



Laser Hybrid Tack Welding of Structural Steel Fillet Weld Joints

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Topics

Problem to Solve

Current Application of Hybrid Laser in Shipbuilding

Equipment and Safety

Preliminary Welding Trials and Results

Metallographic Analysis

Toughness Evaluation

Future Efforts



Problem to Solve

Tack welds made using manual or semi-automatic welding processes

Tack size equal to or greater than required weld size

Mechanized welding over tacks



Current Application of Hybrid Laser in Shipbuilding

Seaming of S-1 materials for ship structure using hybrid laser

Fillet welding of stiffener to deck connections

Handheld laser hybrid for sheetmetal applications



Equipment and Safety

IPG LightWELD 1500 XR



Equipment and Safety

IPG LightWELD 1500 XR



Equipment and Safety

External Interlocks

Fiber Interlock

Nozzle to Workpiece and Trigger Control



Preliminary Welding Trials and Results

Thick and thin materials
3/16" and 1/2" material

Extremes of welding parameters
Power from 950 to 1500 watts
Wire feed speed from 10 to 25 ipm
Travel speed from 10 to 25 ipm
Wobble and frequency

Wide range of heat inputs
2500 J/in for low wattage, high travel
9500 J/in for high wattage, slow travel



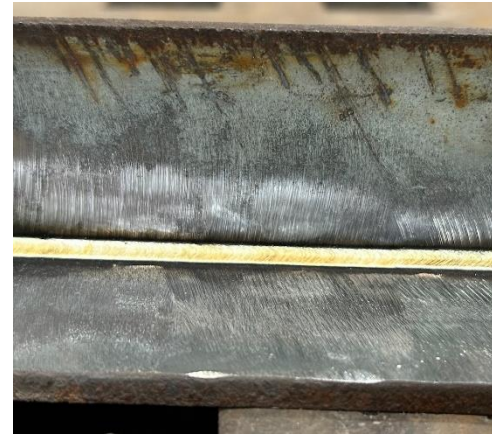
Preliminary Welding Trials and Results

Plate Thickness	Wattage	Wire Feed Speed	Wobble Width	Wobble Frequency	
3/16"	950	10	0	0	
			9	50	
		25	0	0	
			9	50	
		1250	10	0	0
			9	50	
	25	0	0		
		9	50		
	1500	10	0	0	
			9	50	
		25	0	0	
			9	50	
1/2"		950	10	0	0
				9	50
	25		0	0	
			9	50	
	1250		10	0	0
			9	50	
	25	0	0		
		9	50		
	1500	10	0	0	
			9	50	
		25	0	0	
			9	50	

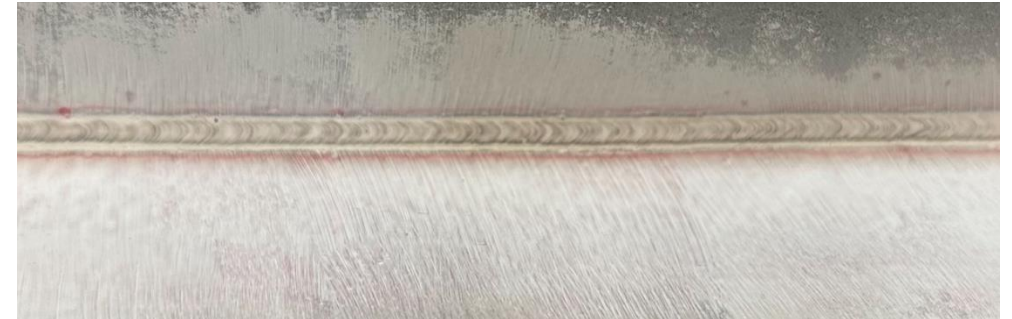


Preliminary Welding Trials and Results

Visual Inspections



Dye Penetrant



Macro Etch



Preliminary Welding Trials and Results

Visual Inspection Results

Low travel speeds and high wobble conditions showed rejectable visual indications

Dye Penetrant Results

All samples passing VT were subject to PT, with all results acceptable

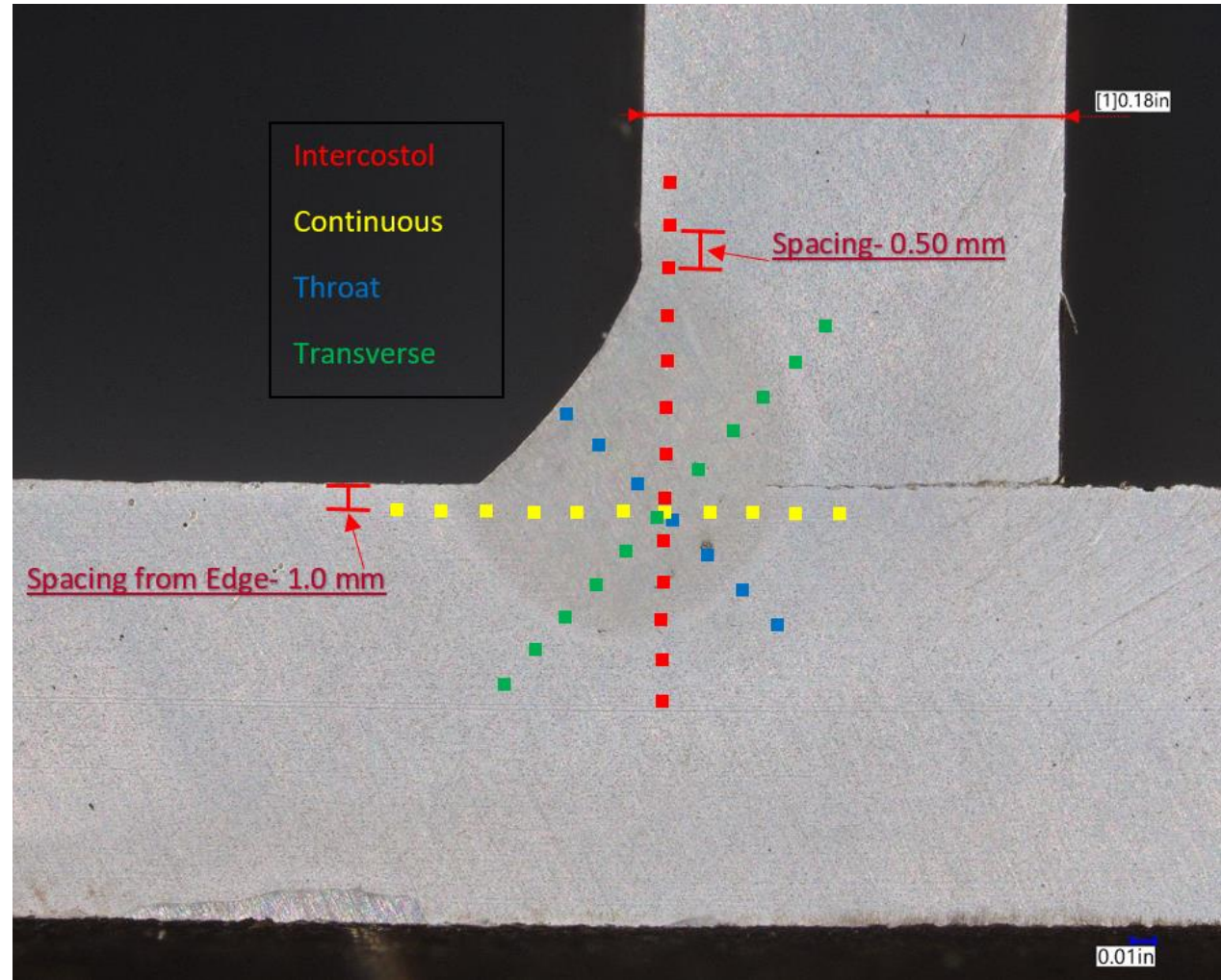
Macro Etch

High travel speeds and high wobble conditions showed lack of fusion in the root

Decreased travel speeds and increased power created larger HAZ and weld cross sections



Hardness Mapping



Preliminary Welding Trials and Results



Preliminary Welding Trials and Results

When travel speed and power were held constant, hardness increased as plate thickness increased

As travel speed increased, with other variables constant, hardness delta decreased between plate thicknesses

Wobble width and frequency had no noticeable influence on hardness

Welding over laser hybrid tacks with conventional welding processes reduced hardness but did not completely consume the tack



