

Use Case

617 Ni-alloy
High temperature,
pressure retaining

For a full copy of Chevron's presentation, please contact Robert.Rettew@Chevron.com

Who am I?

- Welding Nerd for 30+ years
- Materials and welding
- Research and applications
- Codes and Standards
- Now involved in many additive programs
 - AWS, API, ISO TC-261/ASTM F42, MIL, IIW, ABSA, NBIC
- Section III-MF&E (Chair AM-DED), IX (chair Qualifications)
II-CSEF



Who is Lincoln Electric?

A global manufacturer and market leader with 125+ years of expertise.



CONSUMABLES
[FILLER METALS]



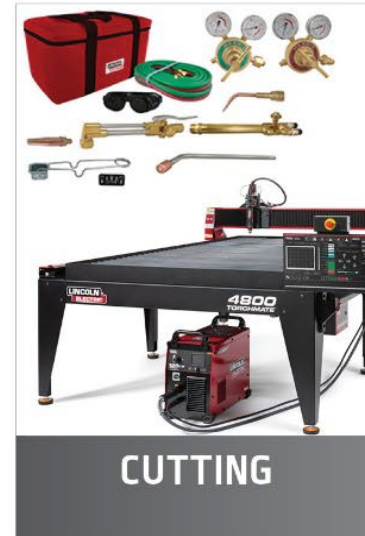
EQUIPMENT



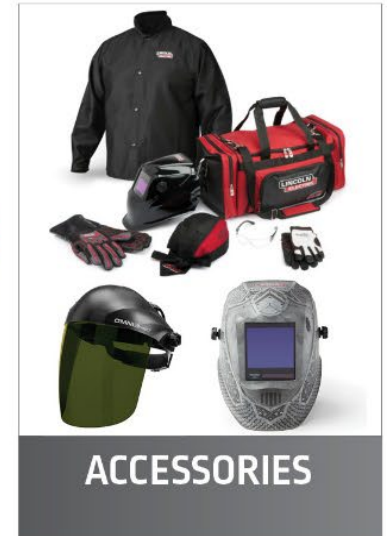
AUTOMATION



FUME CONTROL



CUTTING



ACCESSORIES

- » Founded in 1895
- » \$3.2B in revenue in 2021
- » Market cap of ~\$8B
- » Nasdaq Listed: 'LECO'

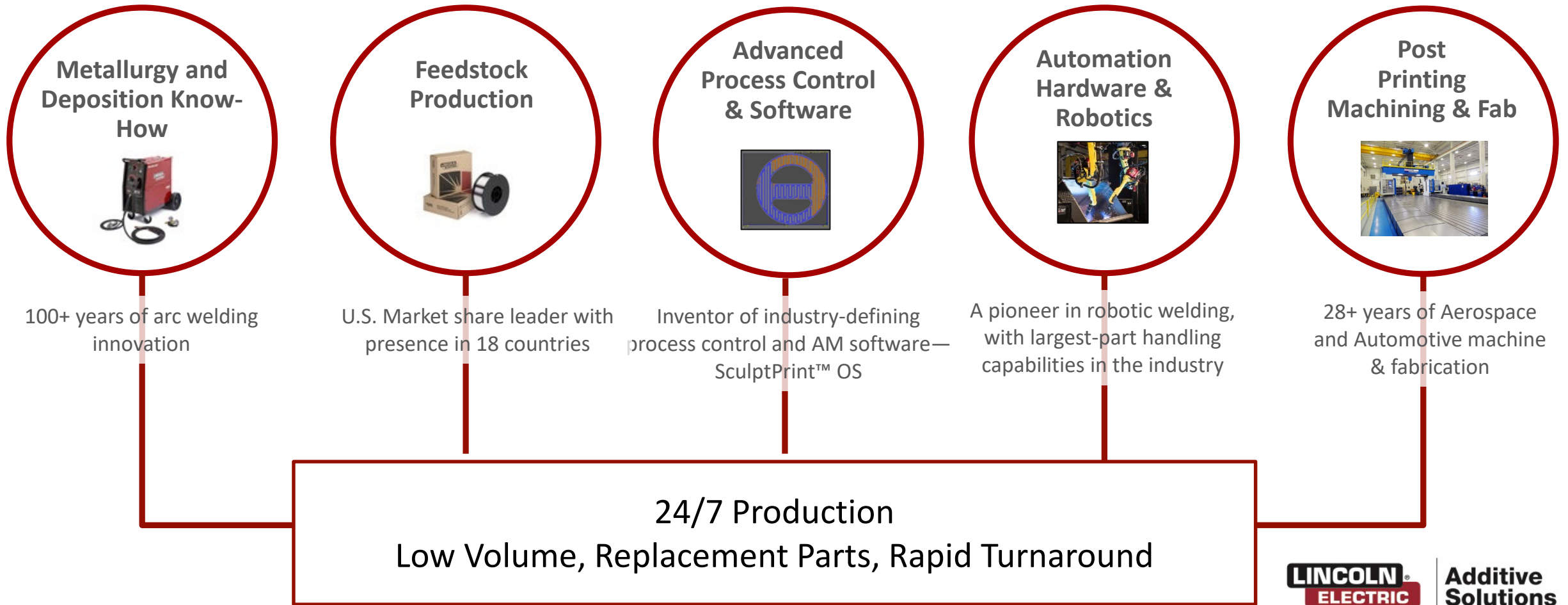
- » HQ in Cleveland, Ohio, U.S.A.
- » 56 manufacturing facilities in 19 countries
- » Distribution and sales to over 160 countries
- » 11,000 employees worldwide



**Additive
Solutions**

What Lincoln Electric brings to Additive Manufacturing

Vertically integrated large-format metal AM service provider





ICAM 2022

ASTM INTERNATIONAL
Helping our world work better

API and ASME Qualification of a Printed Pressure Component

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Teresa Melfi, Lincoln Electric
Matt Sanders, Stress Engineering

www.amcoe.org

- Introduction and Background
- Design, Codes, and Standards
- Qualification & Data Presentation
- Discussion & Conclusions

A Refinery 3D Printing Success Story

- In early 2022, a facility turnaround needed replacements for several components in hydrogen furnace service. These components were critical path to restart the facility.
- Service requirements were 1500F and 300psi, with a design lifetime of 20 years.
- Application was for a furnace header. Previous installation was Alloy 800H with Alloy 617 weldments.
- Existing components were damaged and unusable. Replacement using traditional methods estimated ~3 months.
- 3D printing was used to deliver replacements in just under 4 weeks, **avoiding a significant shutdown.**



Piping components being printed at Lincoln Electric Additive Services



(left) Digital part verification, (right) Final Installation

Three Value Drivers for the Energy Sector

1. Revolutionize Spare Parts – Existing Designs
 - On-demand spare part supply prevents shutdowns
 - ‘Digital Warehouse’: Reduce overhead cost associated with spare parts inventory
2. Improve Existing Designs
 - Weight reduction
 - Performance improvement
3. New Materials
 - Improved Material Properties
 - Functional Gradient Materials

- Chevron has been working on additive manufacturing since 2017, with a first internal guideline in 2019 and participation in 2021's API 20S publication.
- Prior to the pressure containing WAAM application discussed today, Chevron has conducted 4+ pilot applications in non-pressure-containing service in a variety of services.

