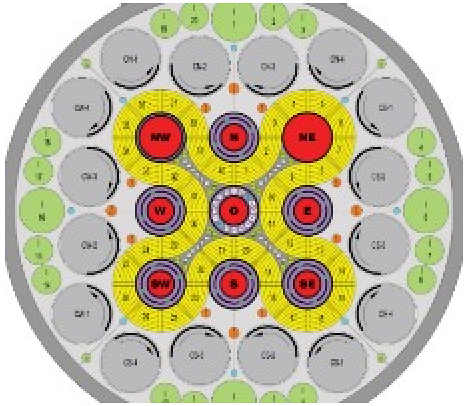
Irradiation Testing of Materials Produced by Additive Friction Stir Manufacturing



U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Irradiation Testing of Materials Produced by Additive Manufacturing

OVERVIEW

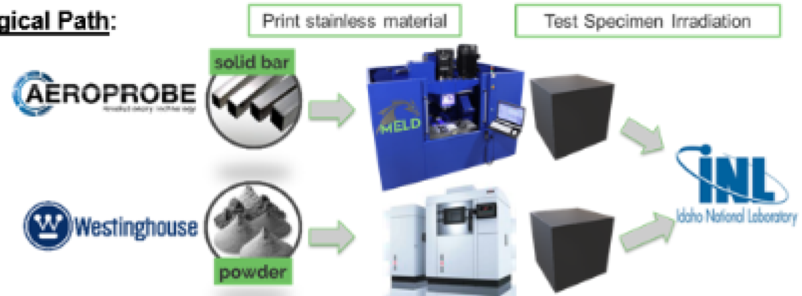
Purpose: The purpose of this work is to perform irradiation and post-irradiation examination of materials produced by the MELD process and laser powder bed additive manufacturing. MELD is an innovative, disruptive, and potentially transformative solid-state thermomechanical process that was recently pioneered and demonstrated by Aeroprobe. To use this technique for fabrication of Light Water Reactors (LWR), Small Modular Reactors (SMR) and advanced reactor internal components, it is necessary to evaluate the effect of irradiation on the material properties, which is the main goal of this project.

Objectives:

- Fabricate stainless steel test specimens via the MELD and laser powder bed AM processes.
- Create a baseline for stainless steel material properties manufactured by these AM processes.
- Expose stainless steel specimens to irradiated environment
- Evaluate the irradiated material properties and compare to baseline.

IMPACT

Logical Path:



Outcomes: The results of this work will begin to provide data needed by design engineers to utilize additive manufacturing methods in their current and future designs. It is expected that the investigated additive manufacturing processes will have an effect on the deposited material. This work will identify the potential benefits of additive, as well as the possible challenges that will need to be overcome to truly realize the utilization of additive manufacturing for the use of reactor component fabrication.

DETAILS

Principal Investigator: Chase D. Cox, Ph.D.

Institution: Aeroprobe Corporation

Collaborators: Westinghouse, INL

Duration: 3 years

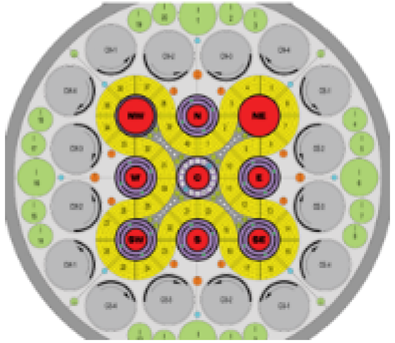
Total Funding Level: $408,549

TPOC: Bruce Landrey

Federal Manager: Tansel Selekler

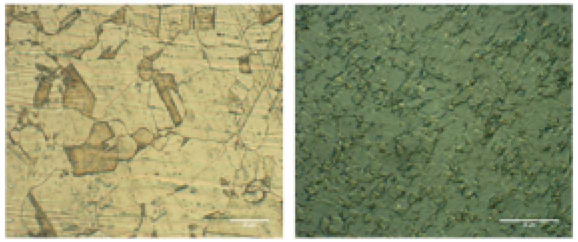
Workscope: NSUF-1.2

PICSNE Workpackage #: NA-18010601



RESULTS

Results: Materials fabricated by both processes have been prepared for analysis. This work will continue during the next reporting period. Below is an image showing a comparison of 316L stainless steel (left) as seen in plate and (right) fabricated via MELD. The refined microstructure may improve performance in an irradiated environment.



As-Received 316L   As-MELDed 316L

Accomplishments:

- Test Specimens for Irradiation tests have been fabricated
- Test capsule has been fabricated
- Test capsule is currently being irradiated

WOMAN-OWNED SMALL BUSINESS

MADE IN AMERICA

MELD Manufacturing Corporation

a wholly owned subsidiary of Aeroprobe Corporation

MELD Manufacturing Corporation, a Woman-Owned Small Business, is the inventor and sole-offeror of the MELD process, a patented and award-winning, large-scale metal additive technology.

Patent x 15

2018 R&D 100 WINNER

2019 GOLD WINNER – APPLIED TECHNOLOGY CLEAN MANUFACTURING

2018 WINNER – CREATE THE FUTURE CONTEST

2018 WINNER – INNOVATION AWARD

2018 R&D 100 WINNER – MARKET DISRUPTOR

2019 WINNER PEOPLE'S CHOICE – DOD MAINTENANCE INNOVATION CHALLENGE

2019 FINALIST – U.S. ARMY

Our experienced, passionate team has successfully developed MELD from concept to a mature process that is well positioned to bring an immediate and impactful benefit to the warfighter. We can enable the use of advanced materials, improve logistics, and bring this revolutionary technology to the fight.

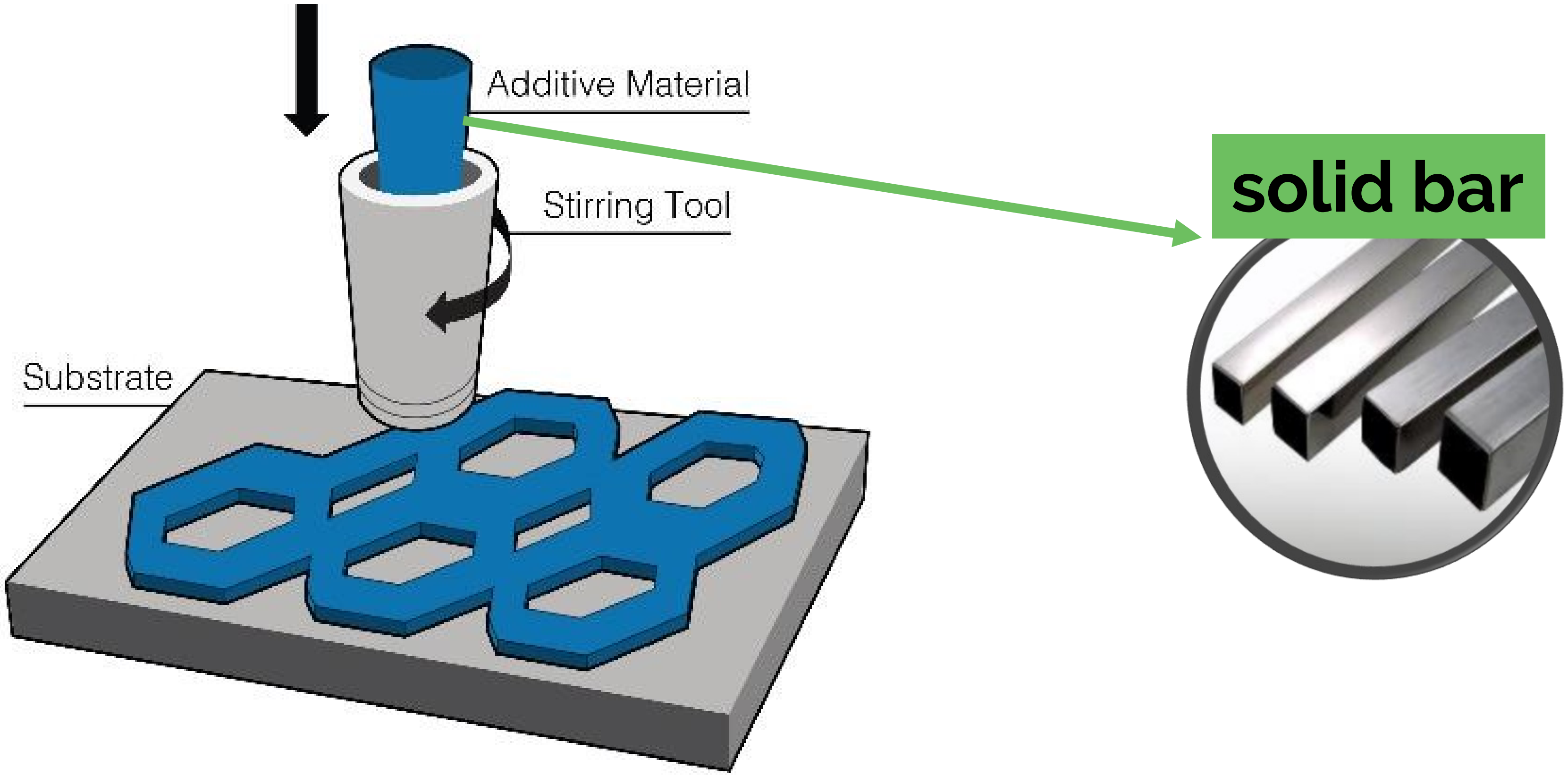
Presenter Contact Information:
Chase D. Cox, Ph.D., Director of Technology | Chase.Cox@MELDManufactuirng.com