Laser Hybrid Tacks Welded over with FCAW

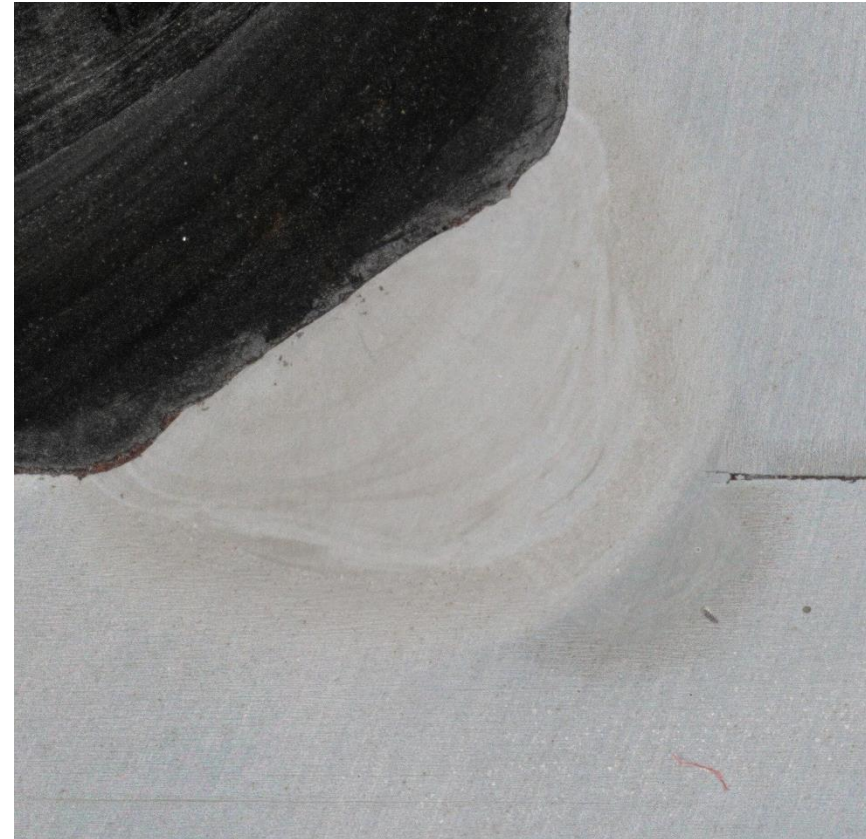


Preliminary Welding Trials and Results



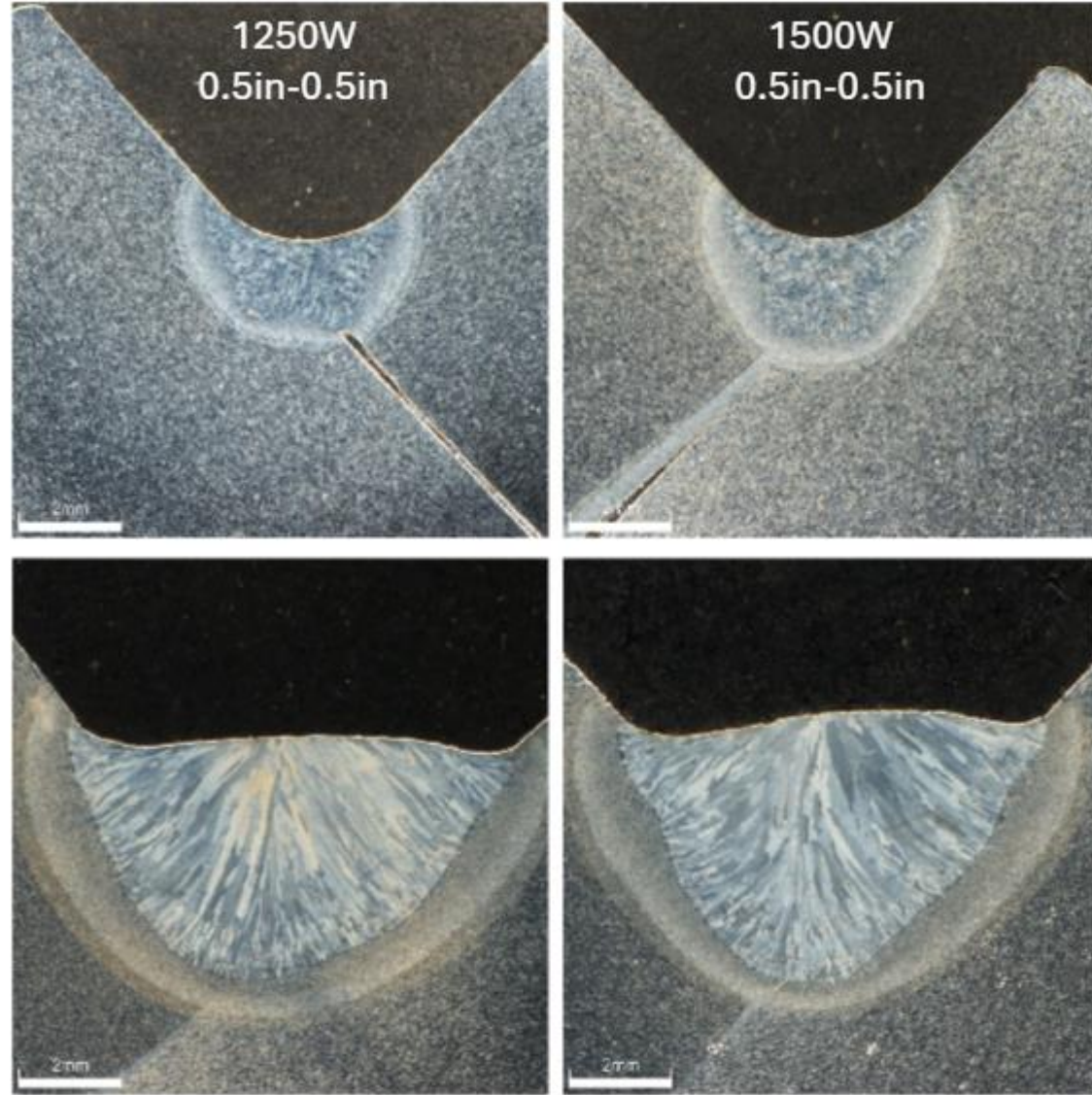
Laser Hybrid Tacks Welded over with FCAW

Preliminary Welding Trials and Results



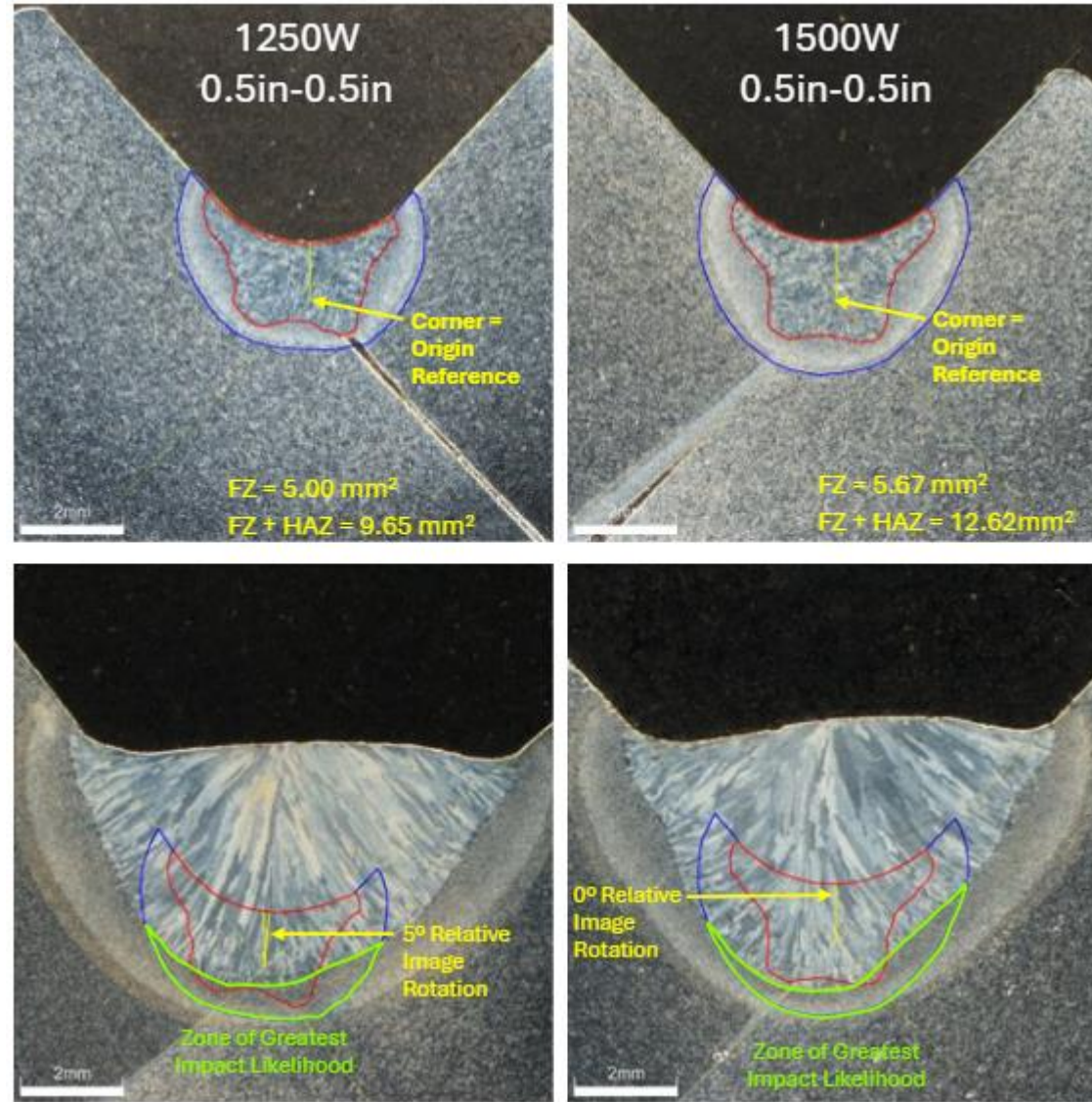
Metallographic Analysis

Extent of Prior Tacks in Rewelded Samples (0.5in-0.5in)



