NAVAL NUCLEAR LABORATORY | Technology

Certification of the First Powder Bed Fusion Component in the US Naval Nuclear Propulsion Plant

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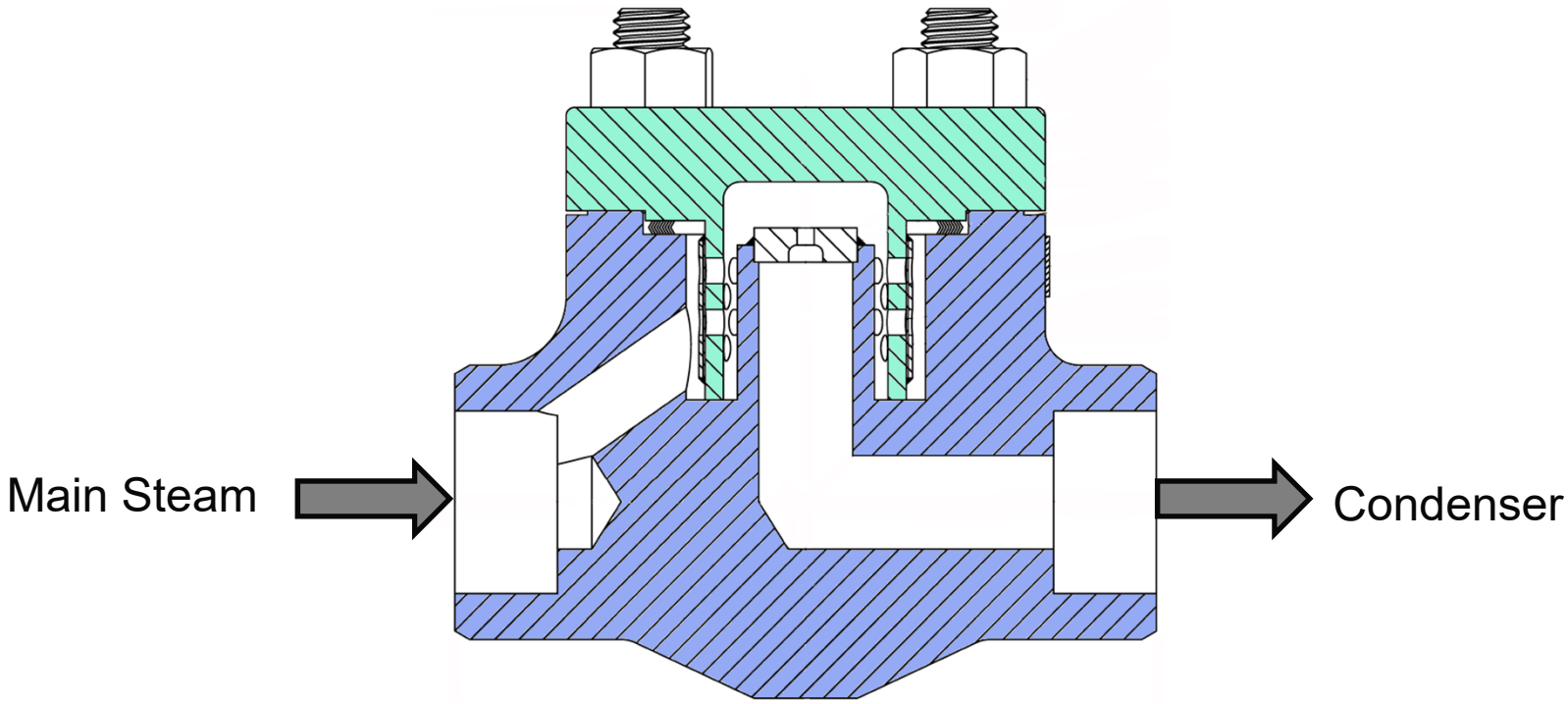
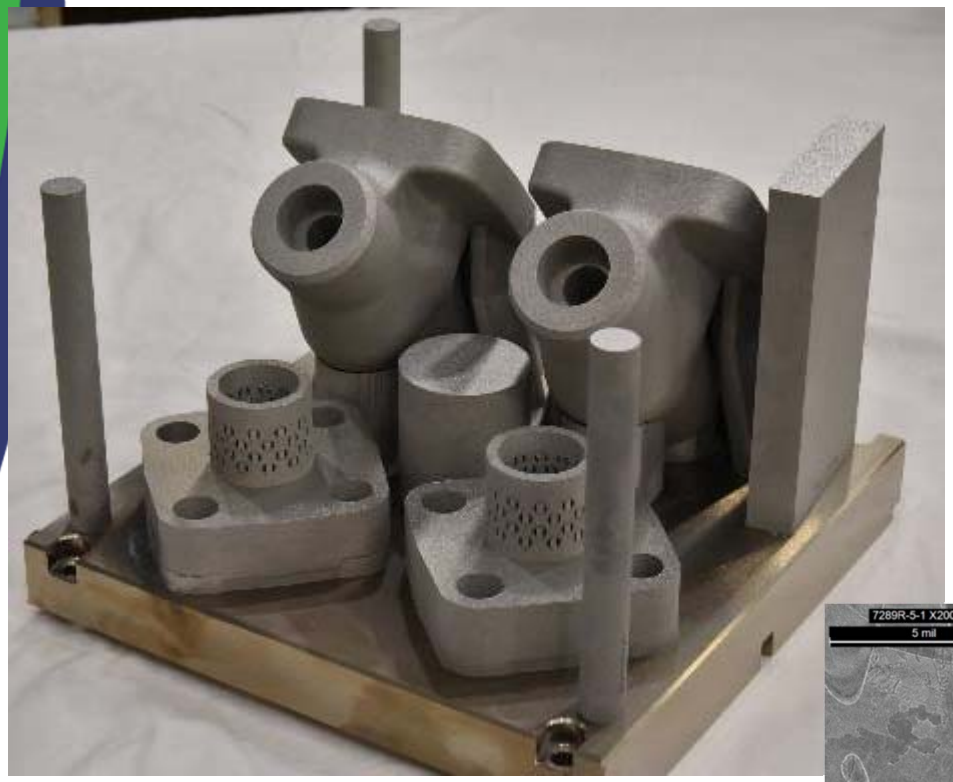
Purpose

