What's New in Weld Metal Additive Manufacturing

National Board

May 15, 2023

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Outline

- Background
- Use Cases
  - Equipment
  - Piping System
- What this means to AIs and Chiefs
- What this means to Owners and Insurers
- How to be ready (for the unexpected)

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A Little Background

LARGE SCALE

Additive Manufacturing

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Who am I?

- Welding Nerd for 30+ years
- Materials and welding
- Research and applications
- Codes and Standards
- Now involved in many additive programs
  - AWS, ASME, API, ISO/ASTM, MIL, IIW, ABSA, NRC, DOE, NBIC
- Welding Advisor to the BOT

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Who is Lincoln Electric?

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

- 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

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What Lincoln Electric brings to Additive Manufactuing

Vertically integrated large-format metal AM service provider

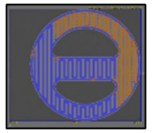
Metallurgy and Deposition Know-How

100+ years of arc welding innovation

Feedstock Production

U.S. Market share leader with presence in 18 countries

Advanced Process Control & Software



Inventor of industry-defining process control and AM software—SculptPrint™ OS

Automation Hardware & Robotics

A pioneer in robotic welding, with largest-part handling capabilities in the industry

Post Printing Machining & Fab

28+ years of Aerospace and Automotive machine & fabrication

24/7 Production
Low Volume, Replacement Parts, Rapid Turnaround

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What's in a Name: Additive Manufacturing or Welding?

Additive Manufacturing (Drama)

- 3D printing, DED, WAAM
- Parts are "builds"
- Uses "feedstock"
- "Black Box" machine
- Non-portable procedures
- Parameters still not well known
- Often not fully dense
- NDT techniques not well established
- Properties often not well understood

Welding (Boring)

- GMAW, GTAW, EBW, LW
- Parts are "weld metal"
- Uses welding electrodes
- Welding systems
- Portable procedures
- Established "variables"
- Fully dense weld metals
- NDT techniques well known
- Material properties well known

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The Process

- See Melfi Video 1

- Click this link:
- https://www.nationalboard.org/Index.aspx?pageID=1552

Use Today . . . and Specifications

- API 20S (in use, and being updated)
- AWS D20.1 (in use, and being updated)
- Navy Technical Publication (in use, and being updated)
- ASME
  - Section IX QW-600 to publish in 2023
  - Section VIII, III, B31, B16 (in committee / ballot)
  - NBIC, ABSA, TSSA, etc in development
- ISO / ASTM

- Weld metal buildup has been used for decades
  - See http://www.sperkoengineering.com/html/Additive.pdf

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Use Case

Old Machinery

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Case Study –Bearing Housing

- Cracked Flange
- Pre-WWII Part
- No Prints
- 3D Laser Scanned
- Modifications in CAD
- Printed
- Machined
- Put into service

All this in 2 weeks !!

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As-received Part (actually, an assembly)