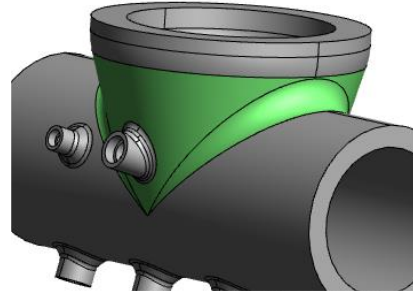


Workflow of an Urgent WAAM Job



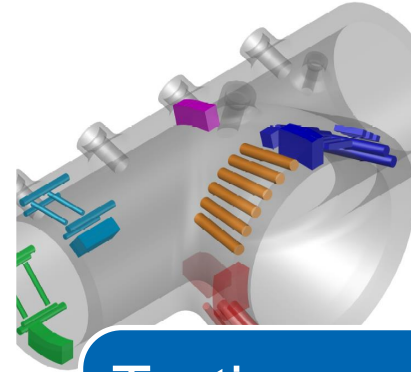
ID the Need

- Four tees required, Alloy 800H @ 1100lb weight each.
- 4 week delivery timeframe to avoid extending the project



Design & Engineering Review

- Review of existing data showed Alloy 617 weldments were suitable.
- Optimized design to



Testing

- ASME 3020 Qualification using test walls
- API 20S using sacrificial part
- Additional testing including creep,



Final Inspection & Installation

- API 20S volumetric NDT: RT and PAUT
- Machining of weld bevels

Design, Codes, and Standards

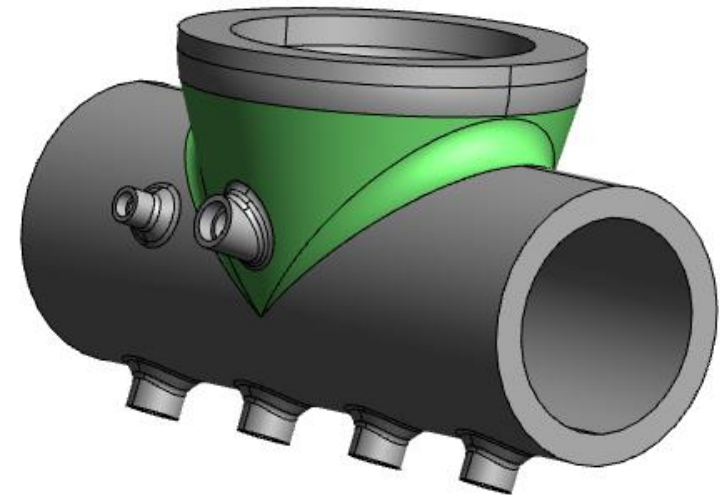


Printed Components Design

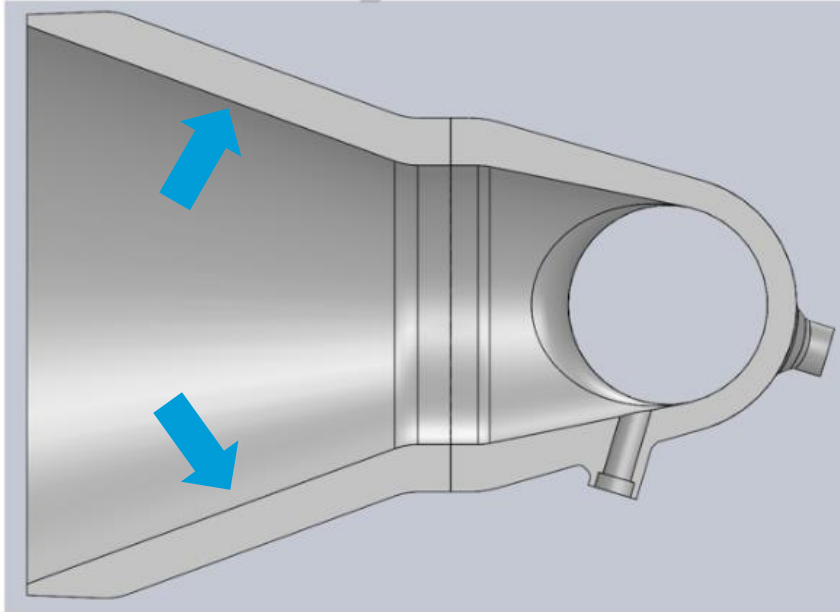
- Printing of a replacement part is permissible per expert review of API 530 (construction design document), combined with API 20S (3D printing standard) and ASME 3020 (code case permitting additive manufacturing).
- Design has been based on a 3D model of the original part.
- Alloy 617 is used for the new part. Compared to the old part (Alloy 800H), this has a higher allowable design value and increased strength/life at elevated temperature.
- The design is supported by a successful FEA model at design conditions (>1500F, 300psi).

Factors of Conservatism:

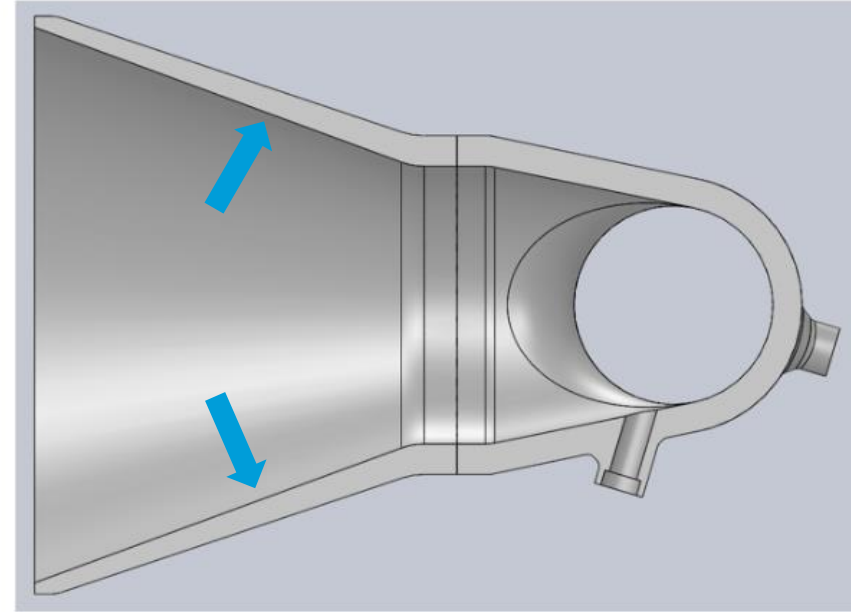
- 617 is already field proven – it is the weld consumable used in F-8620
- New design does not take credit for additional strength of 617.
- New design is derated by a conservative joint factor.



Success Side Story: Nimble Redesign & Production



Original Part (left) weighed ~1200lb. We did not have enough weld wire to build this!



New design (right) weighs ~840lb. This was crucial to success.

Digital redesign of the part was conducted on a Thursday night by FEA and design engineers. We communicated the new design to the supplier on Friday morning and printing started the same day. The part was on a truck by the following Tuesday.

Relevant Documents

API 530 Calculation of Heater-tube Thickness in Petroleum Refineries

Covers calculation methods for heater tube thickness

- Formulae are based on mostly based ASME B31.3, Section VIII Division 1 and 2 with appendices covering high temperature data for suitable materials.
- Cast components (like the old tee) and components made from additive manufacturing (like the new tee) are neither addressed nor prohibited in this standard.

