Irradiation Testing of Materials Produced by Additive Friction Stir Manufacturing
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 those AM processes.
- Expose stainless steel specimens to irradiated environment.
- Evaluate the irradiated material properties and compare to baseline.

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 Selekder

Workscope: NSUF-1.2

PICSNE Workpackage #: NA-18010601

IMPACT

Logical Path: [Diagram showing the process flow from MELD to irradiation testing]

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.

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.

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

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@MELDManufacturing.com
What is MELD?

How does it work?
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 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.
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.
MELD and Laser Powder Bed Microstructure

As-MELDed 316L

Laser Powder Bed 316L\(^1\)

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)
Specimen Fabrication Plan

1. Procure Certified 316L Material
2. Print “bulk” material
3. 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

Yield Strength (MPa) 462 470 310
Ultimate Tensile Strength (MPa) 724 530 620
Elongation (%) 40.6 54 30

## Program Schedule

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<thead>
<tr>
<th>Task</th>
<th>Year-1 FY2019</th>
<th>Year-2 FY2020</th>
<th>Year-3 FY2021</th>
<th>Year-4 FY2022</th>
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<td>Fabrication of MELD 316L and microstructure characterization</td>
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<td>Determination of the mechanical properties of MELD 316L</td>
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<tr>
<td>Fabrication of laser powder bed 316L and microstructure characterization</td>
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<tr>
<td>Determination of the mechanical properties of laser powder bed 316L</td>
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<td>Stress corrosion cracking experiments</td>
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<td>Report documenting the mechanical and stress corrosion cracking properties of the tested alloys compared to requirements for the nuclear industry</td>
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<td>Design &amp; Assessment of ATR Irradiation</td>
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<td>Fabrication of Irradiation Capsules</td>
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<td>ATR Irradiation</td>
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<td>PIE-Mechanical Testing/ Microstructural Analysis</td>
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<td>Final Project Report</td>
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### STATUS

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<tr>
<th>Event</th>
<th>Status</th>
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<tr>
<td>Final Design Review</td>
<td>Completed</td>
<td>Apr-19</td>
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<tr>
<td>Final Design Acceptance</td>
<td>Completed</td>
<td>May-19</td>
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<tr>
<td>Experiment Green Tagged (QC approved Experiment Assembly configured) and Ready for Insertion</td>
<td>Completed</td>
<td>Aug-19</td>
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<tr>
<td>Initial Insertion</td>
<td>Completed</td>
<td>Oct-19</td>
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<tr>
<td>Final (4th) Irradiation Cycle</td>
<td>Tentative</td>
<td>2/4/21 through 4/8/21</td>
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<tr>
<td>Extraction</td>
<td>Tentative</td>
<td>Apr-21</td>
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<tr>
<td>Shipment to PIE Facility (HFEF)</td>
<td>Tentative</td>
<td>Sep-21</td>
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Nov. 2018 \hspace{100px} Dec. 2020
Presentation of Research


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

<table>
<thead>
<tr>
<th></th>
<th>B8</th>
<th>L3 (new model, information not yet public)</th>
<th>K2</th>
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</thead>
<tbody>
<tr>
<td>Cubic build space</td>
<td>3ft³ [0.085m³, 85K cm³]</td>
<td>6.75 ft³ [0.191m³, 191K cm³]</td>
<td>81.6ft³ [2.31m³, 2,310K cm³]</td>
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<tr>
<td>Build volume (x, y, z)</td>
<td>36in x 12in x 12in 91.4cm x 30.5cm x 30.5cm</td>
<td>36 in x 18 in x 18 in 91.4cm x 45.7cm x 45.7cm</td>
<td>82in x 43in x 39in 208cm x 109cm x 99.1cm</td>
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<tr>
<td>Table size</td>
<td>42in x 18in 106.7cm x 45.7cm</td>
<td>51 in x 23 in 129.5cm x 58.4cm</td>
<td>86in x 43in 218cm x 109cm</td>
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<tr>
<td>Overall dimensions (footprint) (L x W x H)</td>
<td>10ft x 11ft x 11ft 3.05m x 3.35m x 3.35m</td>
<td>10.2 ft x 7.6 ft x 13.3 ft 3.11m x 2.32m x 4.05m</td>
<td>20.5ft x 15.3ft x 14.5ft 6.25m x 4.66m x 4.42m</td>
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