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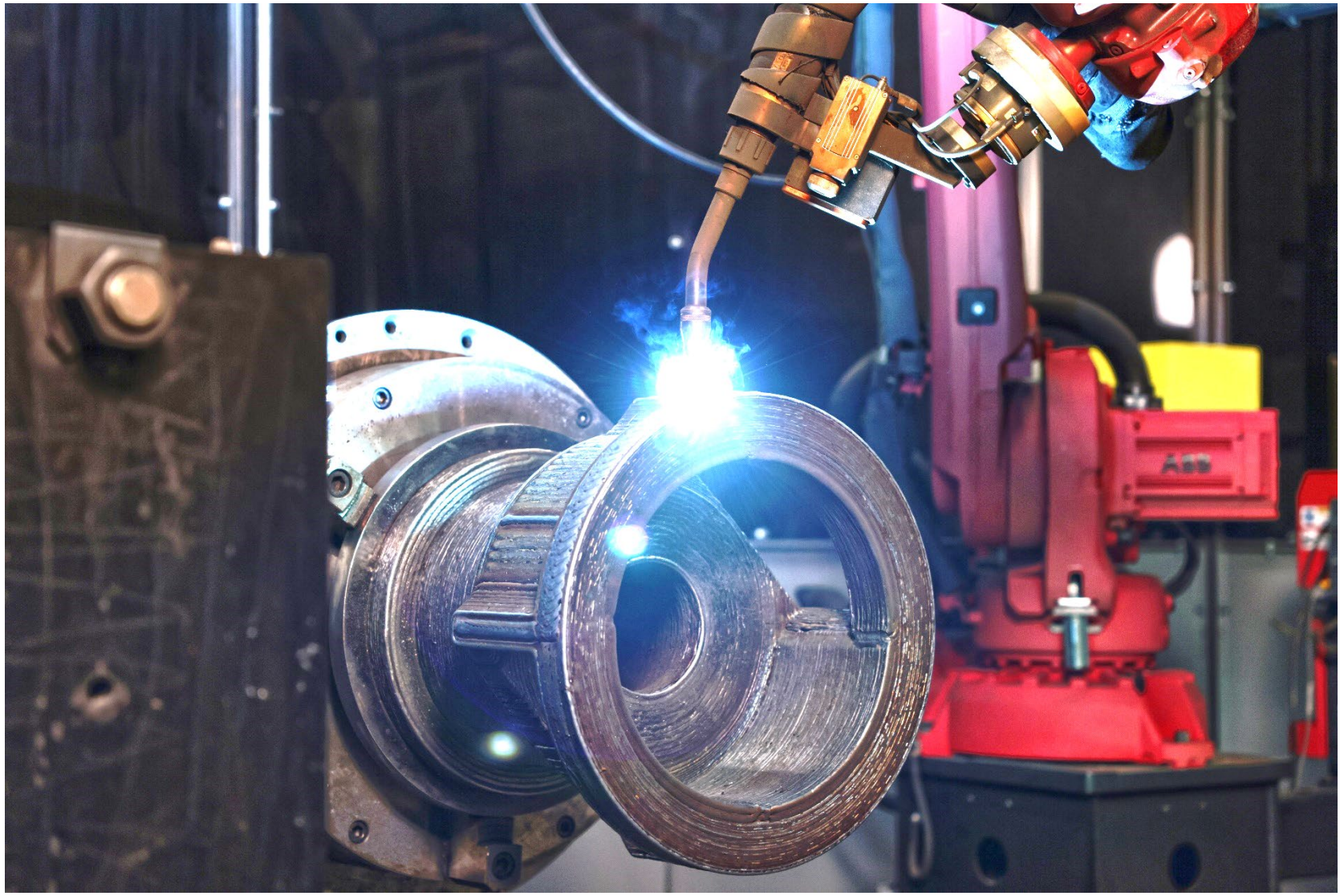
Create 3D CAD File (Model)