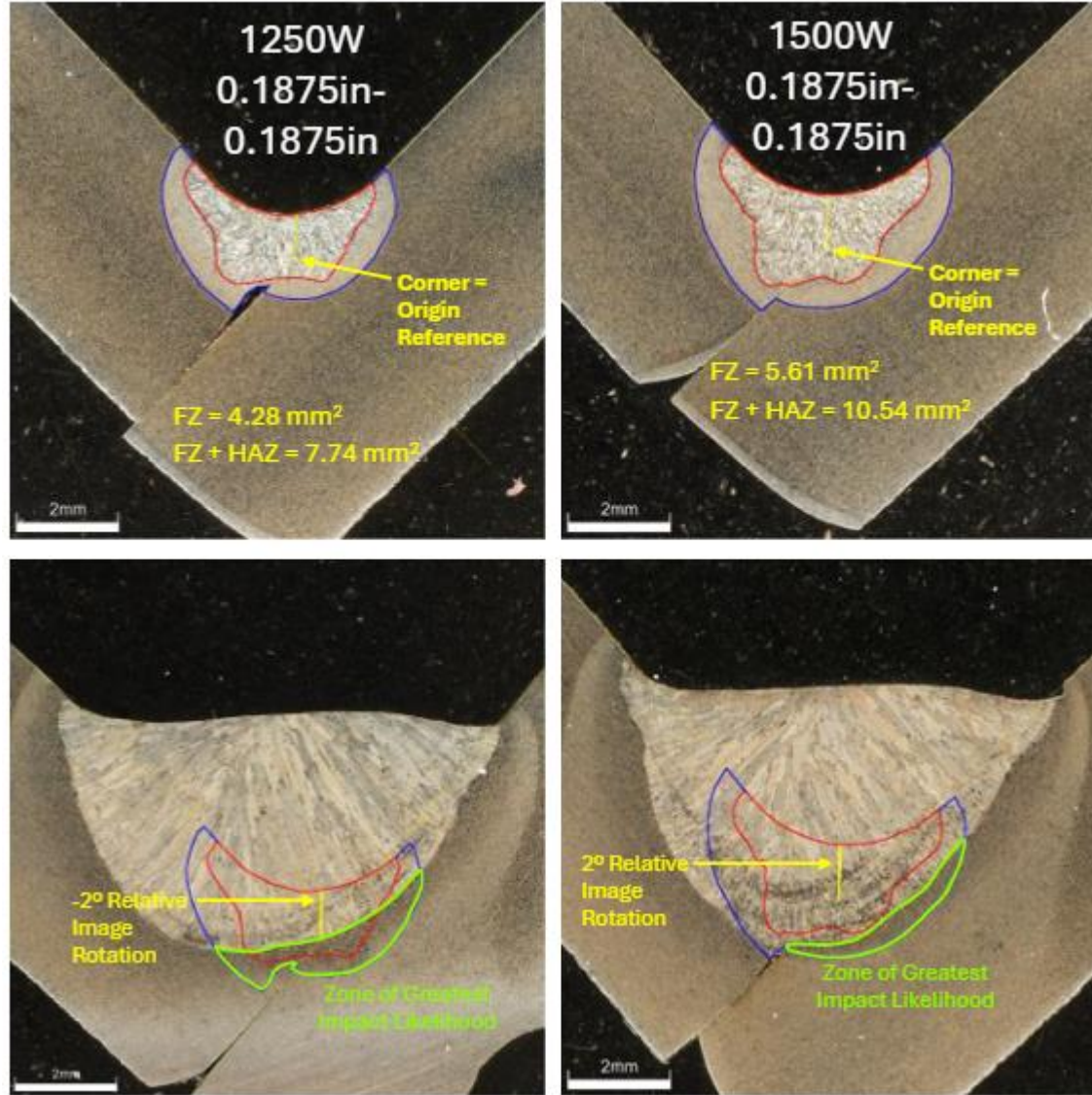
Metallographic Analysis

Extent of Prior Tacks in Rewelded Samples (0.5in-0.5in)



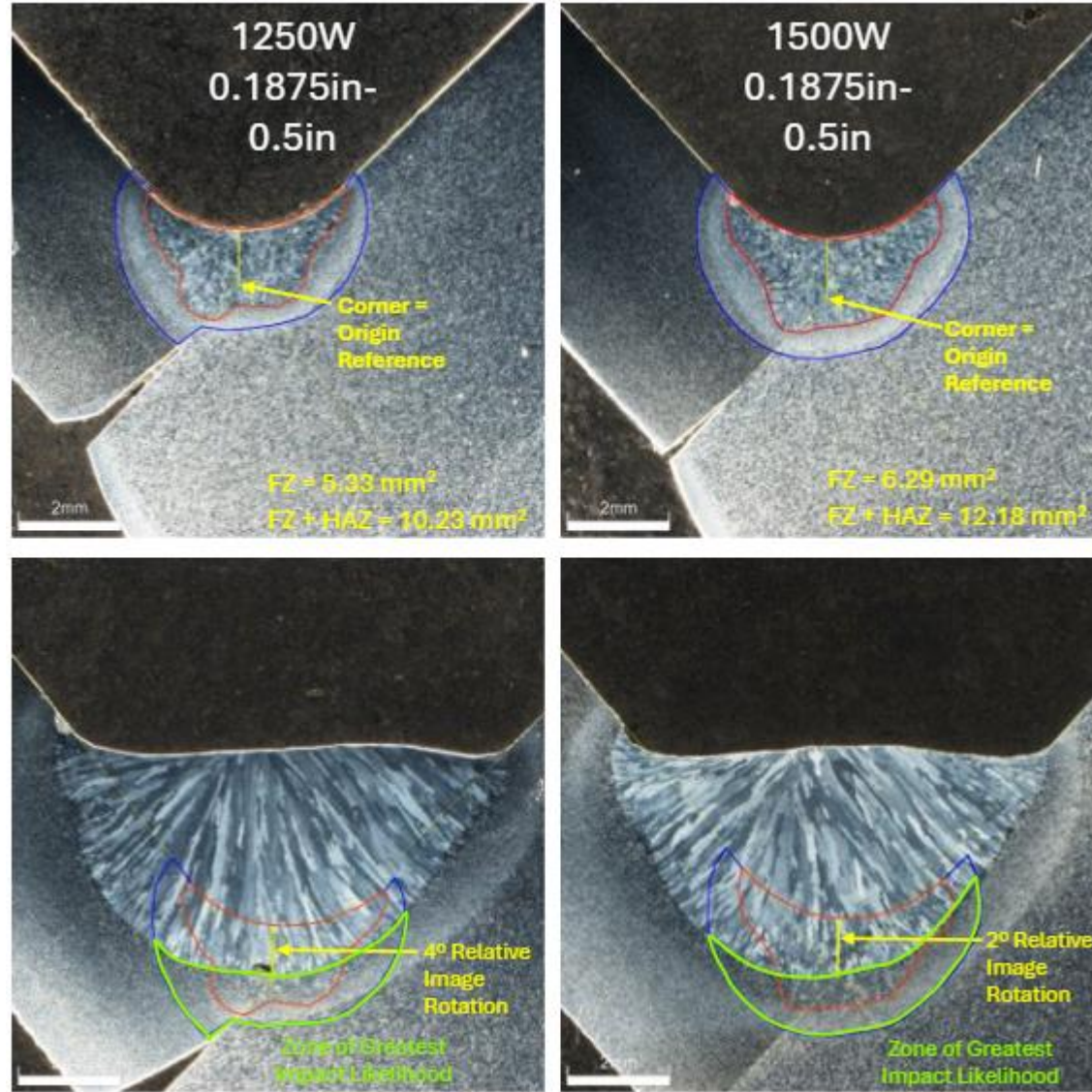
Extent of Prior Tacks in Rewelded Samples (0.1875in-0.1875in)

Metallographic Analysis



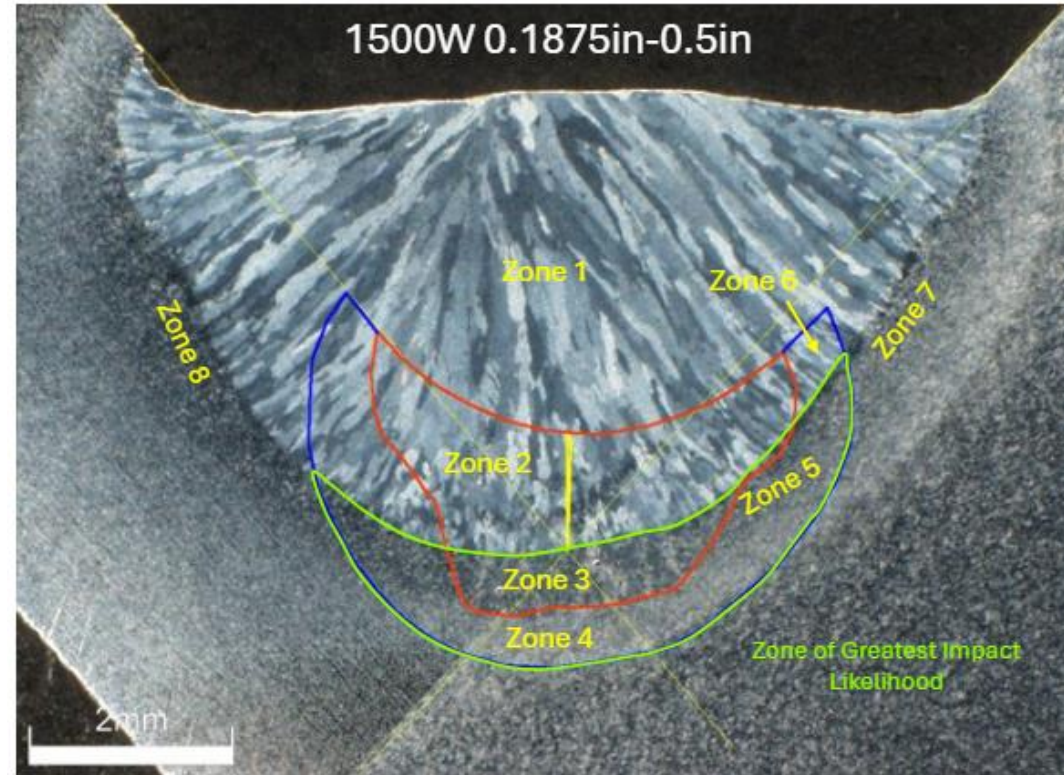
Extent of Prior Tacks in Rewelded Samples (0.1875in-0.5in)

