Comparison of Three GMAW Transfer Modes in WAAM of Duplex Stainless-Steel Walls

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BACKGROUND

To demonstrate LeTourneau University's identity as a Christian polytechnic university, wire arc additive manufacturing (WAAM) was selected as a strategic area for development. In 2024, LeTourneau University purchased two Yaskawa welding robots, which provided an excellent opportunity to establish WAAM capabilities within the welding engineering program.

OBJECTIVES

- Establish standard WAAM practices at LETU
- Compare advanced transfer modes (CMT, RMD, STT)
- Characterize microstructure, hardness, and ferrite content of fabricated walls using WAAM
- Establish a foundation for robotic WAAM of complex objects

METHODOLOGY

Substrate – A36 steel; feedstock – 2209 duplex stainless steel

		C	Mn	Si	P	S	Cu	Cr	Ni	Mo	N	Fe
Substrate	**A36**	0.25 - 0.29	1.03	0.280	0.040	0.050	0.20	-	-	-	-	balance
Feedstock	**2209**	0.02	1.46	0.41	0.020	0.001	0.06	23.10	8.60	3.30	0.17	balance

Parameter Development (57 tests total)

- Wire diameter comparison (0.035” vs. 0.045”)
- Shielding gas (90/10 vs. 75/25 Ar/CO_2)
- Start/stop optimization (0.3s crater fill + 1.0s delayed start)

CMT Welding Parameters	
Current	165 A
Voltage	17.2 V
Crater fill	0.3 s
Start Delay	1 s
Interpass Temp	<300 C
CTTWD	½ in
TRAVEL SPEED	7.9 in/min

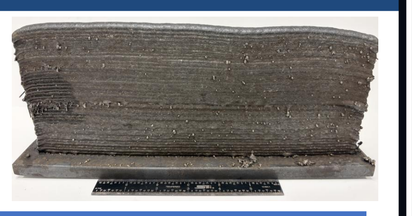
RMD Welding Parameters	
Current	140 A
Arc Adjust	10%
Arc Control	50
Voltage	18.2 V
Crater fill	0.2 s
Start Delay	0.5 s
Interpass Temp	<200 C
CTTWD	½ in
TRAVEL SPEED	8.0 in/min

STT Welding Parameters	
Current	130 A
Tail out/Hot start	10 / 5
Voltage	16.5 V
Crater fill	0.2 s
Start Delay	0.5 s
Interpass Temp	<200 C
CTTWD	½ in
TRAVEL SPEED	5.0 in/min

Mechanical Testing and Material Characterization

- Tensile tests and CVN impact tests
- Optical microscopy (50X, 100X)
- Vickers microhardness (5 indents per region)
- Ferrite percentage using point counting method (ASTM E562)
- Ferrite number using a Ferrite-Check Meter (ISO 17781)

Three DSS Walls Using CMT, RMD and STT

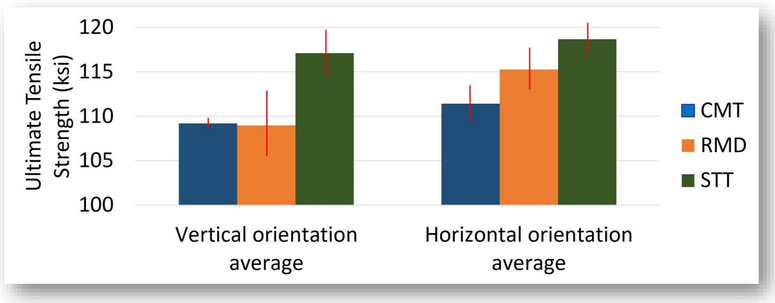


	Weld layers	Height	width	Visual inspection
CMT wall	45	5.25"	0.530"	Spill at starts
RMD wall	71	5.03"	0.510"	Spatter, Drips, "Rats Nest"
STT wall	42	4.53"	0.515"	Spatter, Cold, Layer failure