What is MELD?

How does it work?

MELD: How it works

- The MELD tool and feedstock material are rotated while applying downward forces resulting in the plastic deformation and subsequent deposition of the feedstock material.

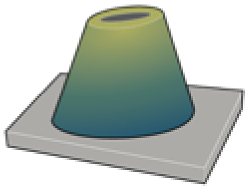


MELD More Than Additive Manufacturing

MELD is a solid-state metal deposition process used for:

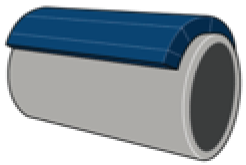
ADDITIVE MANUFACTURING

Make high quality near net shape parts at a high production rate



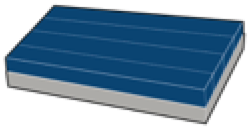
REPAIR

Repair even unweldable metals – from casting defects to equipment in the field



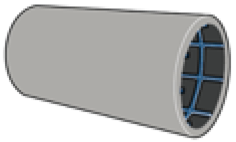
COATINGS

Protect parts with wear resistant coatings that will not delaminate



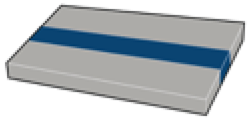
SECONDARY PROCESS

Open up primary manufacturing options by adding features after

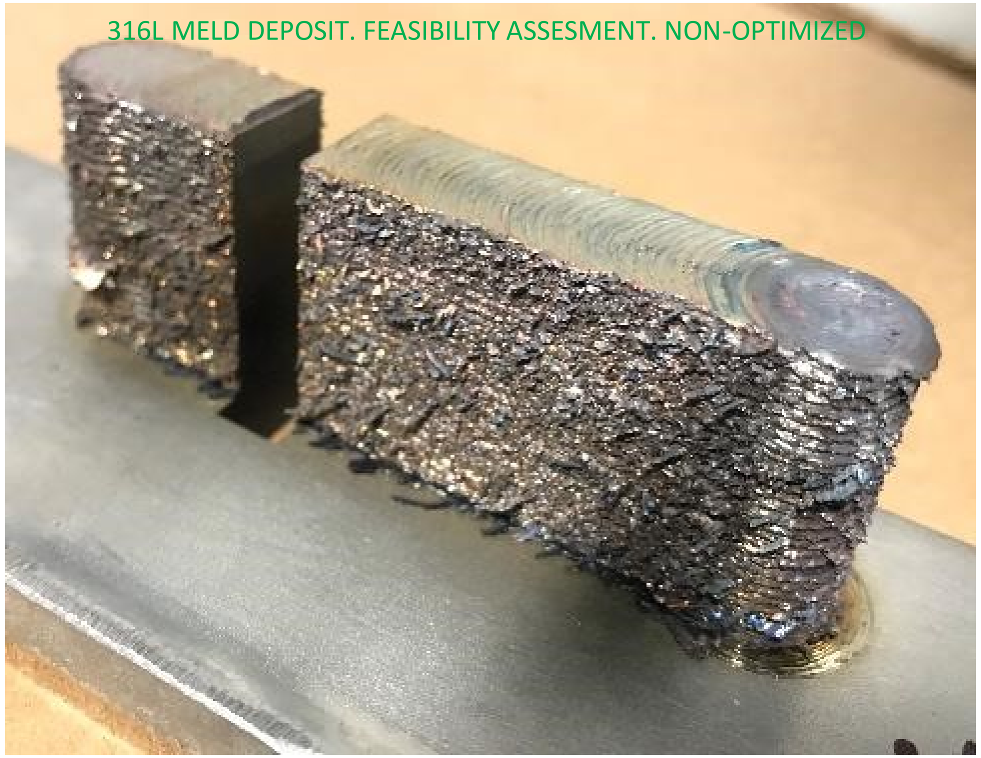


JOINING

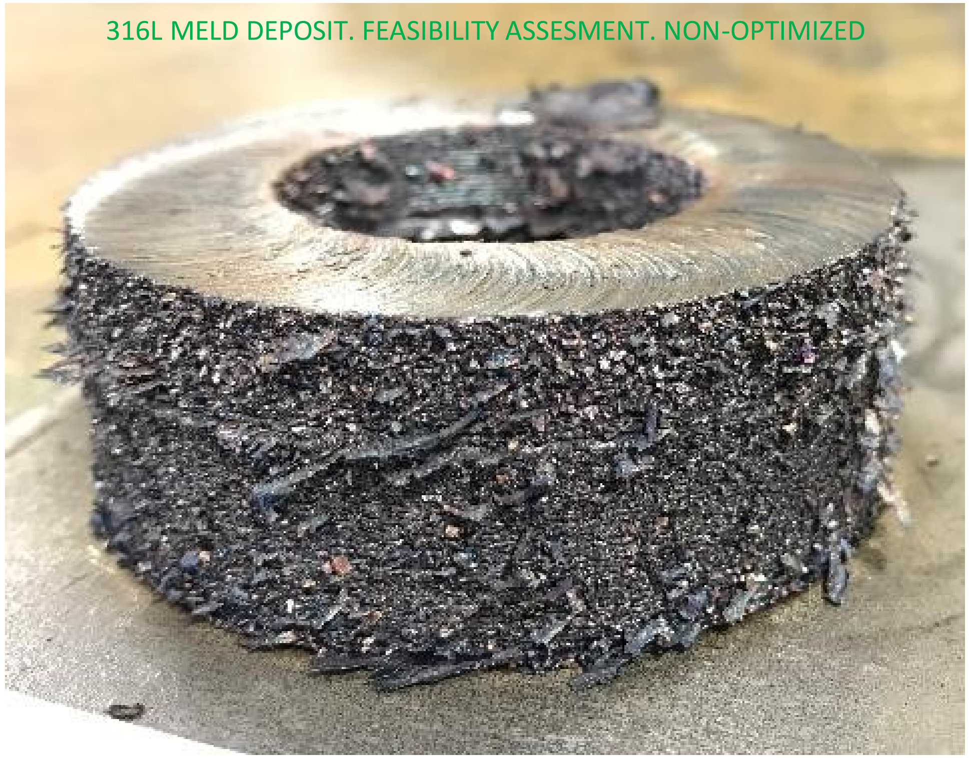
Join same or dissimilar materials



316L MELD Deposits: Linear and Cylindrical



