Robotic Arc Directed Energy Deposition Additive Manufacturing

GMA-P DED Standard Qualification Builds – Stainless Steel Demonstration

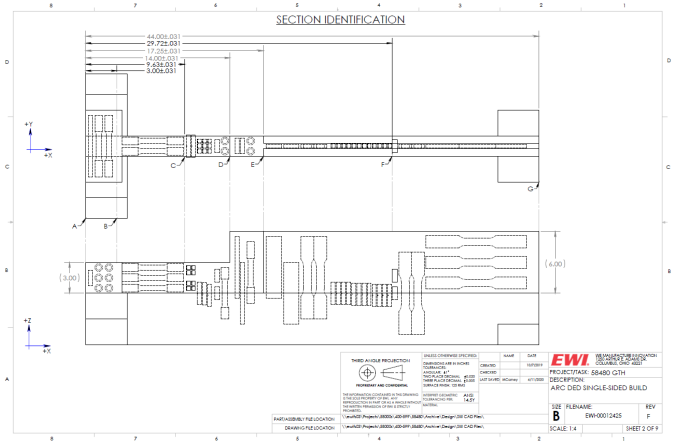
Michael Carney, Dennis Harwig,
and Nick Kapustka, EWI

Acknowledgement

This content was developed in the National Shipbuilding Research Program – Advanced Shipbuilding Enterprise (NSRP-ASE) Research Announcement (RA) Project 2019-375-004 and in partnership with the Naval Sea Systems Command Technology Office (NAVSEA 05T) Additive Manufacturing Program.

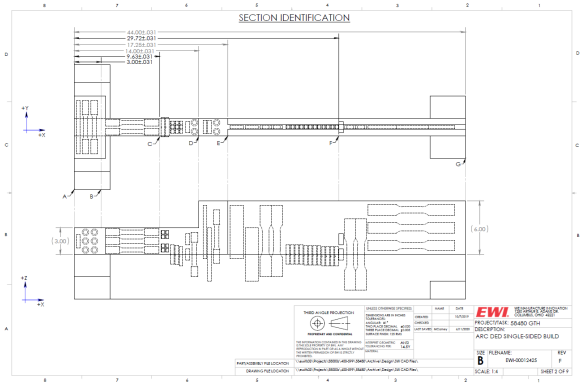
NAVSEA DED AM Procedure Qualification

- Portfolio of DED AM procedure qualification schemes are being developed
  - Scheme selection is based on process fidelity and platform application
- Each procedure qualification scheme consists of:
  - Standard qualification build (SQB) design
  - Nondestructive evaluation (NDE) test map
  - Specimen test matrix
  - Procedure Qualification Test Report form
- EWI is supporting NSWCCD with development of the qualification schemes
- As part of the NSRP RA project, one procedure qualification scheme from the NAVSEA portfolio was demonstrated



