Scaling Up of 3D Printed Castings

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NSRP All Panel

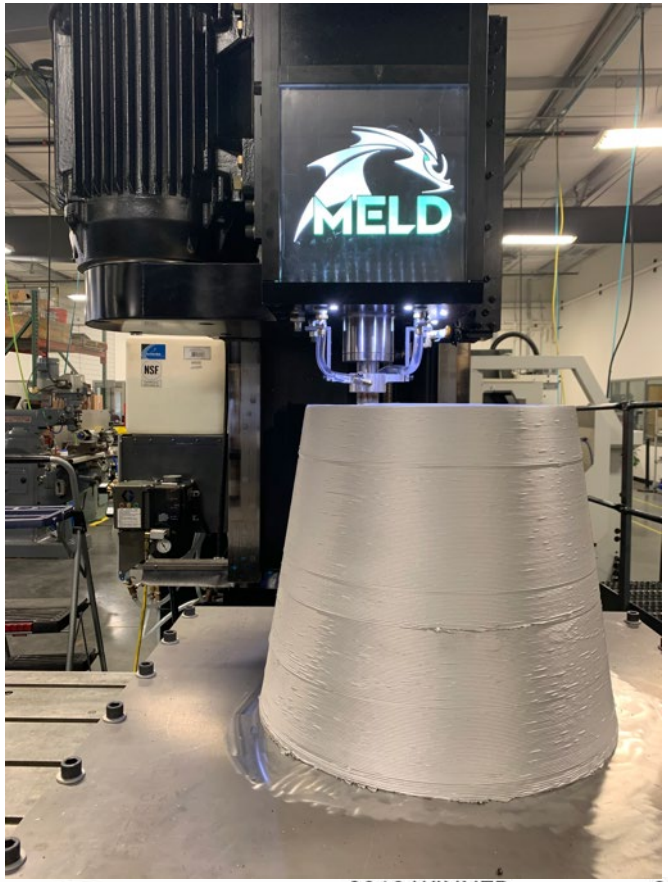
MELD Manufacturing Method

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

WOMAN-OWNED
MADE IN AMERICA

2018 R&D 100 WINNER

2019 GOLD WINNER
EDISON AWARDS GOLD 2019 WINNER
APPLIED TECHNOLOGY
CLEAN MANUFACTURING

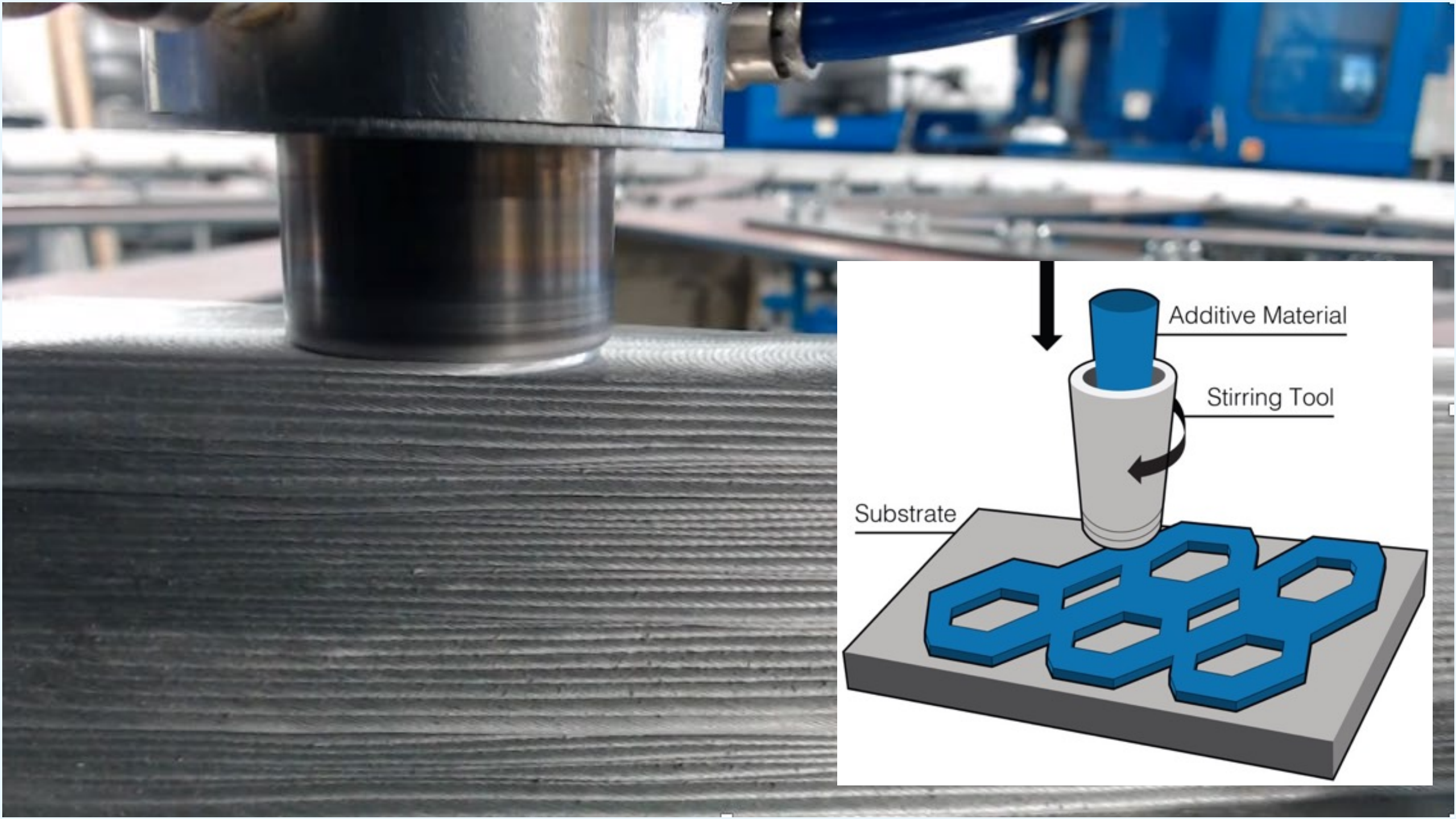
2018 WINNER
Create the Future DESIGN CONTEST
CREATE THE
FUTURE CONTEST