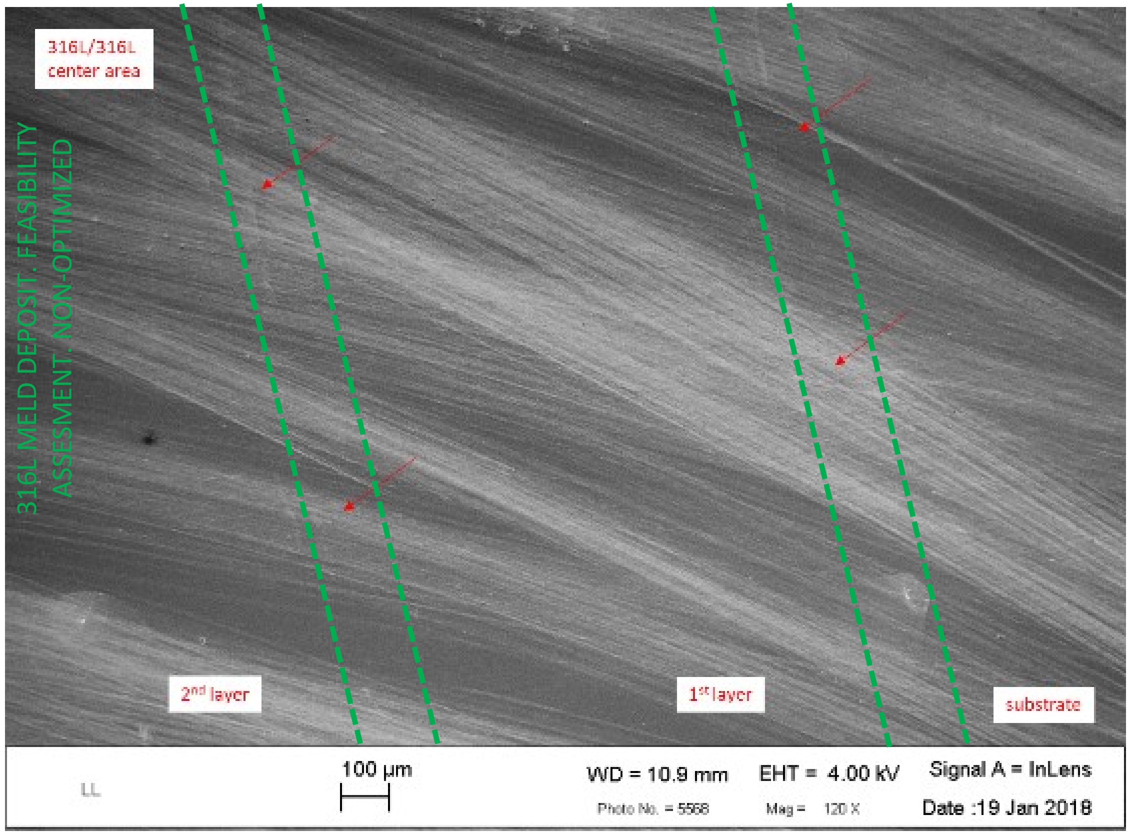
Linear deposit of 316L stainless steel. This MELD deposition is approximately 3 IN long x 1.1 IN tall x 0.6 IN wide.



Cylindrical MELD deposit of 316L stainless steel. The OD of this specimen is 2.6 IN, the ID is 1.3 IN and the overall height is 1 IN.

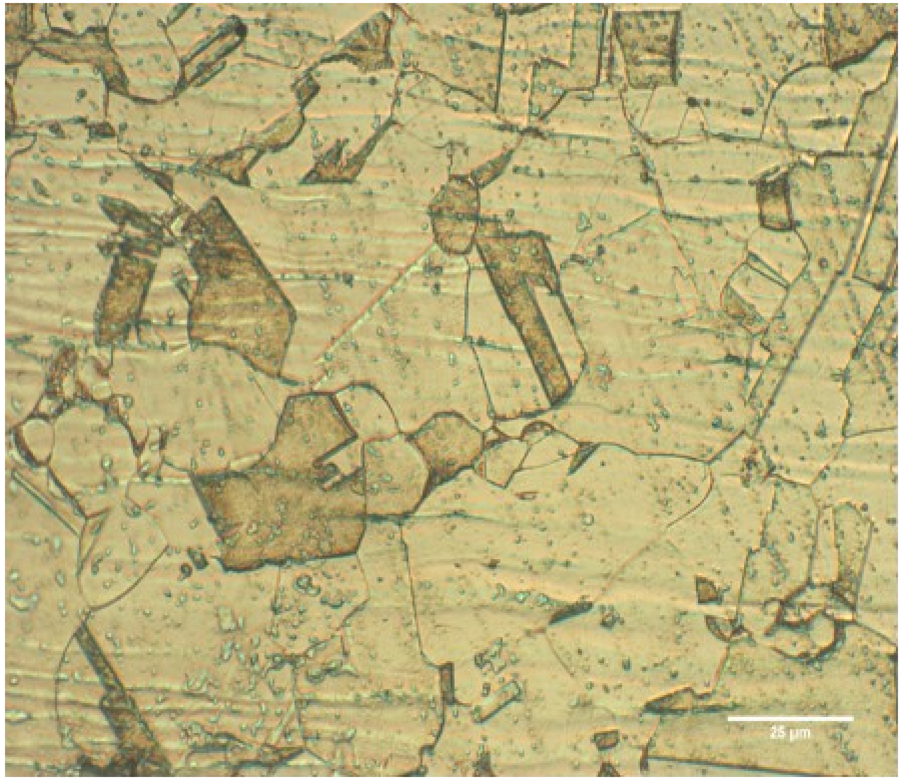
SEM image of 316L MELD Interfaces

- An SEM image of a representative 316L specimen deposited by the MELD process was taken. Within this image the interface between the substrate and the 1st deposited layer as well as the interface between the 1st and 2nd deposited layers can be seen. To help identify the interfaces red arrows have been superimposed as well as green dashed lines on either side.

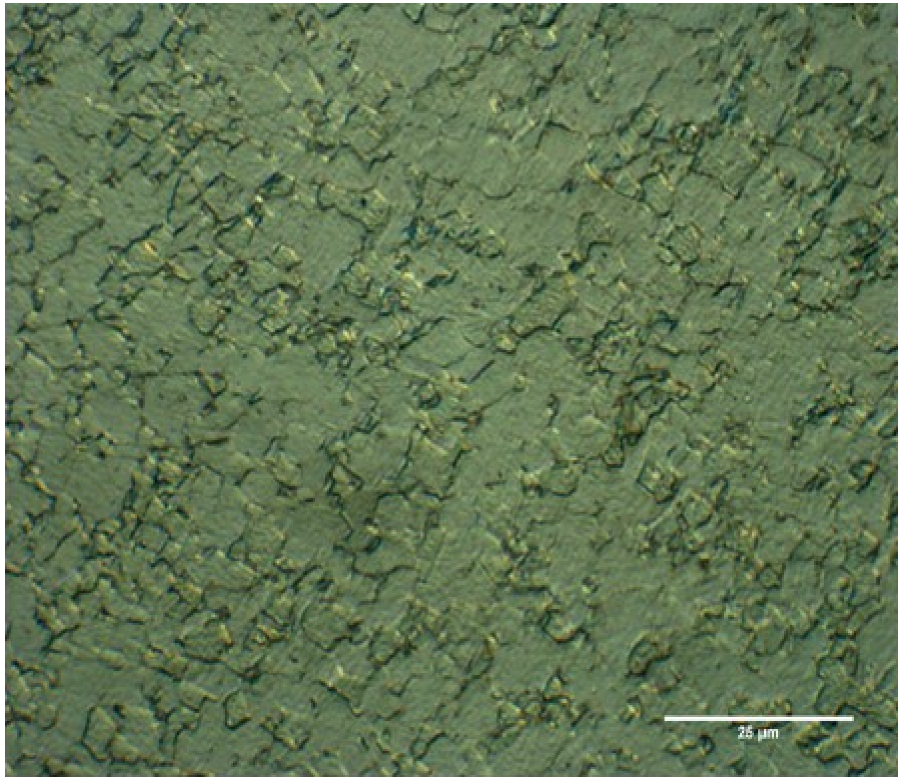


Metallographic Images of MELDed 316L

Metallographic images of the as-received 316L revealed an average grain size ranging from 5-50 µm. Images of the as-MELDed 316L revealed an average grain size from 1-10 µm. The as-MELDed 316L stainless steel material had a finer and more uniform grain structure.