- See Melfi Video 2

- Click this link:
- https://www.nationalboard.org/Index.aspx?pageID=1552

Printing Part



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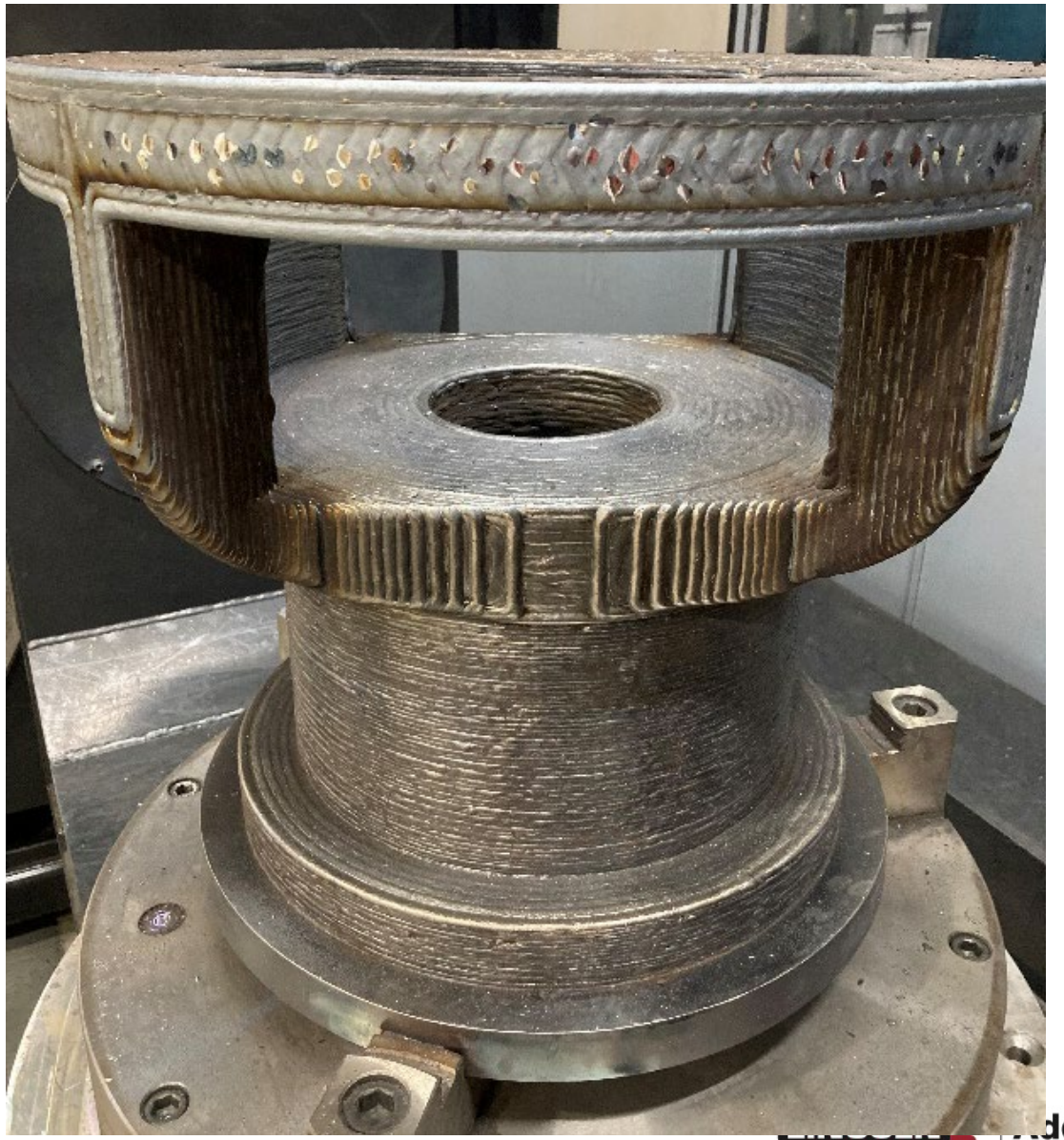

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Replacing Castings and Forgings – Lincoln Use Cases

1930's machinery—
mixer blade
Low carbon steel
1,100lb (500kg)
Conformal cooling
channels vs. gun
drilled holes

Extrusion Cylinder
High-strength
low-alloy steel
8,000lb (3,600kg)
3D Printing—6 weeks
Forging—6 months

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Use Case

617 Ni-alloy

High temperature, pressure retaining

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

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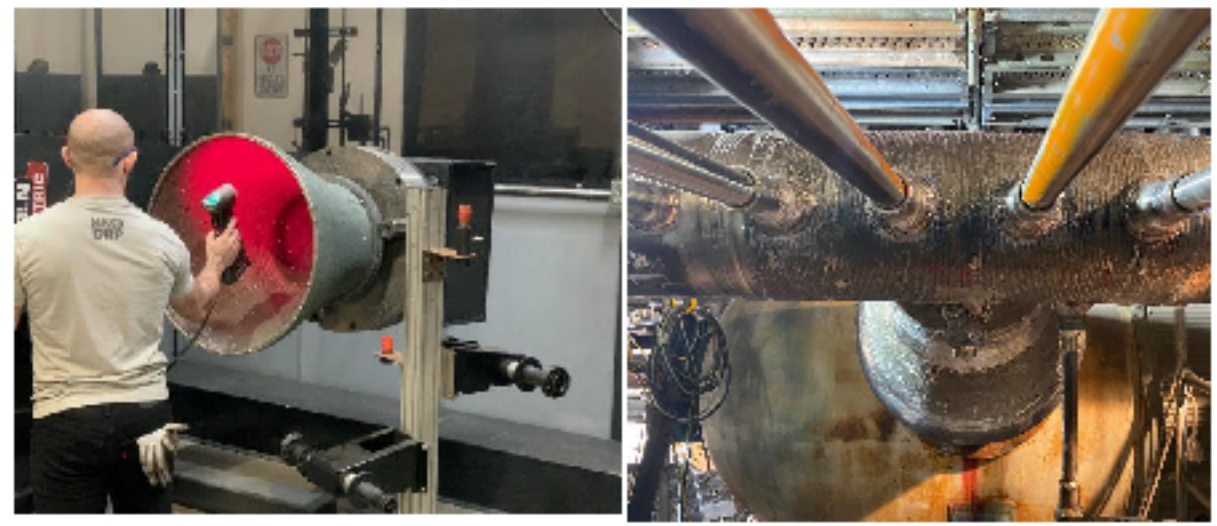
A Refinery 3D Printing Success Story

