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Real Time Non-Destructive Evaluation During 3D Manufacturing of Metal Parts

AMMT Industry Workshop
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LER Technologies, Inc.

Innovation . Precision . Achievement

Acknowledgment

Acknowledge contributions by Paul LoVecchio, Gary Winter, Michael Talmadge, Steve Bond and Sandra Tavitian

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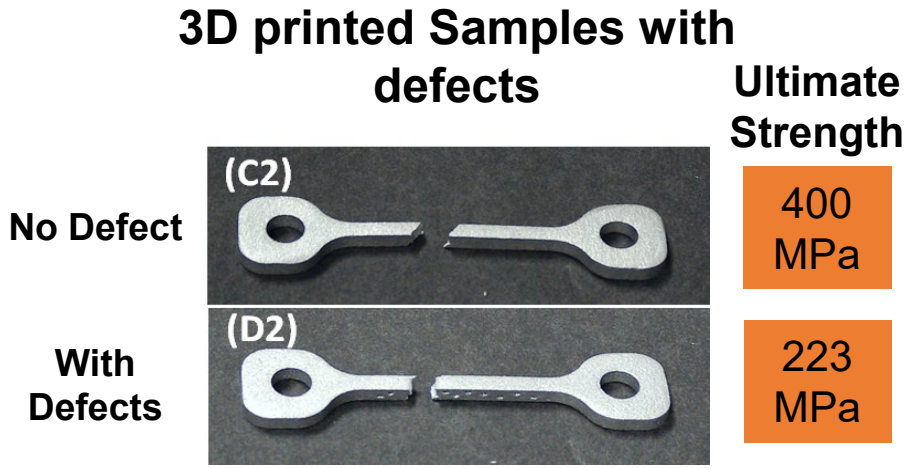
Need Addressed

- Currently metal parts are inspected AFTER additive manufacturing (AM), making it inefficient and costly.
- These risks prevent industries, like aerospace and nuclear, from fully embracing the advantages of AM.



Need a real-time, non-destructive evaluation (NDE) technology to detect defect, in-situ, during 3D AM printing of metal parts, nuclear quality.

Solution

- Uses a combination of multi-parameter optical detection techniques
- Each parameter detects different types of defects; final outputs are combined to produce a defect map
- Sensor unit provides:
  - real-time defect indication
  - final part defect map
  - defect information - used as feedback to AM tool.
- Saves time and energy; reduces material loss
- Enables production of higher quality parts
- Field tested (TRL 6) in operational commercial machine

3D printed Samples with defects

Real-time internal defect map

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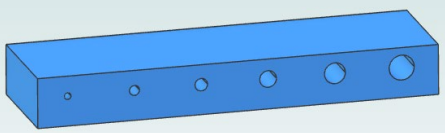
Overview Real Time NDE Inspection Unit



Design Sent to AM

Detected Internal Map

Completed Part

AM* Machine

LER Sensor Unit RTDQ||

Sensor output reveals internal structure and defects such as: Void, bulging, pits, granularity

