Deep Penetration Laser-GMAW Welding

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NSRP Program Technical Representative: Jonathan Roberts (Ingalls)

March 23, 2021
NSRP Welding Technology Panel Meeting

Project Team

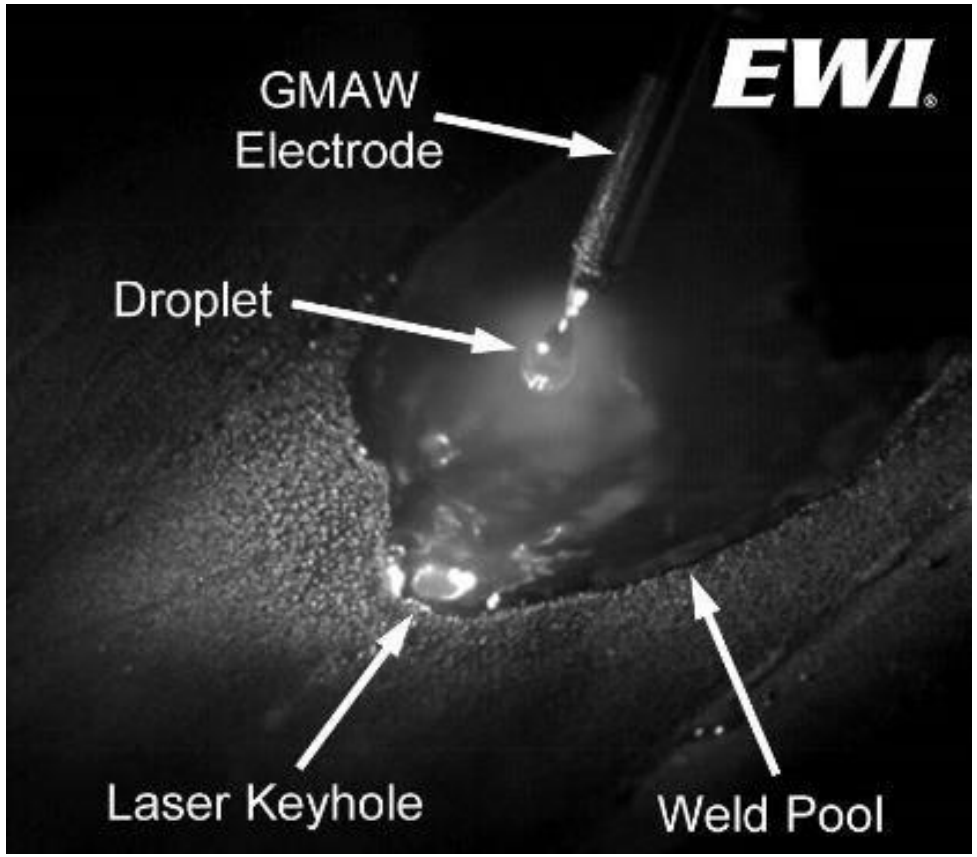
- EWI (prime)
  - Jake Hay (PI), Stan Ream (Principal Engineer), Dean Langenkamp (Engineer), Katie Hardin (PM)
- ATI PM
  - Ryan Schneider
- NSRP Program Technical Representative (PTR)
  - Jonathan Roberts (Ingalls)
- Participant
  - Cody Whiteley (NASSCO)
  - Kevin Roossinck (Ingalls)
  - James Marden (BAE)
  - Matt Sinfield & Dan Bechetti (NSWCCD)

Problem Statement

- Improve panel welding productivity and reduce distortion for Navy shipbuilding

Solution/Approach

- Apply advanced hybrid laser/gas metal arc welding (GMAW) plus tandem GMAW process to accomplish deep penetration single-pass, panel fabrication

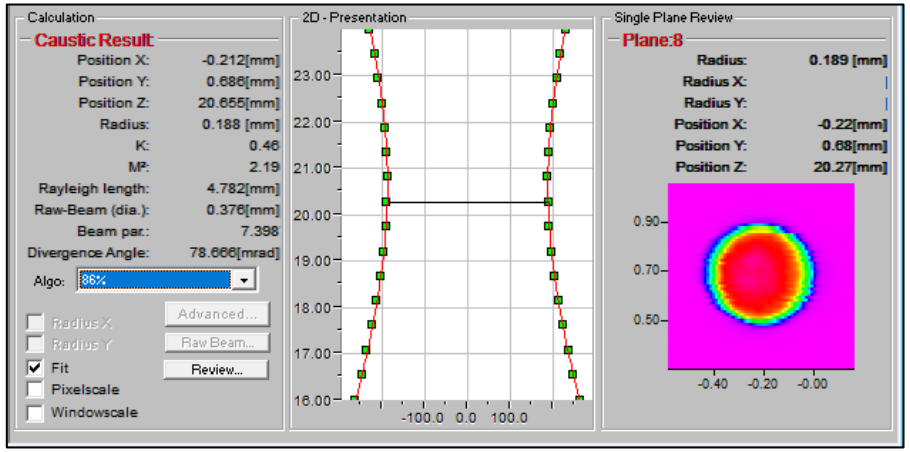


Project Details

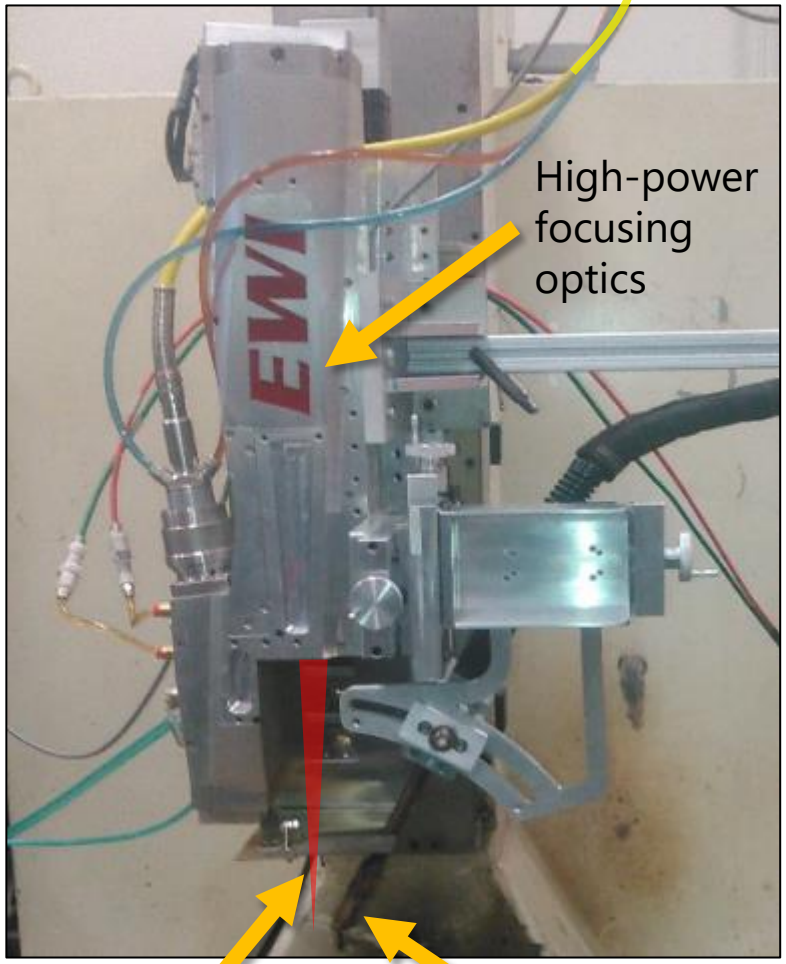
- Material
  - AH-36 – Provided by NAASCO
- GMAW Wire
  - Seamless Flux Cored Wire – Provided by NAASCO
  - AWS A5.36 E71T1-C1A2-CS1
- Quality Specification
  - No Quality Specification was specified
  - MIL-STD 2035 Class A used

Hybrid Laser Arc Welding (HLAW) Setup - Laser

Laser	IPG YLS-20000
Optics	EWI Custom B3
Fiber Diameter	200 µm
Focal Length	800 mm
Theoretical Spot Size	400 µm
Laser Beam Angle	0 Degree (normal)



- The measured spot size (376 micron) agreed with the theoretical value.
- The beam quality was within specification for the 200-micron fiber.