NAVSEA DED AM Procedure Qualification Schemes Development

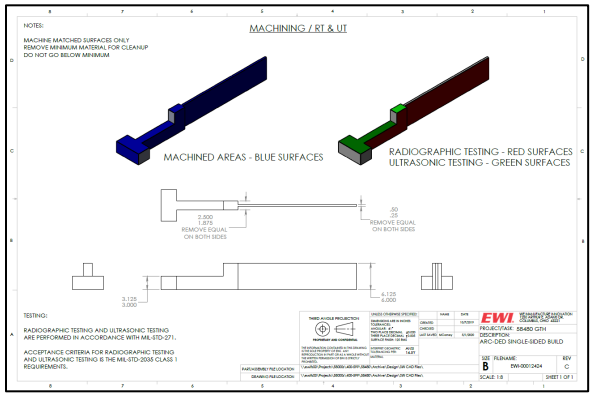
Design



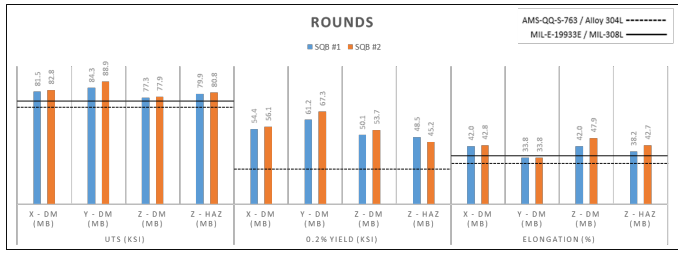
Build

Machine

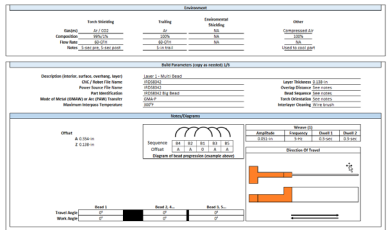
NDE

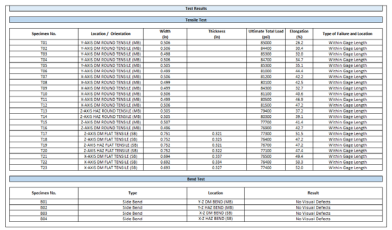


Property Test



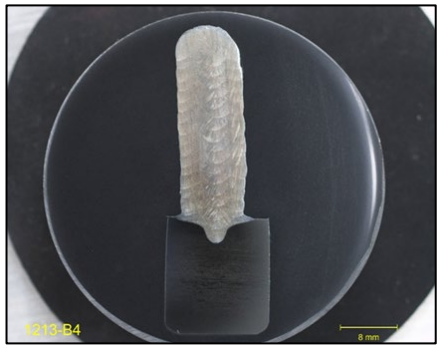
Report



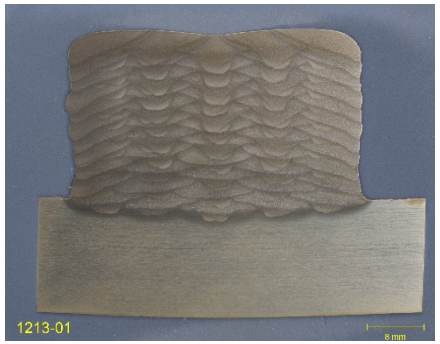


Full-Scale SS-IBP Build Demonstration

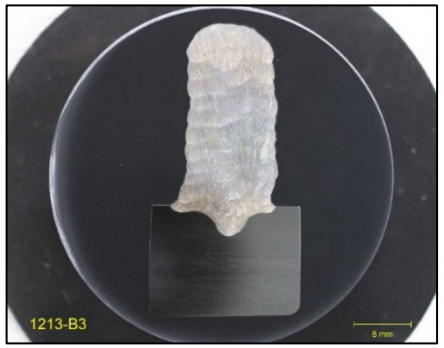
- MIL-308L GMA-P DED on 304L integrated build platform
- Robotic GMA-P procedures developed for two bead sizes
  - Small bead: wire feed speed/travel speed (WFS/TS) ≈ 15
  - Large bead: WFS/TS ≈ 30
  - Preheat/inter-pass temperature limits: 60°F to 350°F
- Full-scale SS-IBP procedure qualification scheme was demonstrated for each bead size.