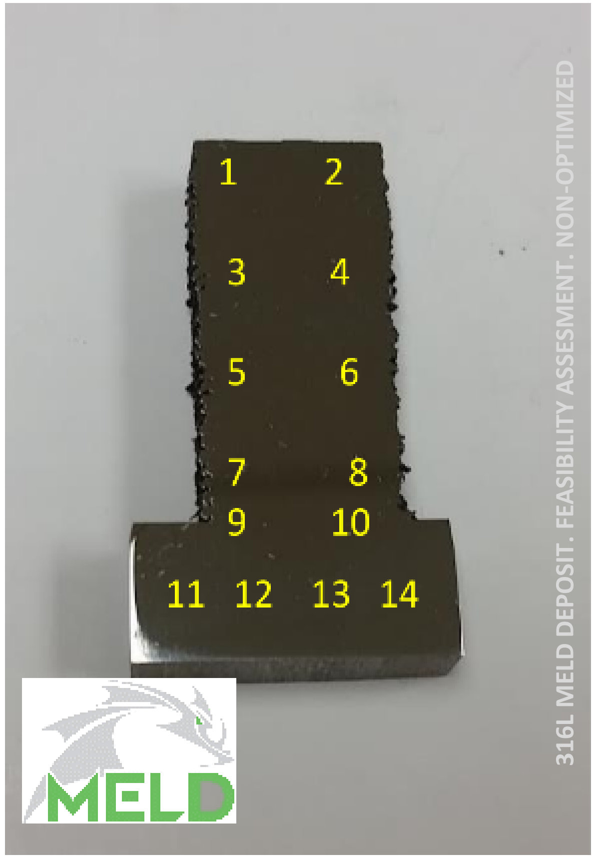
As-Received 316L



As-MELDed 316L

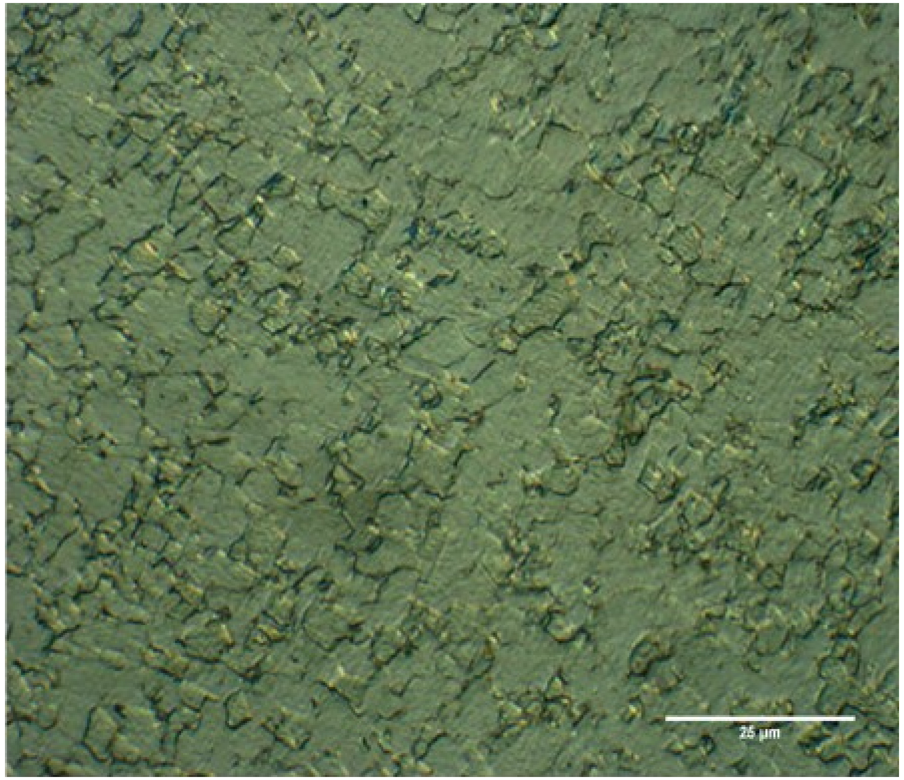
Hardness of 316L MELD Deposition

Analysis of the hardness of the as-deposited 316L material was performed. The average hardness of the as-received 316L material was 266 HV (per material cert). The post-deposition hardness analysis revealed that the hardness of the MELD deposited material was on average 236.1 HV.

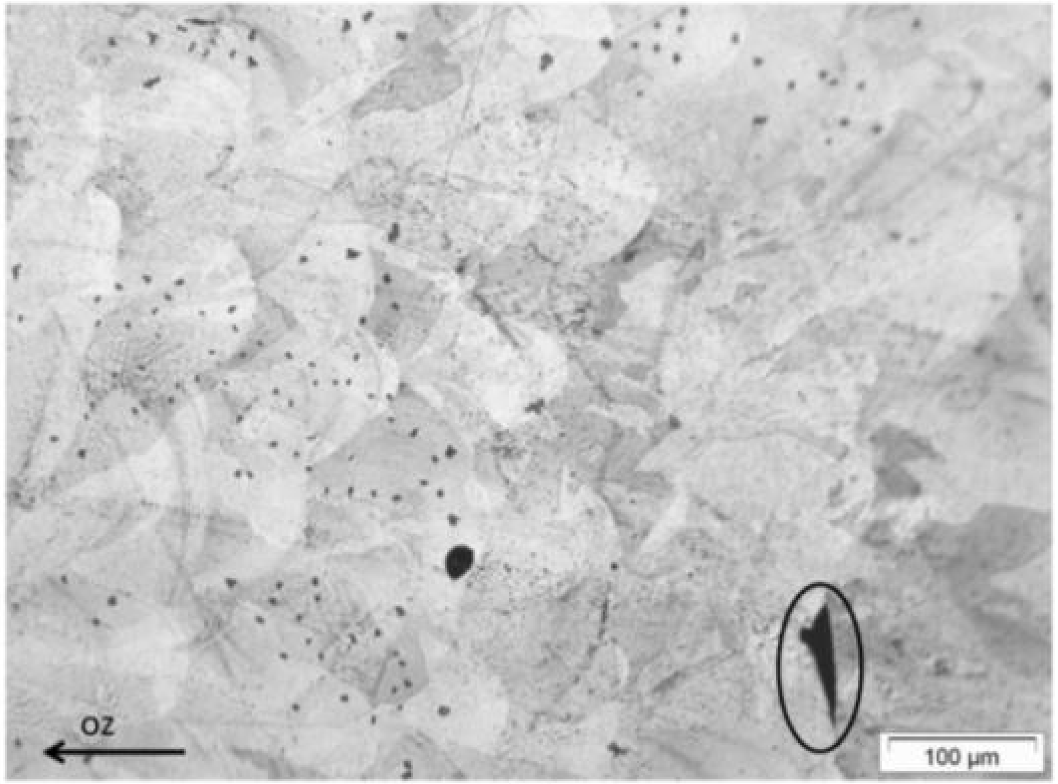


HV - Vickers	
232.8	224.6
236.8	231.5
239.5	238.8
234.8	250
235.5	219.7
196.6	199.7
171.7	164.3
Stir Avg.	236.1
Interface Avg.	227.6
Substrate Avg.	198.15