- First attempt to make AM hardware suitable as a pressure boundary component for submarine propulsion plant operation.
- Step through manufacturing and inspections to identify administrative or technical roadblocks.
- Familiarize designers, pressure equipment safety, and quality groups with new material form.



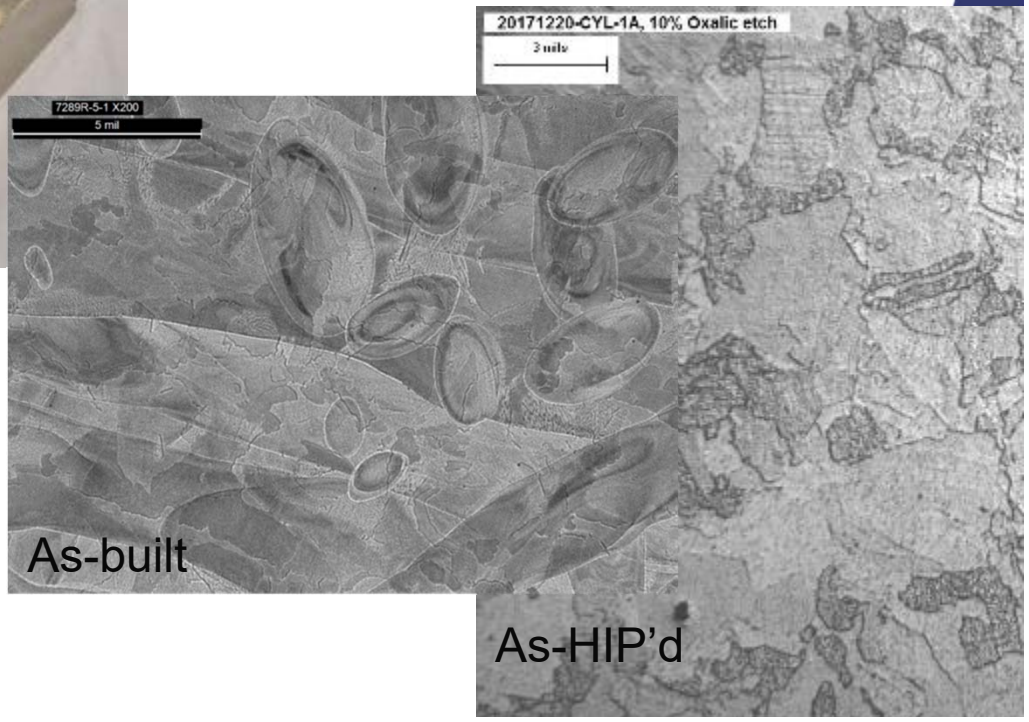
316L Material Processing



NNL
20 µm standard
EOS M290

External Vendor
40 µm proprietary
EOS M280

HIP Cycle
>1900°F, 2 hr, min.