Repeat Detection Process Until Final Layer

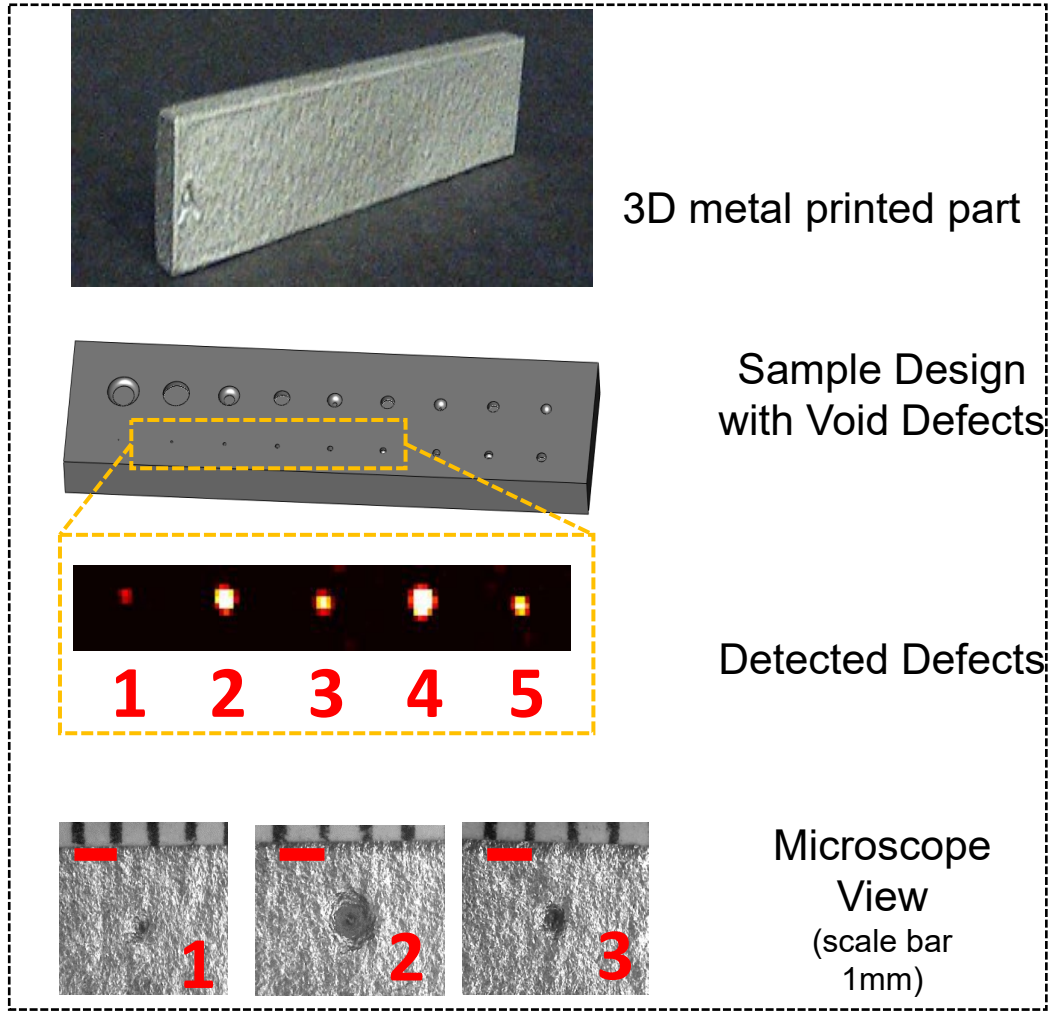
Quality Report

Pass: Continue AM Print
Soft Stop: Correct/modify AM print to compensate defect
Hard Stop: Uncorrectable/Fail, stop AM Print

* AM= Additive Manufacturing; || RTDQ= Real-Time Detection Qualification

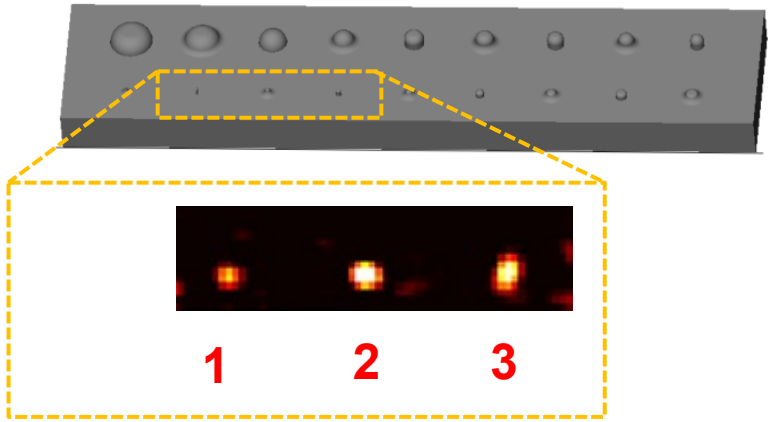
Solution

- Real-time, In-situ, Non-destructive evaluation
- Identifies microscopic defects (surface/subsurface)
- Machine agnostic, add-on sensor
- Catches defects missed by other approaches
- Avoids false readings
- Broad range of sensing capability
- Rapid installation
- Provides an opportunity to correct
- Qualifies the impact of the defect
  - i.e. data correlation with material strength in real-time