MELD and Laser Powder Bed Microstructure



As-MELDed 316L



Laser Powder Bed 316L[1]

[1]Mertens et. al. "Microstructures and Mechanical Properties of Stainless Steel AISI 316L Processed by Selective Laser Melting", Materials Science Forum, 783-786 (2014), pp. 898-903

ATAMM (atom) Project

- Aeroprobe Test of Additively Manufactured Materials (ATAMM)

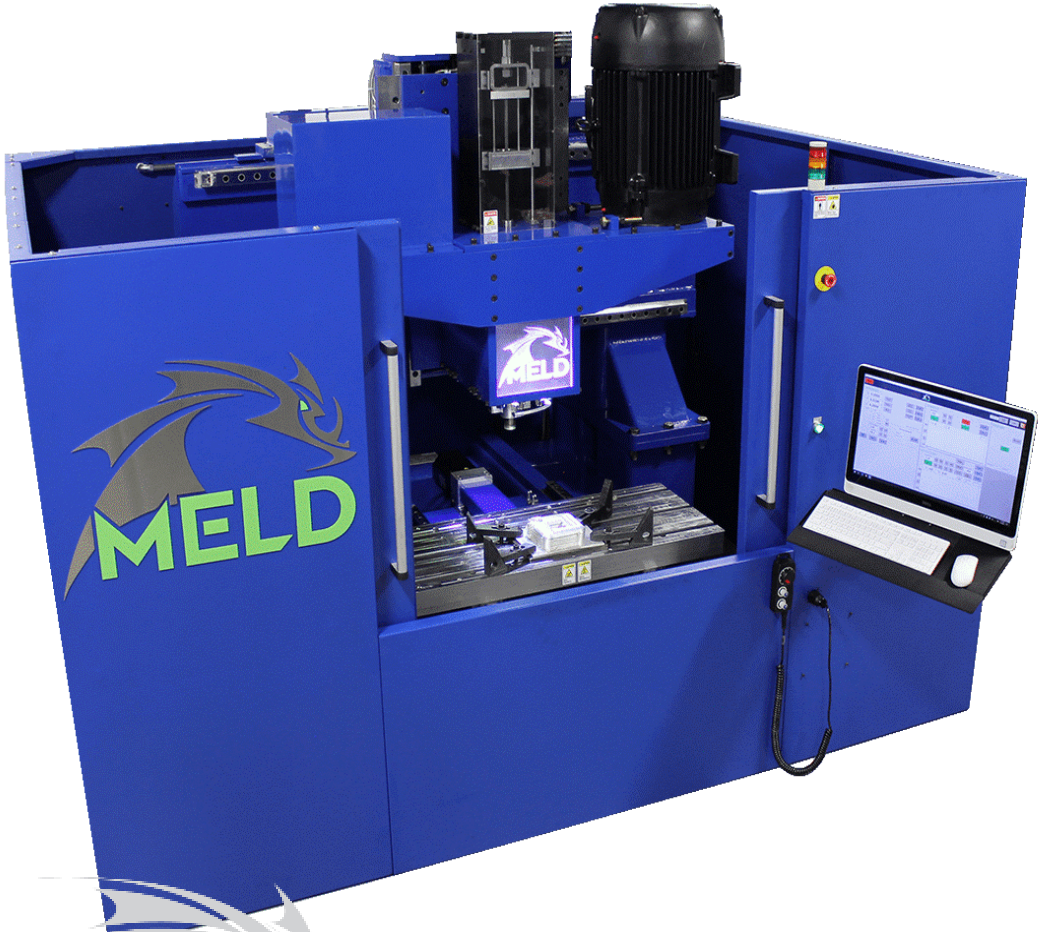
PROJECT OBJECTIVE

The purpose of this work is to perform irradiation and post-irradiation examination of materials produced by MELD and laser powder bed additive manufacturing.

METAL AM: Solid-State vs. Melt-Based

- 316L stainless steel material will be produced by two different additive manufacturing processes allowing a comparison of the effect of various techniques on the evolution of the microstructures generated and respective properties.
- 316L is readily available for most metal AM technologies
- 316L is used through many industries, including nuclear
- What's to gain?
  - An understanding of the advantages and disadvantages of both AM technologies
  - Understanding the potential for nuclear manufacturing applications
  - Insight into the effect of irradiation on the resultant microstructures

MELD Model B8



Machine Specifications

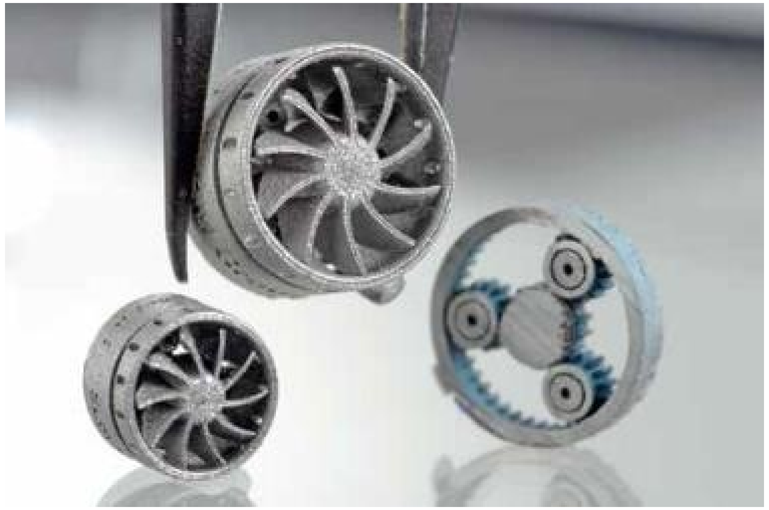
- Table Size: 42" x 18"
- Build Volume: 36" x 12" x 12"
- Overall Dimensions: 120" x 132" x 132"
- Typical Power in Operation: 10-20A
- Build Material: Solid Metal Bar
- Material Range: Wide Variety of Metals
- Native g-code programable
- Customized robust operating system

MELD model B8 is an open atmosphere, 3-Axis CNC milling machine style platform with an easily scalable gantry system for larger parts. Localized gas shielding is available for sensitive materials.

Laser Powder Bed

Machine Specifications: EOS 290

- Build Volume: 9.85" x 9.85" x 12.8"
- Overall Dimensions: 98.4" x 51.2" x 86.2"
- Typical Power in Operation: 8.5 kW max (3.2 kW typ.)
- Build Material: powder