API 20S Additively Manufactured Metallic Components for Use in the Petroleum and Natural Gas Industries

- Provides guidance that includes tensile testing, micrographic examination, and quality control.



Relevant Documents (2)

ASME PTB 13-2021 Criteria for Pressure Retaining Metallic Components Using Additive Manufacturing

- Guidance on design, quality control, and NDE of AM components.
- Intended to be used in conjunction with a governing design code.
- Recommends the use of ASME Section VIII Division 2 Part 5 for design AM components.

ASME Code Case 3020

- Provides guidance on qualifying the Gas Metal Arc Additive Manufacturing (GMAAM) Process as a qualified weld procedure per ASME Section IX.

ASTM B564 Standard Specification for Nickel Alloy Forgings

- Specification for forgings, but for this job we referenced the tensile and mechanical requirements only.



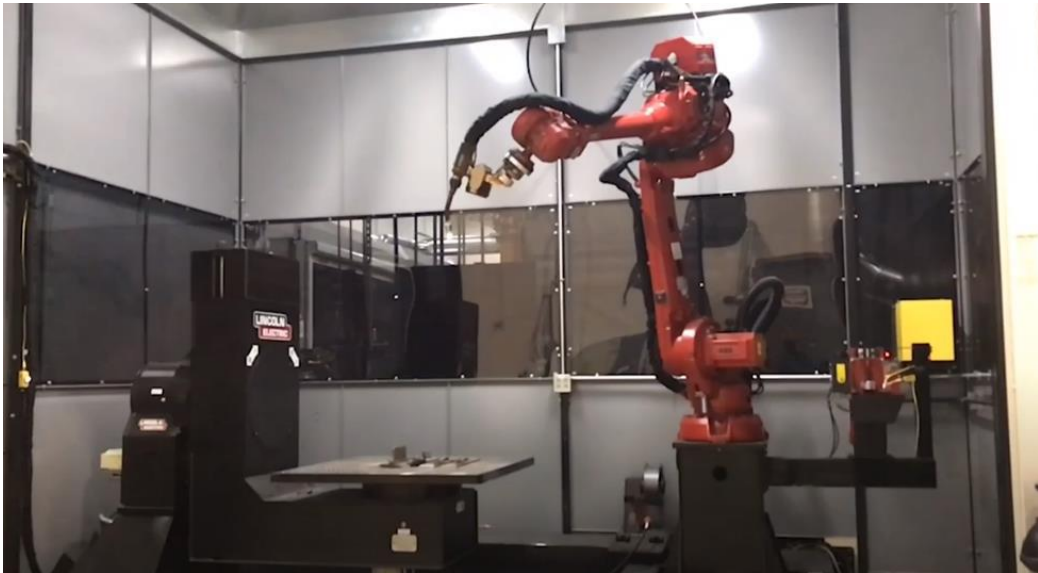
Qualification & Data



Inspection & Testing Summary

- Testing Conducted on Each Piece
 - Dimensional Checks
 - 100% Dye Penetrant surface inspection
 - Phased Array UT of Critical Locations
- Testing Conducted on Witness Coupons
 - Hardness Survey
 - Metallographical Assessment
 - Tensile Testing in multiple orientations
 - Chemistry
- Additional Testing Conducted on First Article
 - Pressure Testing at 6,000psi
 - Tensile Tests at elevated temperature, from wall thickness at various critical locations
 - Local RT Inspection
 - Creep testing using samples from sacrificial part

Production Images

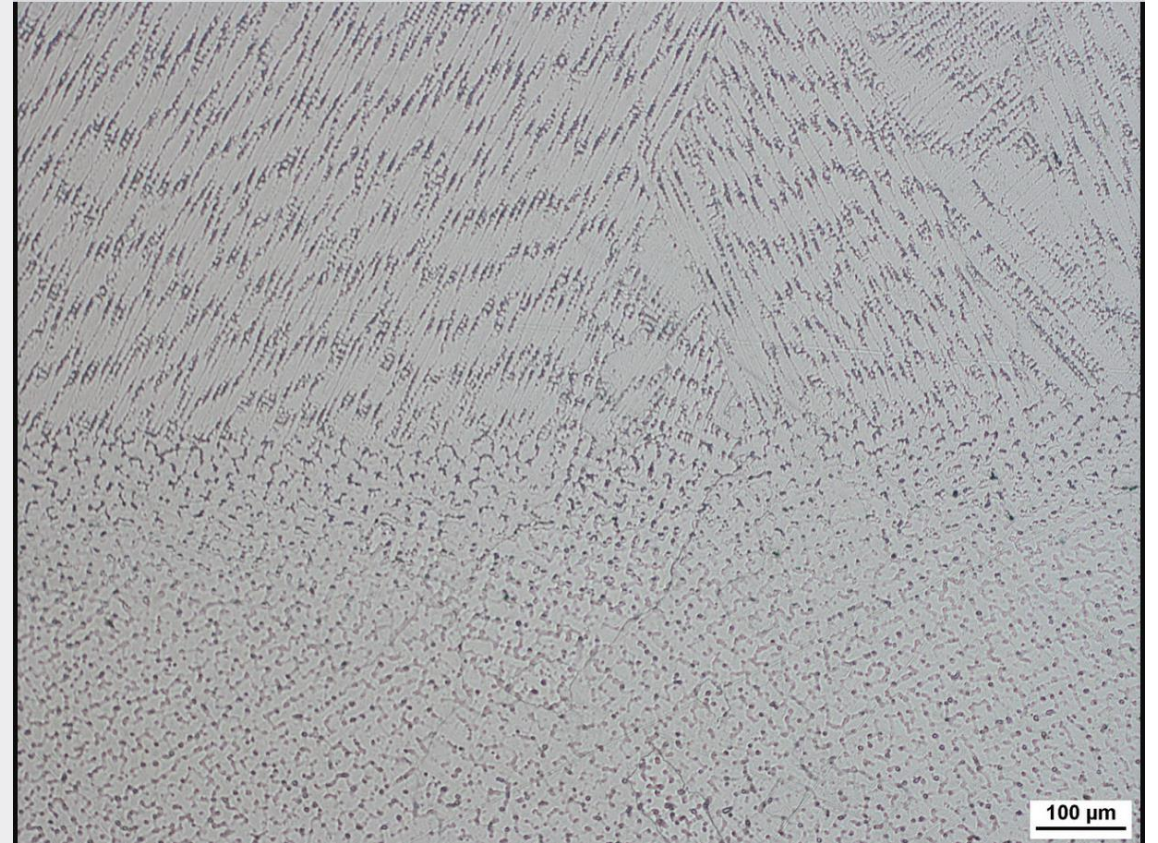
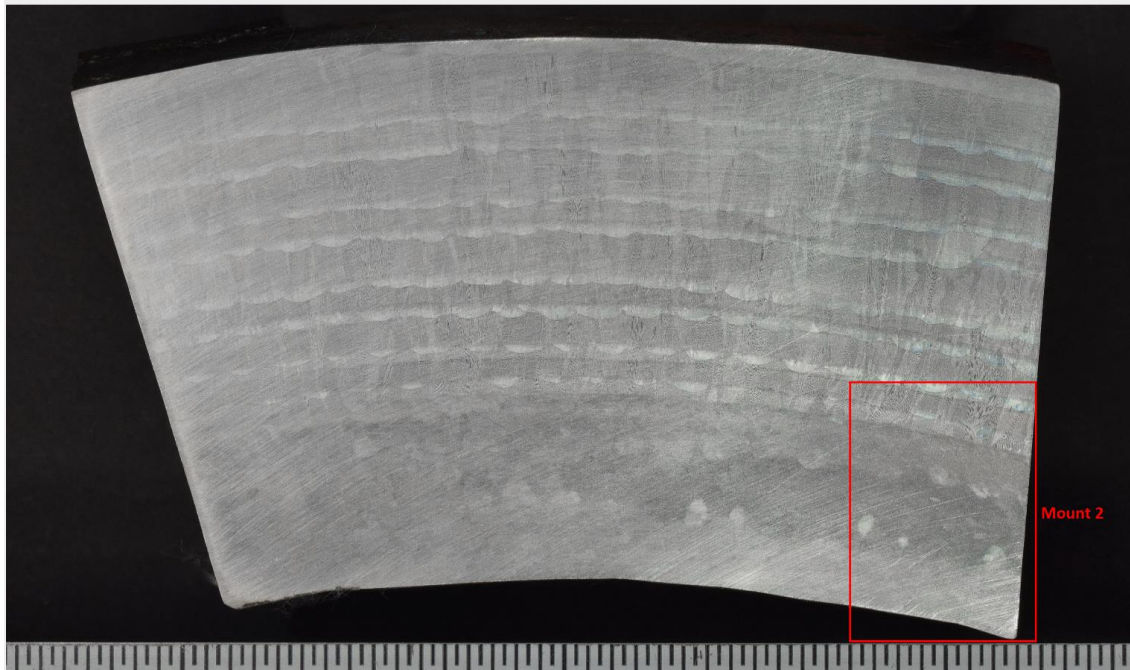