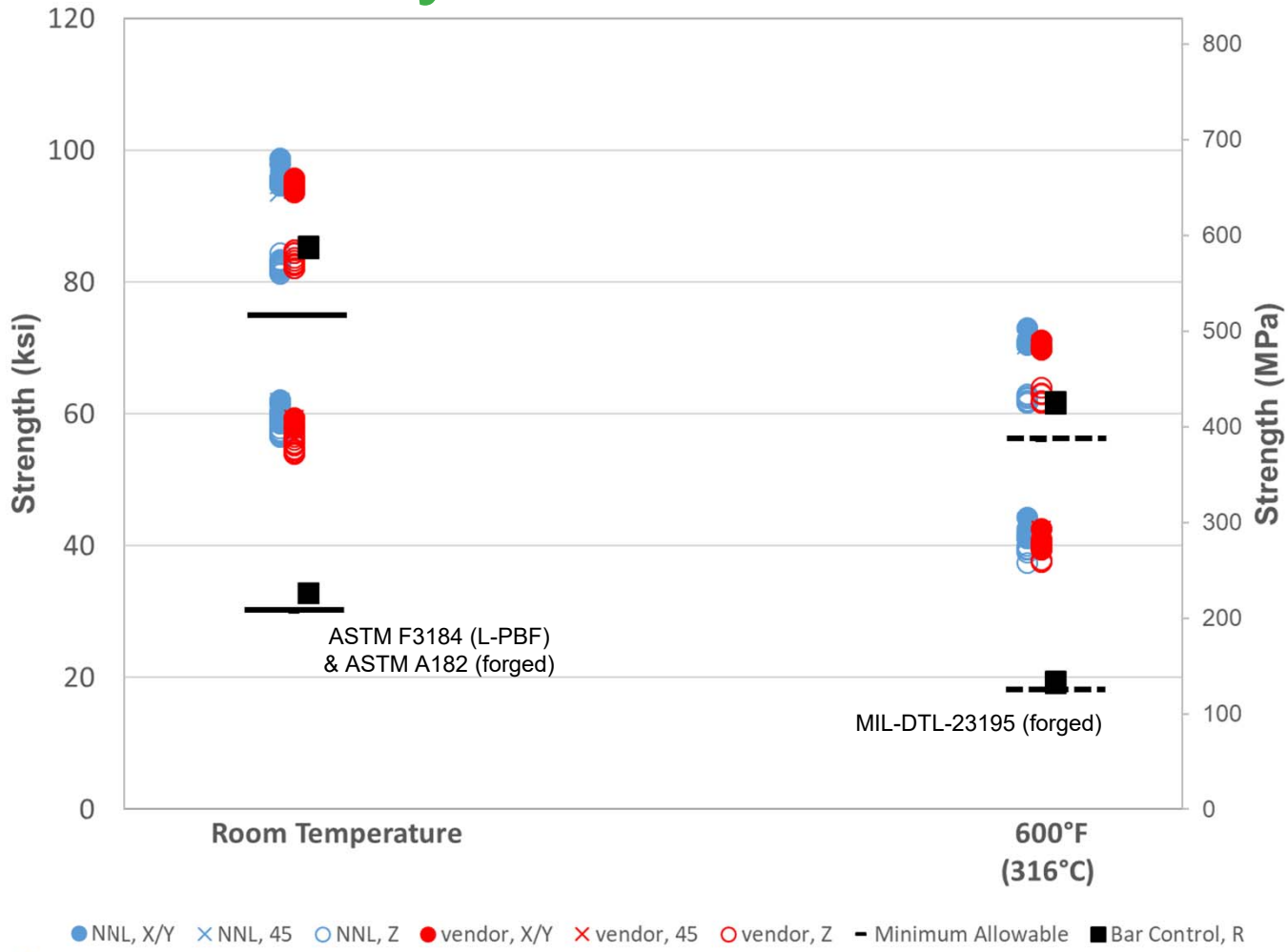


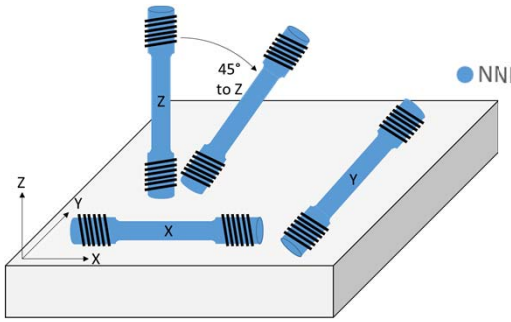
Acceptance Testing

- Geometric equivalence
- ASTM A182 strength, ductility, composition, and intergranular attack resistance
- Density
- Fatigue Crack Growth Rate Screening
- Charpy & Fracture Toughness Screening
- Weldability
- Hydrostatic Test
- Shock & Vibration Test
- Prototypic Steam Test

Certification testing happened in parallel with a large materials development program.