Small Bead – Single Pass



Small Bead – Multi Pass

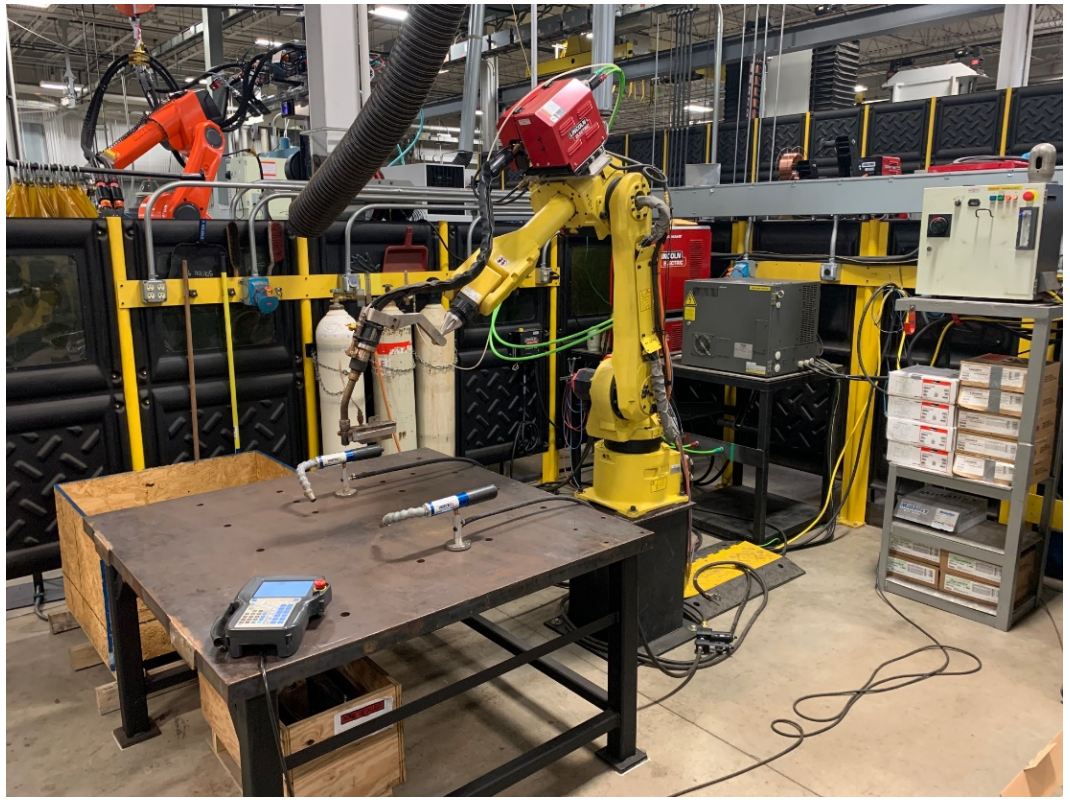


Large Bead – Single Pass

Large Bead – Multi Pass

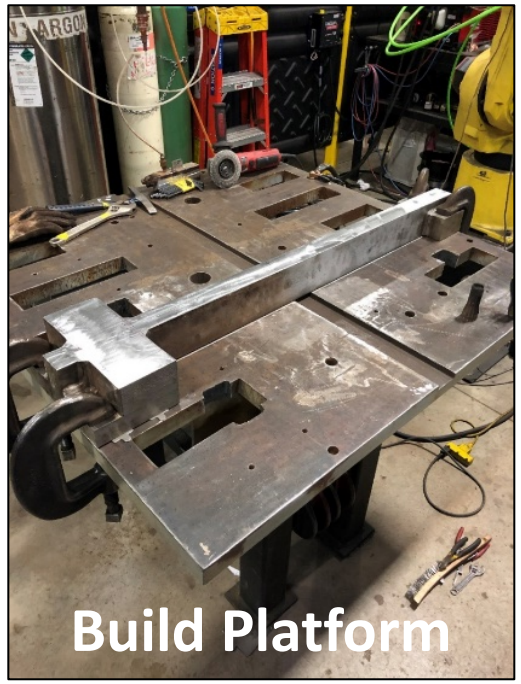
Robotic GMA DED System

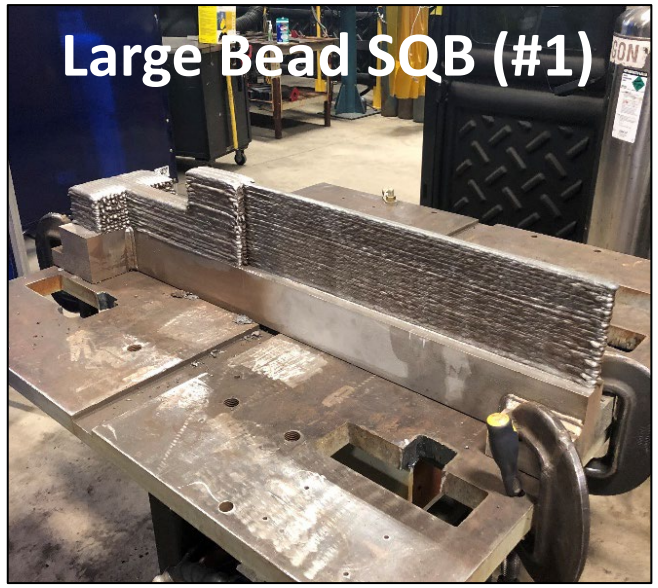
- Lincoln GMA System
  - Power Wave S500 power source
  - AutoDrive 19 Controller
  - AutoDrive 4R220 wire feeder
  - MagnumPro torch
- Cooling system