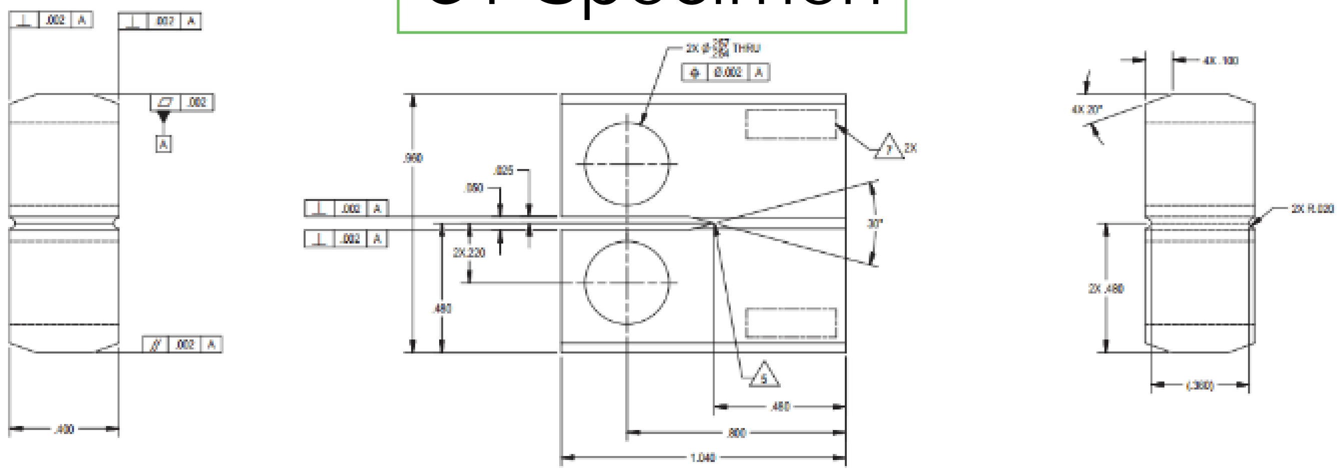


Mechanical Testing: Pre and Post Irradiation

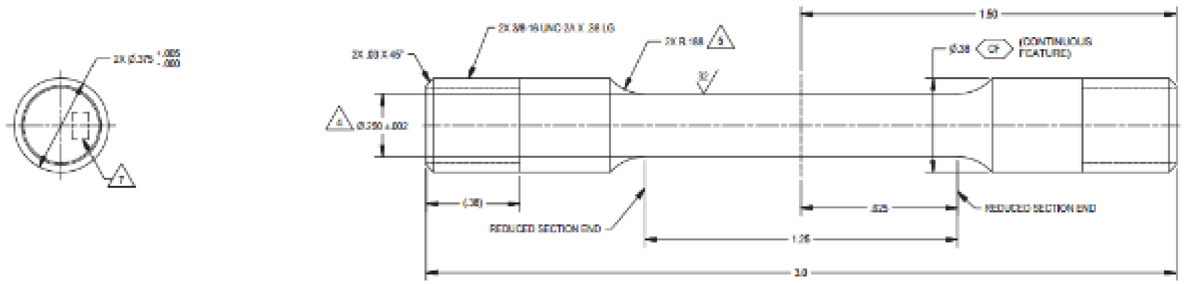
MELDed 316L Test Specimens:
2 Fracture Toughness Tests at room temp
2 Fracture Toughness Tests at 300˚ C
3 Round Dog bone Tensile tests at room temp
3 Round Dog bone Tensile tests at 300˚ C
SCC Testing (CT specimens)

Laser Powder Bed Test Specimens:
2 Fracture Toughness Tests at room temp
2 Fracture Toughness Tests at 300˚ C
3 Round Dog bone Tensile tests at room temp
3 Round Dog bone Tensile tests at 300˚ C
SCC Testing (CT specimens)

CT Specimen

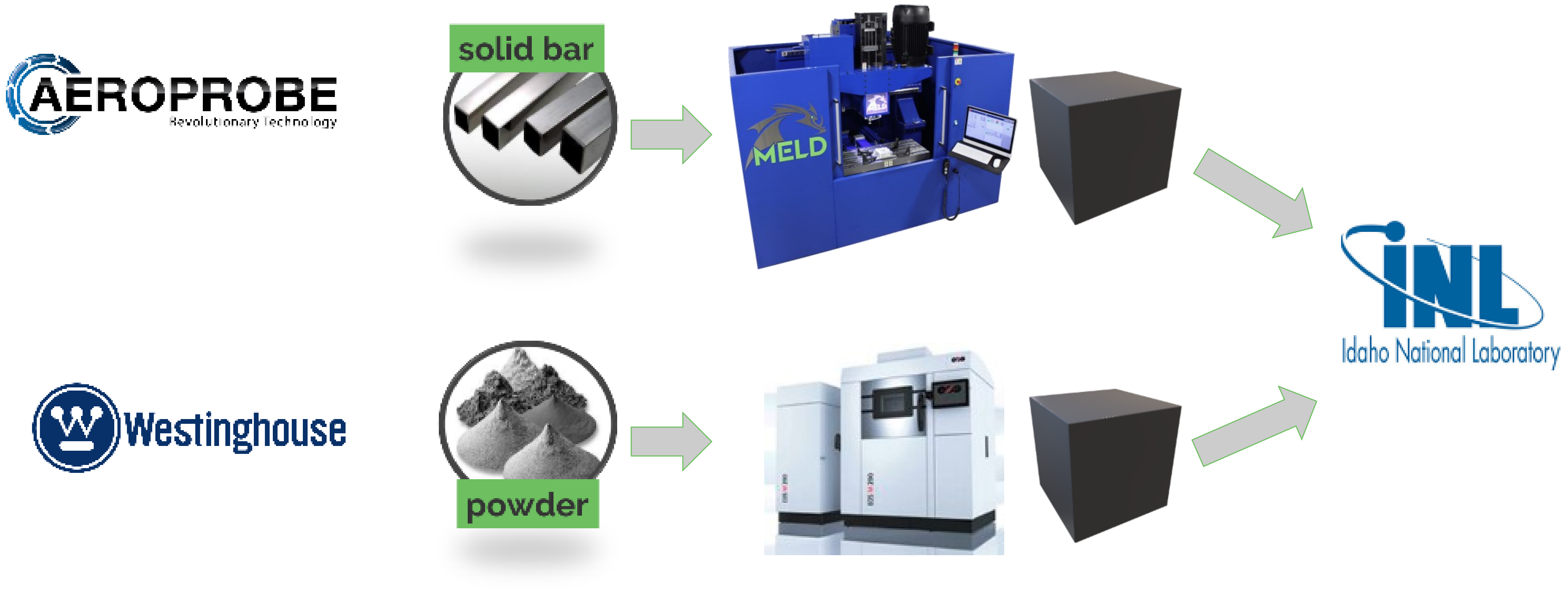


Dog Bone



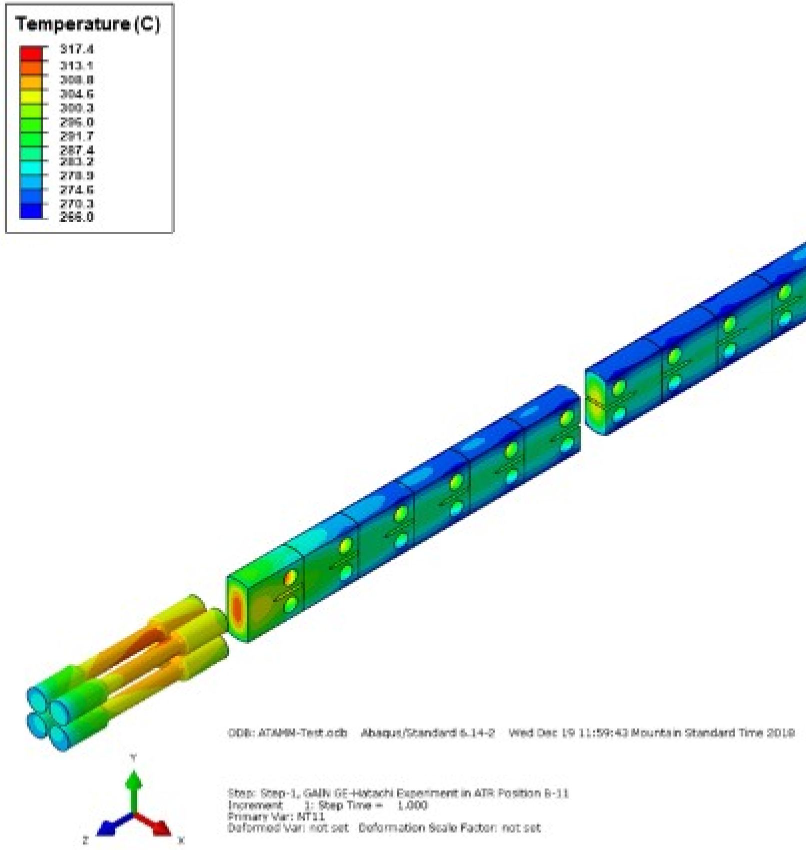
Specimen Fabrication Plan

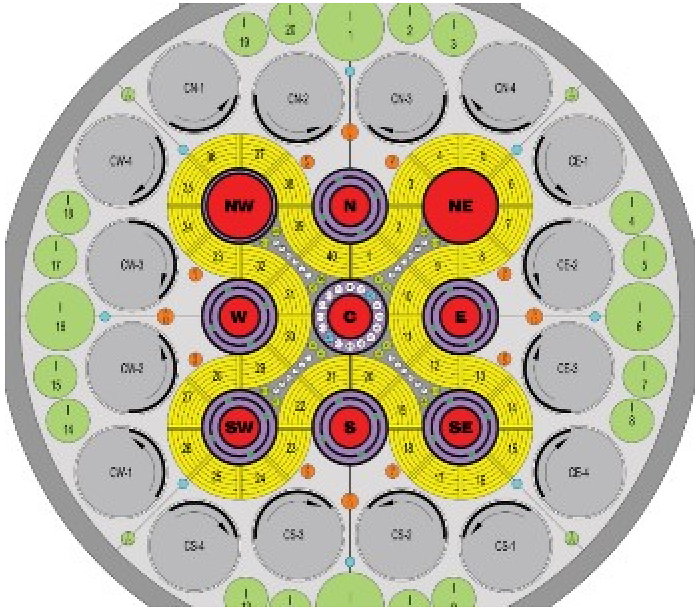
Procure Certified 316L Material	Print “bulk” material	Test Specimen Fabrication