Metallographic Analysis



Metallographic Analysis

Subzones



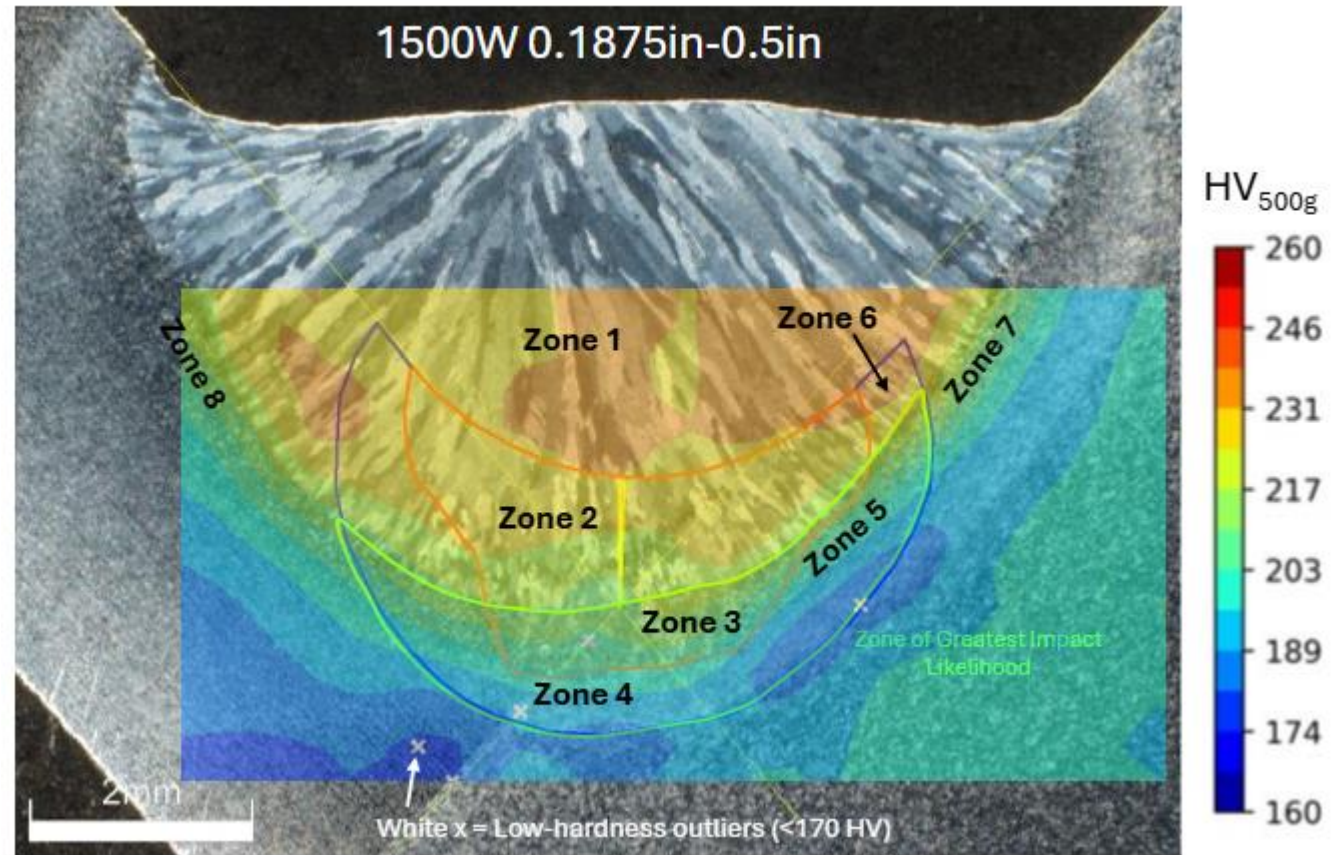
- Zone 1: FCAW FZ
- Zone 2: Laser Tack FZ – FCAW FZ
- Zone 3: Laser Tack FZ – FCAW CG
- Zone 4: Laser Tack CG – FCAW FG/IC
- Zone 5: Laser Tack CG – FCAW CG
- Zone 6: Laser Tack CG – FCAW FZ
- Zone 7: FCAW CG (Thick)
- Zone 8: FCAW CG (Thin)

FZ = Fusion Zone
CG = Coarse Grained HAZ
FG = Fine Grained HAZ
IC = Intercritical HAZ



Metallographic Analysis

Coarse Microhardness Map
300 Micron Spacing



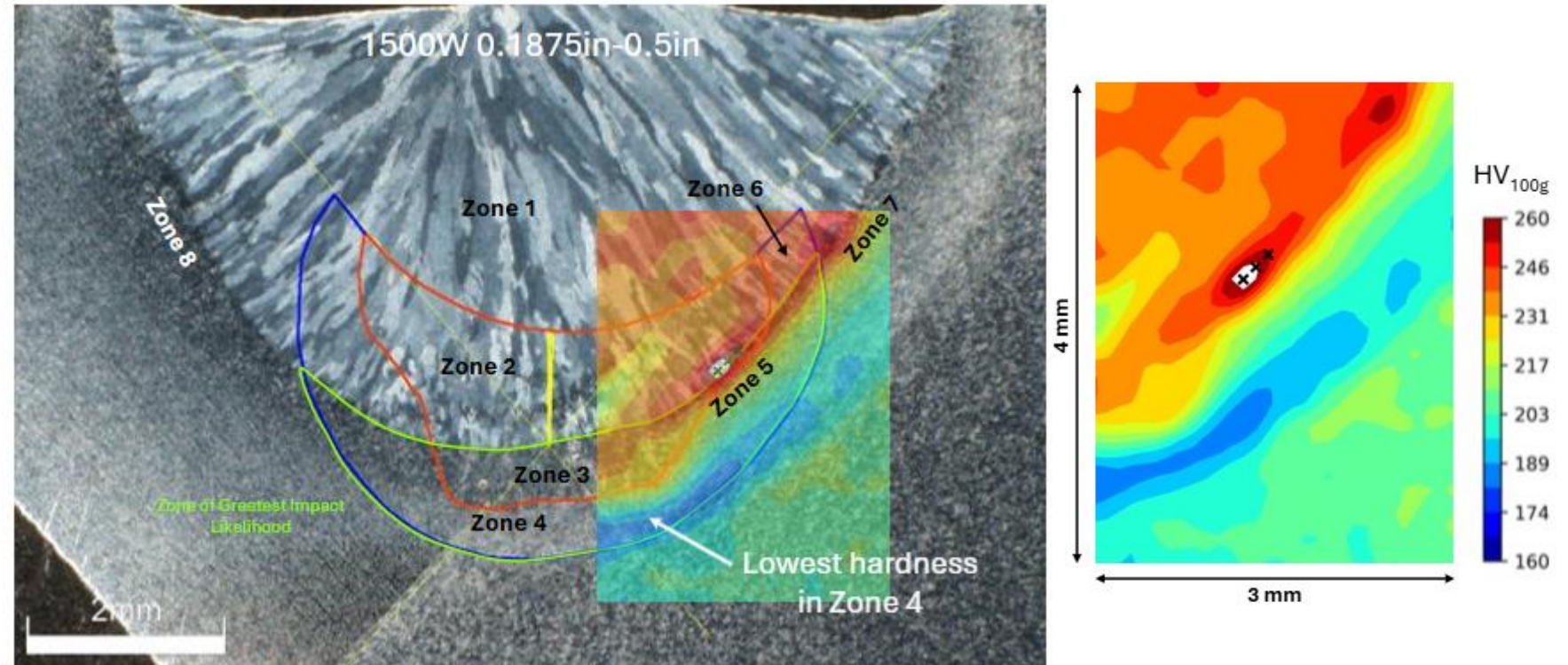
Reference values (5 indents):

- Unaffected Thick: 199 ± 6 HV
- Unaffected Thin: 182 ± 6 HV



Metallographic Analysis

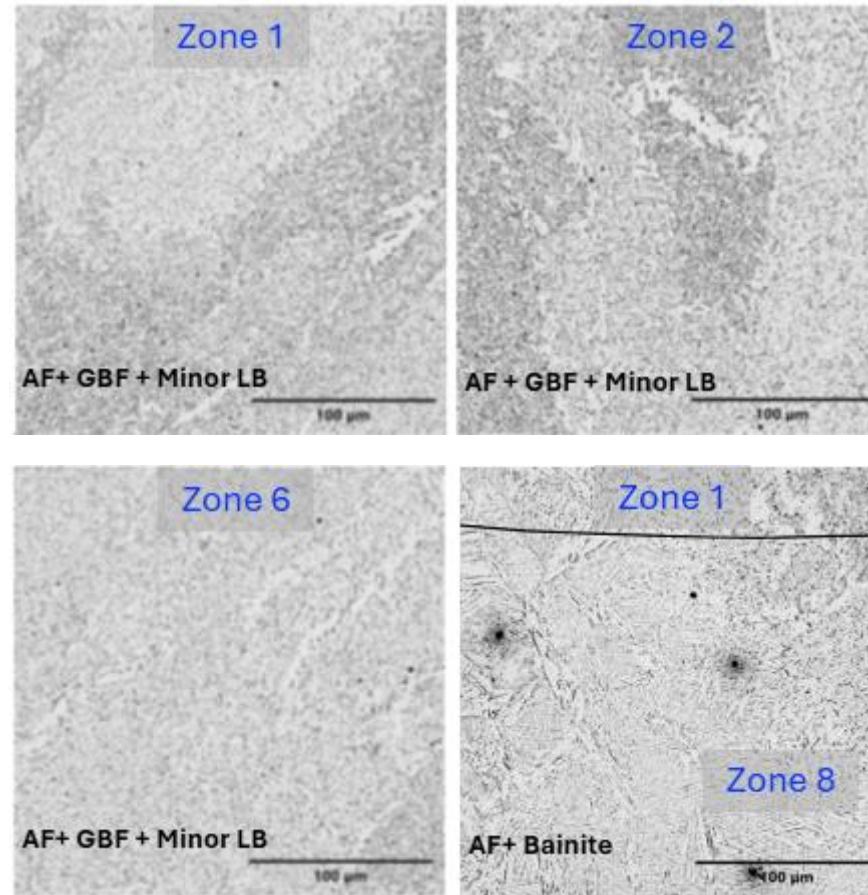
Refined Microhardness Map
100 Micron Spacing



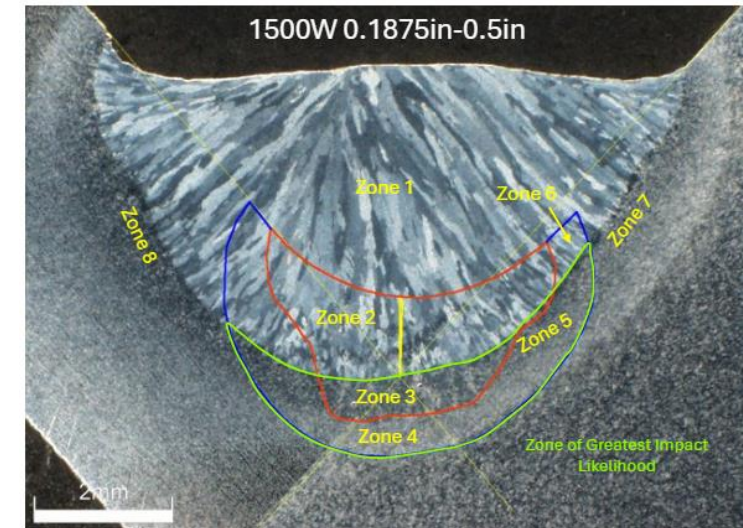
Key Takeaway: Hardness mapping alone does not reflect unique microstructure features that could be determinantal to mechanical properties