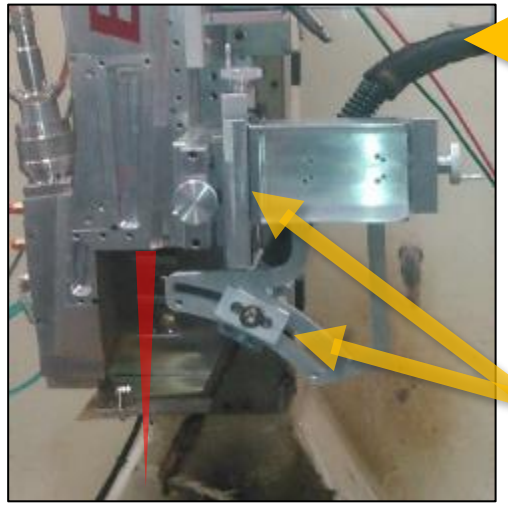


HLAW Setup - GMAW

Control panel

Power supply

Wire feeder



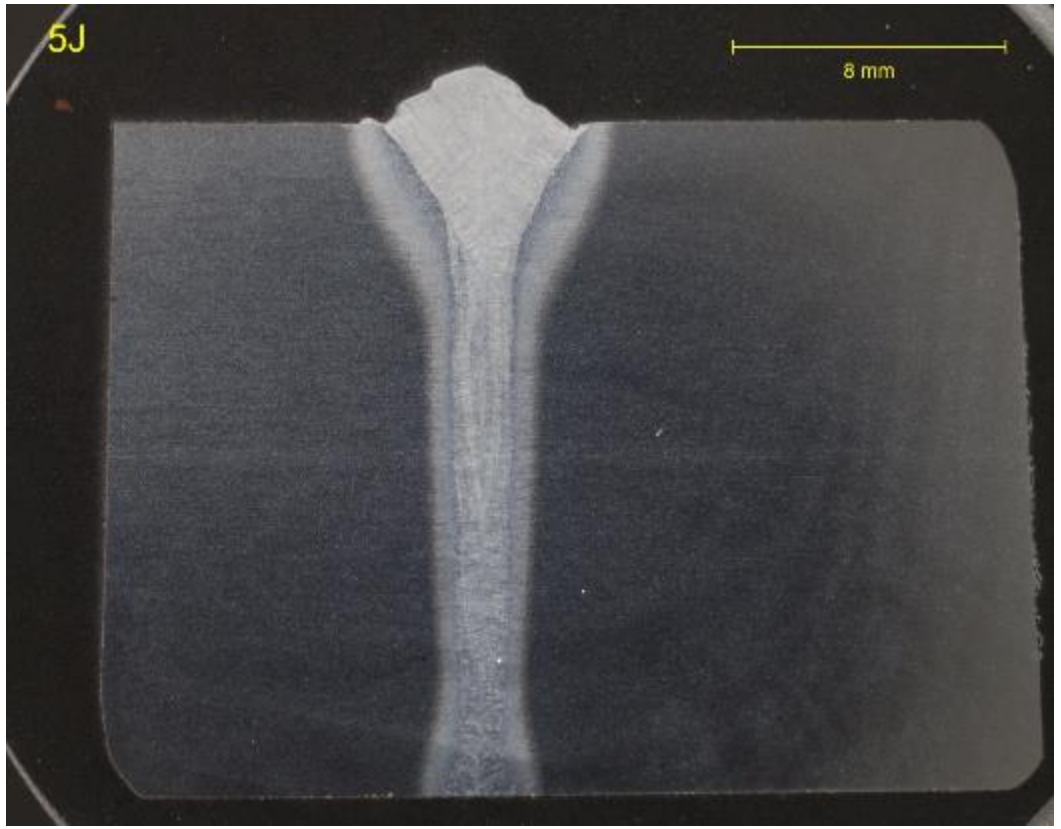
GMAW torch

GMAW alignment relative to laser

Results - HLAW Bead on Plate (BOP)

- 107 BOP trials were conducted with varying visual inspection results.
- Parameter set 5J resulted in acceptable top and back side results for this point in the development process.

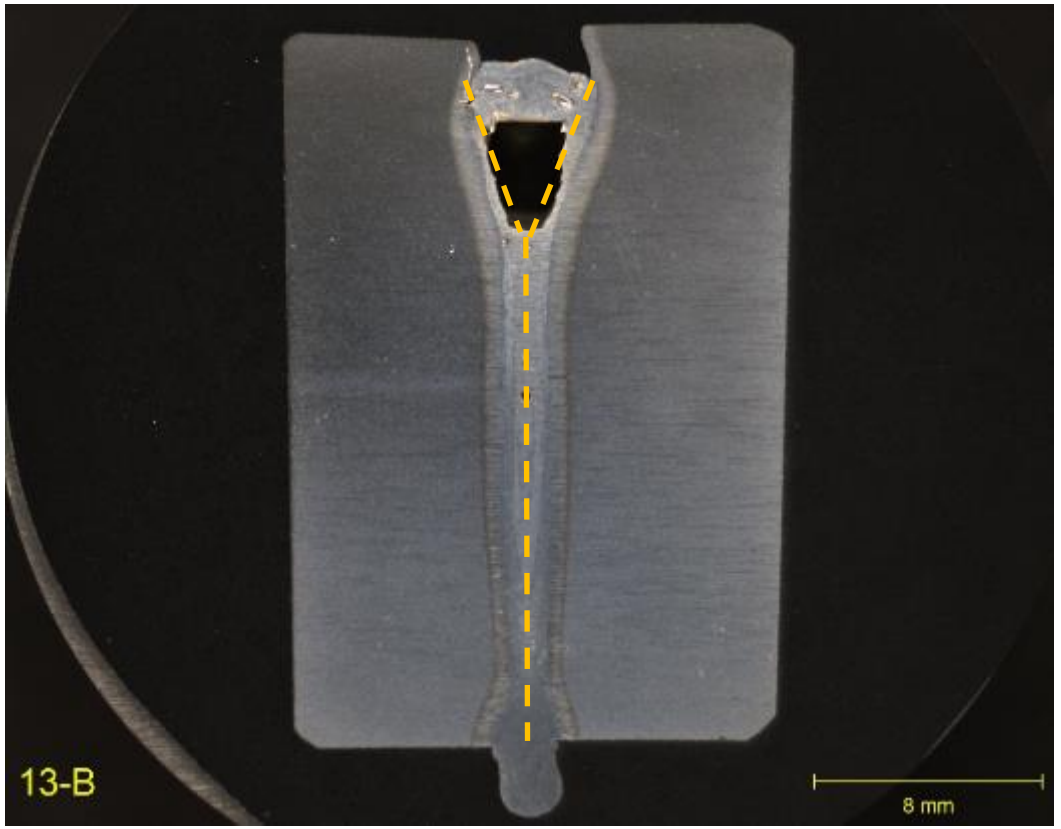
Laser Power (kW)	20
Travel Speed (IPM)	65
GMAW WFS (IPM)	500
GMAW Trim	1.00
GMAW Wire Stick Out (in)	0.5
Beam To Wire (mm)	2



Results – V-Groove Joint Design – 13B

- 17 trials were conducted on V-Groove joint prep.
- All samples exhibited back side humping and most showed evidence of process instability.