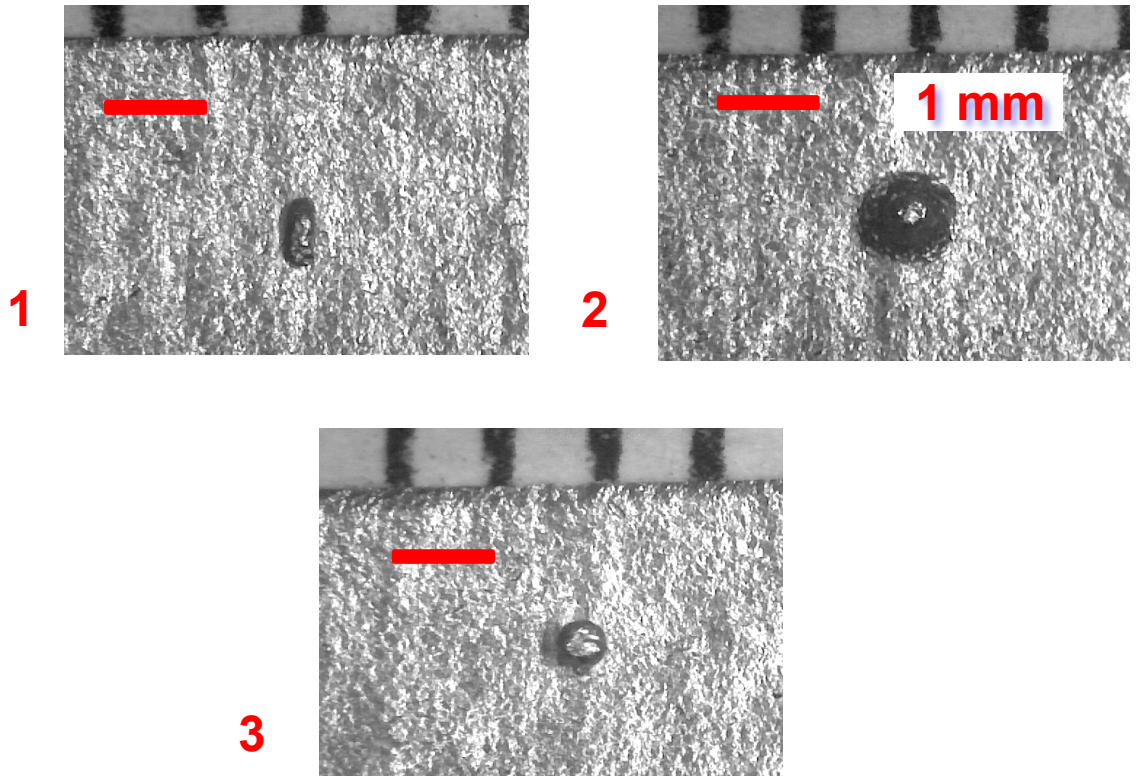
Detection in Different Environments

Sample Design



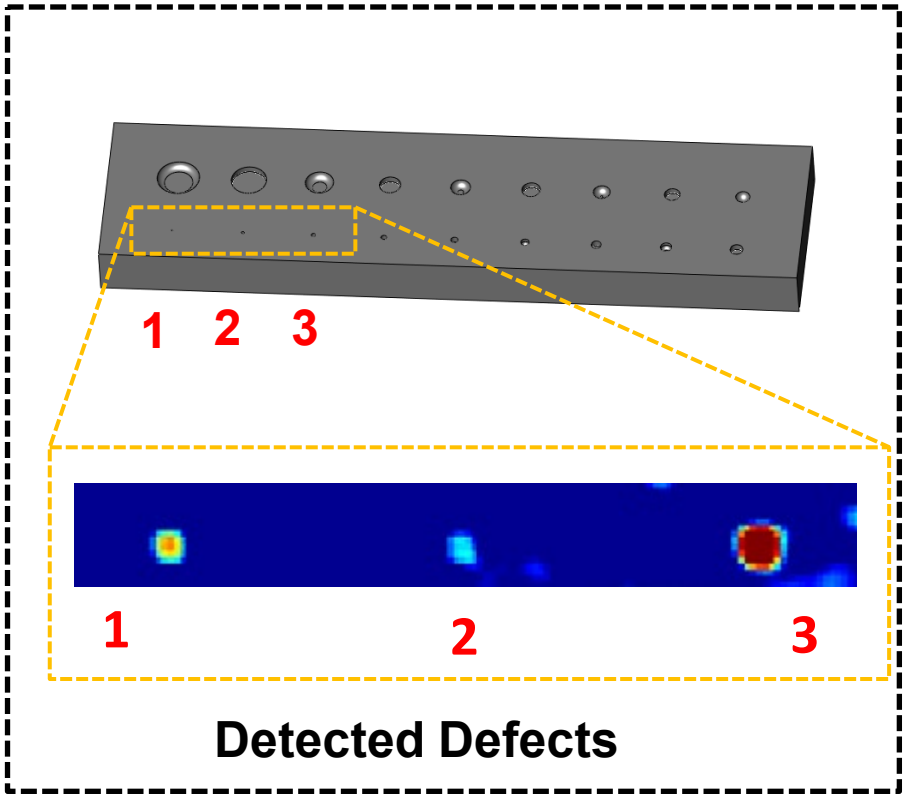
Detected Defects

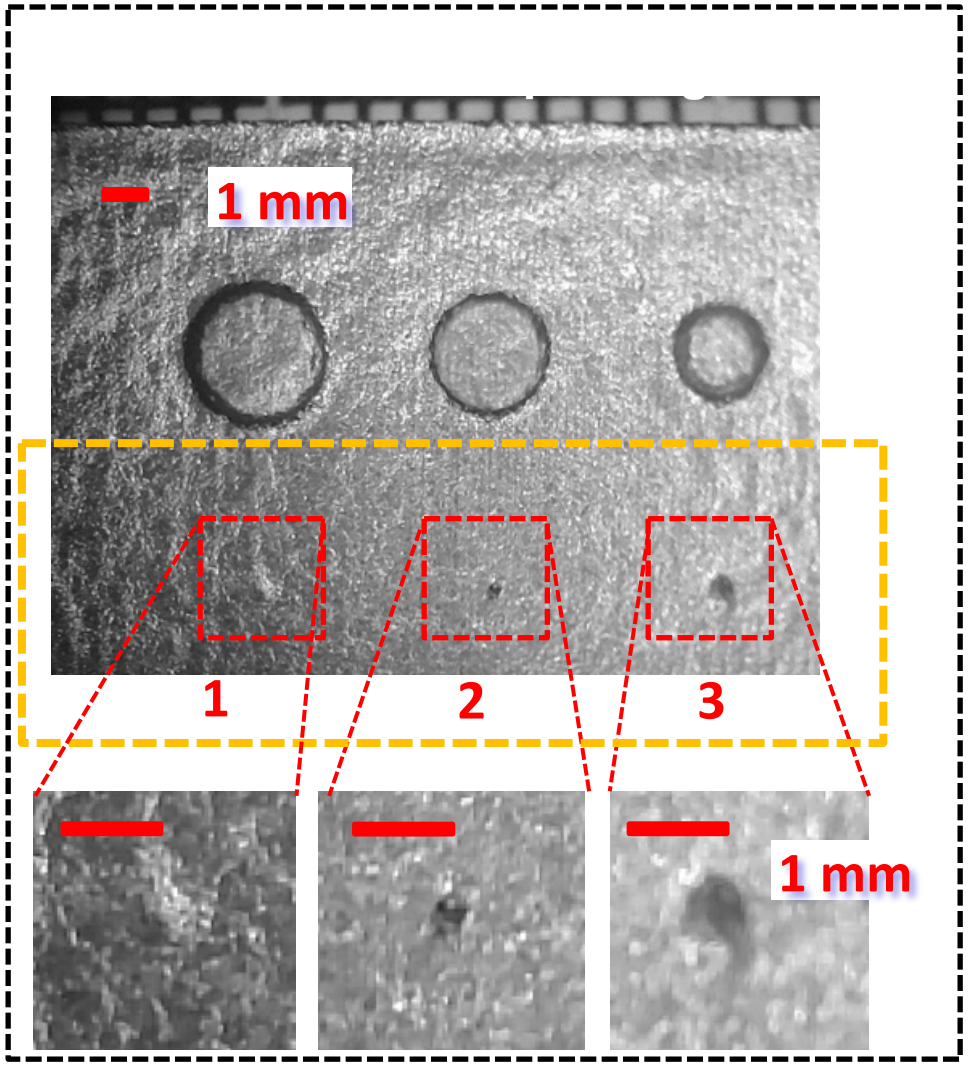
Microscope Images



- Tests in simulated DMLS chamber
- Bulging defects
- Inconel 718 sample

