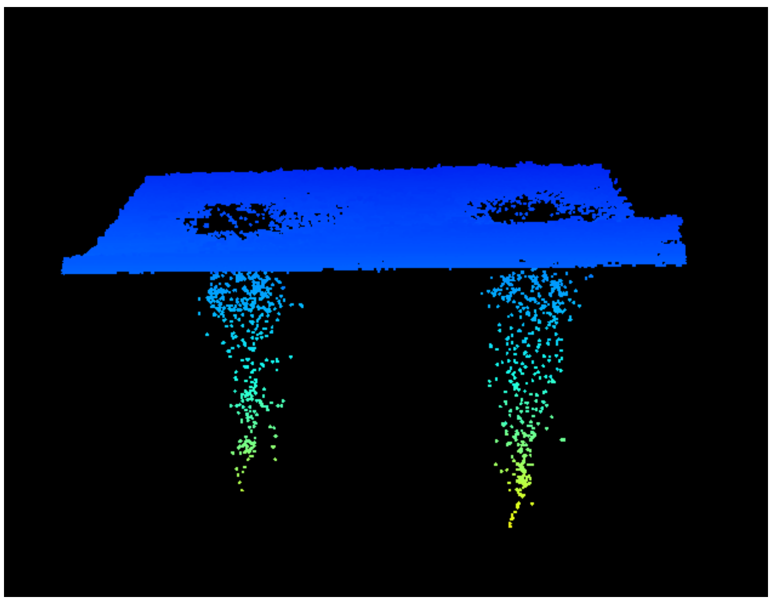
- Evaluate ICIT technology for real-time feedback of the pre-weld, in-weld, and post-weld conditions with NASSCO
  - For each data category, evaluate monitoring quality by working with NASSCO and reviewing the data from Tasks 2 and 3.
- Evaluate potential to provide feedback to prior operations and guidance to future operations to drive first-time quality and minimize risk of downstream repair.
- Evaluate preferred measurements and implementation strategy
  - Summarize strategy in the final report.
  - Potential from going from monitoring to quality control will also be assessed.

Task 5 – Assessment of ICIT Implementation Impact and Requirements (OSU, NASSCO)

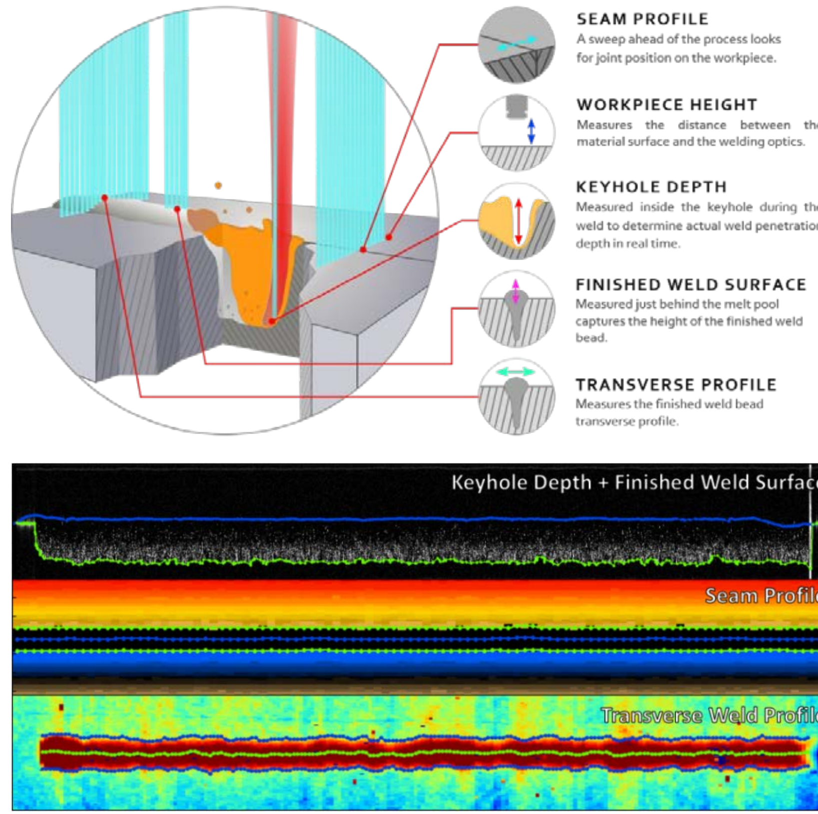
- The task will be used to establish process metrics for using inline coherent imaging technology on hybrid panel butt welding stations at NASSCO.
- Metrics will be established for cost and infrastructure requirements to implement the ICIT system.
- This assessment will be included in the final report, and used to determine future transition plans.

Project Status

- Designed test matrices and testing procedures
- Designed weld fixture
- Autogenous laser welds in progress
- Quality scenario tests in-process



3D resolution of pulsed laser keyhole morphology



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

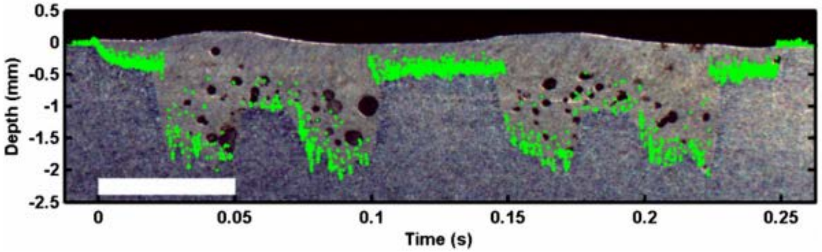
Project Benefits

ICIT offers first-time quality capability

- Real-time pre-weld, in-weld, and post-weld measurements.
- Immediate correction of weld quality issues.

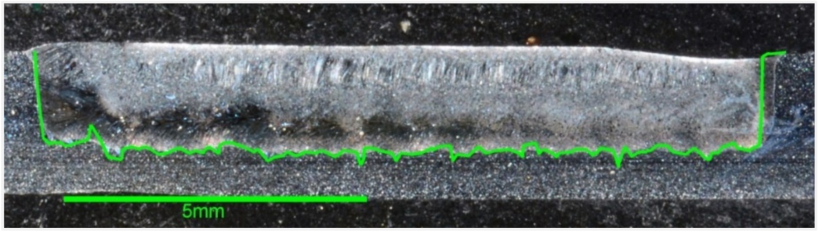
ICIT provides control platform for partial penetration fillet applications

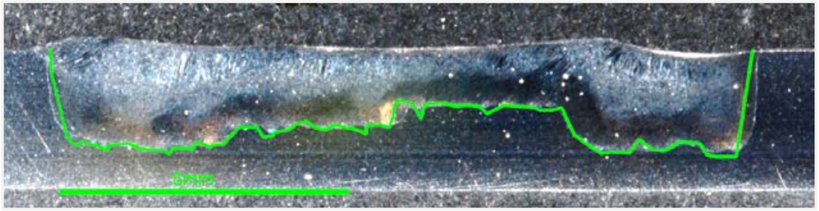
- Double-sided welding longitudinal stiffeners to panels.
- Structural T-beam manufacturing.



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

[1] P. J. L. Webster *et al.*, "Automatic laser welding and milling with in situ inline coherent imaging," *Opt. Lett.*, vol. 39, no. 21, p. 6217, Nov. 2014, doi: 10.1364/OL.39.006217.





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

Questions?

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