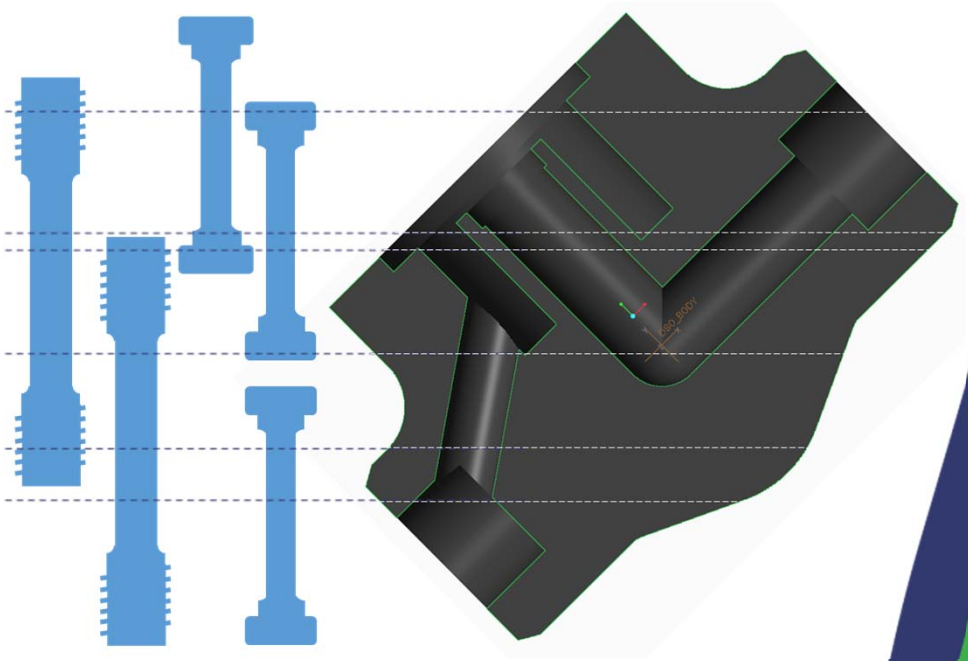
Tensile Summary

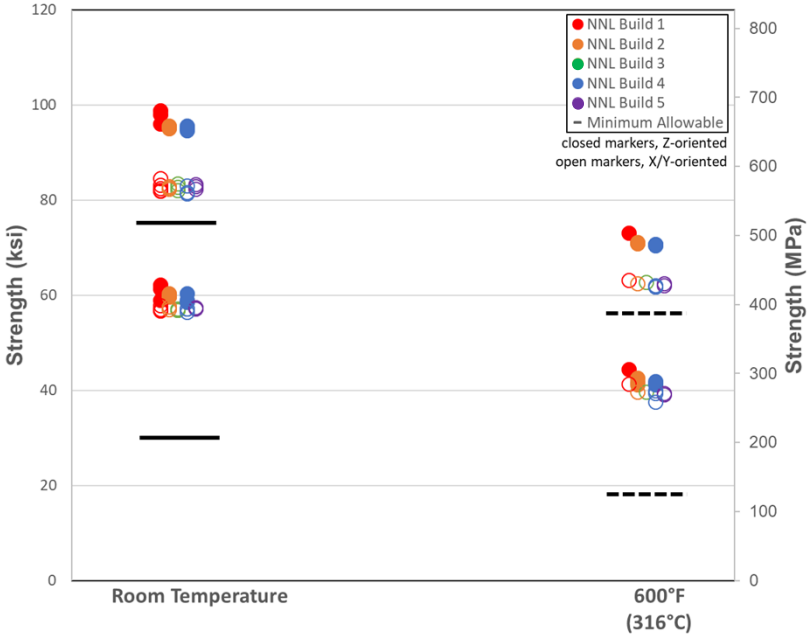




Process Knowledge Gained

- NNL Build 1 had many interruptions due to balling and excess powder supply.
- Microscopy, radiography, & mechanical data suggest the build was successfully recovered each time.