2018 WINNER
rapid + tct
INNOVATION AWARD

2018 R&D 100 WINNER
MARKET DISRUPTOR

2019 WINNER
PEOPLE'S CHOICE
DOD MAINTENANCE
INNOVATION CHALLENGE

2019 FINALIST
U.S.ARMY
TECHSEARCH

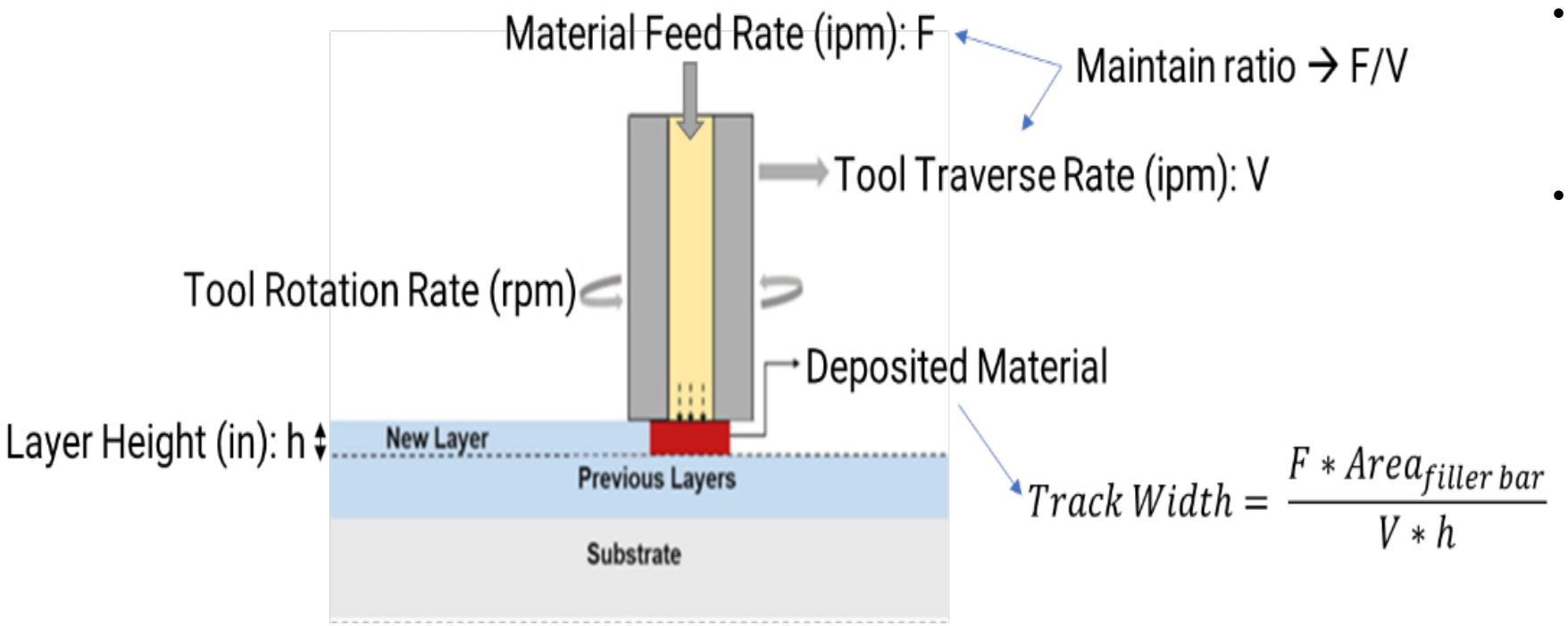

Additive Material
Stirring Tool
Substrate

MELD Print Capabilities

MELD Process

Key Parameters for MELD Process:

Tool Rotation Rate, Material Feed Rate, Tool Traverse Rate, Layer Height



$$Track\ Width = \frac{F * Area_{filler\ bar}}{V * h}$$

- 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

	B8	L3	K2
Cubic build space	$3ft^3$	$14.2\ ft^3$	$81.6ft^3$
Build volume (x, y, z)	36in x 12in x 12in	45 in x 23 in x 23 in	82in x 43in x 39in
Table size	42in x 18in	51 in x 23 in	86in x 43in
Overall dimensions (footprint) L x W x H	10ft x 11ft x 11ft	10.2 ft x 7.6 ft x 13.3 ft	20.5ft x 15.3ft x 14.5ft
All machines			
Typical power in operation:	10-20A	Build material:	Solid Metal
International power required:	3-phase, 400V, with 125 A, 50 Hz	Material range:	Wide Variety
USA power required:	3-phase, 400V, with 125 A, 60 Hz	Open air operation:	Yes

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

Task	Q1 - 3/1	Q2 - 6/1	Q3 - 9/1	Q4 - 12/1
Project Setup and Kickoff Meeting				
Printed Part Selection				
Stirring Tool Modification				
Stirring Tool Manufacturing				
Stirring Tool Testing				
Conduct Test Program				
Review and Document Testing				
Prepare Final Project Report				
Quarterly Status Reports				