- 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

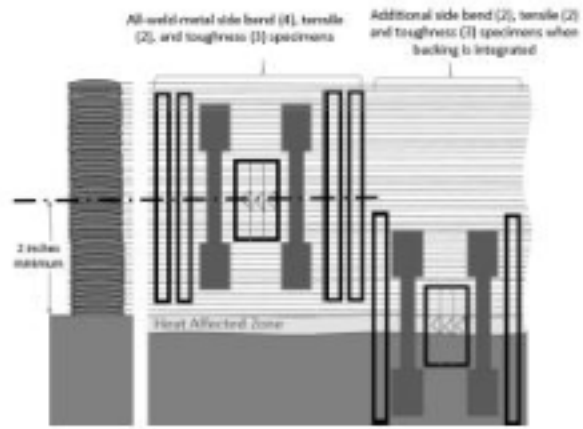


(left) Digital part verification, (right) Final Installation

ASME 3020 Qualification

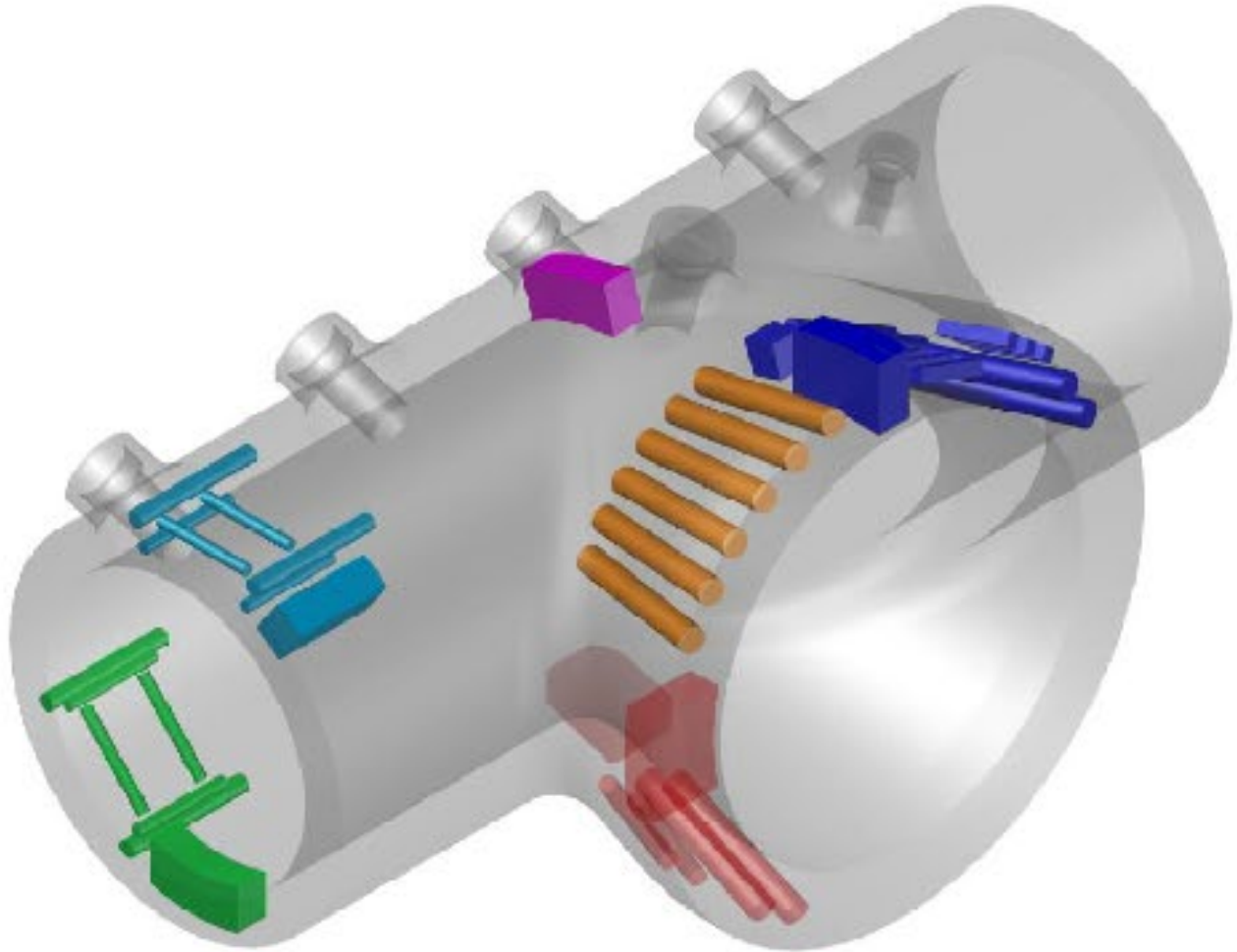
Cooling Rate	Wall Thickness	Yield Strength	Ultimate Strength
(type)	*(type)*	*(ksi)*	*(ksi)*
Slow *High Heat Input & High Interpass*	Thin	49.9	99.0
		51.0	100.0
	Thick	59.0	103.0
		60.5	102.0
		58.0	103.0
		58.0	102.0
		61.5	104.0
		58.0	103.0
Fast *Low Heat Input & Low Interpass*	Thin	57.0	96.5
		56.0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