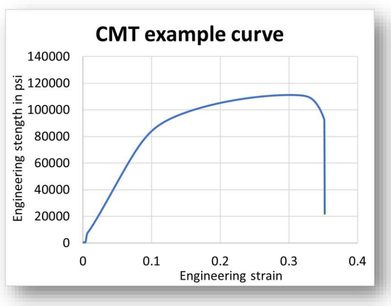
CONCLUSION

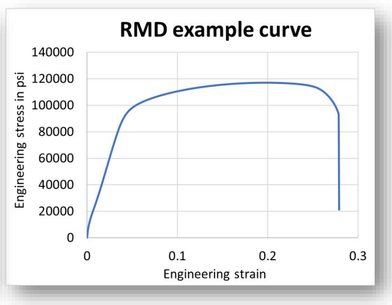
- CMT transfer mode shows minimum spattering, smoothest wall surface and optimal bead height.
- RMD shows severe spattering during building and rough wall surface. The bead height is the minimum, which means the maximum building pass required.
- The CMT wall shows slightly superior toughness but the STT wall shows the highest tensile strength.
- The ferrite number in three walls are all around 40 from top to bottom.
- In general, CMT is the best transfer mode for DSS 2209 wall building.

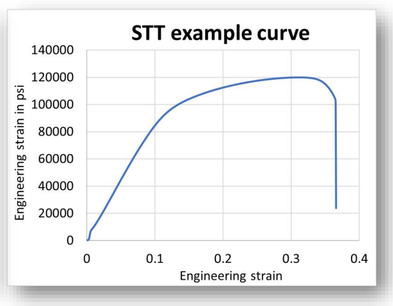
RESULTS & DISCUSSION



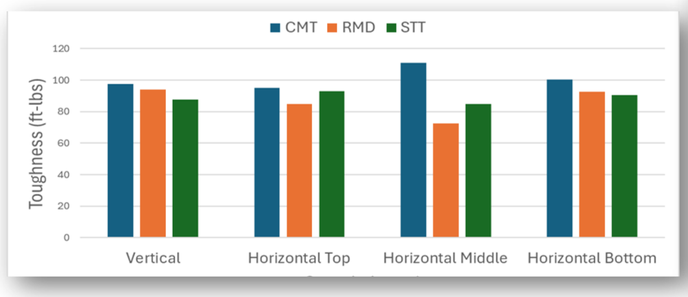
2209 weld metal tensile strength from the Manufacturer is 105 ksi (minimum) Three walls’ strength is all above this value