Printed Components Testing

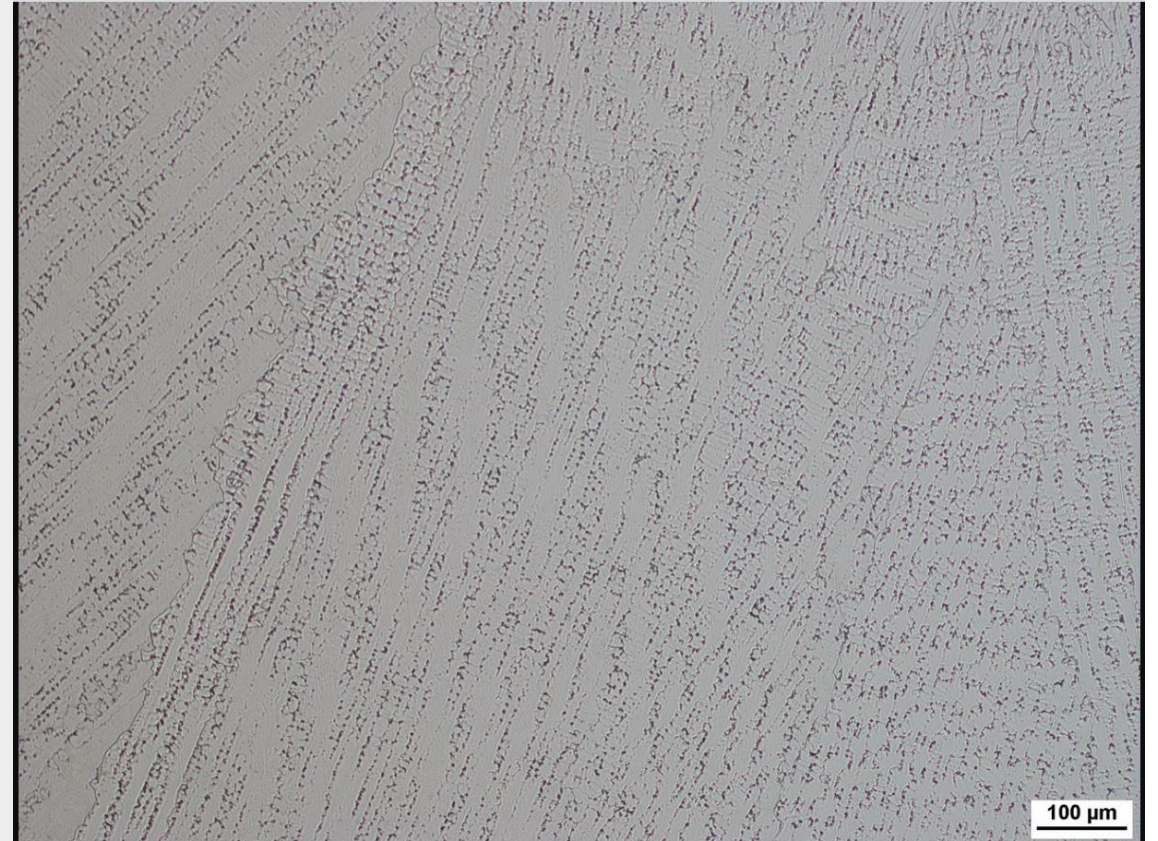
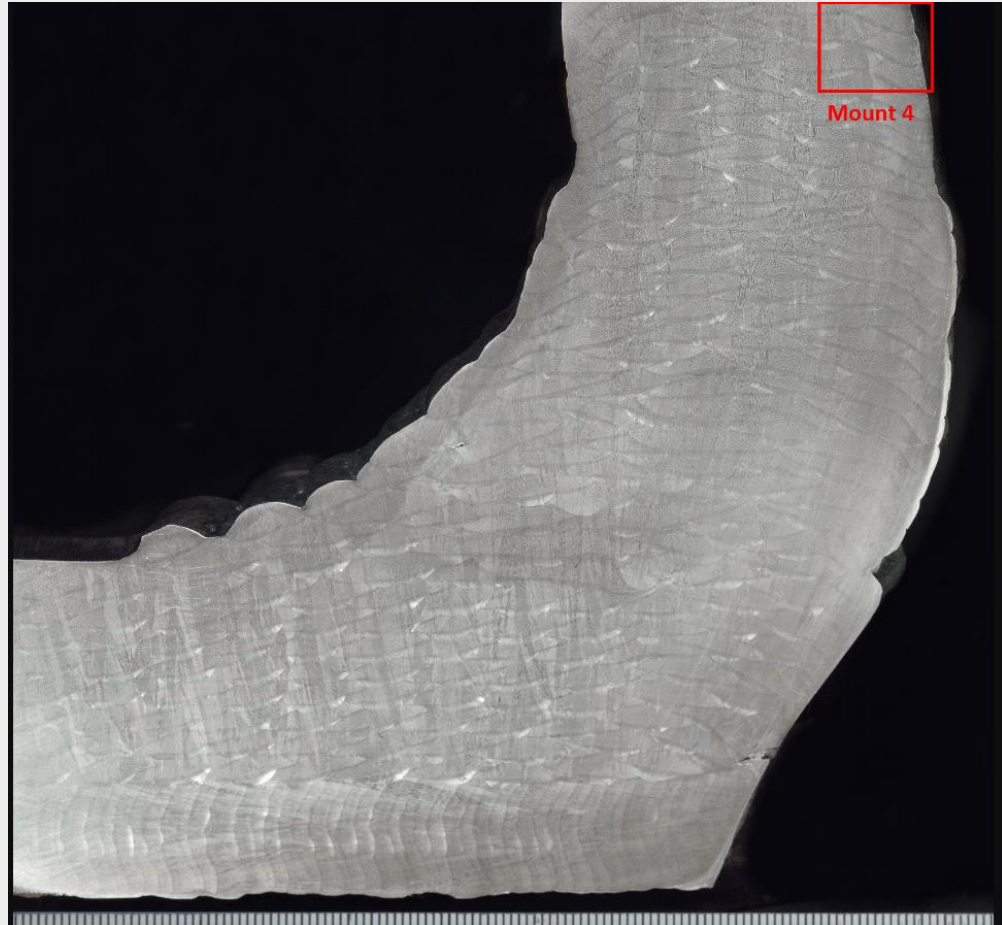
- Hydrotest (photo on right)
- Acoustic Emissions
- Phased Array Ultrasonics in critical areas, require special qualification
- Radiographic Inspection of 100% Volumetric
- Dye Penetrant 100% surface