  - Vortec Frost Free Guns connected to an air supply and solenoid
- Infrared (IR) temperature sensor
- Fanuc robot system
  - ARC Mate 120iBe 6-axis robot
  - R-30iA controller



SS-IBP SQB Coupons

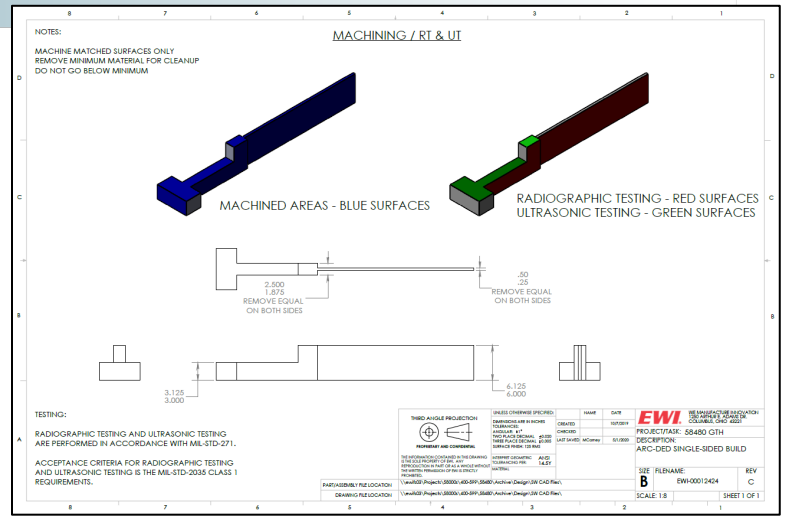
- Large Bead SQB (#1)
  - Total passes: 632
  - Wall: 64 layers
  - Block: 45 layers
- Small Bead SQB (#2)
  - Total passes: 1154
  - Wall: 88 layers
  - Block: 61 layers