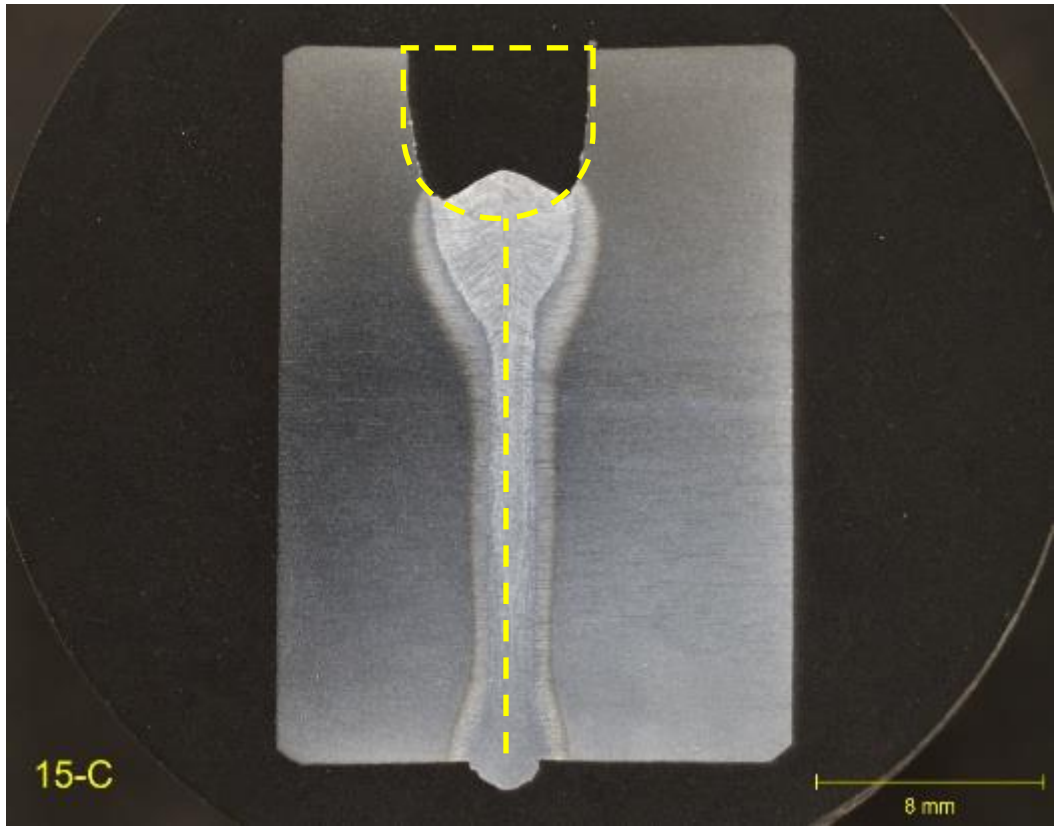
Laser Power (kW)	20
Travel Speed (IPM)	72
GMAW WFS (IPM)	500
GMAW Trim	1.05
GMAW Wire Stick Out (in.)	0.5
Beam to Wire (mm)	2



Results – U-Groove Joint Design – 15C

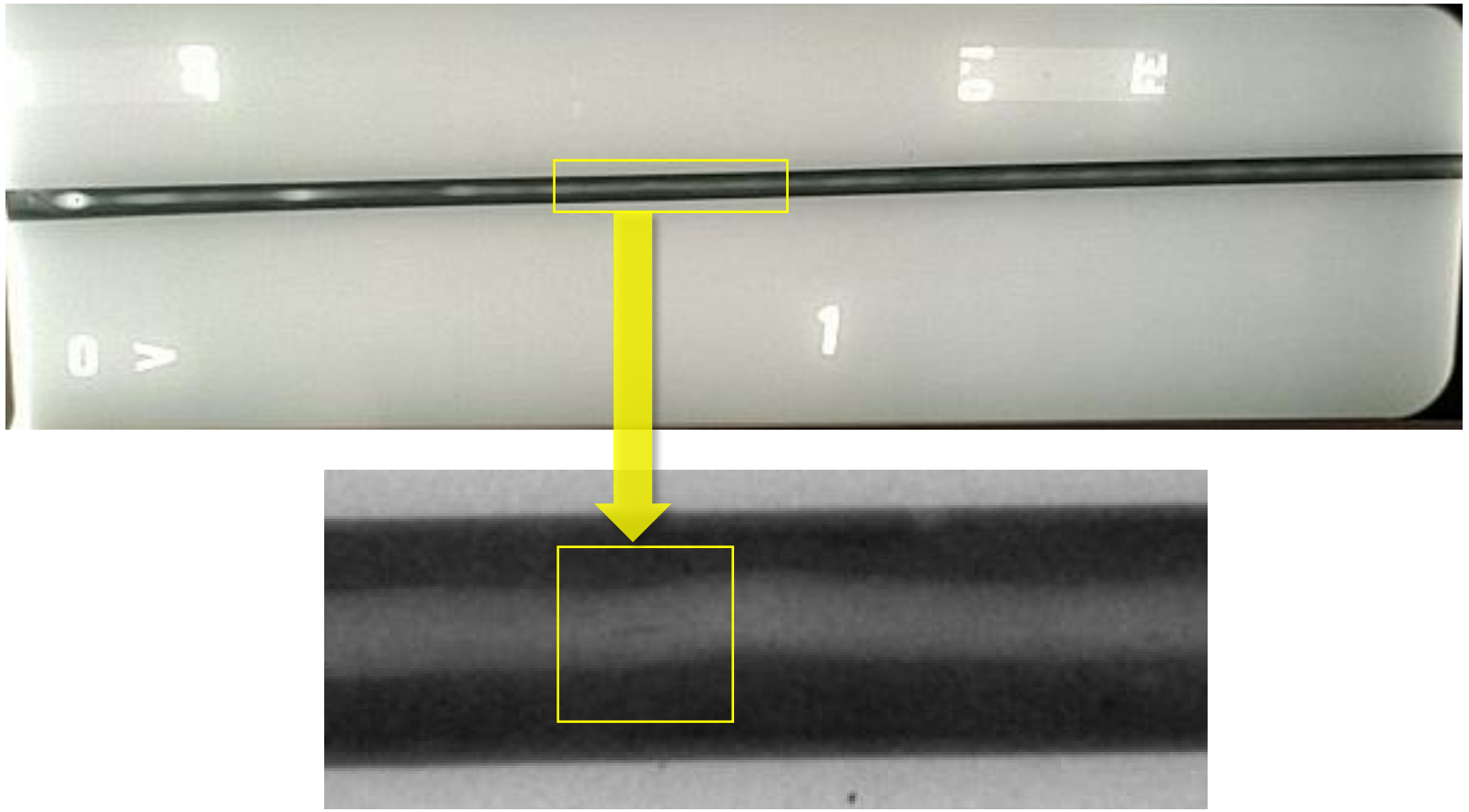
- 116 HLAW trials have been conducted on U-Groove joint preparation.
- All U-Groove joints have shown significant improvement in weld quality and process stability.