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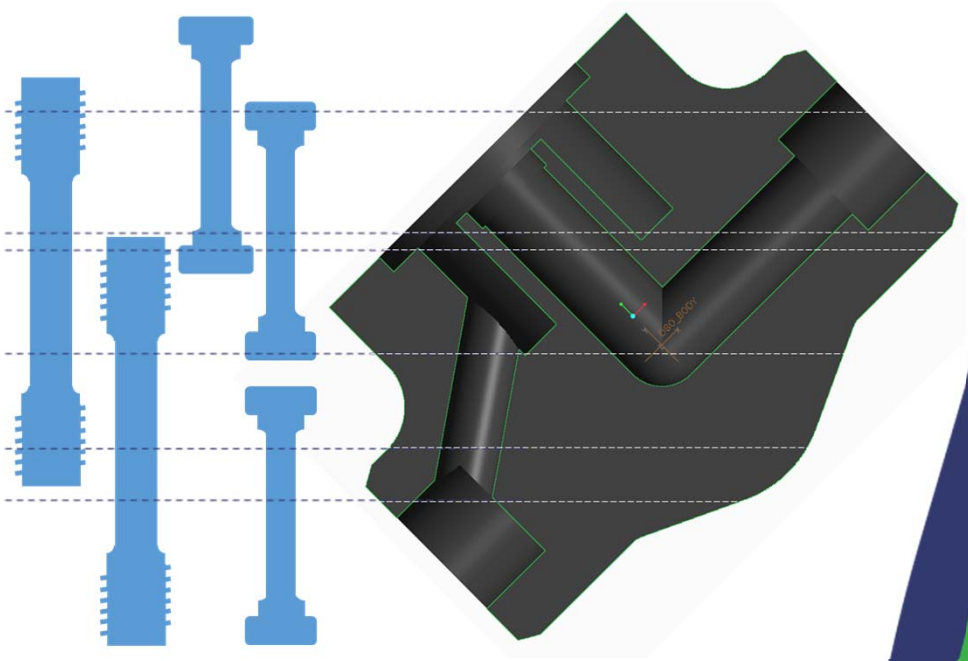
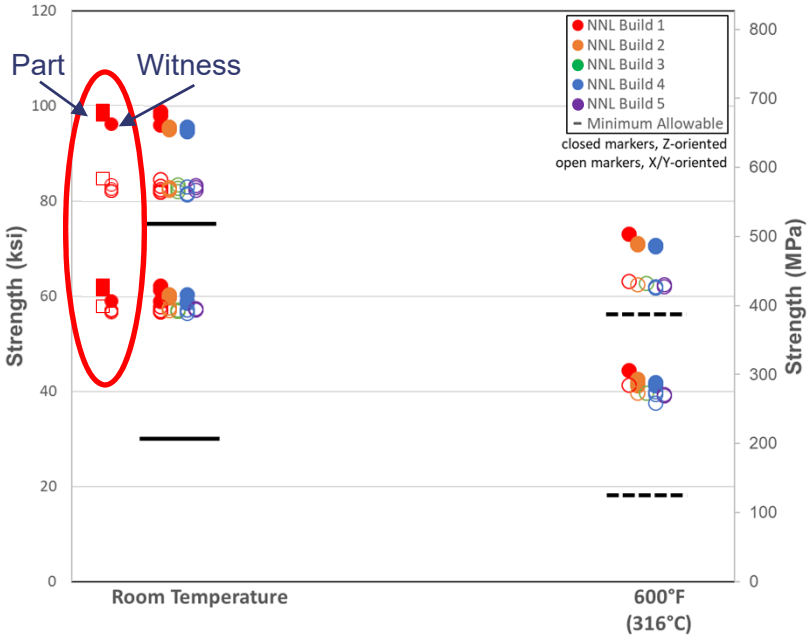
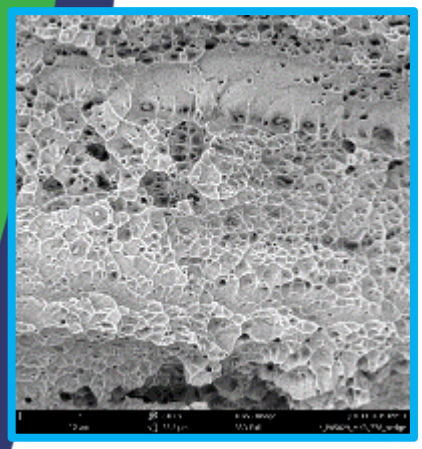
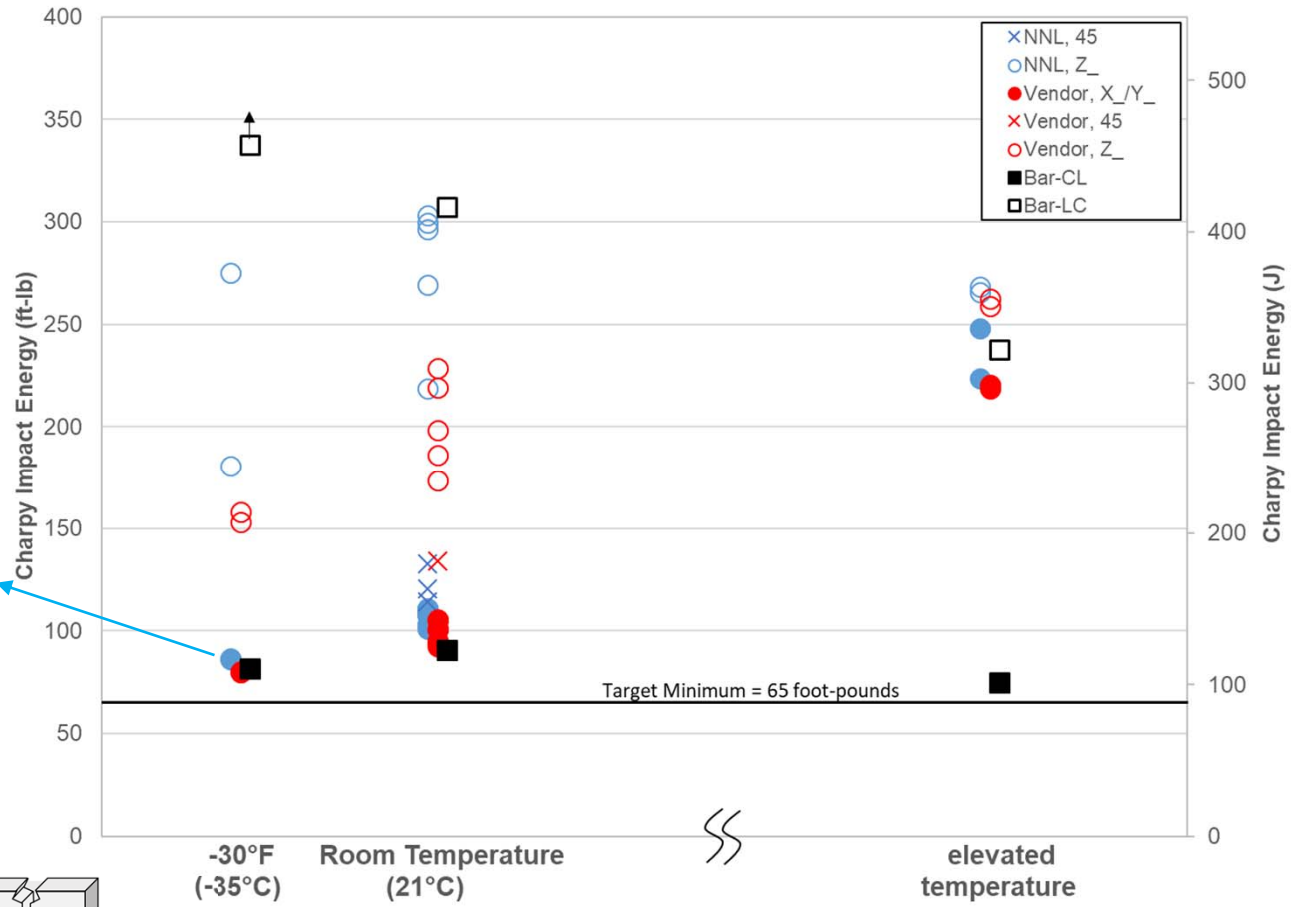


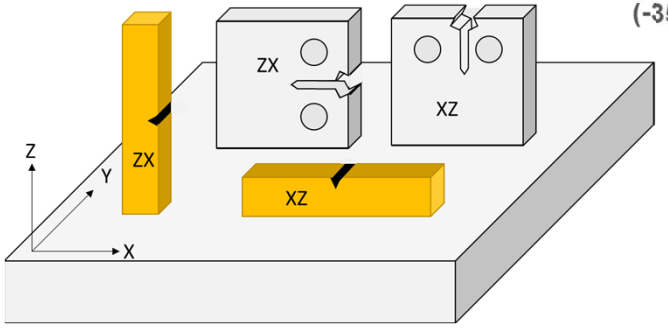


Part appears stronger and less ductile than witness coupons, though differences were small.

