Scaling Up of 3D Printed Castings

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NSRP All Panel
MELD Manufacturing Method

MELD is a solid-state process, meaning the material does not reach the melting temperature during the process.

Because of this, MELD is able to produce high-quality wrought materials and parts with low residual stresses and full density and is not susceptible to porosity, hot-cracking, or other common problems that plague melt-based technologies.

Shown: MELD L3 Model Machine
MELD Manufacturing Method

Relevance to Shipbuilding:

- Open air operation allows for scaling up
- Solid metal input reduces danger of powder metal
- No melting means all alloys can be used
- Fully dense parts have wrought and forged properties
- Used for 3D printing and repair
MELD Print Capabilities
The MELD process is performed by passing the filler material through the hollow rotating tool (stirring tool).

- Frictional heating creates robust metallurgical bond.
- Subsequent layers are created by raising the tool by the desired layer height.

Advantages:
- Significant grain refinement
- Wrought material properties
- Fully dense depositions without secondary processing such as hot isostatic pressing or sintering.
- Distortion in the as-built parts is significantly lower than fusion-based AM processes.
## MELD Printers

<table>
<thead>
<tr>
<th></th>
<th>B8</th>
<th>L3</th>
<th>K2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubic build space</td>
<td>3ft³</td>
<td>14.2 ft³</td>
<td>81.6ft³</td>
</tr>
<tr>
<td>Build volume (x, y, z)</td>
<td>36in x 12in x 12in</td>
<td>45 in x 23 in x 23 in</td>
<td>82in x 43in x 39in</td>
</tr>
<tr>
<td>Table size</td>
<td>42in x 18in</td>
<td>51 in x 23 in</td>
<td>86in x 43in</td>
</tr>
<tr>
<td>Overall dimensions</td>
<td>10ft x 11ft x 11ft</td>
<td>10.2 ft x 7.6 ft x 13.3 ft</td>
<td>20.5ft x 15.3ft x 14.5ft</td>
</tr>
<tr>
<td>(footprint) L x W x H</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### All machines

<table>
<thead>
<tr>
<th>Typical power in operation</th>
<th>10-20A</th>
<th>Build material:</th>
<th>Solid Metal</th>
</tr>
</thead>
<tbody>
<tr>
<td>International power required</td>
<td>3-phase, 400V, with 125 A, 50 Hz</td>
<td>Material range:</td>
<td>Wide Variety</td>
</tr>
<tr>
<td>USA power required</td>
<td>3-phase, 400V, with 125 A, 60 Hz</td>
<td>Open air operation:</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Project Goals

The project goals were to:
- To deposit material at a higher rate
- Demonstrate printing capability in aluminum to keep costs down.
- Identify potential nozzle head materials that can be procured and tested for longevity in a future project.

The reach goals were to:
- Successfully print a part using the increased deposition rate.
- Conduct metallurgical analysis on the printed parts to ensure the quality met expectations.
## Project Task Schedule

<table>
<thead>
<tr>
<th>Task</th>
<th>Q1 - 3/1</th>
<th>Q2 - 6/1</th>
<th>Q3 - 9/1</th>
<th>Q4 - 12/1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Setup and Kickoff Meeting</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Printed Part Selection</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Stirring Tool Modification</td>
<td></td>
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</tr>
<tr>
<td>Stirring Tool Manufacturing</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Stirring Tool Testing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conduct Test Program</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Review and Document Testing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prepare Final Project Report</td>
<td></td>
<td></td>
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<tr>
<td>Quarterly Status Reports</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
Task Schedule Expanded

- Project Setup and Kickoff Meeting - Q1 Effort
  - Determine SOW
  - Develop Schedule
  - Hold Kickoff Meeting
- Determine Part to be Printed – Q2 Effort
  - Conduct Survey or Submit Candidates to be printed (including dimensions)
- Stirring Tool Modification – Q2 Effort
  - Larger opening for increased deposition rate
- Stirring Tool Manufacturing – Q3 Effort
  - Fabricating nozzle head from ‘tool steel’
- Stirring Tool Testing – Q3/Q4 Effort
  - Ensure fabricated stirring tool prints under normal operating conditions
- Conduct Test Program – Q3/Q4 Effort
  - Test for increased deposition rate
  - Create final part
  - Test metallurgical properties
- Review and Document Testing – Q4 Effort
  - Review Deposition Rate
  - Document Nozzle Performance Results
- Prepare Final Project Report – Q4 Effort
  - Collectively combine all reporting MELD has conducted into final report format
- Quarterly Status Reports
Increasing Deposition Rate

- Larger Tool/Nozzle
  - More usable material per tool mass

- Larger Feedstock
  - More depositable material available per tool/nozzle
Printing Results

• Layers
  • Halved the number of layers per build

• Deposition Track
  • 33% wider deposition track

• Deposition Rate
  • Increased from 50.6 to 180 $\text{in}^3/\text{hr}$
Deposition Rate Comparison
Quality Testing: Mechanical Properties

Reported properties taken in z axis (short transverse)
EB Part Candidate - Flat Copper Tube Cold Plate

Front

Back
Metallurgical Analysis

• Sample Testing:
  • Grain structure changes
  • Hardness
  • Micro grain structure changes

• Metallurgical Results:
  • A solid bond was formed between the base plate and the deposited material and the material was uniform throughout.
# Future Nozzle Head Material Options

<table>
<thead>
<tr>
<th>Material</th>
<th>Additive</th>
<th>Hardness [GPa]</th>
<th>Fracture toughness [MPa.m(^{1/2})]</th>
</tr>
</thead>
<tbody>
<tr>
<td>WC</td>
<td>Co</td>
<td>10-20</td>
<td>5-20</td>
</tr>
<tr>
<td></td>
<td>Ni</td>
<td>15-20</td>
<td>10-15</td>
</tr>
<tr>
<td></td>
<td>ZrO(_2)</td>
<td>18-23</td>
<td>4.5-6.5</td>
</tr>
<tr>
<td></td>
<td>Al(_2)O(_3)</td>
<td>16-25</td>
<td>6-10</td>
</tr>
<tr>
<td></td>
<td>TiB(_2)</td>
<td>18-22</td>
<td>6-8</td>
</tr>
<tr>
<td></td>
<td>cBN</td>
<td>20-25</td>
<td>10-15</td>
</tr>
<tr>
<td>W-Re</td>
<td>-</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>pcBN</td>
<td>-</td>
<td>23-27</td>
<td>4-6</td>
</tr>
<tr>
<td>ZrB(_2)</td>
<td></td>
<td>15-23</td>
<td>3-4</td>
</tr>
<tr>
<td>TiB(_2)</td>
<td></td>
<td>25-27</td>
<td>6-8</td>
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</tbody>
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Questions?