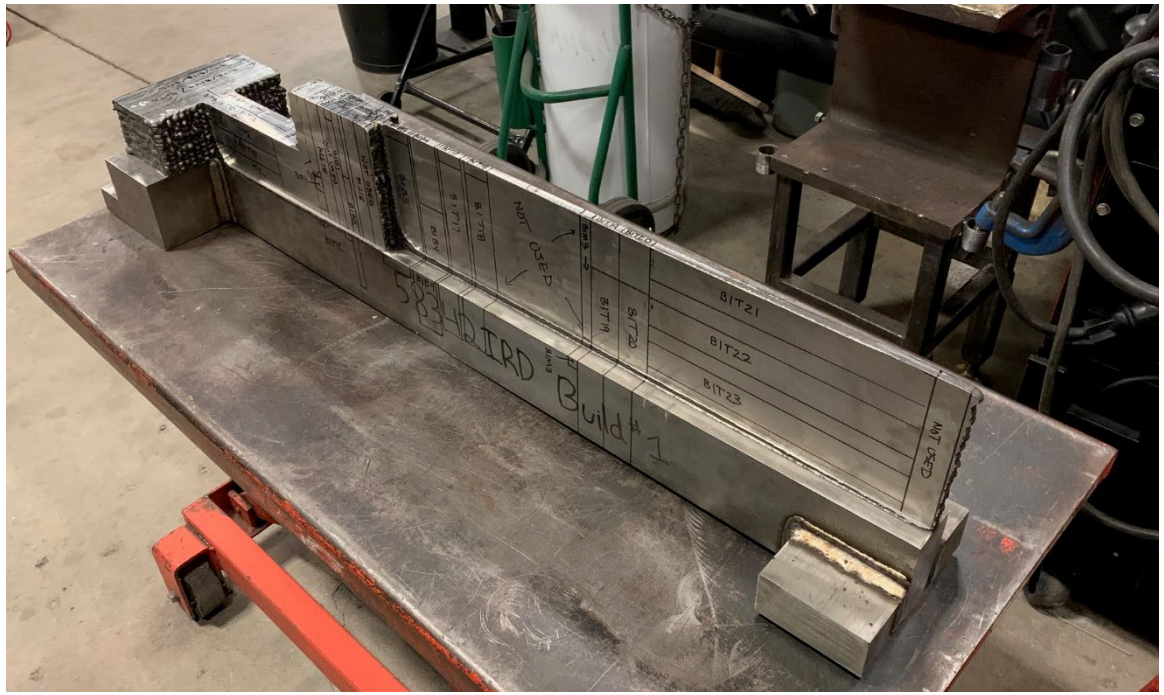
NDE Testing

- Machining prior to radiographic testing (RT) and ultrasonic testing (UT)
- Application
  - RT and UT performed: MIL-STD-271 Acceptance criteria: Class 1 MIL-STD-2035
  - NDE requirements being defined during Tech Pub development
- Results
  - Large bead SQB (#1)
    - Meets Class 1 RT and UT
  - Small bead SQB (#2)
    - Meets Class 1 UT
    - Meets Class 1 RT – one location 2 in. from the end of the wall (porosity)



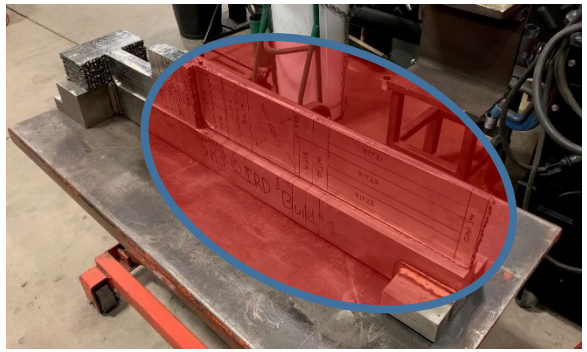
Specimen Test Matrix – SS-IBP SQB

- Specimen types
  - Tensile
  - Bend
  - Metallographic
- Specimen locations
  - Deposit metal
  - Interface/heat affected zone
- Specimen orientation
  - Wall: X, Z
  - Block: X, Y, Z