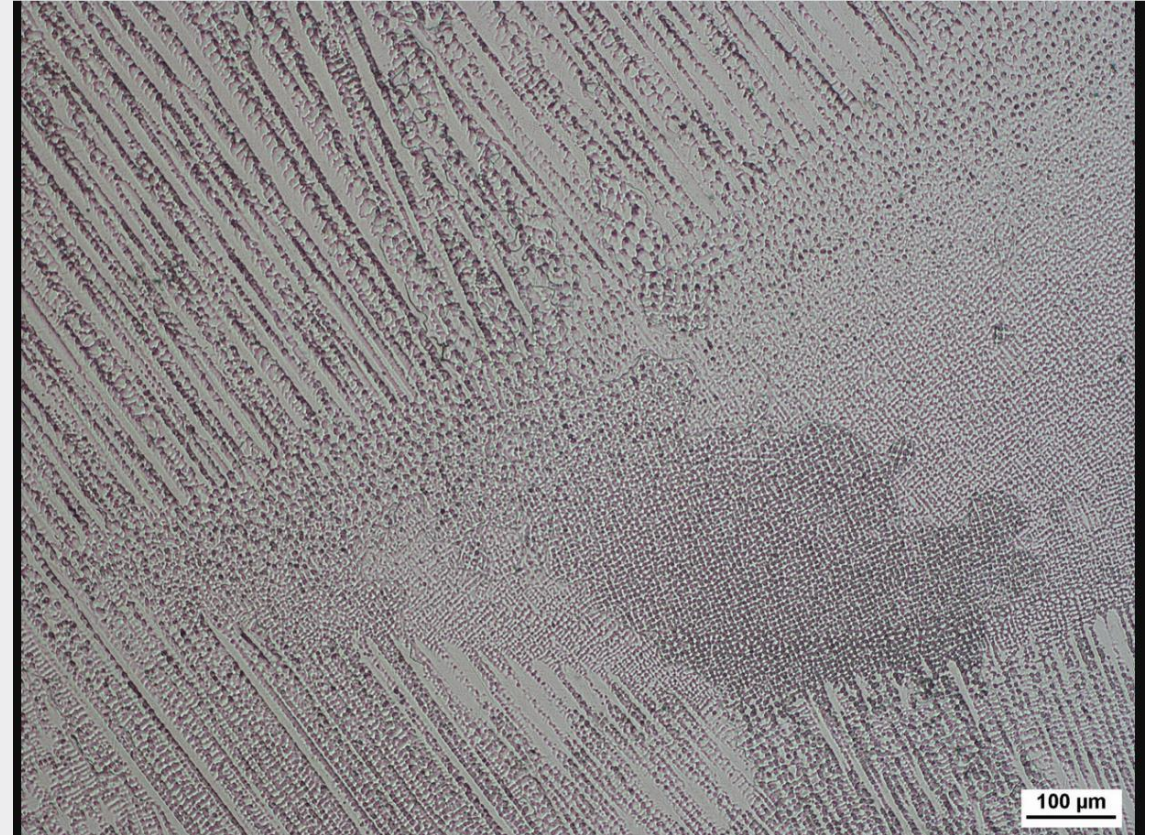
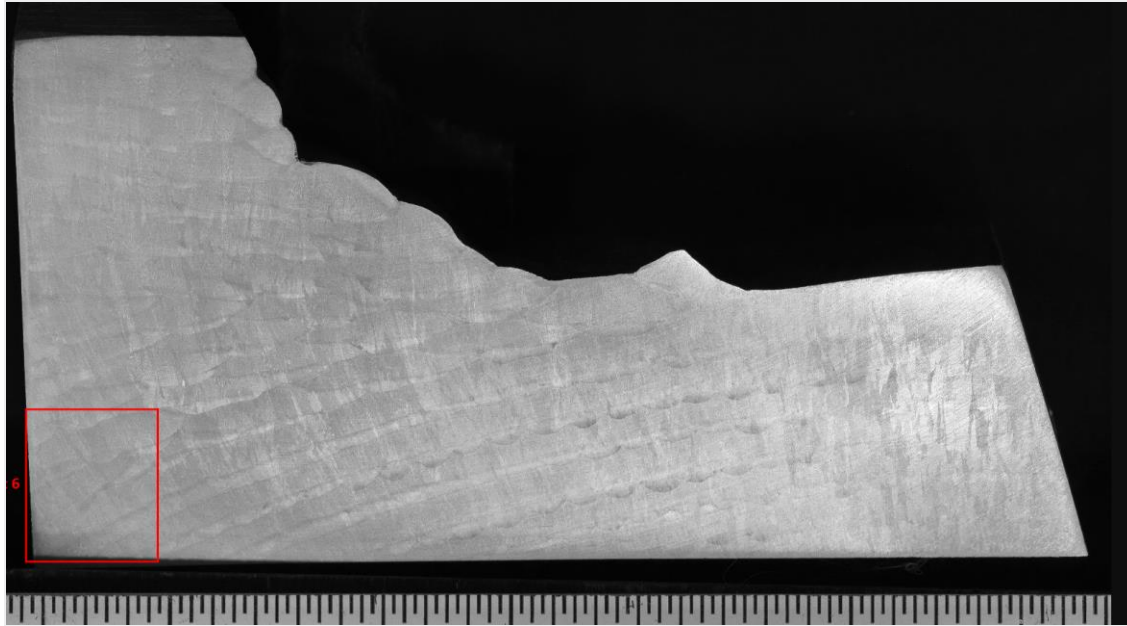
Micrographs



Micrographs (2)