Laser Power (kW)	19
Travel Speed (IPM)	65
GMAW WFS (IPM)	500
GMAW Trim	1.05
GMAW Wire Stick Out (in.)	0.5
Beam to Wire (mm)	2

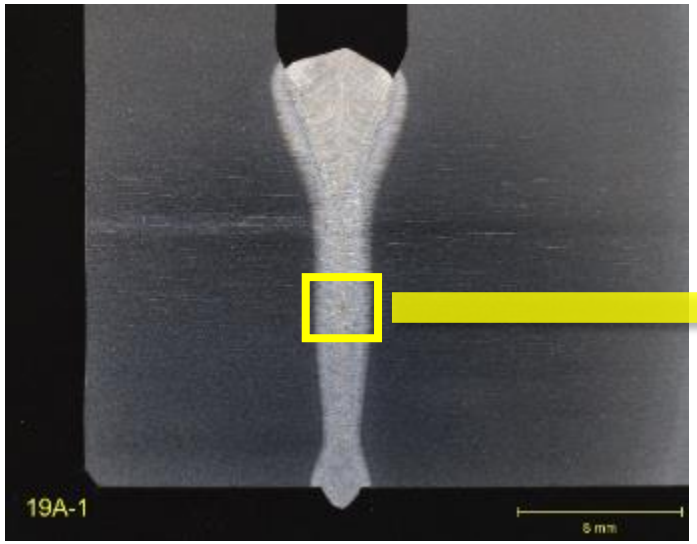


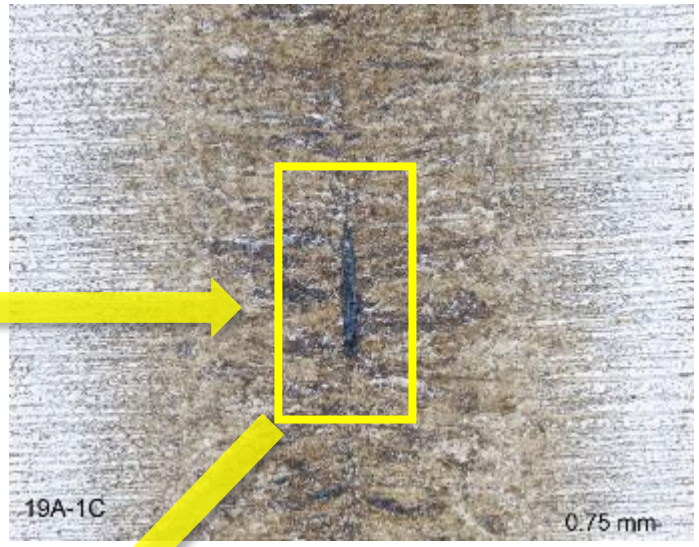
Results –19A – Radiography

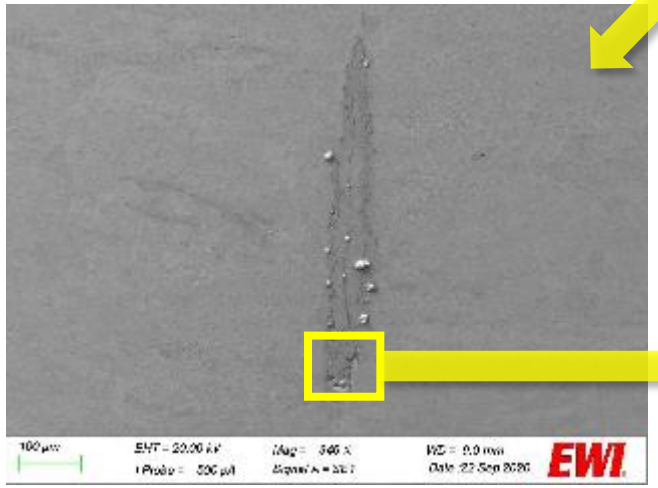
- A full-length weld was completed using parameters from 15C.
- Lack of fusion (LOF) defects found.