Experiment Description

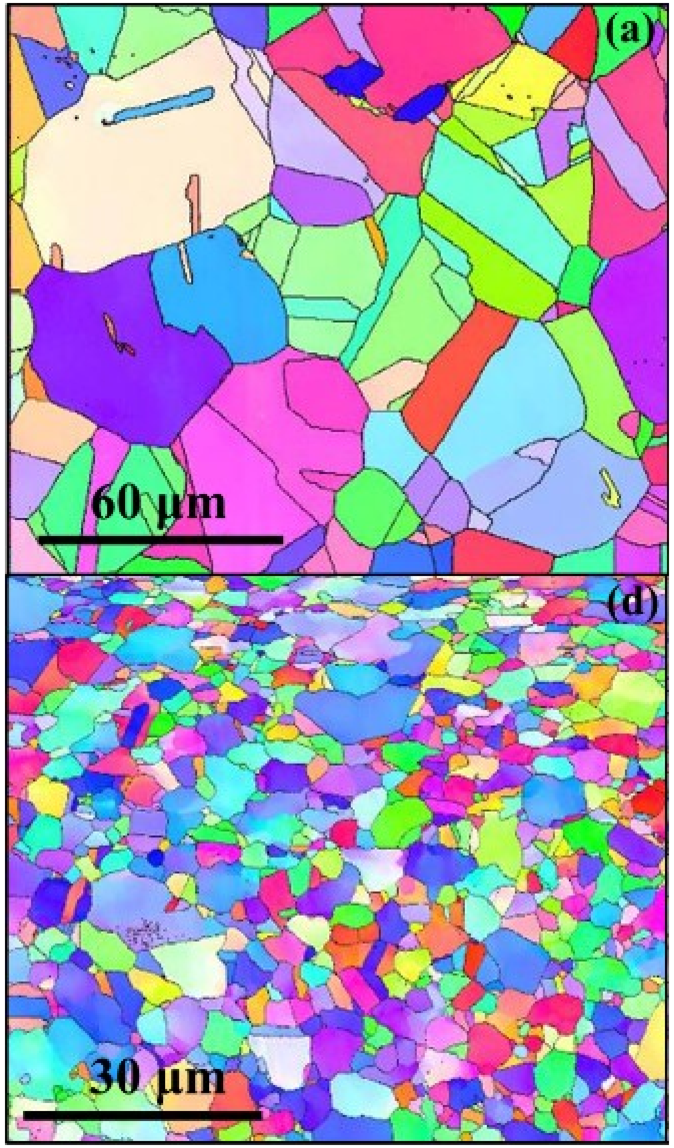
- Position: B10
  - Large B (1.5” diameter)
  - Thermal Flux: 1.1E+14
  - Fast Flux: 1.6E+13
- Use the GE-Hitachi Design (Drawings 605757-605760)
- Insertion Cycle: 168A (Oct, 2019)
- Number of Cycles: 4
- Programmatic Objectives:
  - DPA : 1-1.4
  - Temperature: 280-300°C



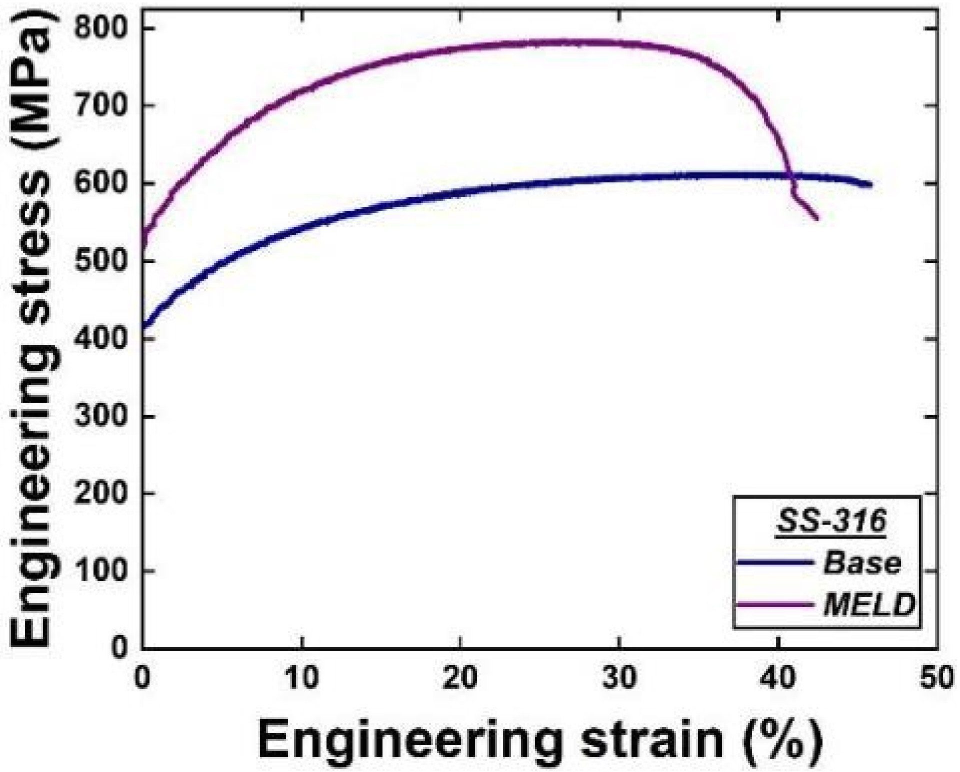


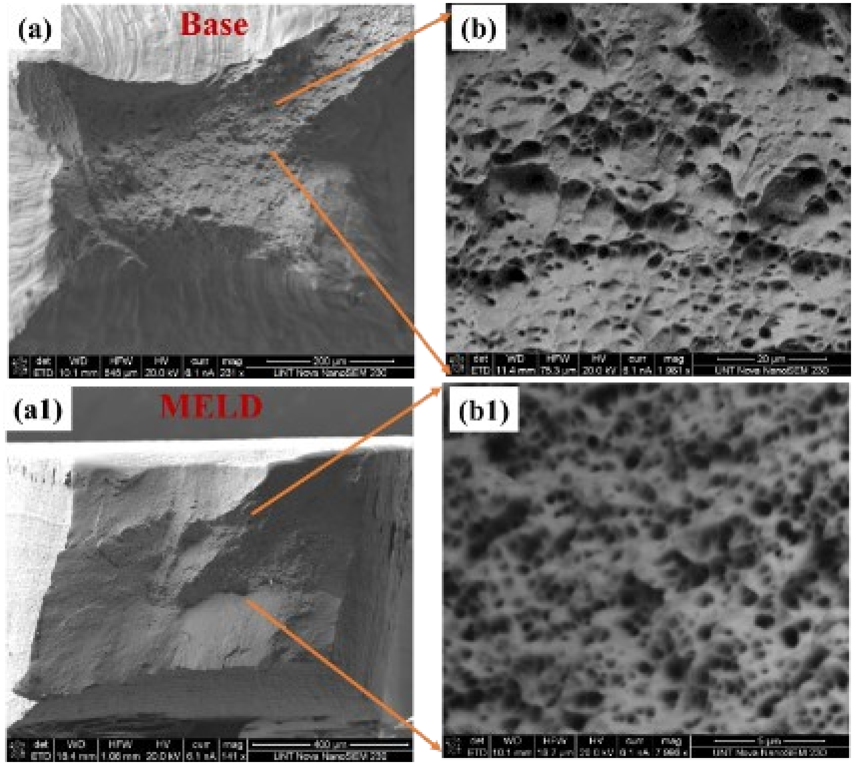
EBSD of MELD deposited 316L

- Average grain size of MELD processed sample is ~ 3 µm, whereas for the base material it is ~50 µm.
- Low angle grain boundary fraction is larger in MELD processed sample than base material.
- High dislocation density has been observed at the grain boundaries of MELD processed samples which can activate additional deformation mechanisms in the material.



