Impact of Hand-Held Laser Tack Welding on Fillet Welds for Shipbuilding Applications

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1. Background

Motivation: Hand-Held Laser Tack Welding (utilizing a portable laser with wire feed) produces deep, compact tack welds that could eliminate oversized tacks. However, it is not yet qualified for Navy shipbuilding due to the lack of established standards and uncharacterized effects on weld properties.

Objectives:
- Reveal the microstructural characteristics in HSLA-65 fillet welds made by the hybrid process: initial handheld laser tack welding step followed by the subsequent flux core arc weld (FCAW).
- Understand the microstructural formation mechanisms for process and microstructure optimization, which eventually leads to performance optimization.

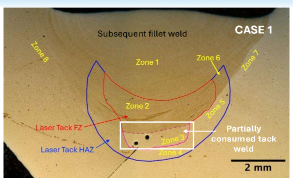
Hand-held laser tack welding

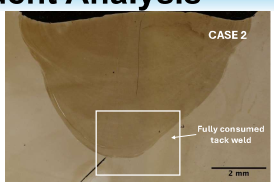
Source: AccTek Laser, Mar. 03, 2023

2. Experimental Procedure

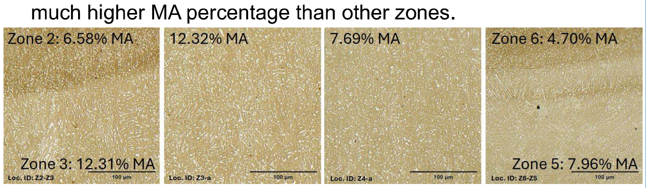
- Optical Microscopy was performed in the heat affected zone (HAZ), fusion zone (FZ), and reheated regions for microstructural constituent identification using different etching methods:
- Martensite/austenite (MA) constituent etch using a modified Le Pera's etch [1]
  - Step 1: a 1g sodium metabisulfite + 100 ml distilled water solution and a 4g picric acid + 100 ml pure ethanol solution were mixed just before etching. The sample was immersed in the mixture for 20s, removed, and rinsed/immersed in isopropanol.
  - Step 2: electrolytically etch in a solution of 5g picric acid, 25g sodium hydroxide, and 100ml of distilled water with a voltage of 5v for 100s-140s. Afterwards, rinse the sample in water..
- Nital etch for ferritic microstructural characteristics using 3% nitric acid in ethanol for bainite formation. A cotton ball was immersed in the Nital solution; the sample was swabbed with the wet cotton ball for 10-15 seconds and then immediately thoroughly rinsed with DI water and blow dried with a heat gun.

3. MA Constituent Analysis





- The MA etching results on two hybrid weld samples (i.e., laser tacked and FCAW rewelded) are analyzed, with the subzones labeled based on the thermal history experienced.
- Unconsumed tack weld FZ reheated by subsequent weld (Zone 3) of Case 1 was revealed effectively by MA etch, which exhibited a much higher MA percentage than other zones.



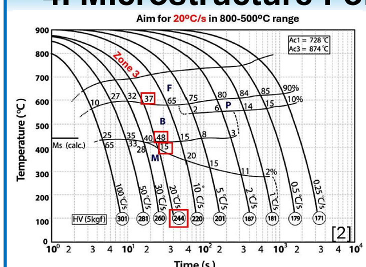
Laser Tack + FCAW (Case 1)

Zone #	Zone Description	Total Image Area Assessed (μm^2)	% MA	Number Density > 3 μm^2 (mm^{-2})	Median Aspect Ratio > 3 μm^2	Mean Aspect Ratio > 3 μm^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

FCAW Only (Control Case)

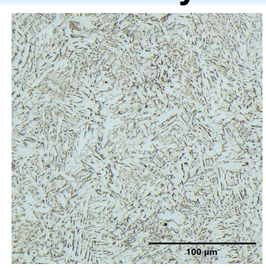
Zone #	Zone Description	Total Image Area Assessed (μm^2)	% MA	Number Density > 3 μm^2 (mm^{-2})	Median Aspect Ratio > 3 μm^2	Mean Aspect Ratio > 3 μm^2
Eq. 1	FCAW FZ	123620	3.09%	243	2.12	2.17
Eq. 2	FCAW FZ (Equiv. 2)	111643	2.18%	45	Insufficient Sample Size	Insufficient Sample Size
Eq. 3	FCAW CG (Equiv. 3)	107137	3.29%	513	2.79	3.47
Eq. 4	FCAW FC/IC (Equiv. 4)	54695	1.75%	366	1.72	2.27
Eq. 5	FCAW CG (Equiv. 5)	80192	2.84%	262	3.38	4.55
Eq. 6	FCAW FZ (Equiv. 6)	61801	2.66%	178	2.55	2.37
Eq. 7	FCAW CG (Thick)	54695	3.20%	201	2.40	3.37
Eq. 8	FCAW CG (Thin)	95160	1.70%	389	3.35	4.39

4. Microstructure Formation Analysis



CCT Diagram showing zone 3 characteristic cooling rate

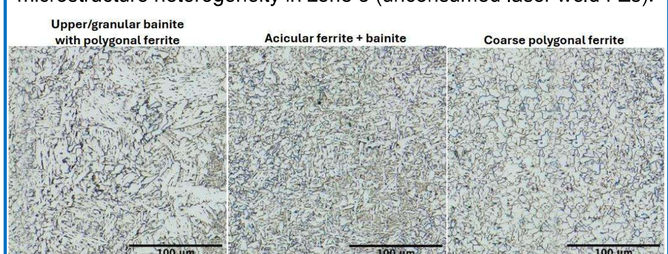
- Zone 3 experienced a thermal history that is expected to result in high fractions of bainite and MA constituents.



Zone 3 in a single pass fillet weld

- Nital etch of zone 3 showed large amounts of upper bainite laths and some lower bainite plates throughout the microstructure.

Within vertical traverse of a multi-pass weld, with single-sided hand-held laser welds placed along one groove face across the thickness, the complex thermal cycles from subsequent arc passes induced microstructure heterogeneity in zone 3 (unconsumed laser weld FZs).



Zone 3 in Pass 2 *Zone 3 in Pass 6* *Zone 3 in Pass 10*

- The reheated Zone 3 microstructure in early passes generally exhibited bainite laths.
- Near the top of the multi-pass weld, it no longer resembles zone 3 of the single hybrid fillet weld as no more bainite laths or plates are visible, it appears to be mostly polygonal ferrite.

5. Conclusions/Future Work

- Unconsumed laser tack weld FZ (zone 3) possesses higher fractions of upper and lower bainite as well as a 50-70% higher area fraction of martensite-austenite constituent than that of equivalent HAZ in weld samples without the laser tack weld.
- This combination of high fractions of upper and lower bainite and MA constituent is expected to induce lower toughness. This makes zone 3 an area of interest for property evaluation, although it is a relatively small zone.

Future Work:
- Conduct mechanical testing to reveal the impact of zone 3.
- Identify the contributing factors governing formation of zone 3 (e.g., operator variability, laser settings, holding angle) and establish robust guideline to eliminate it consistently.

Acknowledgments

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Refences:

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