Void Detection in SS 316

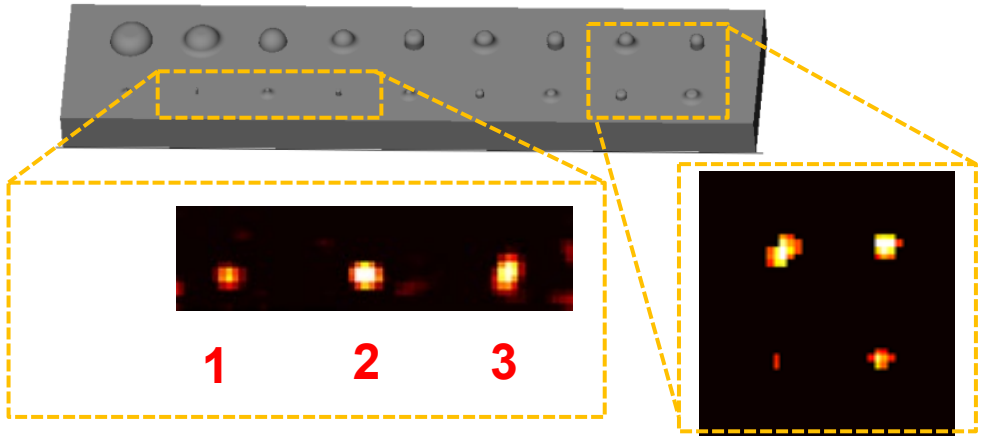




- Void depth 0.5 mm
- Smallest detected voids barely visible under a microscope

Detection in two Environments

Sample Design

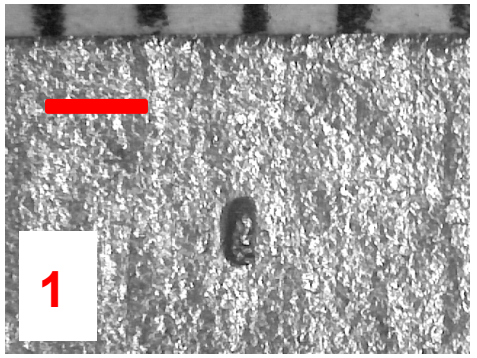


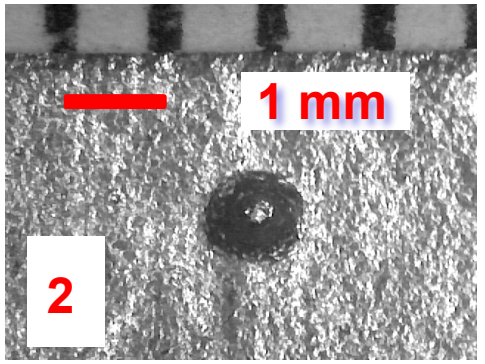
A) Detected Defects

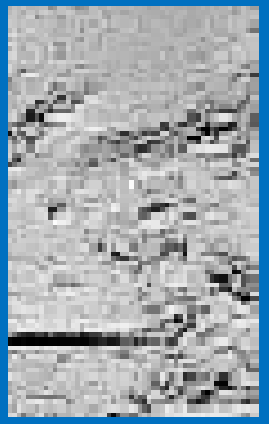
(B) Detected Defects metal powder

- (A) Inconel sample
- (B) SS 316 sample in metal powder
- (C) Photograph of SS 316 in metal powder
- Improvements enabled ability to detect in most difficult machine environments