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

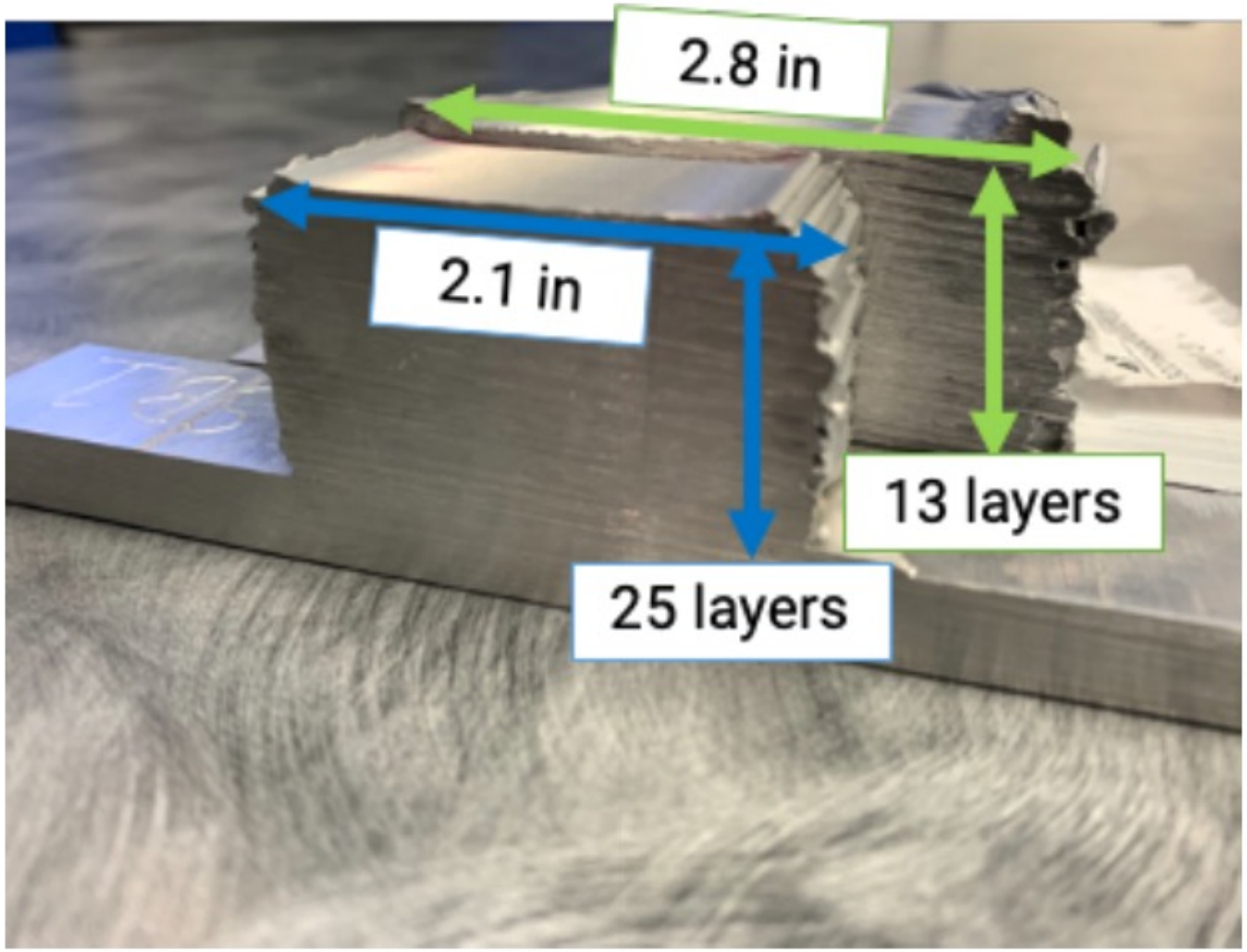
Increasing Deposition Rate