Nital Etched Microstructures, Outside ZGIL



- AF = acicular ferrite
- GBF = grain boundary ferrite
- PF = polygonal ferrite
- LB = lower bainite
- UB = upper bainite



Metallographic Analysis

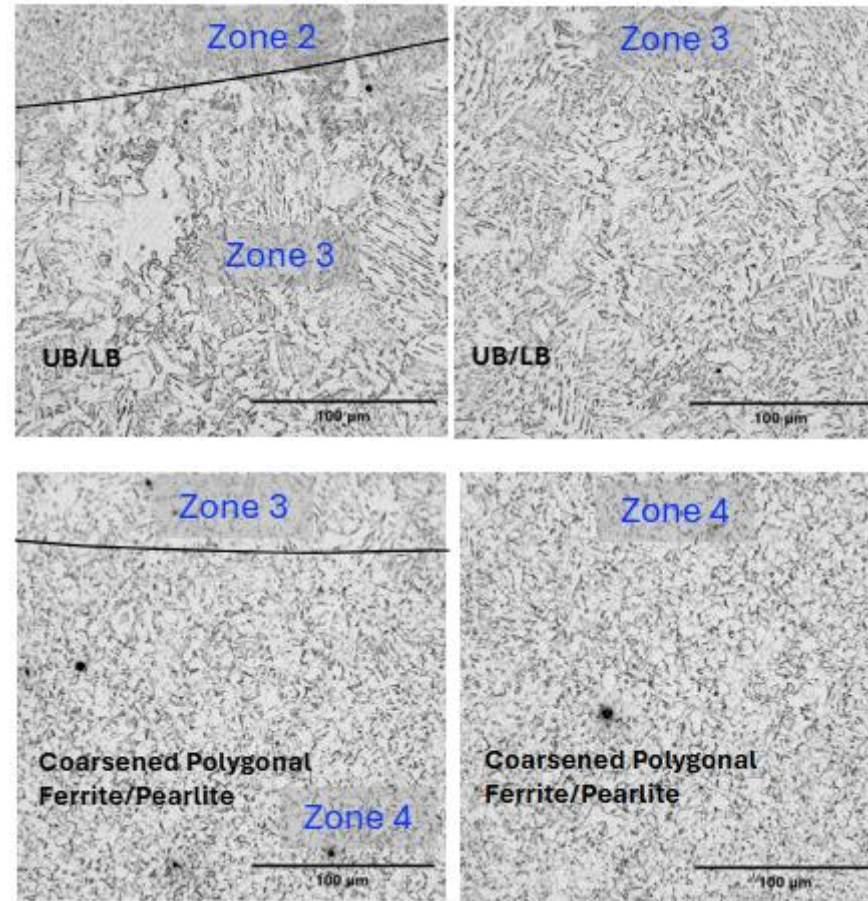
Key takeaway: FCAW FZ and all remelted regions have similar microstructure (Zones 1, 2, and 6)



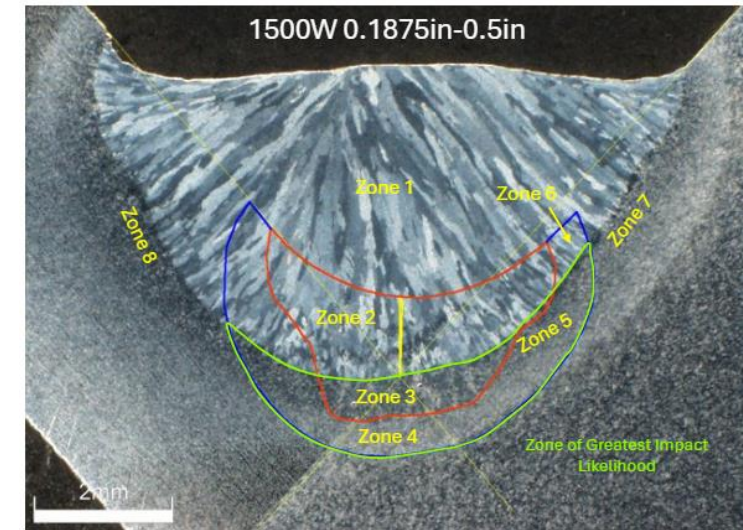
Metallographic Analysis

Nital Etched Microstructures, Within ZGIL

Lower toughness microstructures



- AF = acicular ferrite
- GBF = grain boundary ferrite
- PF = polygonal ferrite
- LB = lower banite
- UB = upper banite