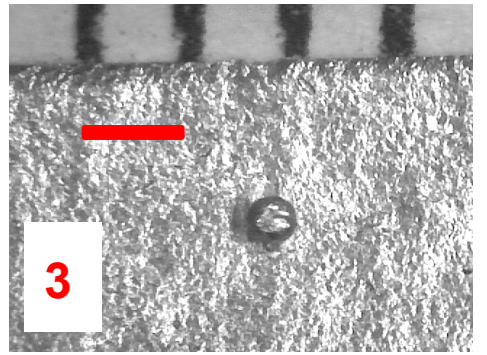
Microscope Images







(C) Photograph of Sample embedded in metal power



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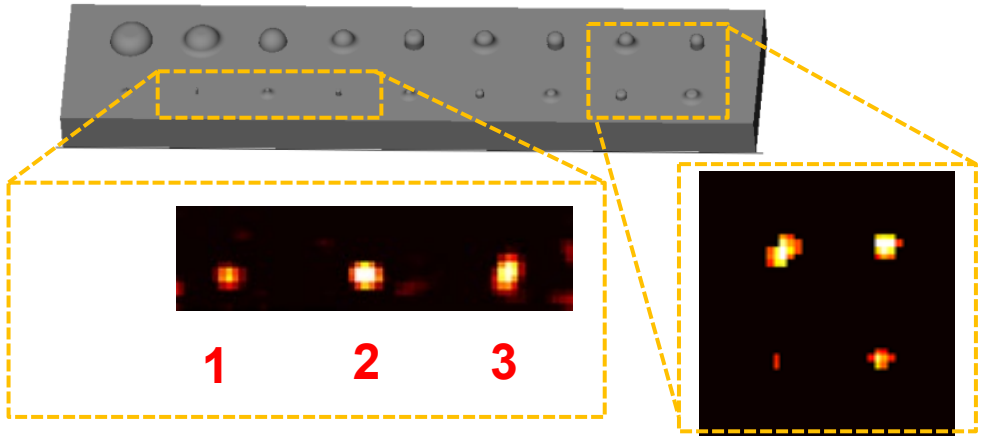
Detection in two Environments

Sample Design



A) Detected Defects

(B) Detected Defects - metal powder

- (A) Inconel sample
- (B) SS 316 sample in metal powder
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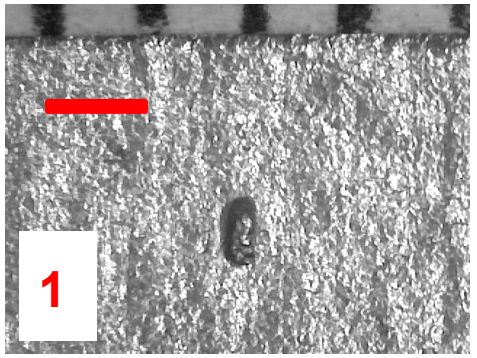
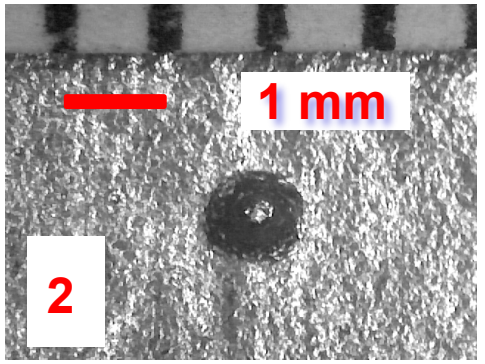
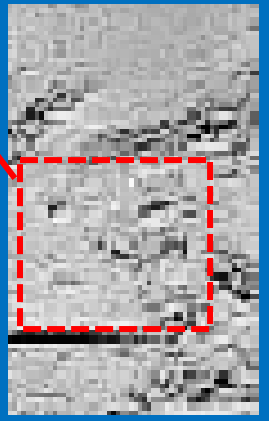
- Improvements enabled ability to detect in most difficult machine environments

Microscope Images







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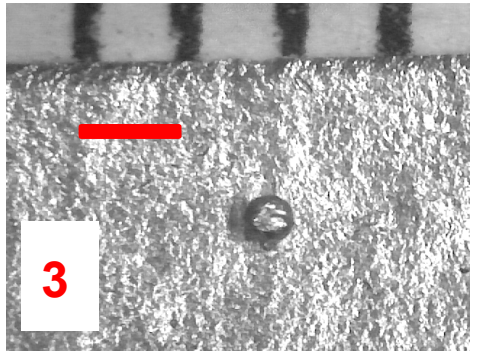
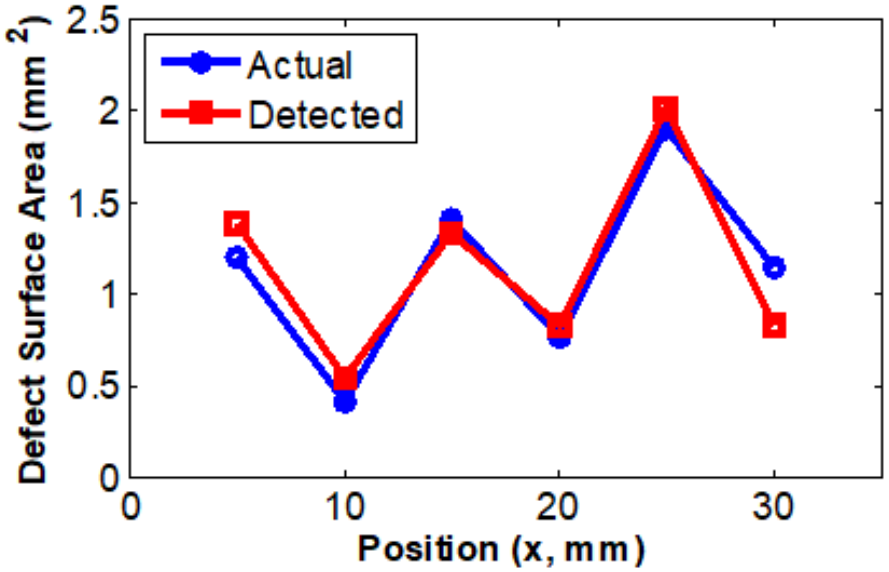