Impact Energy & Toughness Summary

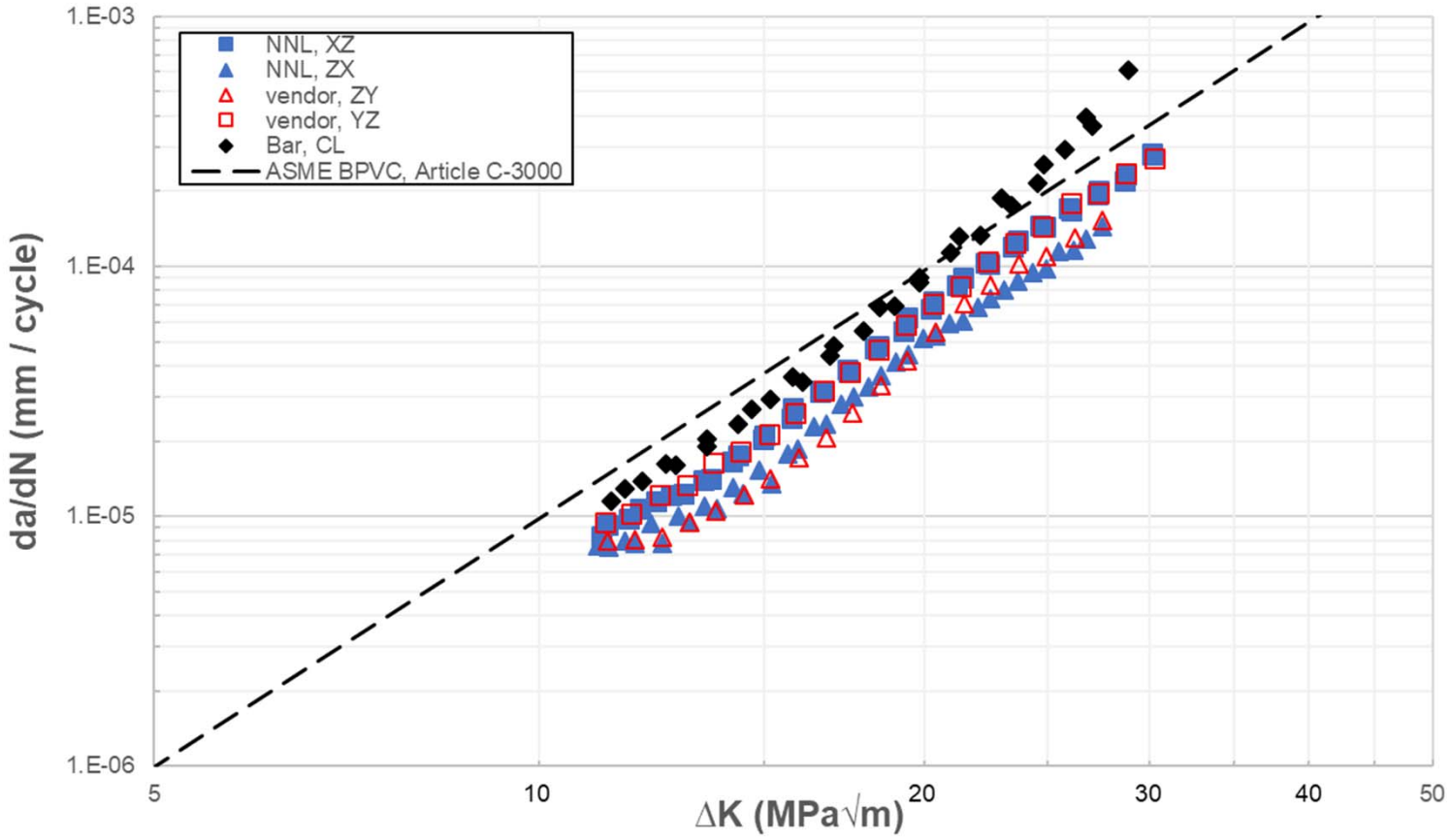






J-integral testing at room temperature also revealed high toughness of L-PBF materials (>2600 in-lb/in^2 or >455 kJ/m^2).

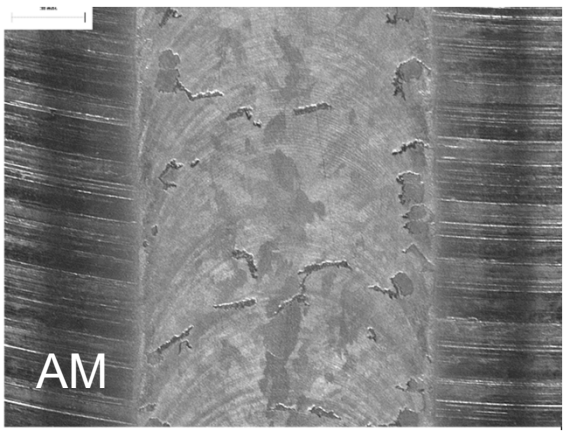
Fatigue Crack Growth at elevated temp.