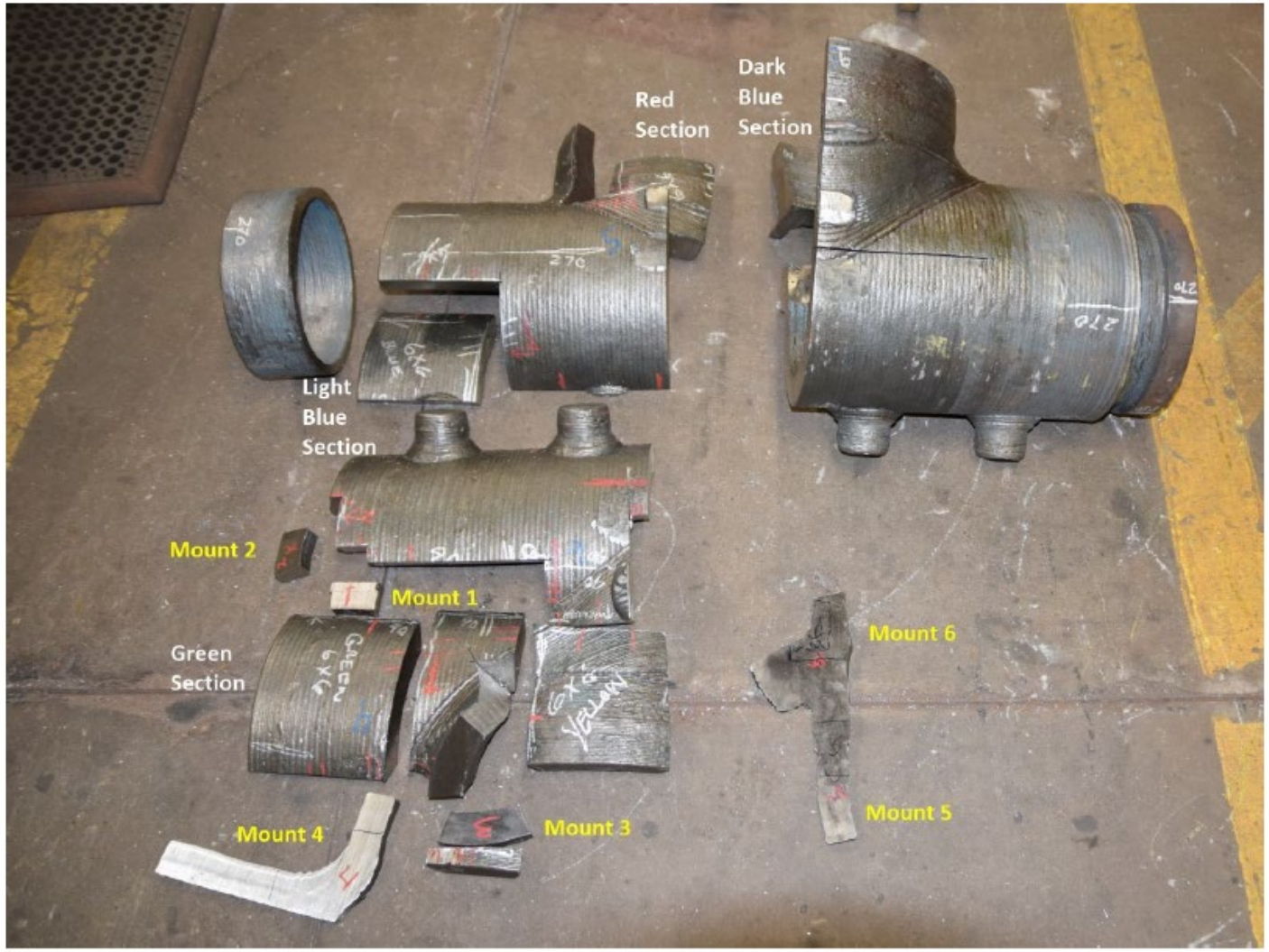
Figure 1
Specimen Locations for Layer Widths Less Than or Equal to $\frac{1}{2}$ in. (12 mm)