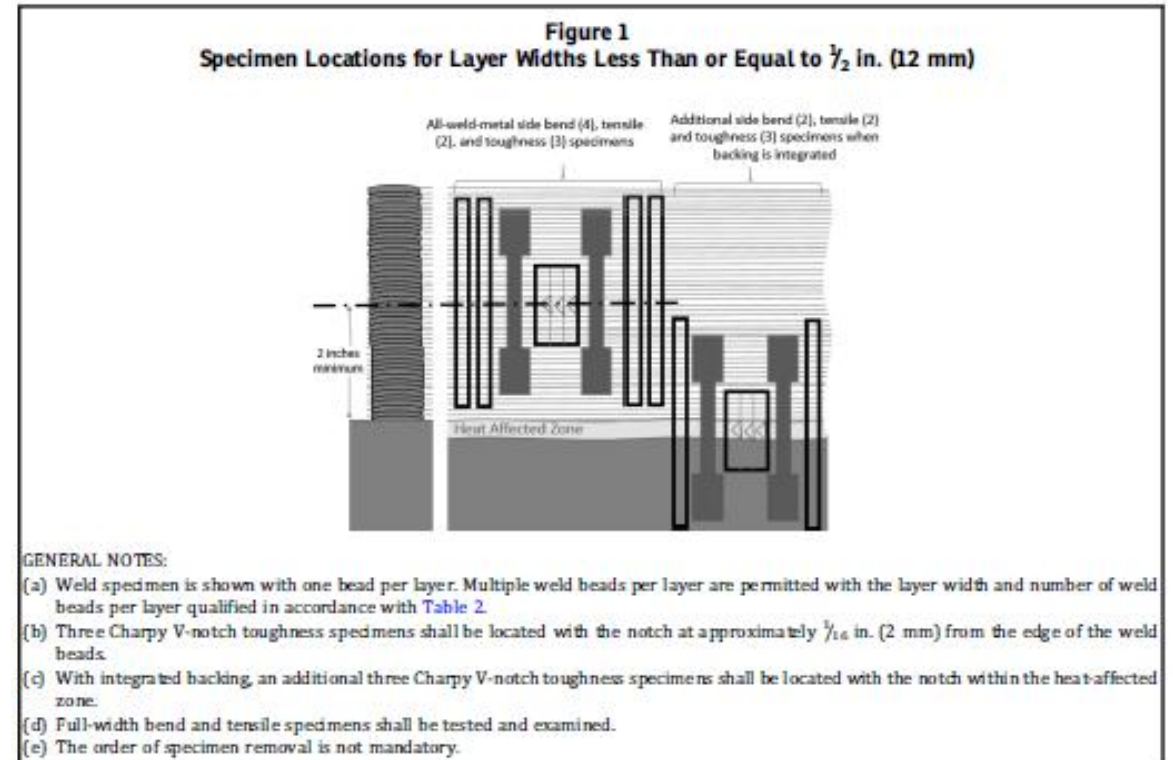


Micrographs (3)