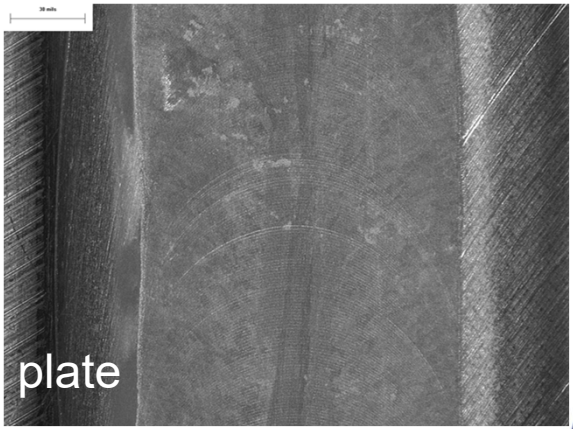


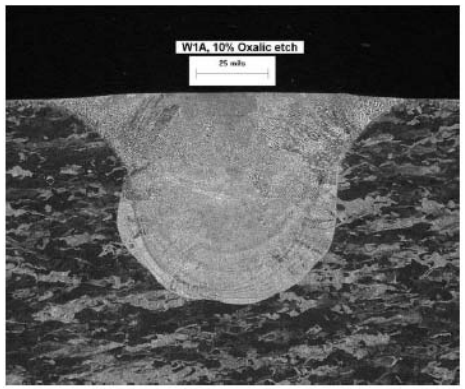
AM Weldability Trial: autogenous GTA

Bead on plate at same conditions

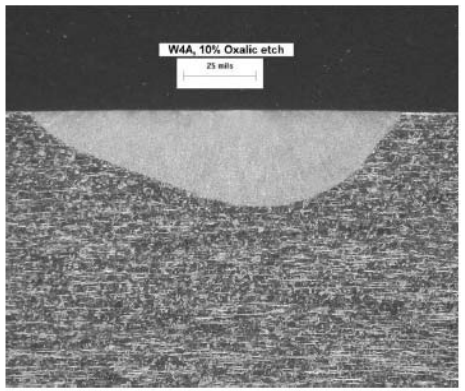
Increased penetration in AM material, likely due to increased O content (540ppm vs. <10ppm)







Transverse



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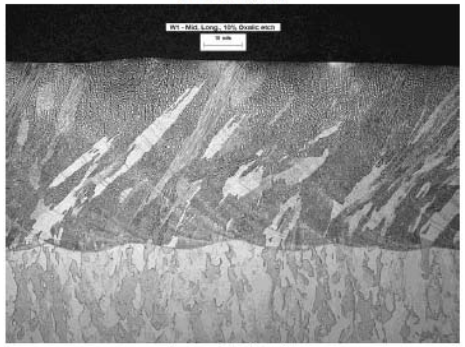
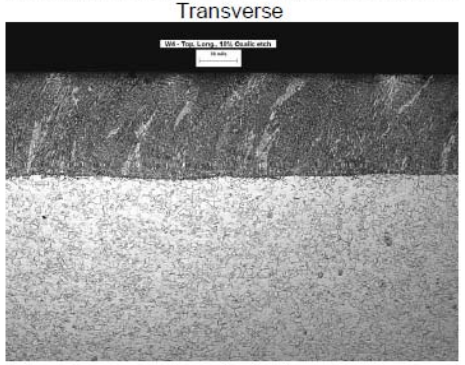


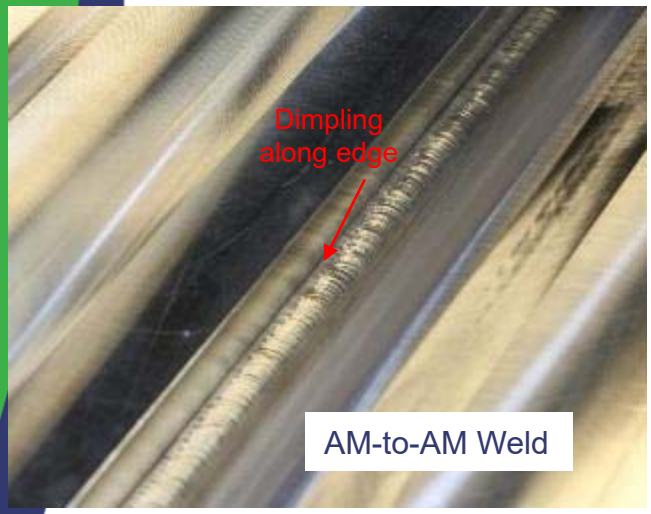
Longitudinal



Longitudinal

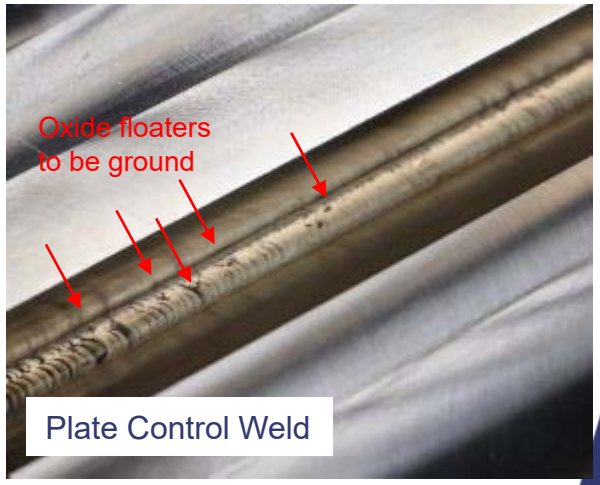
Autogenous welding acceptable for strainer assembly.