Key takeaway: Unconsumed fusion zone of laser weld, Zone 3, is area of interest



Metallographic Analysis

Factors Affecting MA (martensite-austenite) Influence on Toughness

Overall Fraction

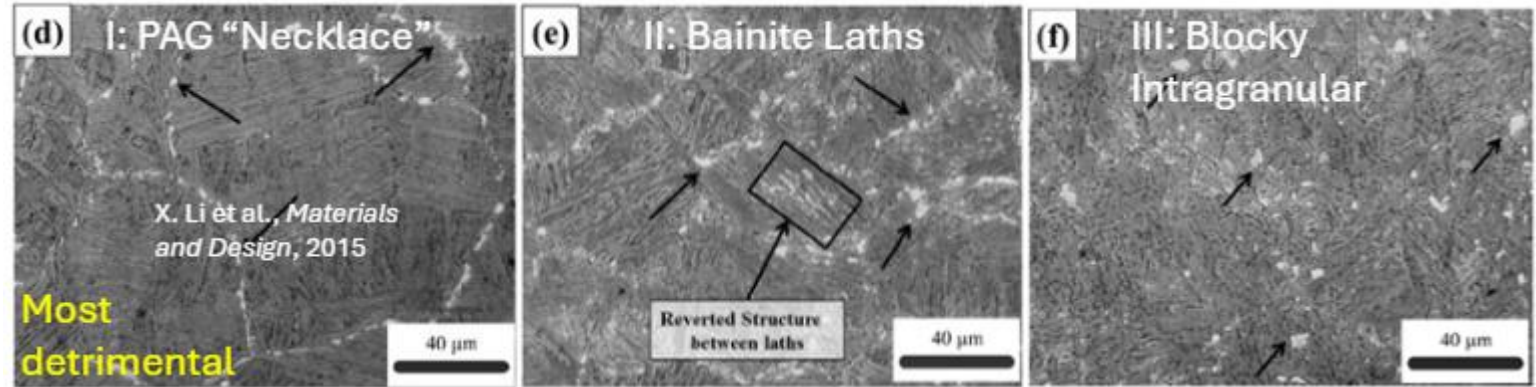
Distribution

Intra-Particle Morphology

Aspect Ratio

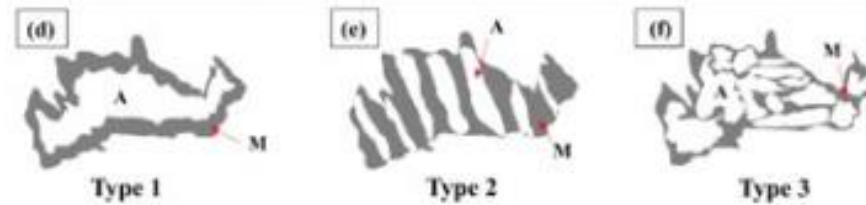


Factors Affecting MA Influence on Toughness

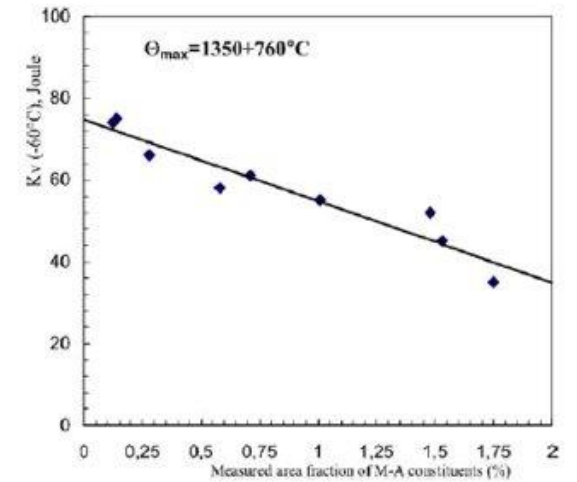


MA (martensite/austenite) constituents within microstructure

Metallographic Analysis



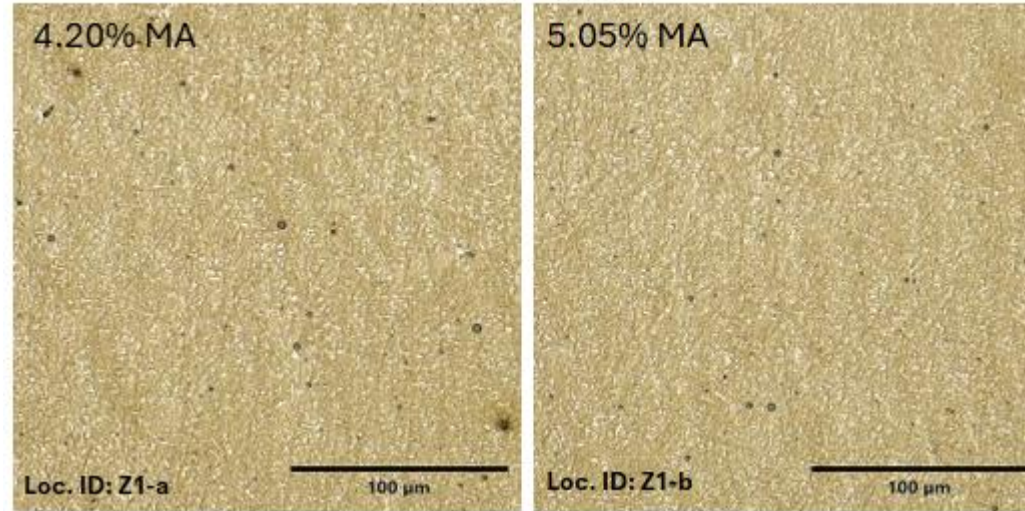
Submicron resolution of MA



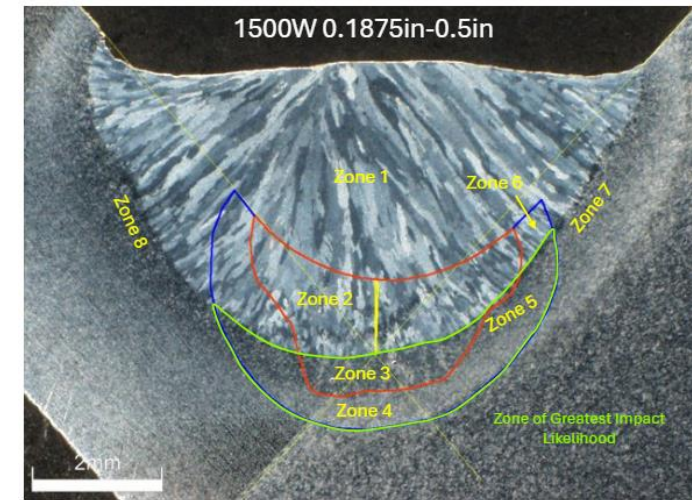
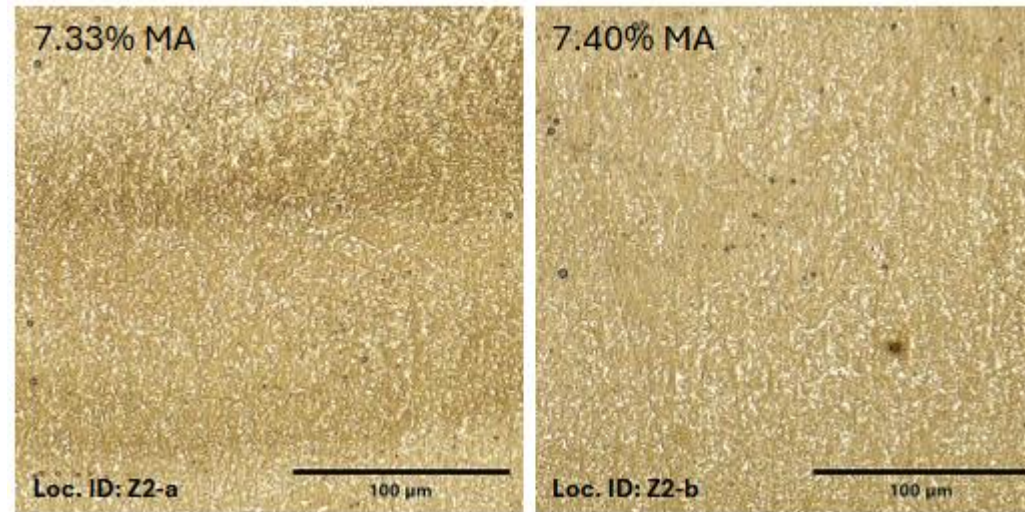
Metallographic Analysis

MA Etch, Weld Metal Zones

Zone 1: FCAW FZ



Zone 2: Laser Tack FZ – FCAW FZ

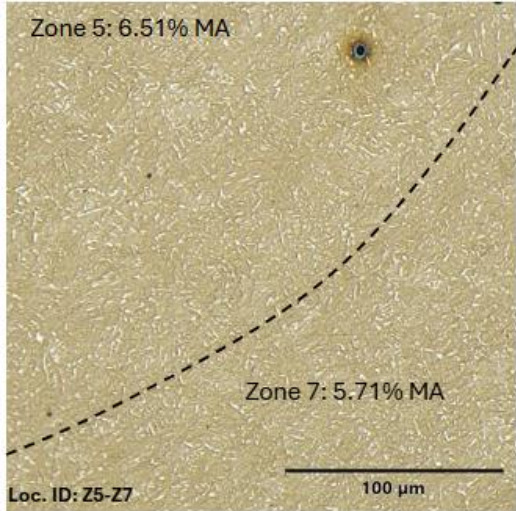


Zone 1 becomes baseline.

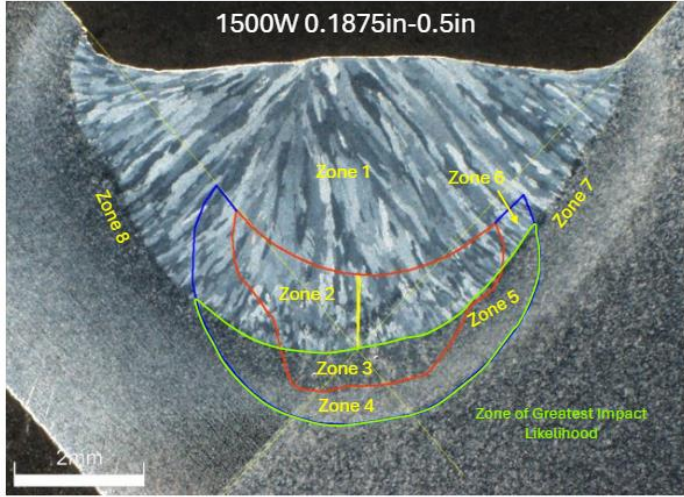
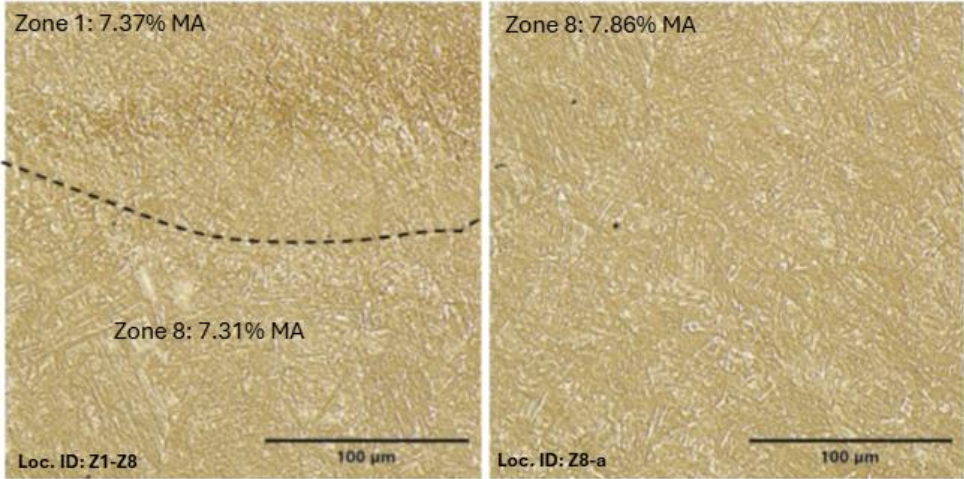


MA Etch, Unaffected FCAW CGHAZ Zones

Metallographic Analysis

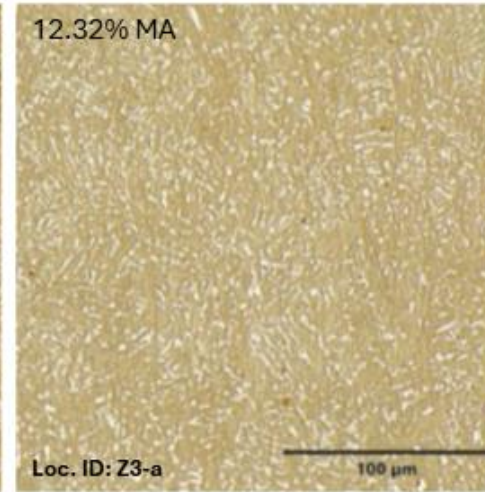
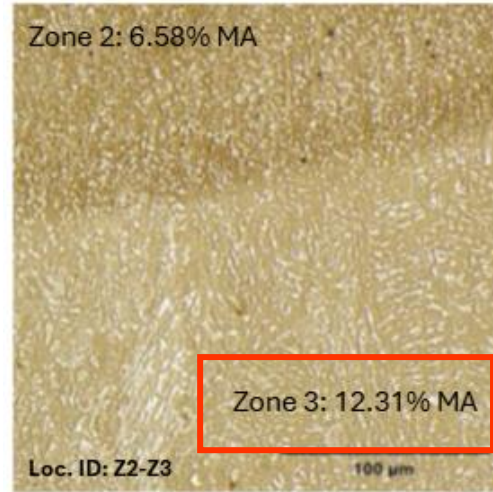


Zone 8: FCAW CG (Thin)

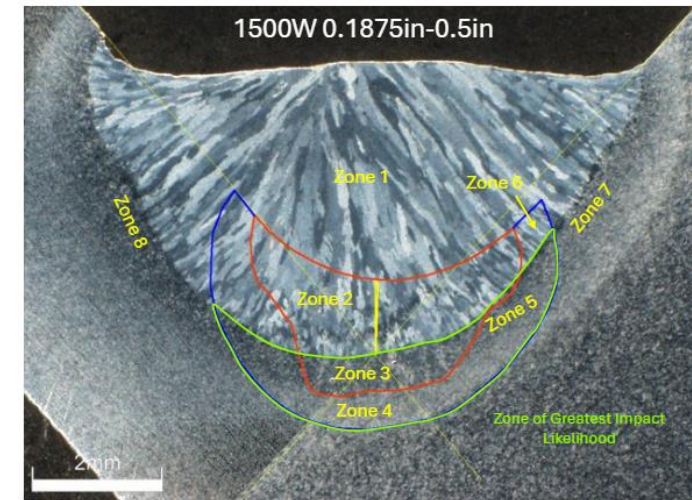
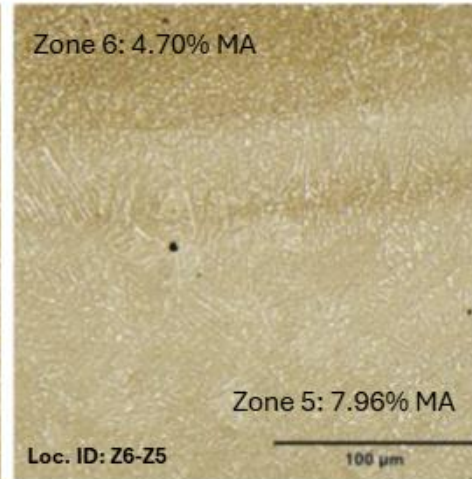
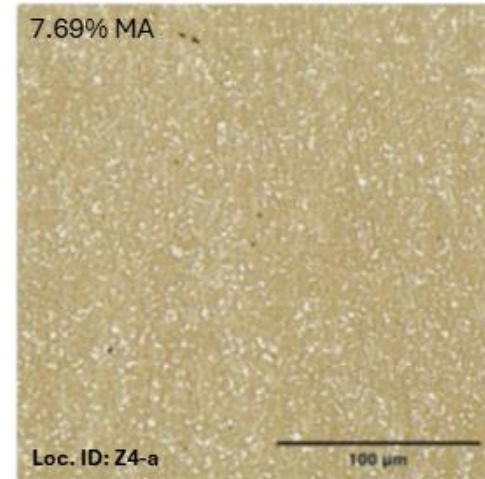