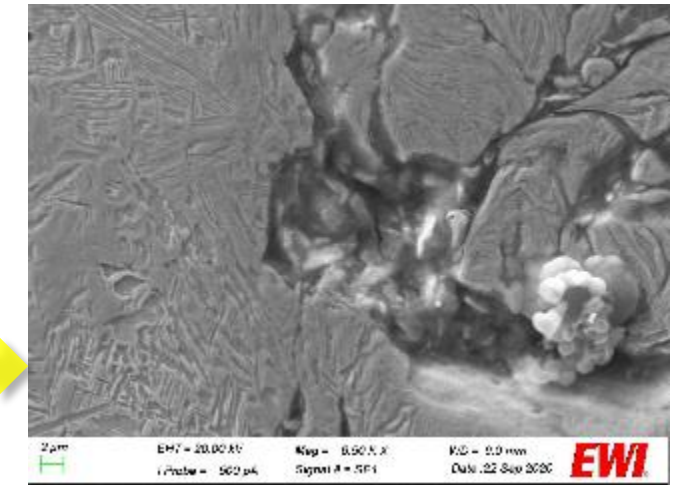


Results –19A – SEM/EDS Analysis





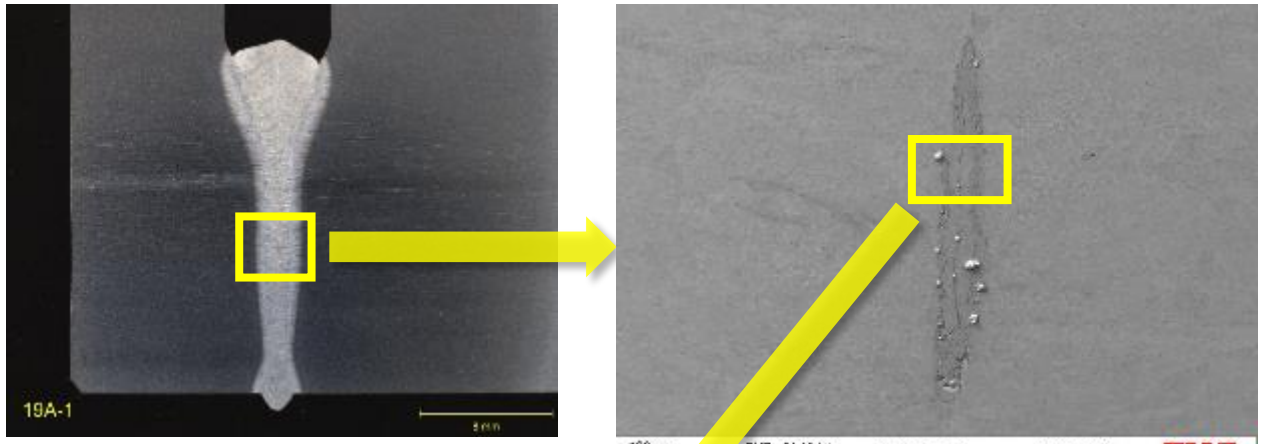


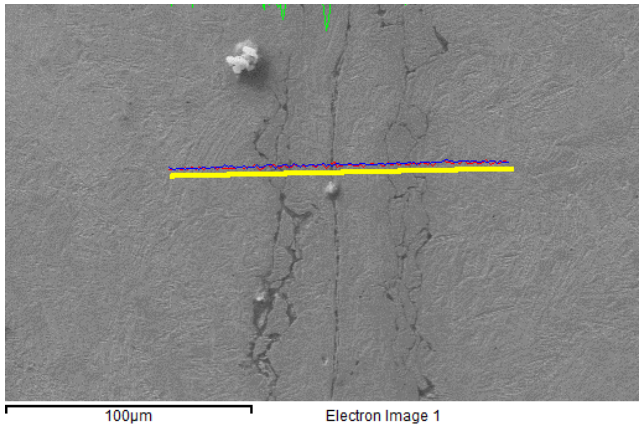


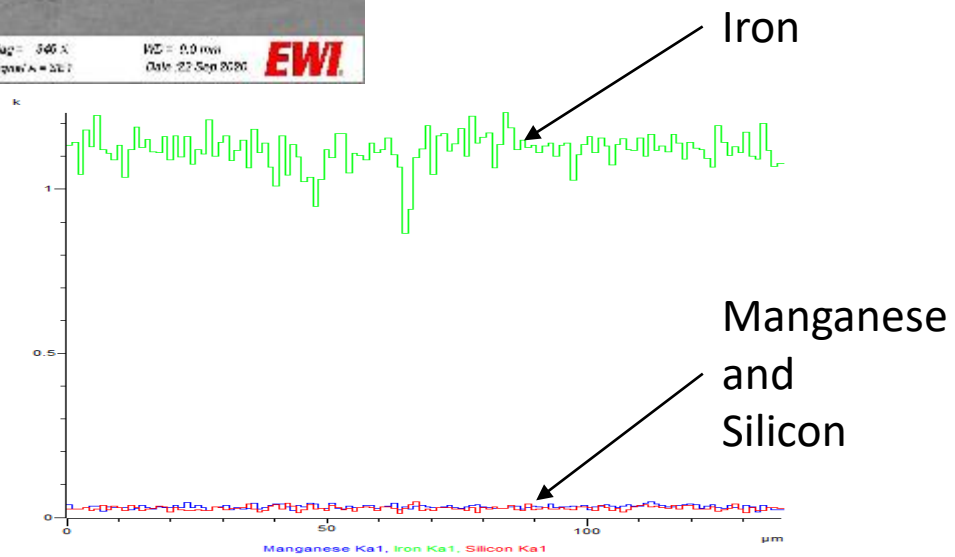
- A cross section was completed, and the defect was located.
- Further metallographic and scanning electron microscopy/energy dispersive spectroscopy (SEM/EDS) analysis of LOF defect indication from radiography

Results –19A – SEM/EDS Analysis

- Further metallographic and SEM/EDS analysis of LOF defect indication from radiography
- No foreign inclusion found

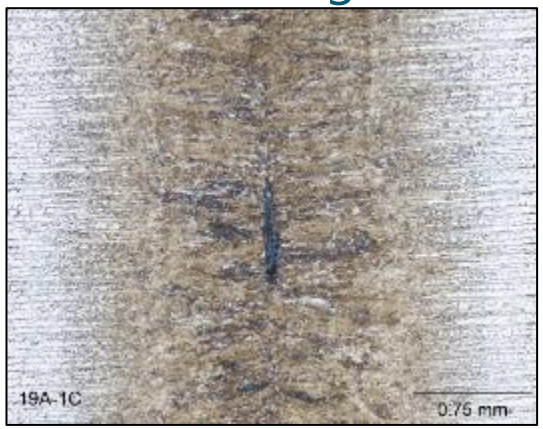


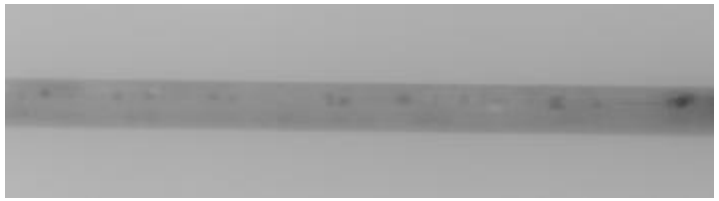




Laser/HLAW Development

- To eliminate this solidification defect, joint and HLAW setup changes have been investigated.
  - Travel speed and laser power adjustments (40-90 IPM and 17.5-20 kW)
  - Beam to wire spacing (2-8 mm)
  - Joint configuration, intentionally introducing a gap
  - Laser spot size (301, 400 and 716 µm)
  - Laser only
- 400 µm spot size resulted in solidification defect (original setup).
- 301 µm spot size setup results in porosity.
- 716 µm spot size setup results in excessive backside humping.
- Process isolation - Each process provides an acceptable weld.
  - A laser only weld was completed and x-rayed with no defects.
  - A GMAW only weld was completed and x-rayed with no defects.
- Further development revealed that the solidification defect is present in some laser only welds.