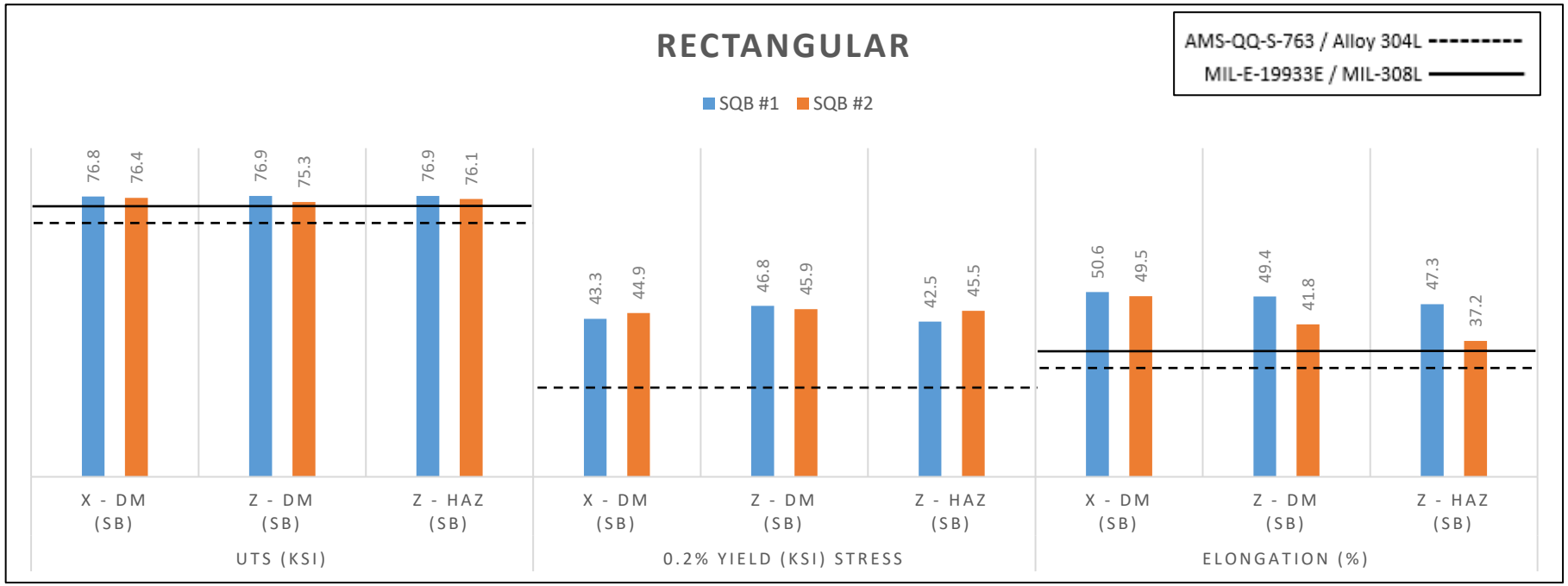


Wall – Test Results

- All bend test specimens passed.
- Average tensile test values for each group are shown.



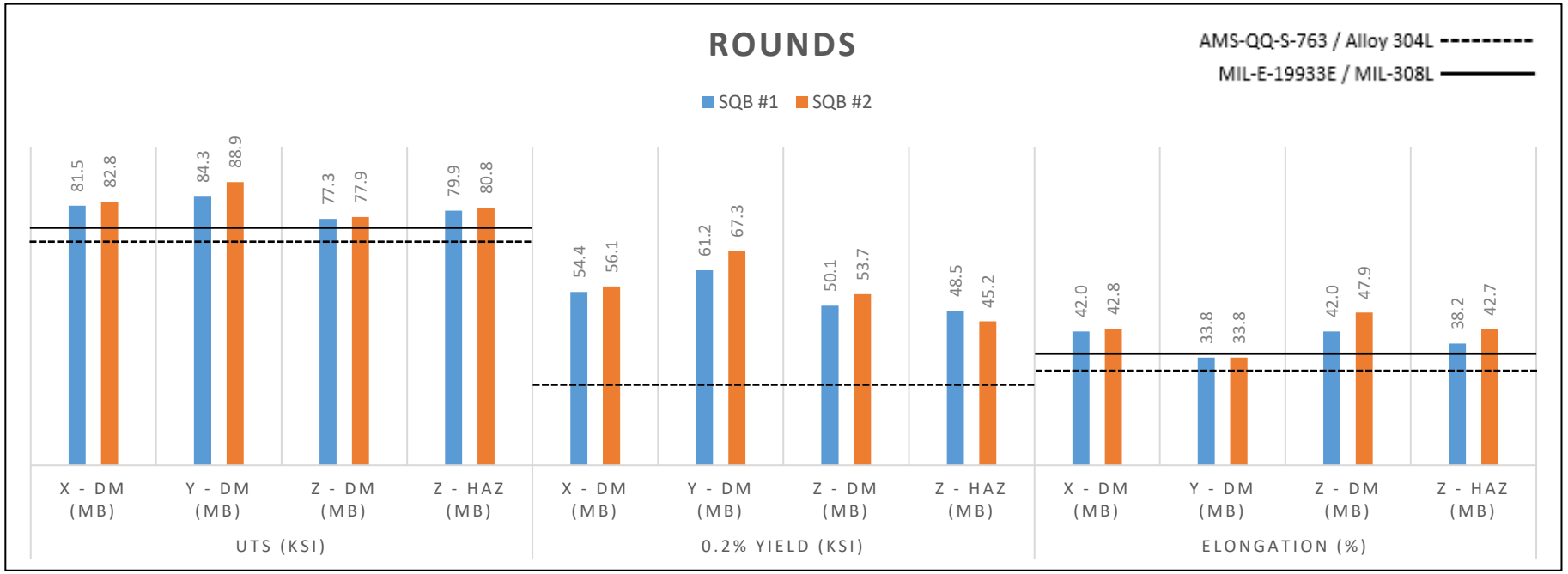
Specification	Type	Minimum Ultimate Tensile Strength	Minimum Yield Strength	Minimum Elongation
AMS-QQ-S-763	Alloy 304L (Build Platform)	70-ksi	25-ksi	30%
MIL-E-19933E	MIL-308L (Wire)	75-ksi	N/A	35%