GENERAL NOTES:
(a) Weld specimen is shown with one bead per layer. Multiple weld beads per layer are permitted with the layer width and number of weld beads per layer qualified in accordance with Table 2.
(b) Three Charpy V-notch toughness specimens shall be located with the notch at approximately $\frac{1}{16}$ in. (2 mm) from the edge of the weld beads.
(c) With integrated backing, an additional three Charpy V-notch toughness specimens shall be located with the notch within the heat-affected zone.
(d) Full-width bend and tensile specimens shall be tested and examined.
(e) The order of specimen removal is not mandatory.

Specimen Locations from Sacrificial Article

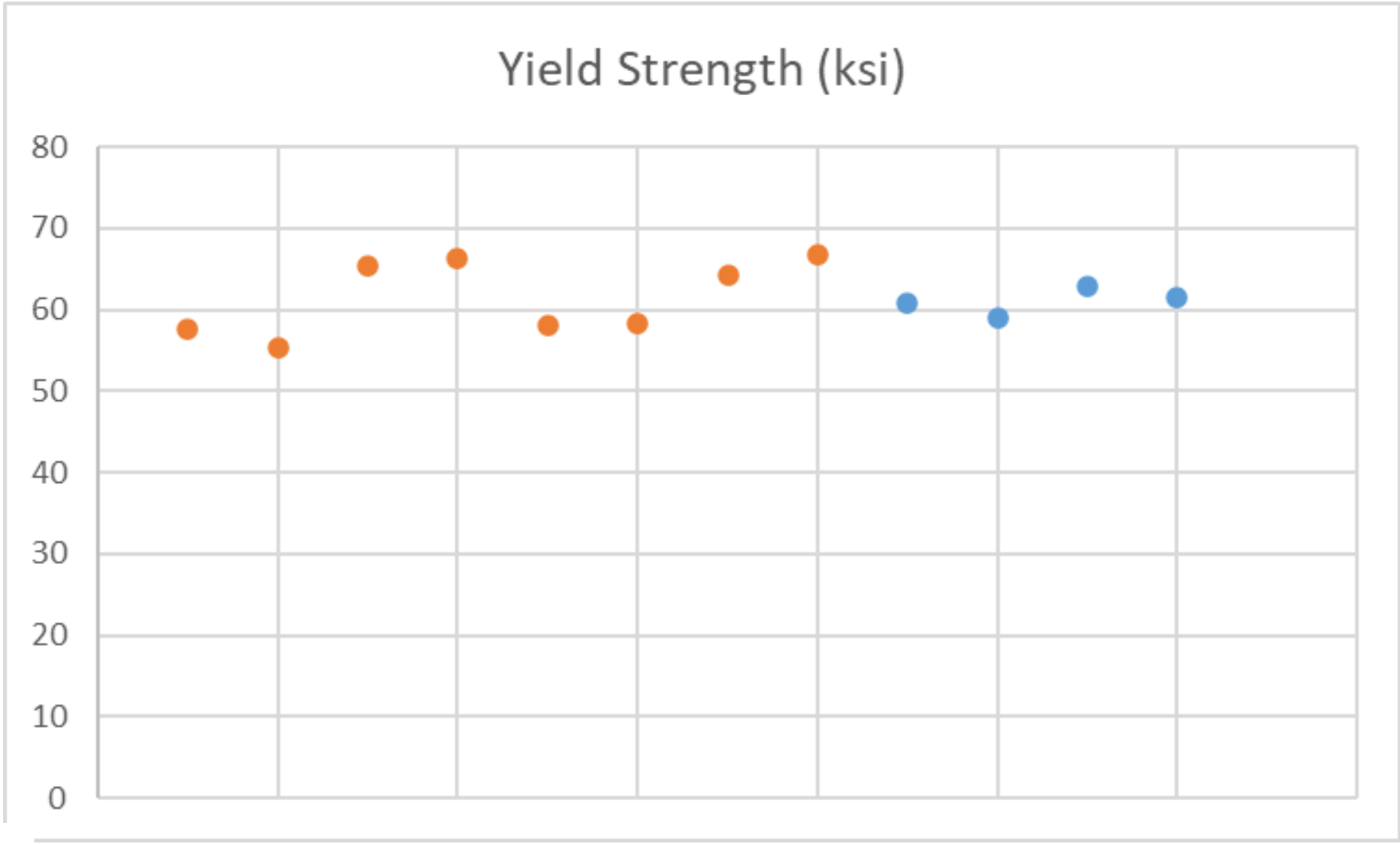




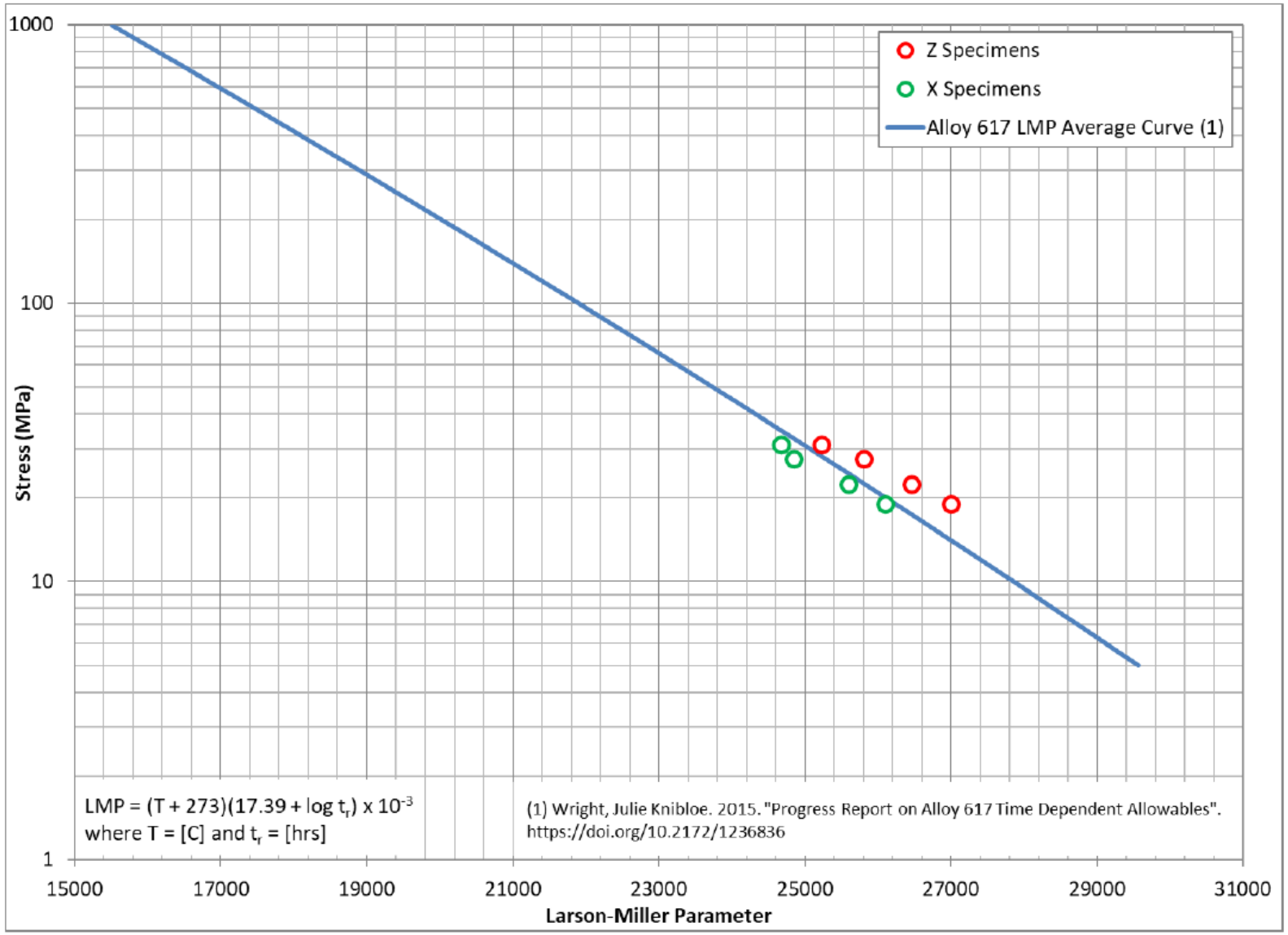
Tensile Testing from Sacrificial Part

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



Creep Testing



What this Means for Authorized Inspectors and Chiefs

Today

- Piping systems might contain this material
  - May not be obvious by appearance
  - Treated in B31.3 as an unlisted material