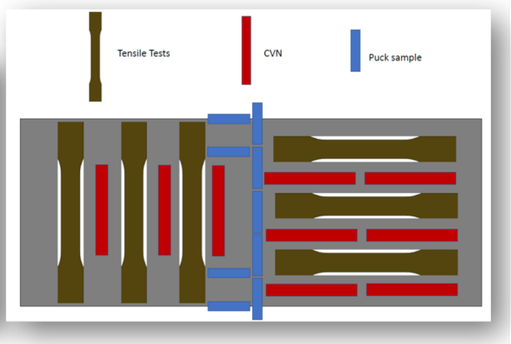


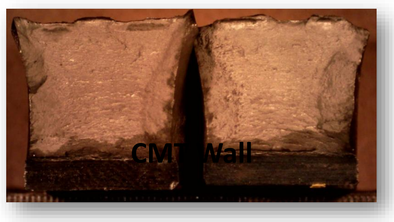


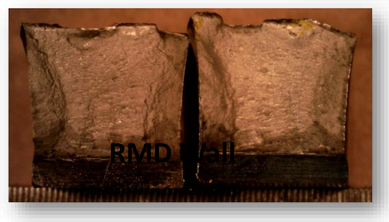


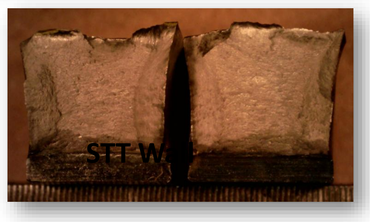
Charpy V-Notch Testing



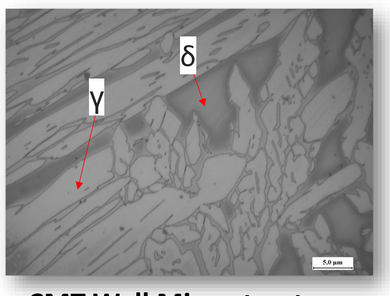




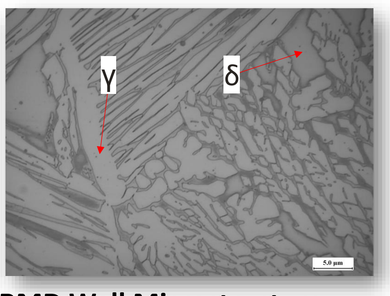




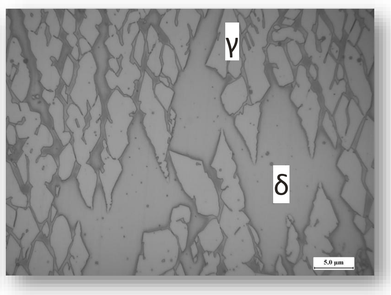
Microstructure Characterization



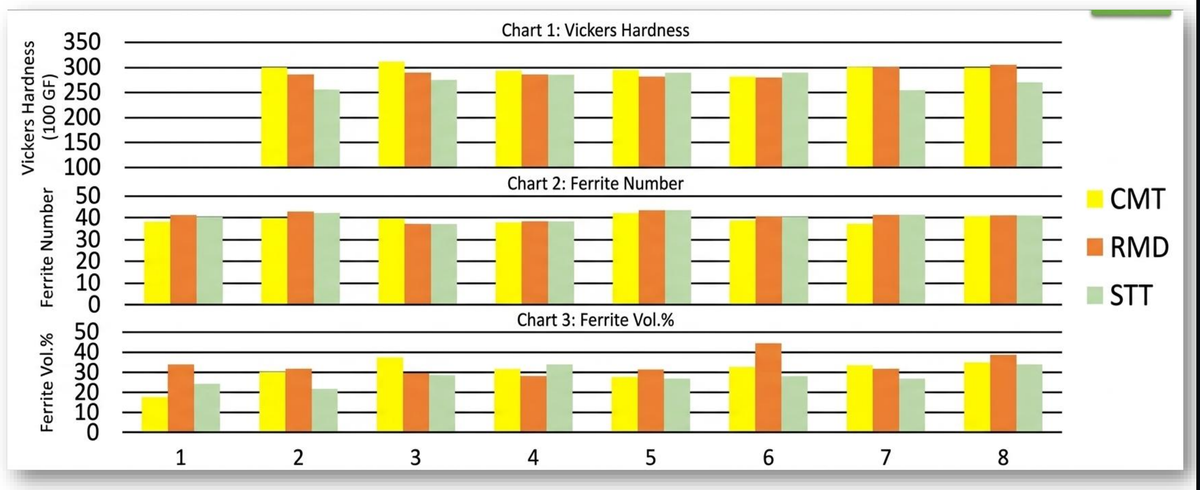
CMT Wall Microstructure

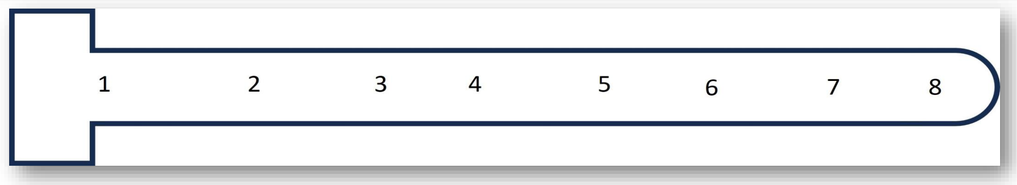


RMD Wall Microstructure



STT Wall Microstructure





AKNOWLEDGEMENT

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