Block – Test Results

- All bend test specimens passed.
- Average tensile test values for each group are shown.

Specification	Type	Minimum Ultimate Tensile Strength	Minimum Yield Strength	Minimum Elongation
AMS-QQ-S-763	Alloy 304L (Build Platform)	70-ksi	25-ksi	30%
MIL-E-19933E	MIL-308L (Wire)	75-ksi	N/A	35%



Procedure Qualification Test Report for DED

- Used to document procedures and test results for standard qualification builds
- Sections
  - General
  - Materials
  - Machine
  - Build parameters
  - Post processing
- Sections (cont.)
  - Tensile test results
  - Charpy test results
  - Hardness test results
  - Etc.
- Forms used by EWI are shown
  - Will need updated based on publication of Tech Pub

Environment

	Torch Shielding	Trailing	Enviromental Shielding	Other
Gas(es)	Ar / CO2	Ar	NA	Compressed Air
Composition	99%/1%	100%	NA	100%
Flow Rate	60-CFH	60-CFH	NA	NA
Notes	5-sec pre, 5-sec post	5-in trail		Used to cool part

Build Parameters (copy as needed) 1/6

Description (interior, surface, overhang, layer)	Layer 1 - Multi Bead		
CNC / Robot File Name	IRD58342	Layer Thickness	0.138-in
Power Source File Name	IRD58342	Overlap Distance	See notes
Part Identification	IRD58342 Big Bead	Bead Sequence	See notes
Mode of Metal (GMAW) or Arc (PAW) Transfer	GMA-P	Torch Orientation	See notes
Maximum Interpass Temperature	300°F	Interlayer Cleaning	Wire brush

Notes/Diagrams

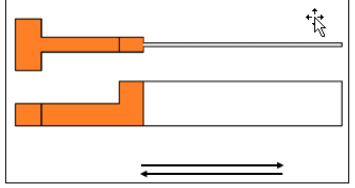
Offset
A 0.354-in
Z 0.138-in

Sequence	B4	B2	B1	B3	B5
Offset	A	A	0	A	A

Diagram of bead progression (example above)