- Installation by welding
  - Mild, low-alloy and stainless steels are assigned P-No in Section IX
  - Based on the filler used to make the part
  - Nickel and other alloys will be in 2025

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By Year-end ???

- Section VIII code case
- Section III code case
- B16 code case

- The weld metal part is treated as material, not a component
  - Generally similar rules to forgings, etc.
  - MTR would be more extensive
  - Part stamping, testing, etc. would not change

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Chiefs

- Expect State Specials or variance requests until NBIC and ASME catch up
- Extensive data packages until rules are set in Section VIII, III, I
- Generally FEA to determine allowable flaw sizes
- Design, material and installation don’t really change

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What Owners and Insurers can do Today

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How does this help industry

- Lots of cool stuff
  - Easier and faster installation
  - Dissimilar metal welds (transition pieces)
  - New designs
- Reduce material waste
- Part consolidation
- Less inventory of spare parts

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The Biggest Driver Today—TIME

Reduced

Lead time (new parts)

Downtime (replacements)

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Identify trouble spots

- Work with operations, maintenance, procurement
- Identify:
  - Troublesome parts
  - Troublesome materials
  - Troublesome vendors

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Create a “Digital” Inventory

- Scan parts/assemblies that don’t have prints
- Look at inventories and wanna-have inventories
- Set up relationships with additive manufacturers

➔ *Have your part and equipment suppliers do the same*

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Be Ready to Move

- Before the unexpected happens…
  - Send prints and material requirements for pre-qualification
  - Set up and qualify AM vendors (audits, purchasing system, etc.)
  - Provide your qualified AM vendor list to your part and equipment suppliers—they need to be prepared just as much as owner operators!

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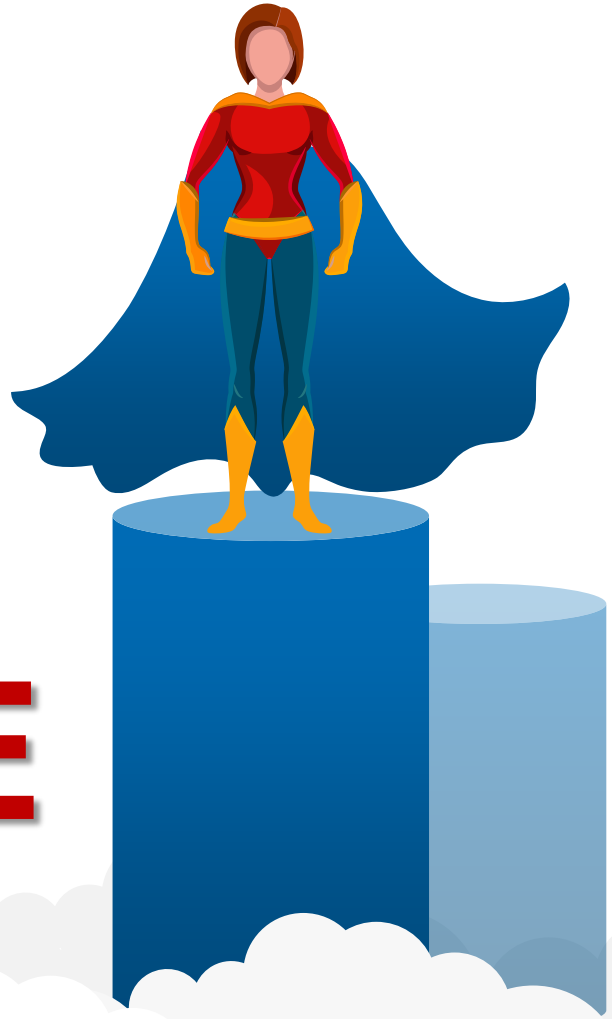
BE THE HERO

When you

REDUCE DOWNTIME



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