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

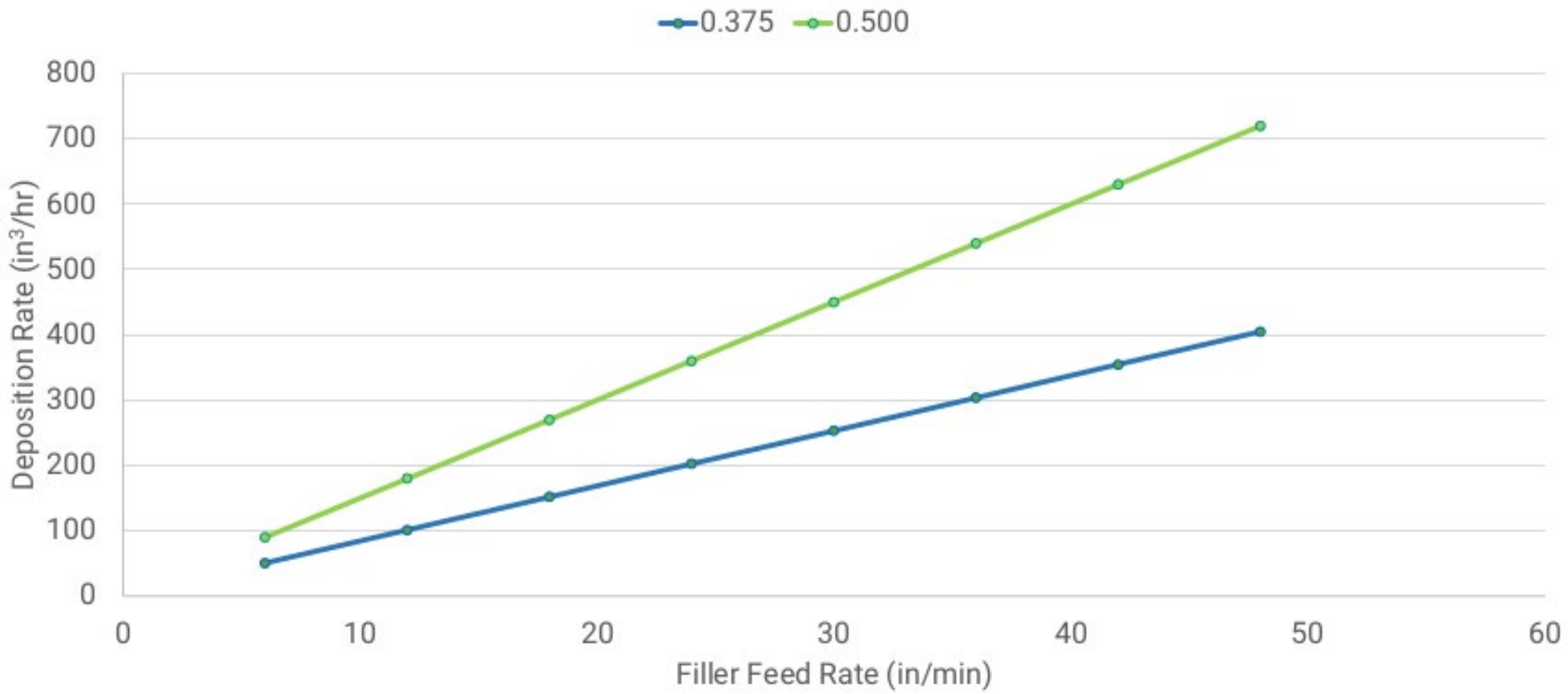
- Larger Feedstock
  - More depositable material available per tool/nozzle