Weave (1)			
Amplitude	Frequency	Dwell 1	Dwell 2
0.051-in	5-Hz	0.3-sec	0.3-sec

Direction Of Travel



	Bead 1	Bead 2, 4...	Bead 3, 5...
Travel Angle	0°	0°	0°
Work Angle	0°	0°	0°

Test Results

Tensile Test

Specimen No.	Location / Orientation	Width (in)	Thickness (in)	Ultimate Total Load (psi)	Elongation (%)	Type of Failure and Location
T01	Y-AXIS DM ROUND TENSILE (MB)	0.506		85000	26.2	Within Gage Length
T02	Y-AXIS DM ROUND TENSILE (MB)	0.506		84400	30.4	Within Gage Length
T03	Y-AXIS DM ROUND TENSILE (MB)	0.498		85300	32.0	Within Gage Length
T04	Y-AXIS DM ROUND TENSILE (MB)	0.506		84700	34.7	Within Gage Length
T05	Y-AXIS DM ROUND TENSILE (MB)	0.505		85300	35.1	Within Gage Length
T06	Y-AXIS DM ROUND TENSILE (MB)	0.499		81000	44.4	Within Gage Length
T07	X-AXIS DM ROUND TENSILE (MB)	0.506		81200	42.2	Within Gage Length
T08	X-AXIS DM ROUND TENSILE (MB)	0.499		80100	42.5	Within Gage Length
T09	X-AXIS DM ROUND TENSILE (MB)	0.499		84300	32.7	Within Gage Length
T10	X-AXIS DM ROUND TENSILE (MB)	0.506		81100	40.6	Within Gage Length
T11	X-AXIS DM ROUND TENSILE (MB)	0.499		80500	46.9	Within Gage Length
T12	X-AXIS DM ROUND TENSILE (MB)	0.506		81500	47.2	Within Gage Length
T13	Z-AXIS HAZ ROUND TENSILE (MB)	0.505		79400	37.2	Within Gage Length
T14	Z-AXIS HAZ ROUND TENSILE (MB)	0.505		80300	39.1	Within Gage Length
T15	Z-AXIS DM ROUND TENSILE (MB)	0.507		77700	41.4	Within Gage Length
T16	Z-AXIS DM ROUND TENSILE (MB)	0.496		76900	42.7	Within Gage Length
T17	Z-AXIS DM FLAT TENSILE (SB)	0.751	0.321	77300	51.5	Within Gage Length
T18	Z-AXIS DM FLAT TENSILE (SB)	0.752	0.325	76400	47.2	Within Gage Length
T19	Z-AXIS HAZ FLAT TENSILE (SB)	0.752	0.321	76700	47.2	Within Gage Length
T20	Z-AXIS HAZ FLAT TENSILE (SB)	0.752	0.322	77100	47.4	Within Gage Length
T21	X-AXIS DM FLAT TENSILE (SB)	0.694	0.337	76500	49.4	Within Gage Length
T22	X-AXIS DM FLAT TENSILE (SB)	0.692	0.334	76400	50.3	Within Gage Length
T23	X-AXIS DM FLAT TENSILE (SB)	0.693	0.327	77400	52.0	Within Gage Length

Bend Test

Specimen No.	Type	Location	Result
B01	Side Bend	Y-Z DM BEND (MB)	No Visual Defects
B02	Side Bend	Y-Z HAZ BEND (MB)	No Visual Defects
B03	Side Bend	X-Z DM BEND (SB)	No Visual Defects
B04	Side Bend	X-Z HAZ BEND (SB)	No Visual Defects

Build Demonstration Summary

1. Two stainless steel MIL-308L GMA-P DED builds were completed on 304L SS-IBP. The build design provided a dimensionally stable condition for producing specimens in all directions.
2. The GMA-P DED process produced sound builds that met ultrasonic and radiographic inspection criteria. Bend tests further demonstrated soundness in different planes.
3. Tensile properties of the MIL-308L standard qualification builds met property requirements for filler metal (x-direction).
   - Elongation in y-direction slightly below x-direction requirements
4. New acceptance criteria may be needed for anisotropy effects.

Questions