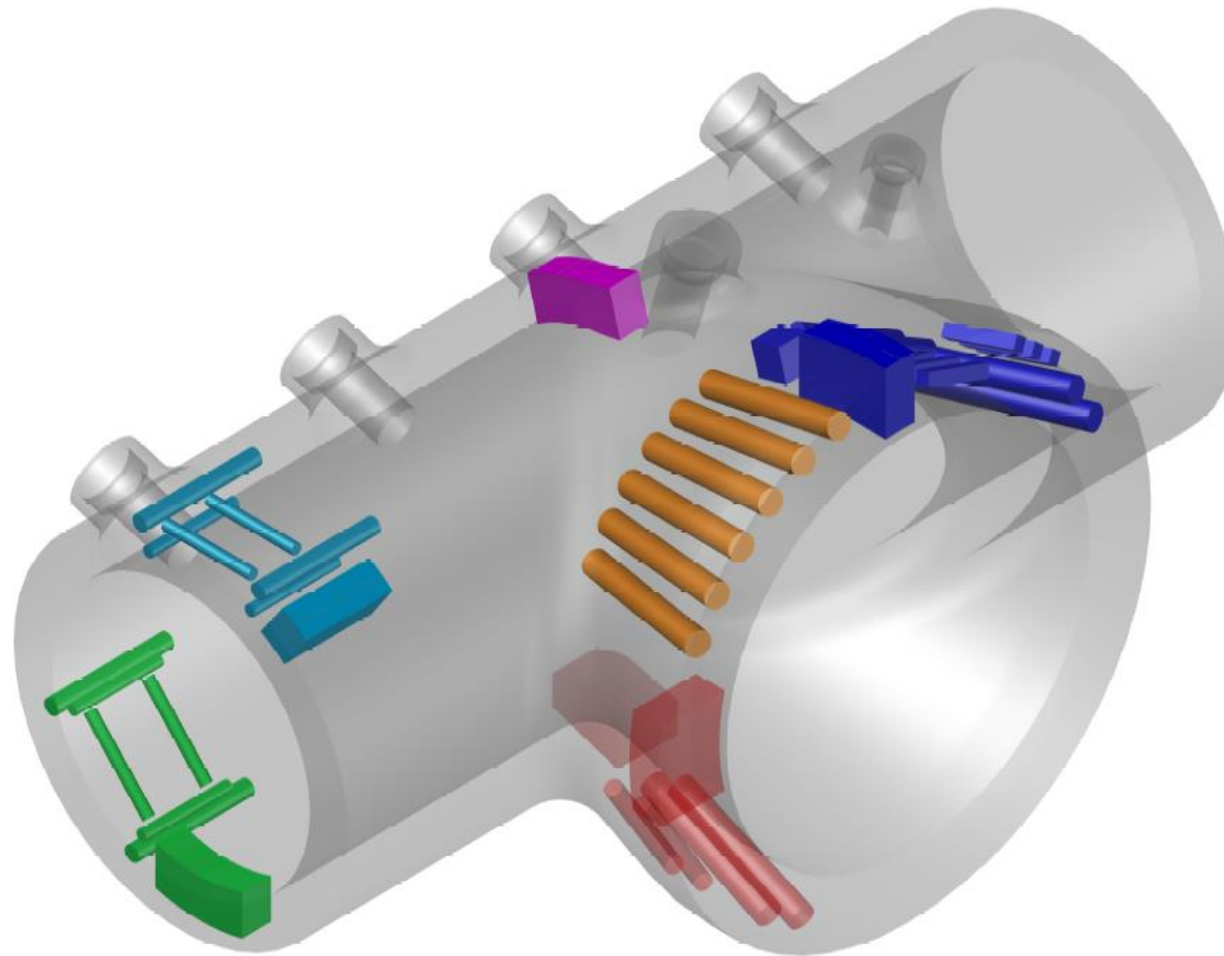


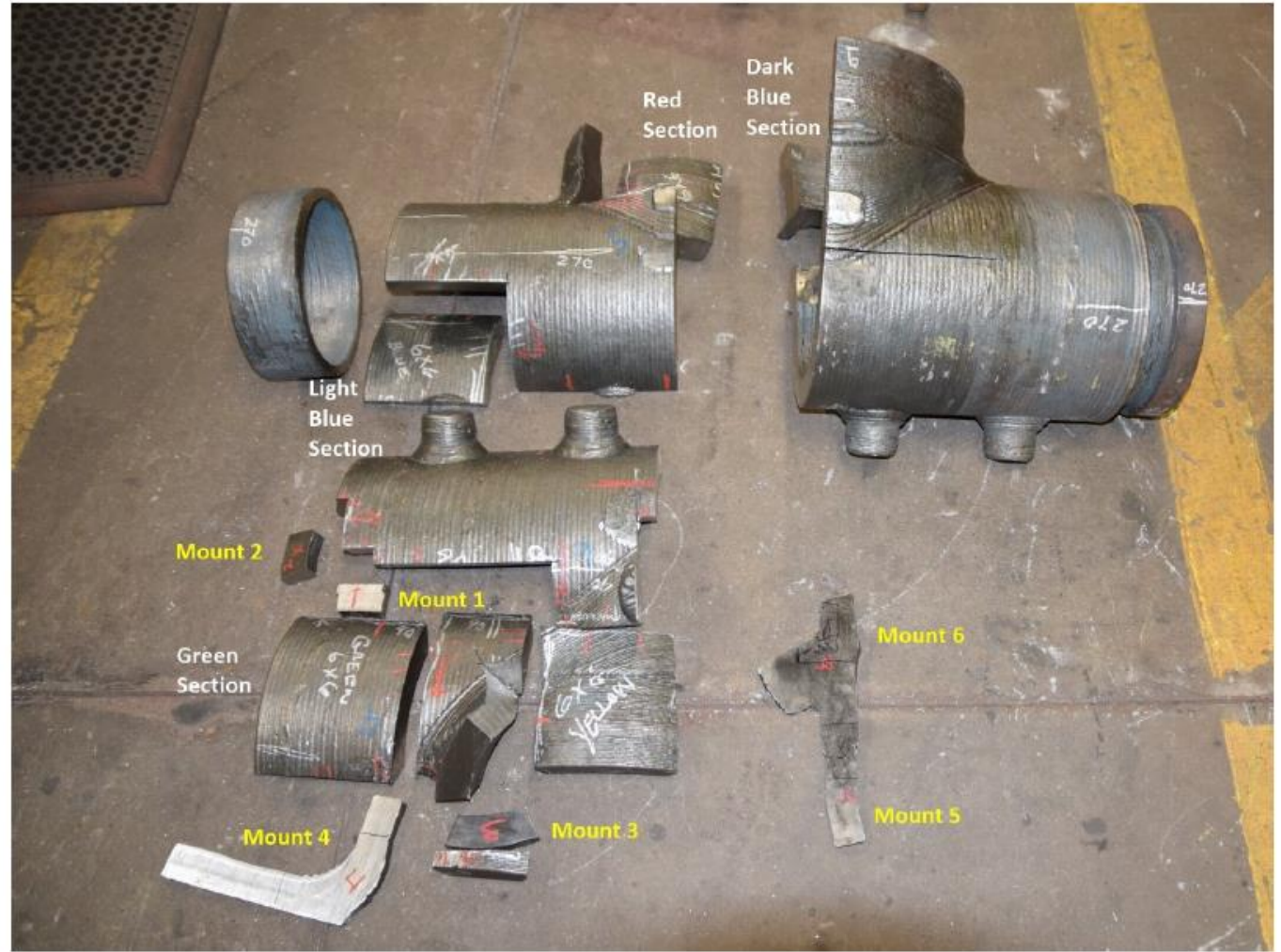
ASME 3020 Qualification

Cooling Rate	Wall Thickness	Yield Strength	Ultimate Strength
<i>(type)</i>	<i>(type)</i>	<i>(ksi)</i>	<i>(ksi)</i>
Slow <i>High Heat Input & High Interpass</i>	Thin	49.9	99.0
		51.0	100.0
	Thick	59.0	103.0
		60.5	102.0
		58.0	103.0
		58.0	102.0
		61.5	104.0
	58.0	103.0	
Fast <i>Low Heat Input & Low Interpass</i>	Thin	57.0	96.5
		56.0	96.5
	Thick	63.5	107.0
		63.5	98.0



Specimen Locations from Sacrificial Article

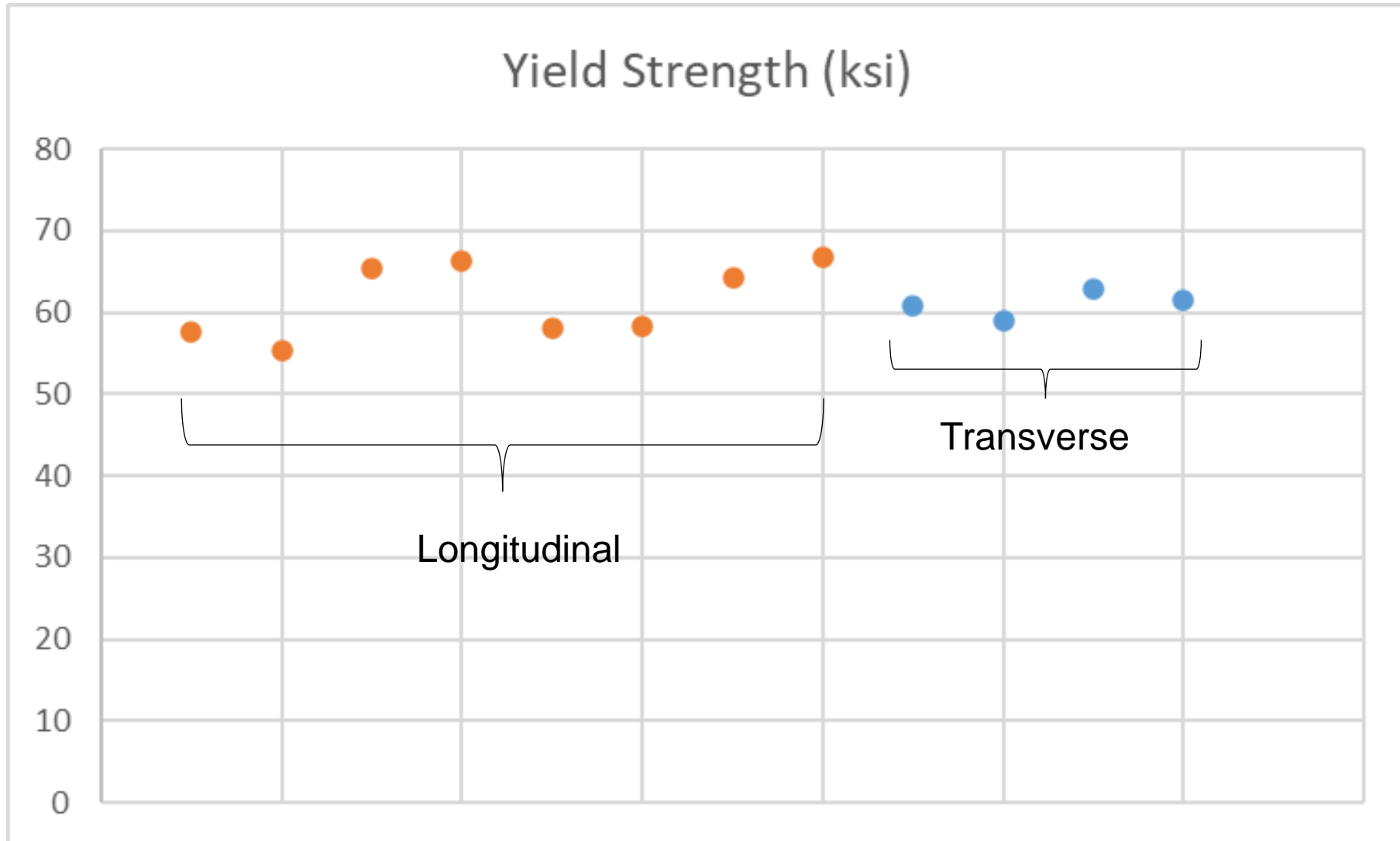




Tensile Testing from Sacrificial Part

Section	Orientation	Location	Yield Strength (ksi)	Tensile Strength (ksi)	Elongation (%)	Reduction of Area (%)
Light Blue	Longitudinal	ID	57.6	102.5	44.8	53.7
			55.4	99.9	40.1	52.6
	Longitudinal	OD	65.5	108.7	40.4	55.0
			66.4	108.7	40.5	51.0
	Transverse	Mid-wall	60.9	106.1	45.5	42.5
			59.0	102.7	34.9	31.1
Green	Transverse	Mid-wall	63.0	107.0	39.9	51.4
			61.6	107.9	37.4	44.0
	Longitudinal	ID	58.0	101.8	43.1	49.4
			58.3	102.2	44.9	57.2
		OD	64.3	109.4	42.1	44.7
			66.7	108.6	42.5	45.8
Red	Longitudinal	Mid-wall	60.9	101.8	47.0	55.2
			60.4	102.4	48.6	55.7
	Transverse		61.0	104.2	44.4	58.7
			61.5	104.7	43.7	51.0
Dark Blue	Longitudinal	Mid-wall	60.6	101.1	46.5	59.2
			60.5	101.1	46.8	59.2
	Transverse		61.4	103.5	40.3	48.7
			62.5	105.4	40.5	54.0