Printing Results

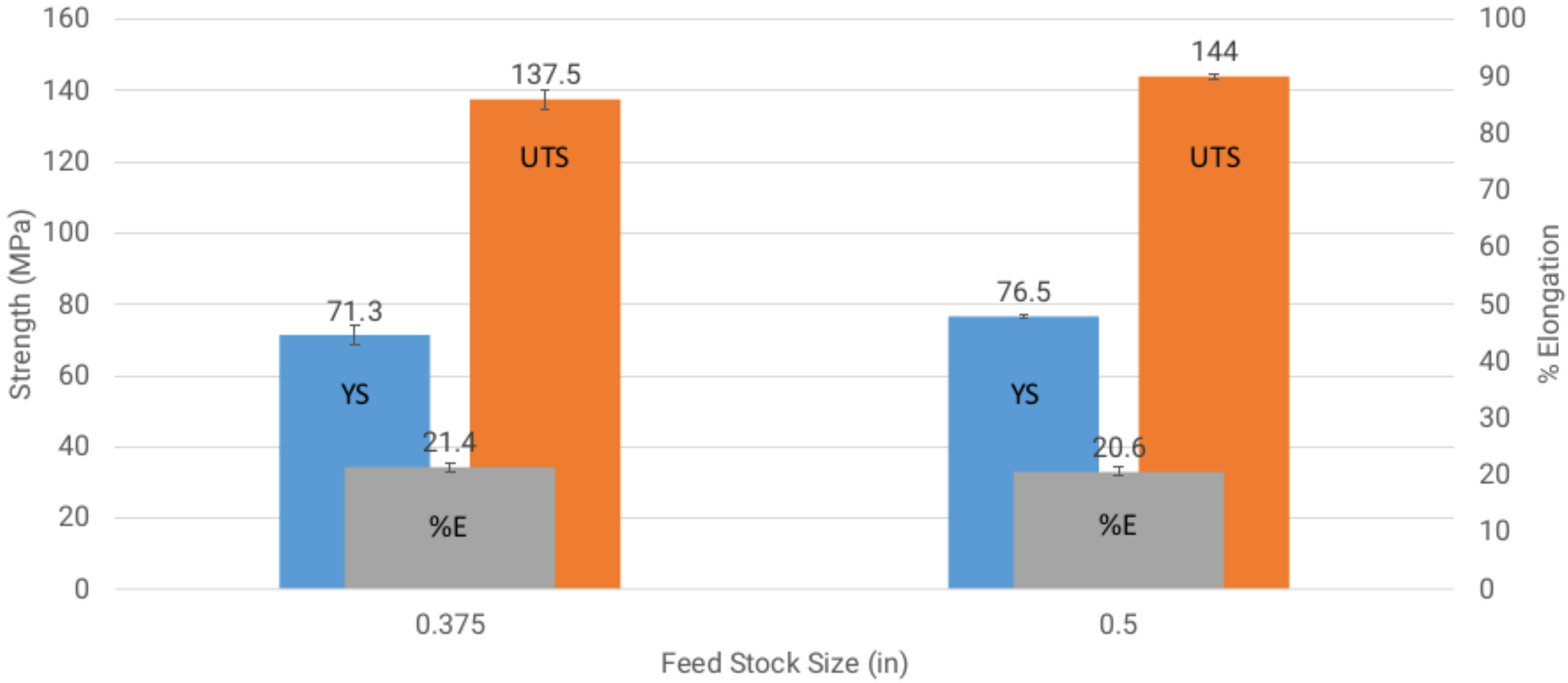
- Layers
  - Halved the number of layers per build
- Deposition Track
  - 33% wider deposition track
- Deposition Rate
  - Increased from 50.6 to 180 $\frac{in^3}{hr}$



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

Material	Additive	Hardness [GPa]	Fracture toughness [MPa.m$^{1/2}$]
WC	Co	10-20	5-20
	Ni	15-20	10-15
	ZrO_2	18-23	4.5-6.5
	Al_2O_3	16-25	6-10
	TiB_2	18-22	6-8
	cBN	20-25	10-15
W-Re	-	7	
pcBN	-	23-27	4-6
ZrB_2		15-23	3-4
TiB_2		25-27	6-8

Questions?