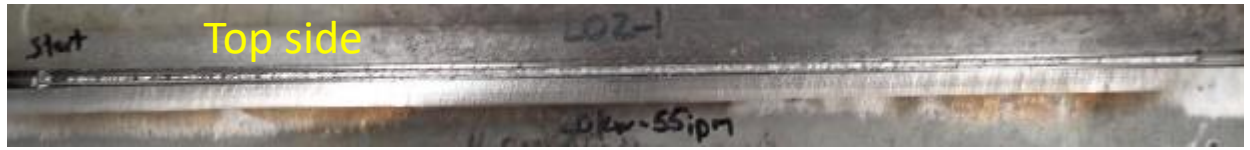


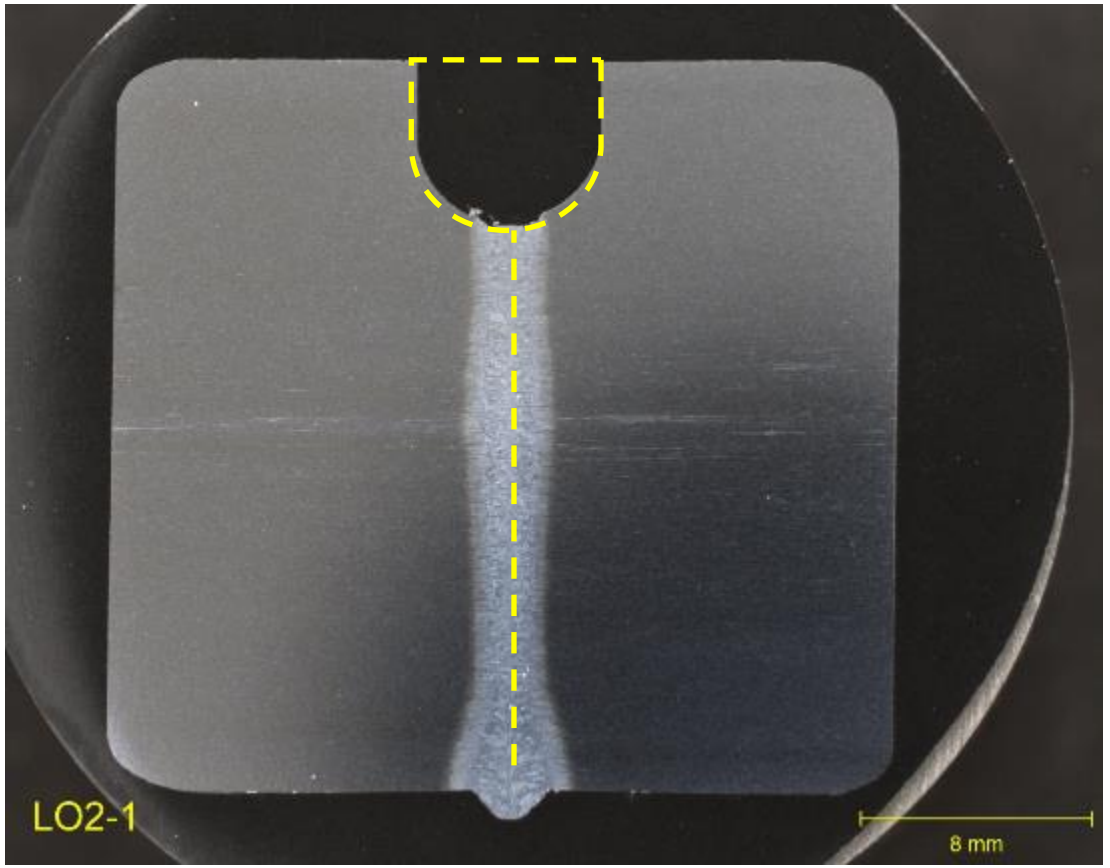


Results – Laser Only Welds

- Laser only welds were completed resulting in excellent weld profile
- HLAW welds result in filler metal mixing about half the weld thickness. Tandem GMAW welds at these travel speeds get significant penetration resulting in similar mixing.

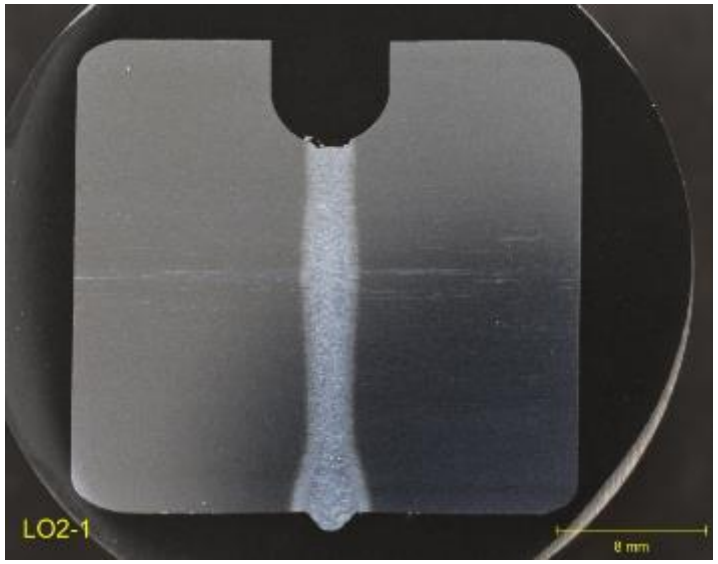
Laser Power (kW)	20
Travel Speed (IPM)	55

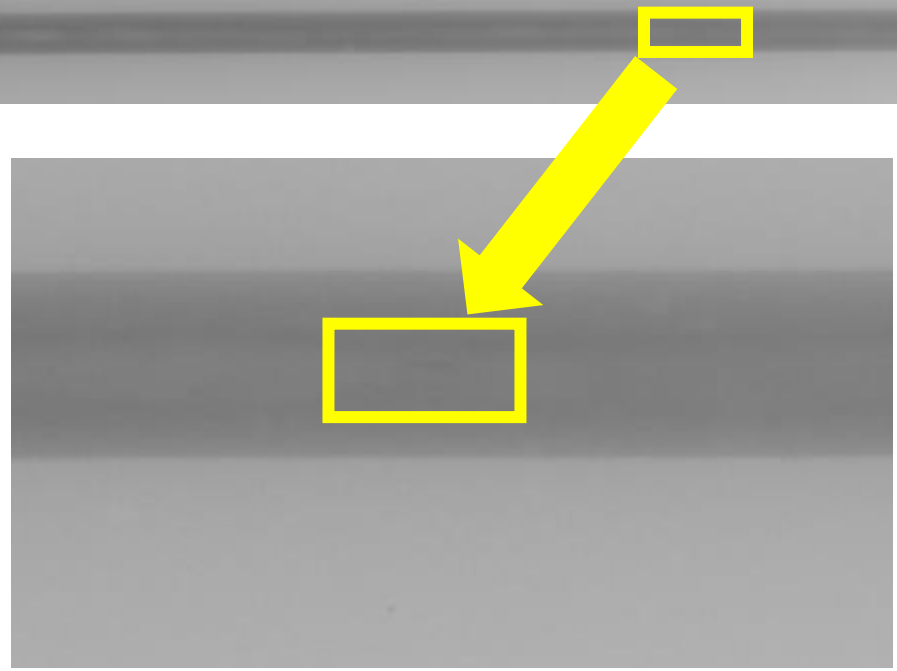




Results – Laser Only Welds

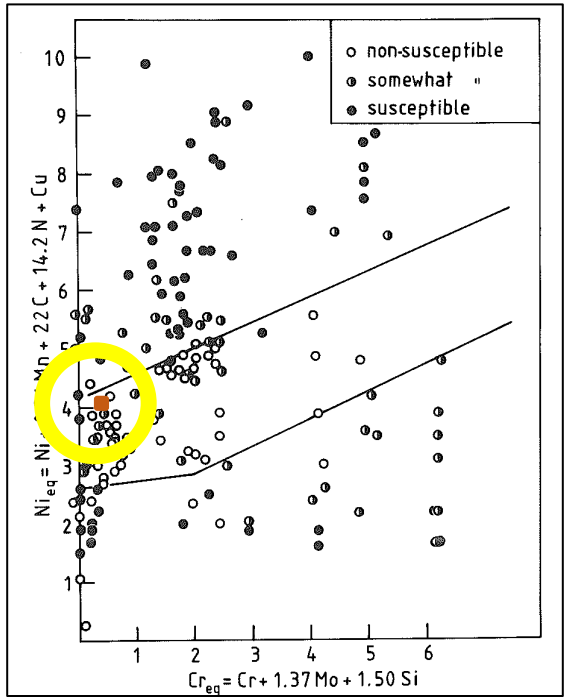
- 18-in. laser only weld resulted in solidification defect as well.
- Acceptable visual inspection results
- Currently investigating other possible causes such as metallurgical