Tensile Testing



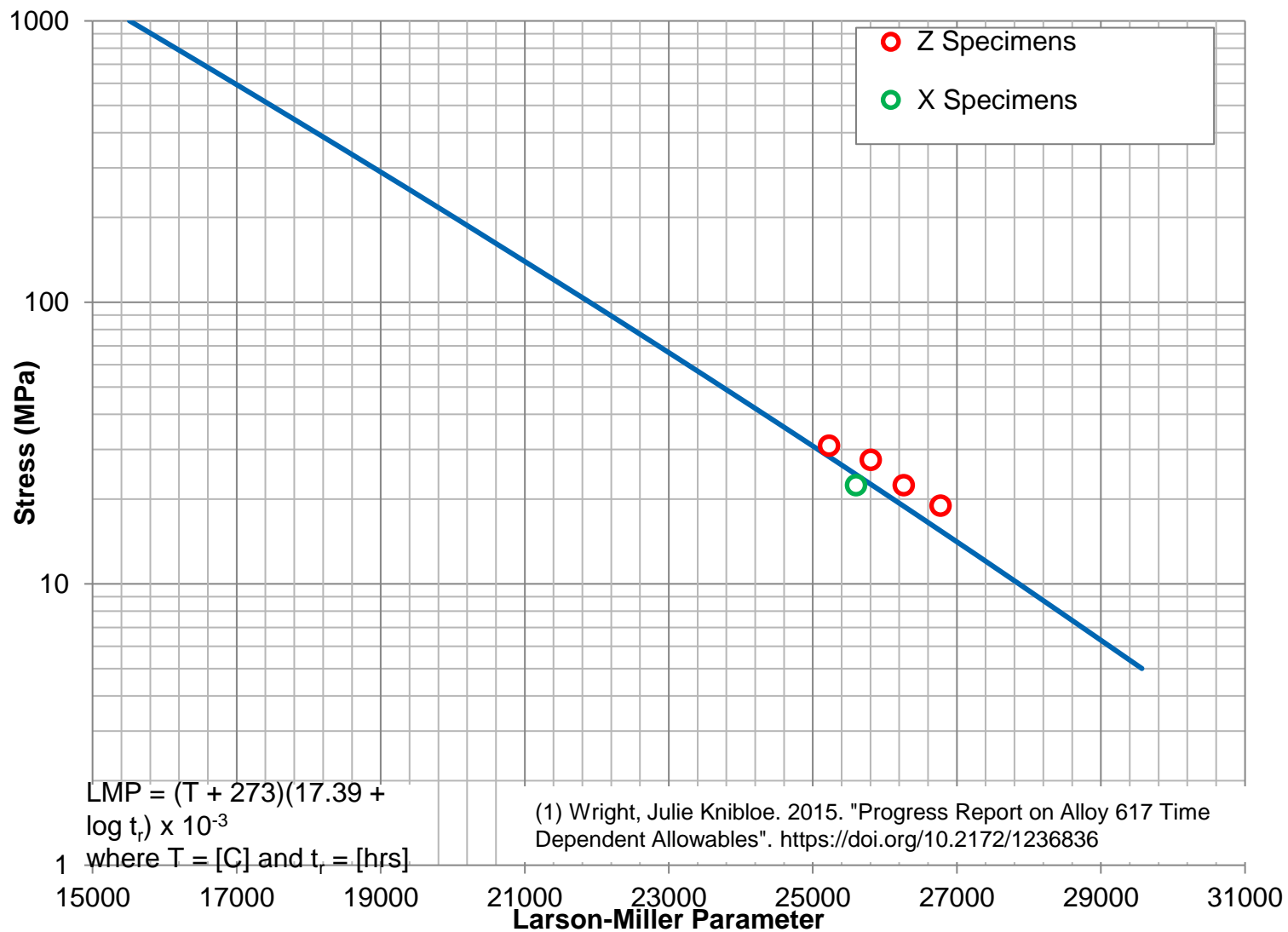
Additional Analysis

Element	Tee	ASME SFA-5.14 ERNiCrCoMo-1
Chromium	21.7	20.0 - 24.0
Cobalt	12.0	10.0 - 15.0
Molybdenum	8.68	8.0 - 10.0
Aluminum	1.25	0.8 - 1.5
Carbon	0.05	0.05 - 0.15
Manganese	0.35	1.0 max
Iron	0.48	3.0 max
Phosphorus	0.009	0.03 max
Sulfur	0.002	0.015 max
Silicon	0.07	1.0 max
Copper	0.01	0.50 max
Titanium	0.34	0.60 max
Nickel	Remainder	Remainder

Section	Orientation	Absorbed Energy (ft.lb)	Percent Shear (%)
Dark Blue	Longitudinal	110	100
		101	100
		101	100
	Transverse	79	100
		91	100
		107	100

CVN @ 0C

Creep Testing



Timeframe Recap

- Week One
 - First Inquiry
 - Meetings & Printability Assessment with Lincoln Electric
 - Determined code case and API guidance
- Week Two
 - Risk Assessment, supported by review of Lincoln and Industry Data
 - Visit to Lincoln, review QA/QC and manufacturing
 - Initial Mechanical Results, Surface Roughness, and FEA model
- Week Three
 - Hydrotest, PAUT, and RT on test piece
 - Grinding & photography of surface indications
- Week Four
 - Delivery of subsequent parts for final machining, inspection, & installation



Conclusions

- We have shown successful delivery of large scale WAAM pressure components on a 4 week timeframe.
- We have successfully completed API 20S AMSL 3 qualification of the delivered parts, along with ASME 3020 code case qualification.
- Inspection techniques such as UT and RT will require modification and qualification if used on as-printed WAAM surfaces.
- In this case we did not require fully machined surfaces, but for future applications this could pose a bottleneck to the rapid delivery of AM parts.



Weld Metal Use in Nuclear Applications

- » Decades of in-service use with “weld metal”
 - DED is within the range of heat input and feedstock used, just more precise
- » German KTA 3201.1, Part 1, Chapter 29 “Shape Welding”
 - A533 grade B, Class 1 or A508 Class 1
 - 8 MnMoNi 5 5 and 10 MnMoNi 5 5
- » AP1000 requires “weld metal buildup”
- » BWR recirc “overlay” repairs for added pressure



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