Mechanical Properties of MELDed 316L



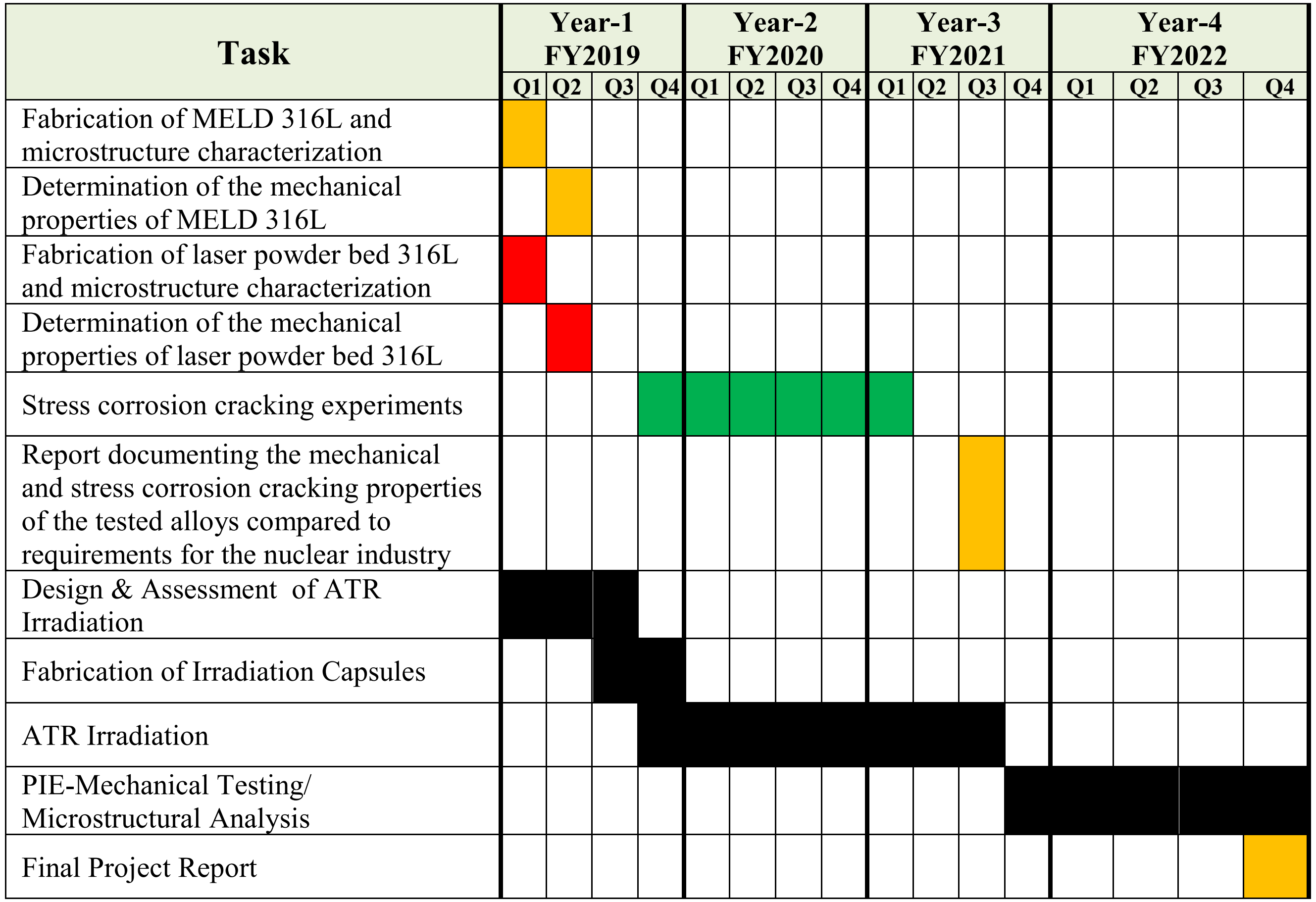


Priyanshi Agrawal, Rajiv S. Mishra
Center for Friction Stir Processing
Department of Materials Science and Engineering
University of North Texas

	MELD 316L	EOS 316L*	ASTM A276
Yield Strength (MPa)	462	470	310
Ultimate Tensile Strength (MPa)	724	530	620
Elongation (%)	40.6	54	30

*https://www.eos.info/en/additive-manufacturing/3d-printing-metal/dmls-metal-materials/stainless-steel

Program Schedule



	STATUS	DATE
Final Design Review:	Completed	Apr-19
Final Design Acceptance:	Completed	May-19
Experiment Green Tagged (QC approved Experiment Assembly configured) and Ready for Insertion:	Completed	Aug-19
Initial Insertion:	Completed	Oct-19
Final (4th) Irradiation Cycle:	Tentative	2/4/21 through 4/8/21
Extraction:	Tentative	Apr-21
Shipment to PIE Facility (HFEF):	Tentative	Sep-21

Nov. 2018

Dec. 2020

Presentation of Research

C. Cox, et. al. "Irradiation Testing of Materials Produced by Additive Friction Stir Manufacturing", 2018 NSUF Program Review, Nov. 2018.

C. Cox, et. al. "A Novel Solid-State Additive Manufacturing Technology in Support of Turbomachinery Sustainment", 2019 IGTI Turbo Expo, Jun. 2019

C. Cox, et. al. "Single Crystal Turbine Blade Root Repair via MELD", 2020 Aeromat Conference and Exposition, Virtual Meeting, Jun. 2020

MELD AM for Energy

- Nuclear applications, including:
  - Defense
  - Space
  - Reactor Design
  - Fusion Reactor Design
  - Fuel
- Oil and Gas:
  - Transition Joints (LNG)
- Turbine:
  - Blade Repair
  - Forging Replacement
- Transportation:
  - Lightweighting

Questions?

MELD MACHINE MODELS

	B8	**L3** **(new model, information not yet public)**	**K2**
Cubic build space	3ft^3 0.085m^3, 85K cm^3	6.75 ft^3 0.191m^3, 191K cm^3	81.6ft^3 2.31m^3, 2,310K cm^3
Build volume (x, y, z)	36in x 12in x 12in 91.4cm x 30.5cm x 30.5cm	36 in x 18 in x 18 in 91.4cm x 45.7cm x 45.7cm	82in x 43in x 39in 208cm x 109cm x 99.1cm
Table size	42in x 18in 106.7cm x 45.7cm	51 in x 23 in 129.5cm x 58.4cm	86in x 43in 218cm x 109cm
Overall dimensions (footprint) L x W x H	10ft x 11ft x 11ft 3.05m x 3.35m x 3.35m	10.2 ft x 7.6 ft x 13.3 ft 3.11m x 2.32m x 4.05m	20.5ft x 15.3ft x 14.5ft 6.25m x 4.66m x 4.42m