Metallographic Analysis

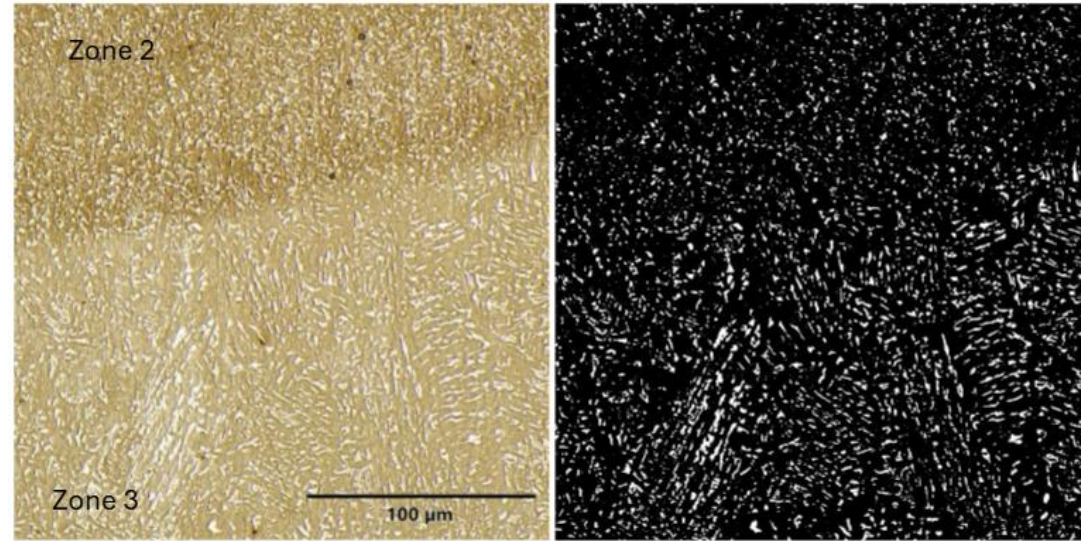
MA Etch, ZGIL Zones Zone 3: Laser Tack FZ – FCAW CG



Zone 4: Laser Tack CG – FCAW FG/IC



MA Etch, Image Thresholding and Statistics Generation



Metallographic Analysis

Zone #	Zone Description	Total Image Area Assessed (μm^2)	% MA	Number Density $> 3 \mu\text{m}^2$ (mm^{-2})	Median Aspect Ratio $> 3 \mu\text{m}^2$	Mean Aspect Ratio $> 3 \mu\text{m}^2$
1	FCAW FZ	133224	5.11%	923	2.24	2.52
2	Tack FZ - FCAW FZ	129488	7.25%	3483	2.14	2.40
3	Tack FZ - FCAW CG	90025	12.32%	12019	2.38	2.84
4	Tack CG - FCAW FC/IC	137420	7.27%	4614	2.02	2.30
5	Tack CG-FCAW CG	75941	7.33%	3147	2.94	3.59
6	Tack CG-FCAW FZ	66785	6.85%	1782	2.18	2.55
7	FCAW CG (Thick)	21911	5.71%	1780	2.52	3.28
8	FCAW CG (Thin)	86288	7.66%	3674	2.81	3.54
Ref -1	Thick Base Mat.	54878	1.45%	36	Insufficient Sample Size	Insufficient Sample Size
Ref -2	Thin Base Mat.	54878	0.08%	36	Insufficient Sample Size	Insufficient Sample Size



MA Etch, Image Thresholding and Statistics Generation

Consistent increase in %MA in Zone 3

Sample	"Zone 3" % MA	"Zone 2" % MA	"Zone 5" % MA
1500 W HLAW - Replicate 1	12.32%	7.25%	7.33%
1500 W HLAW - Replicate 2	7.24%	2.31%	4.85%
1250 W HLAW - Replicate 1	6.94%	3.84%	4.25%

Metallographic Analysis

Key Takeaway: Combination of UB/LB seen in Nital Etch and increased %MA in MA etch confirmed Zone 3 is the performance limiting region



Toughness Evaluation

Can Charpy Impact Testing be Performed?

Standard Charpy impact (CVN) specimen is 10mm thick with 2mm deep notch

Typically taken from full penetration butt weld from material 12 mm thick or greater

Possible to test weld metal and HAZ, dependent on joint design

Options?

Full penetration butt weld with laser process for weld metal impact testing

Laser clad of joint edge followed by welding of full penetration butt weld with FCAW process

Specialized double bevel groove weld with laser root and single FCAW pass on both sides



Toughness Evaluation

Can Charpy Impact Testing be Performed?

Option 1: Full penetration butt weld with laser process for weld metal impact testing

Attempted on 1/2in HSLA65 plate, single bevel with backing

Difficulty in following joint

Tremendous build-up of visible porosity as additional weld passes were made

Various parameters were attempted that were known to provide acceptable fillet welds, with no success in producing sound welds



Toughness Evaluation

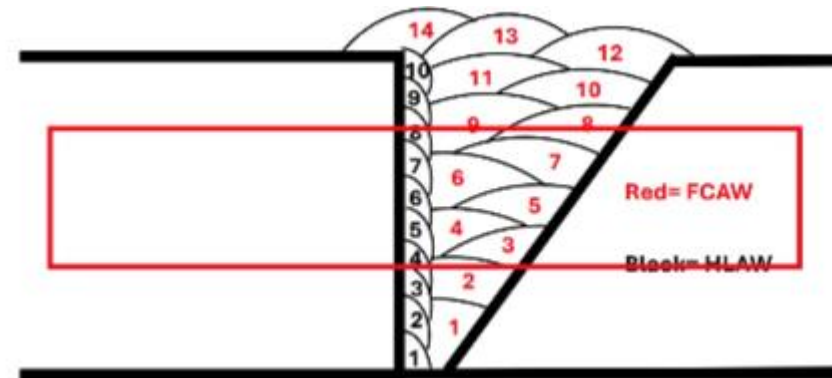
Can Charpy Impact Testing be Performed?

Option 2: Laser clad of joint edge followed and welding of full penetration butt weld with FCAW process

3/4in HSLA65 plate, B2(S)V.1 joint design

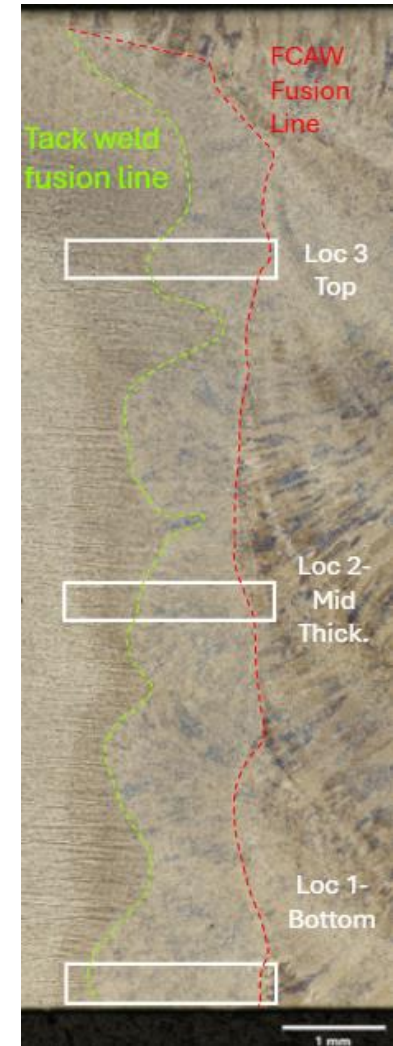
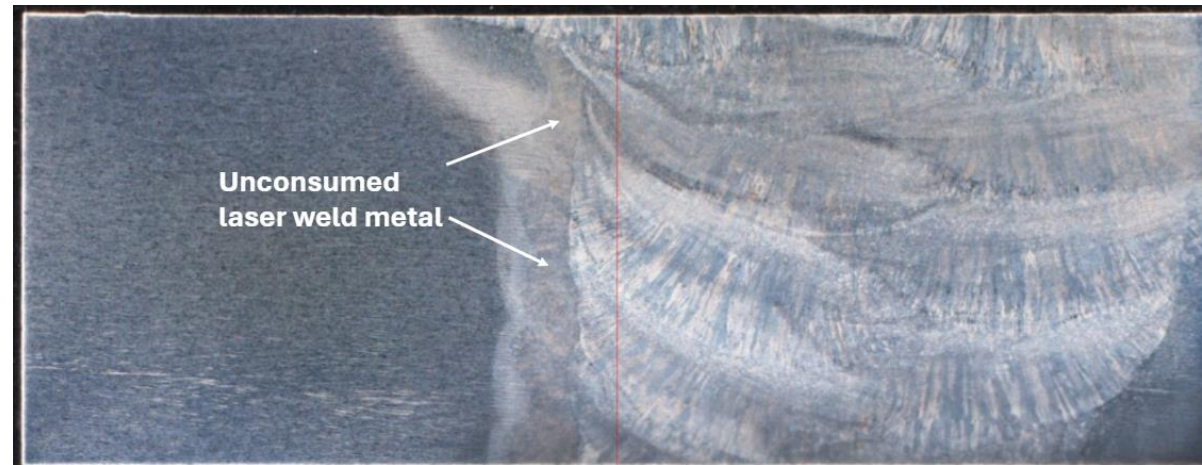
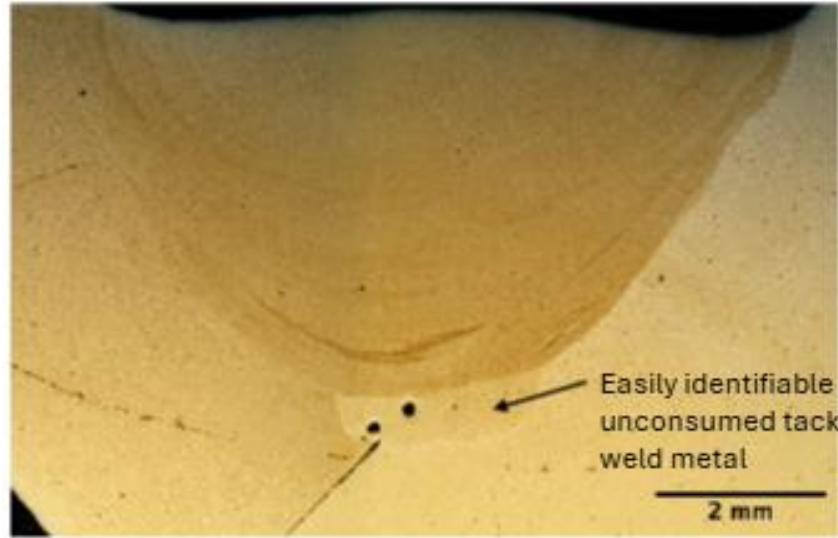
Laser Weld Metal CVN at -20°F (ft-lbs)
264, 264, 208, 78, 158