Results – Material Analysis

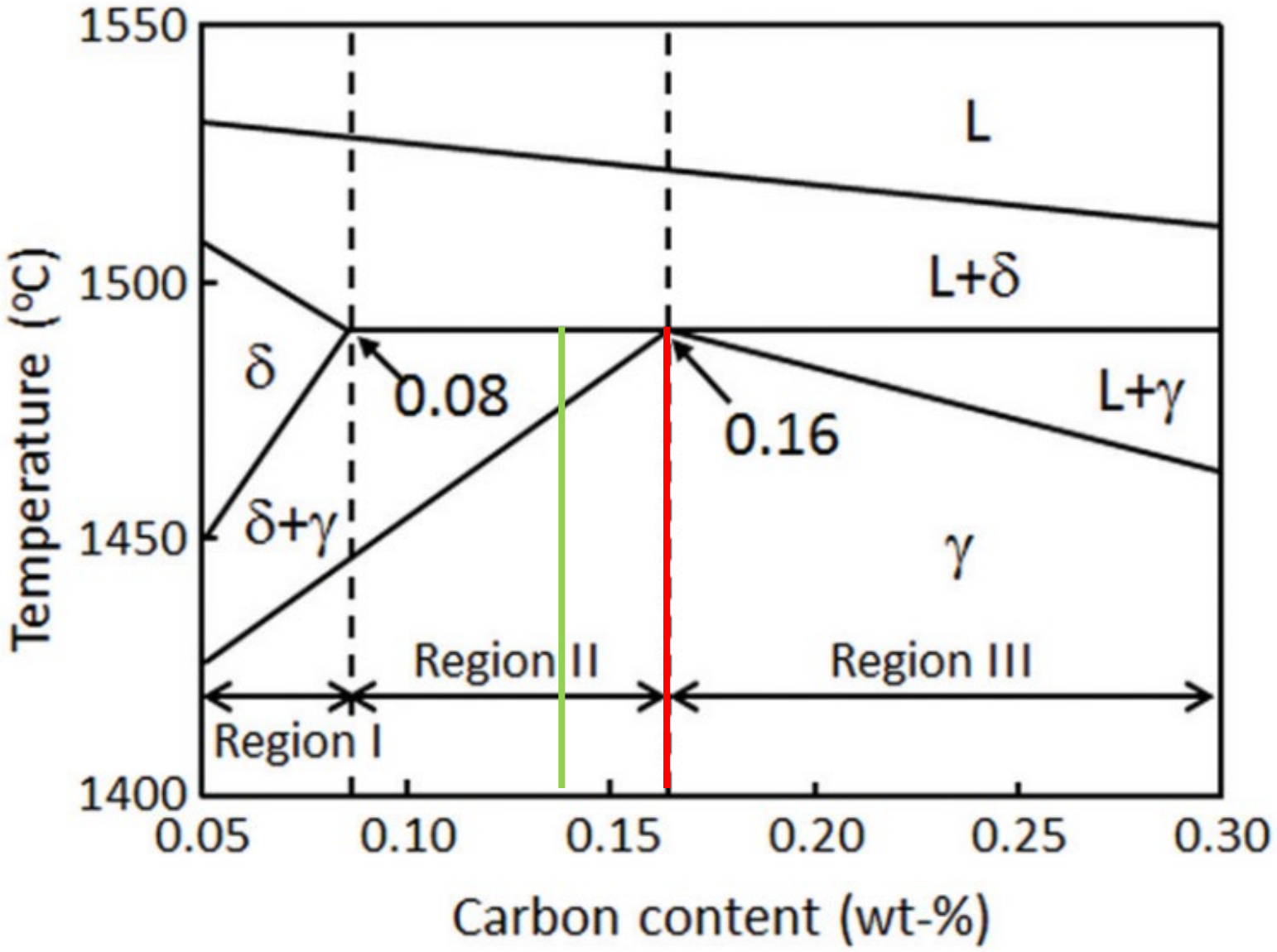
- A material chemistry analysis was done of the provided AH-36 material with results shown to the right.
- Carbon, Phosphorous, Sulfur and Copper content were closely examined
- The effects of these elements are discussed on the following slides.
- Chemistry results in **somewhat** susceptible to cracking



Analyte Name	Units	Result
Specimen ID	N/A	19A-1
Number of Burns	N/A	3
C	%	0.160
Mn	%	1.06
Si	%	0.17
P	%	0.013
S	%	0.002
Cr	%	0.128
Ni	%	0.139
Mo	%	0.046
Cu	%	0.258
V	%	0.038
Al	%	0.028
Ti	%	0.004
Nb	%	0.030
Co	%	0.004
Tungsten	%	0.000
Sn	%	0.000
Boron	%	0.0003
Zr	%	0.000
Fe	%	97.8
Analysis Location	N/A	Base Metal

Results – Material Analysis

- Effect of carbon on solidification cracking
- Current material Carbon content is 0.16% placing it right on the peritectic transformation point. This increases residual strain with fast cooling rates in case of laser welding leading to increased solidification cracking risk
- Lowering the carbon content to approximately 0.14% would generate δ-ferrite which has 10X higher solubility of impurity elements which leads to less interdendritic segregation and reduced risk of solidification cracking.

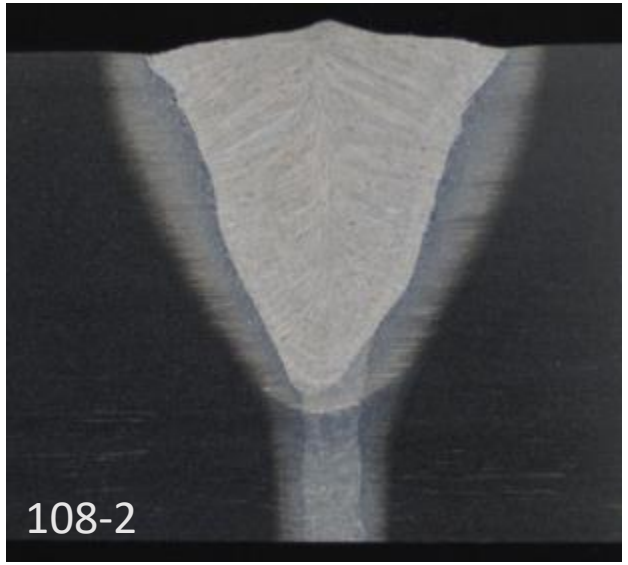


Tandem GMAW

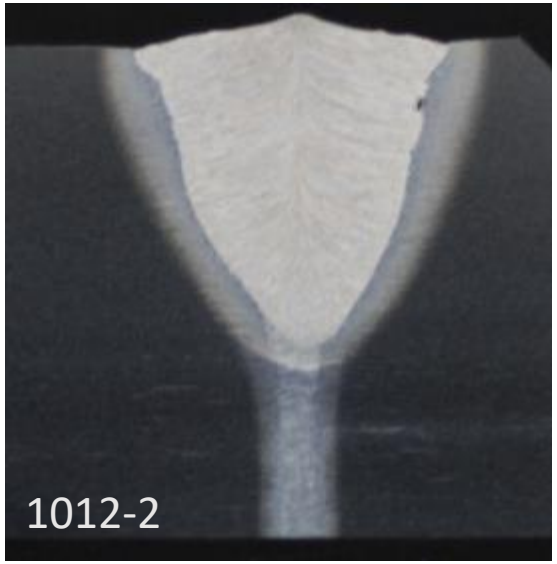
- Cloos Robot and Cloos Tandem GMAW system
  - Robot: Qirox
  - GMAW Power Supply: Qineo PULSE 601 PRO's
  - Partial penetration weld so plates are clamped directly to positioner.

Tandem GMAW - Results

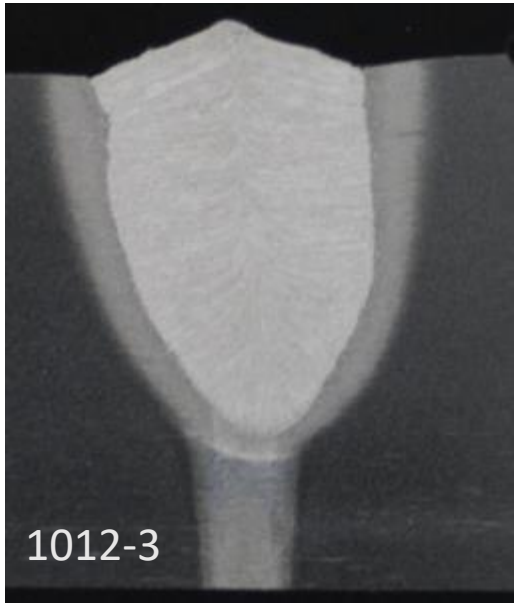
- Eleven tandem GMAW parameter sets have been tested and visually inspected. Four welds were selected for metallographic evaluation.
- Deep GMAW penetration is being achieved through required high current levels driven by high wire feed rates necessary for the shown linear travel speeds.