AM Weldability Trial: wire-fed GTA

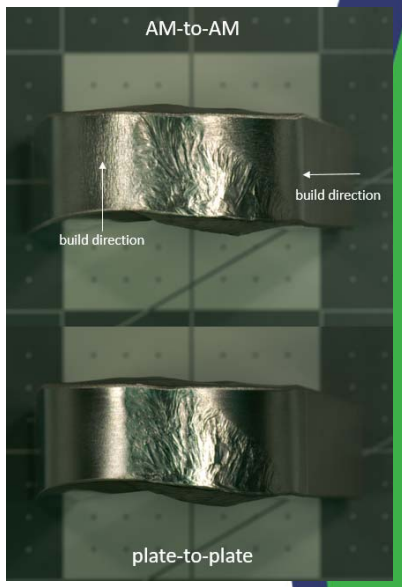


8” long butt joints using AWS-ER316L wire

Welded in accordance with NAVSEA procedure



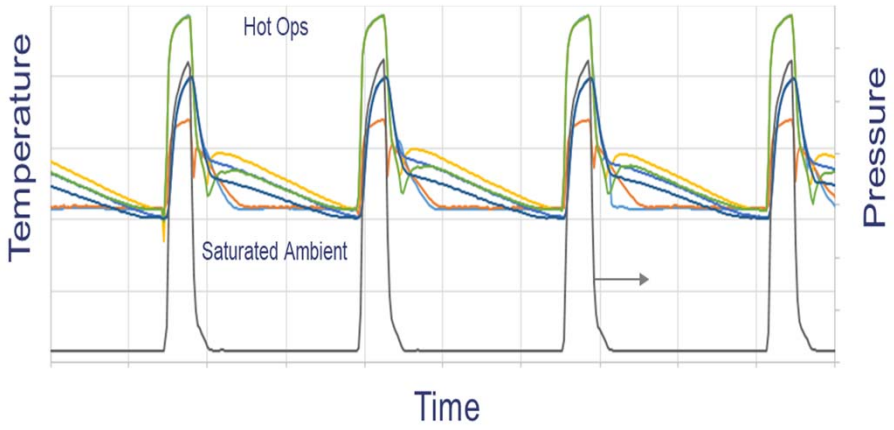
	AM (vert) to AM (horiz)	AM (horiz) to plate	AM (vert) to plate	Plate to plate
Weldable?	none			
Radiography & Penetrant Indications?	none			
Tensile Strength --failure location	81 & 81 ksi (558 MPa) AM (vert)	90 & 92 ksi (621 & 634 MPa) Weld	83 & 83 ksi (573 MPa) AM (vert)	92 & 93 ksi (634 & 641 MPa) Weld
20% Bend	no defects			
Charpy HAZ	> 100 ft-lbs (>136 J) propagation along epitaxy >150 ft-lbs (>203 J) propagation across epitaxy			> 150 ft-lbs



Component Testing

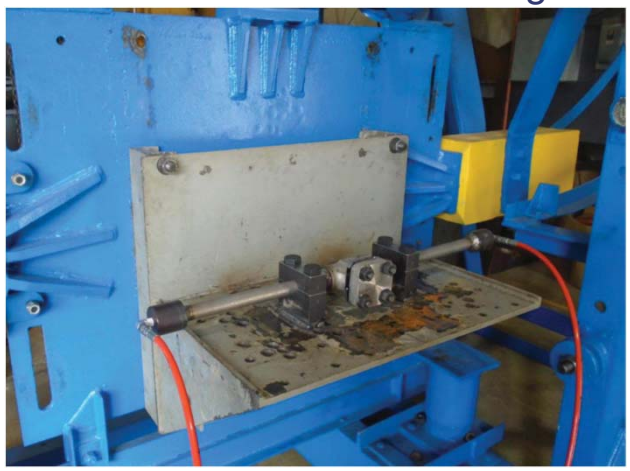
Prototypic Steam

Simulate 1000's of start-up / shutdown cycles and 100's of hot operational hours. Parts did not exhibit cracking or erosion.



Shock & Vibration

Expose DSOs to typical fleet shock loads and worst case vibration frequencies while pressurized. Parts did not leak and were not damaged.



Proof Test

Pressurized to >4.5 times the ASME Group 2.2 maximum allowable working pressure (2160 psig) before leaking at gasket.

Summary

- A focused, case-basis certification plan and final data package was approved by NAVSEA.

Approved in August.

Installed in September.

Steaming in October.

- Subsequently ran a multi-site Design Challenge to encourage adoption by design engineers.