Laser HAZ at -20°F (ft-lbs)
264, 264, 264, 254, 220



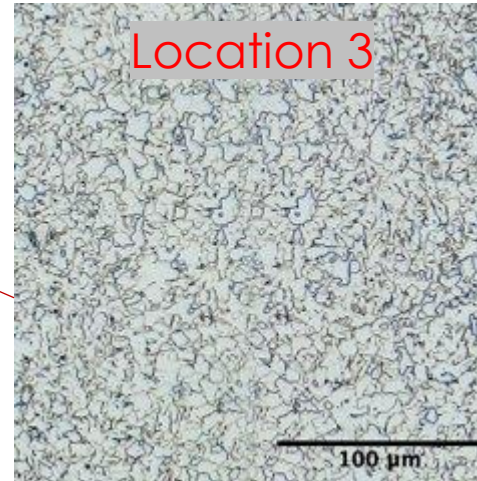
Can Charpy Impact Testing be Performed?

Toughness Evaluation



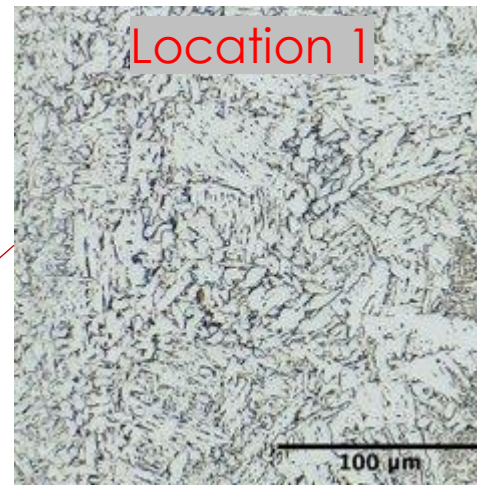
Toughness Evaluation

Can Charpy Impact Testing be Performed?



Intended Zone 3 replicate, top of weld

Bainite fractions not present, Zone 3 was not duplicated through thickness of weld



Intended Zone 3 replicate, bottom of weld

Bainite fractions present, indicates Zone 3 constituents are present



Toughness Evaluation

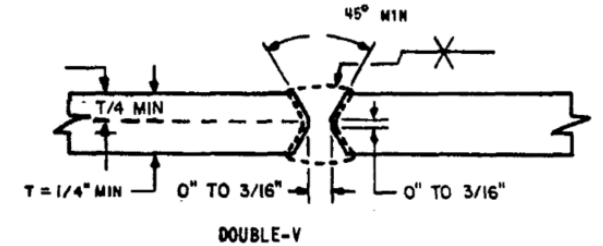
Can Charpy Impact Testing be Performed?

Option 3: Specialized double bevel groove weld with laser root and single FCAW pass on both sides

Using 3/4in HSLA-65 plate

B2V.3

- 90° included bevel angle
- Varying land dimensions
- Varying laser power



Key Takeaways

Parameters sets were established that provided acceptable welds via visual (VT), dye penetrant (PT), and macro etch evaluation

Welding over laser tacks was successful, with no noticeable difference in areas of tacked versus untacked weldment

Metallurgical analysis indicates areas of undesired microstructure in remnant tack weld metal after being welded over

Toughness evaluation is ongoing, with efforts being made to replicated areas of interest in specimens large enough for mechanical testing



Continued Efforts

Continued Toughness Evaluation of Option 3

CSM evaluation of weld cross sections to confirm/validate successful replication of Zone 3 microstructure

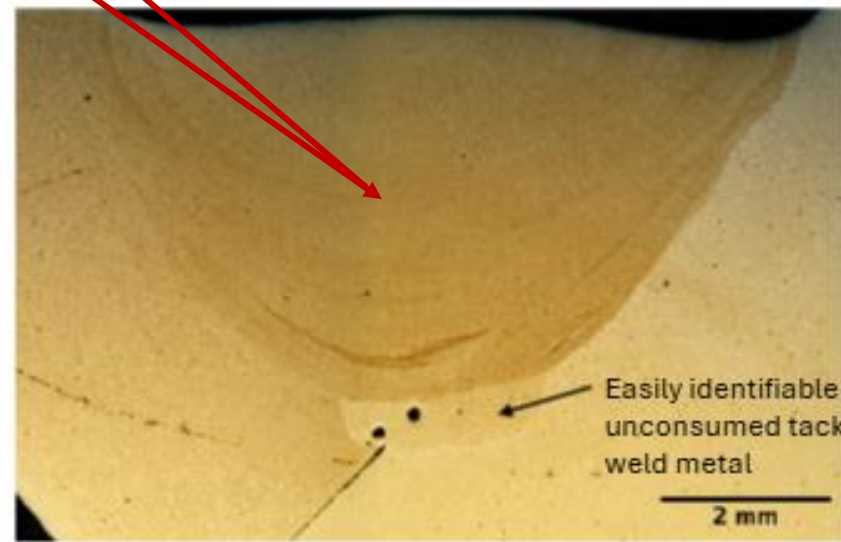
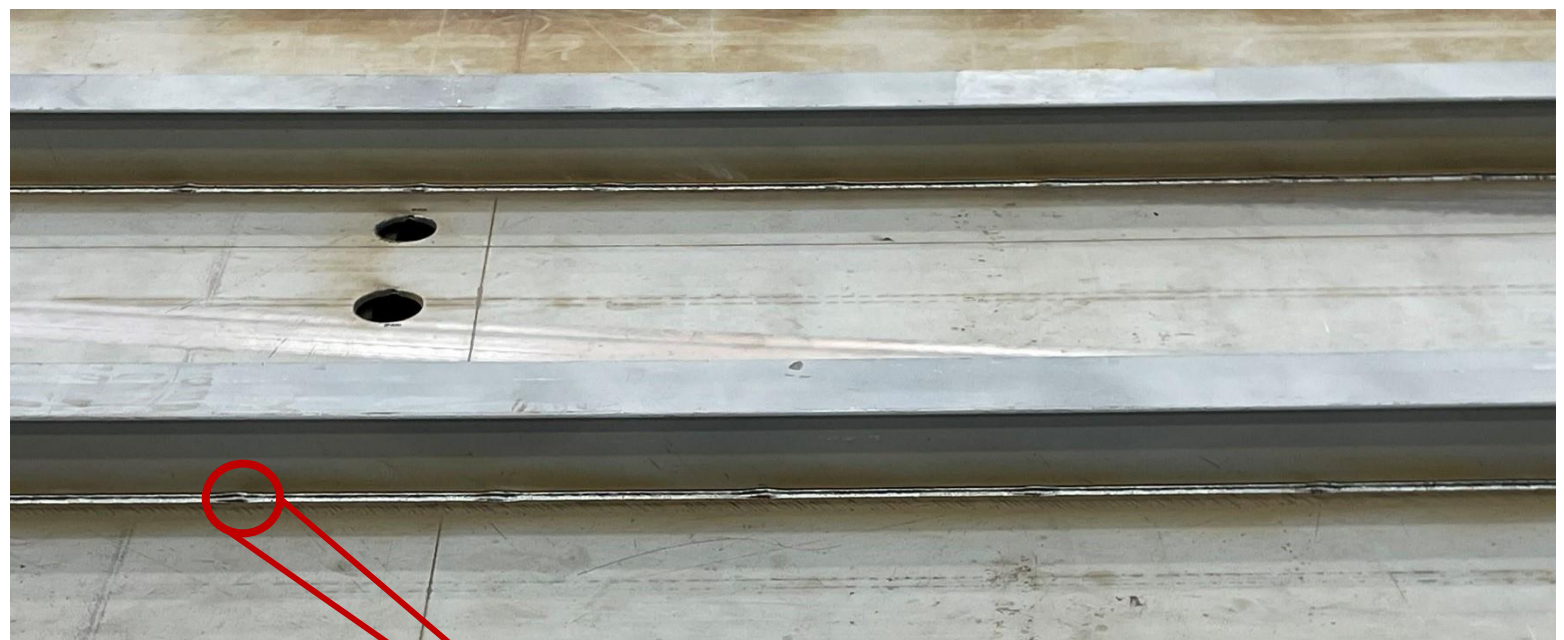
Ingalls to perform CVN testing on samples, isolating Zone 3 impacts

Ingalls to continue to evaluate welding parameters to bound combinations of laser power, wobble width, and wobble frequency

Evaluate welding parameter windows and techniques for mitigating Zone 3



Big Picture



Questions and Comments



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