Travel Speed (IPM)	51
Lead GMAW WFS (IPM)	472.5
Trail GMAW WFS (IPM)	590.5



Travel Speed (IPM)	63
Lead GMAW WFS (IPM)	590.5
Trail GMAW WFS (IPM)	708.7

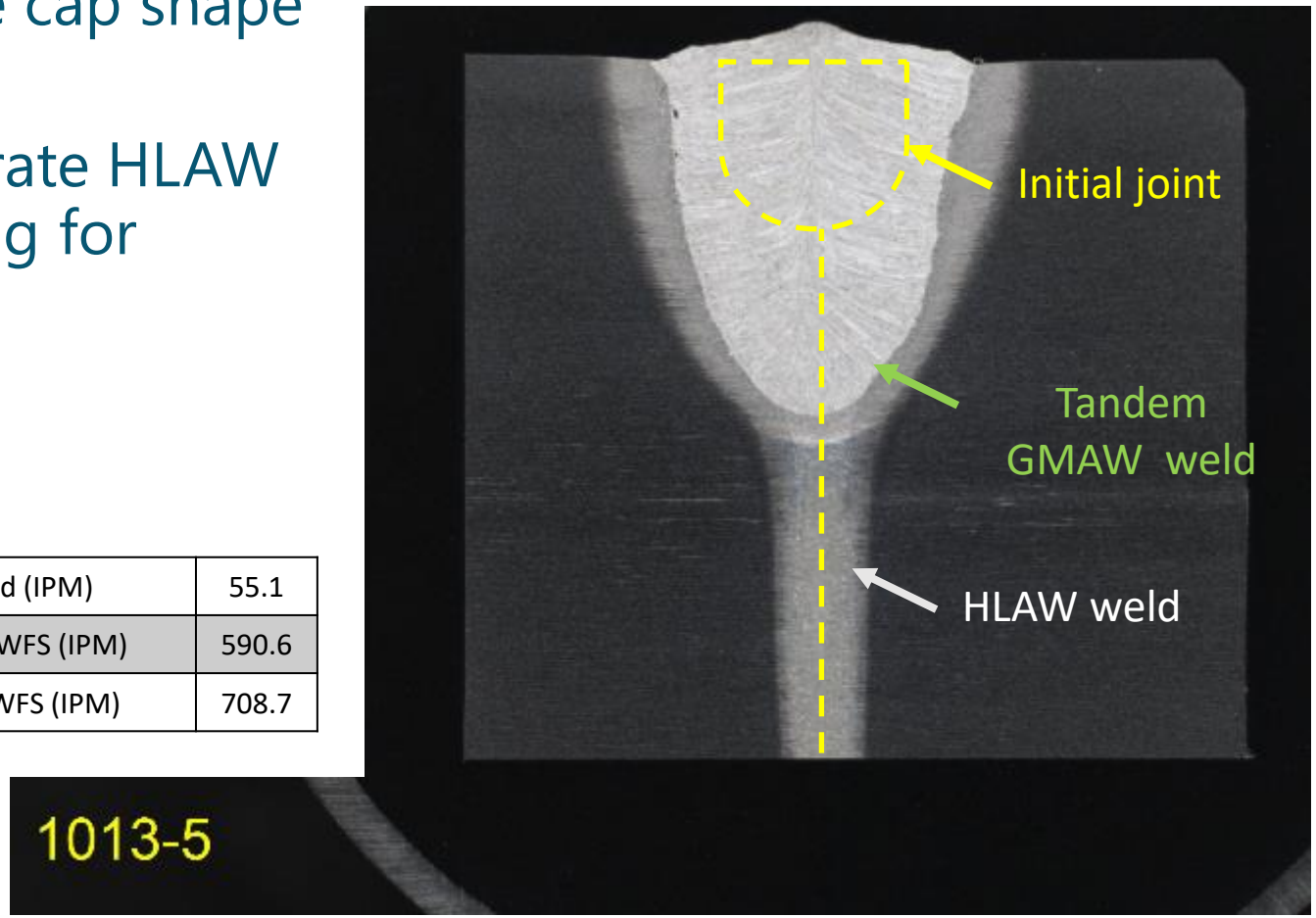


Travel Speed (IPM)	63
Lead GMAW WFS (IPM)	708.7
Trail GMAW WFS (IPM)	826.8

Tandem GMAW - Results

- Current tandem GMAW results
- Smooth toe angles and acceptable cap shape were achieved.
- Most HLAW panel lines have separate HLAW and GMAW motion system allowing for different travel speeds.
- Typical HLAW travel speed: 65 IPM

Travel Speed (IPM)	55.1
Lead GMAW WFS (IPM)	590.6
Trail GMAW WFS (IPM)	708.7



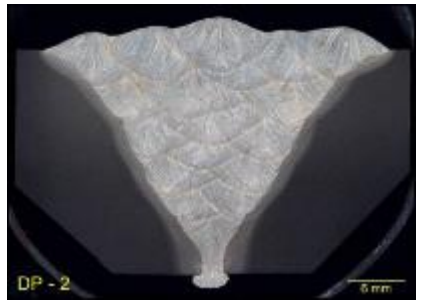
Conclusions and Next Steps

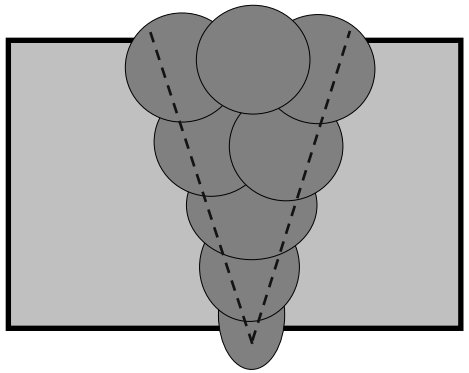
- Defects are found in all welding processes tried, HLAW and laser only.
- No defects experienced in HY-80 material welded on a ¾-in. internal research and development project.
- The AH-36 chemistry used for this development is not a compatible material for HLAW or autogenous laser welding
- Additional development to improve filler metal alloying in HLAW welds would be required.

HY-80 ¾-in HLAW Weld. No indications in cross section or radiography

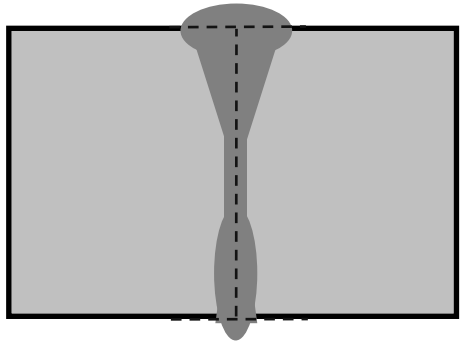
Project Benefits

- Reduced panel manufacturing costs
  - Improved productivity
    - Single pass full penetration weld
    - 40 to 80 IPM welding travel speeds
  - Reduced panel distortion and straightening requirements
- Improved ship performance

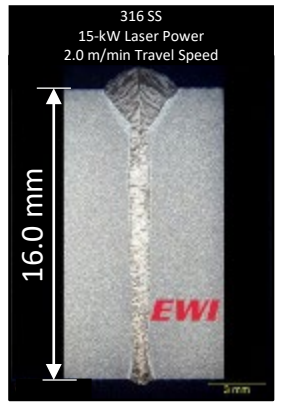




Conventional GMAW
multi-pass



HLAW
single pass



Questions?