Comparison between Detected and Actual Values

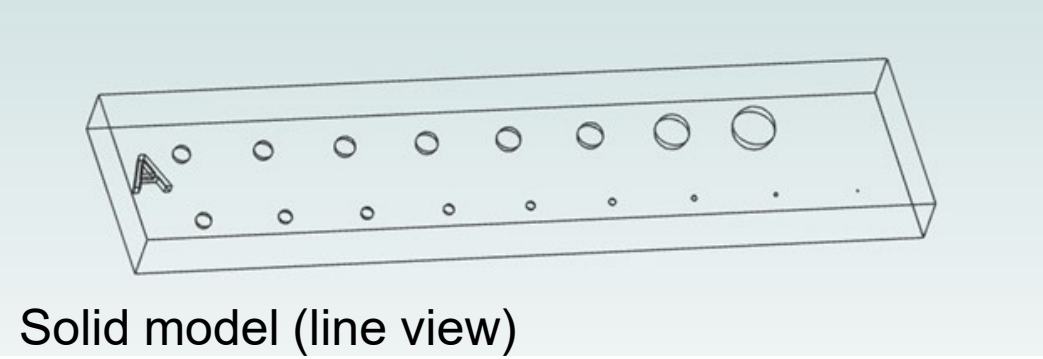
- Compared actual (microscopic inspection) and detected values
- Example includes defect surface area measurements
- High degree of correlation between actual and detected values
- Example of Extracted Parameters
  - Total number of defects detected (in this example = 6).
  - Total defect area (in this example = 6.9 mm^2)



Laser Powder Bed in-Machine Testing - Embedded Voids (p. 1 of 2)

Part Design with Internal Defects

Solid model (fill view)

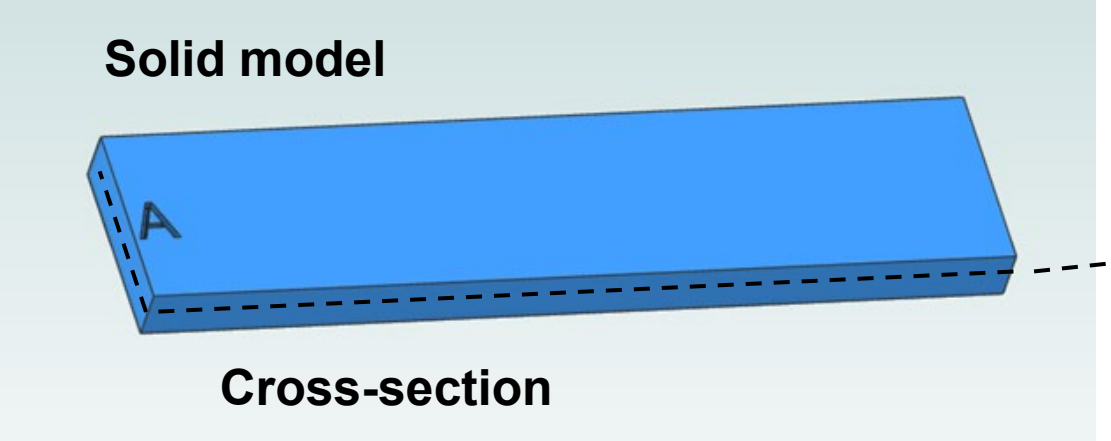


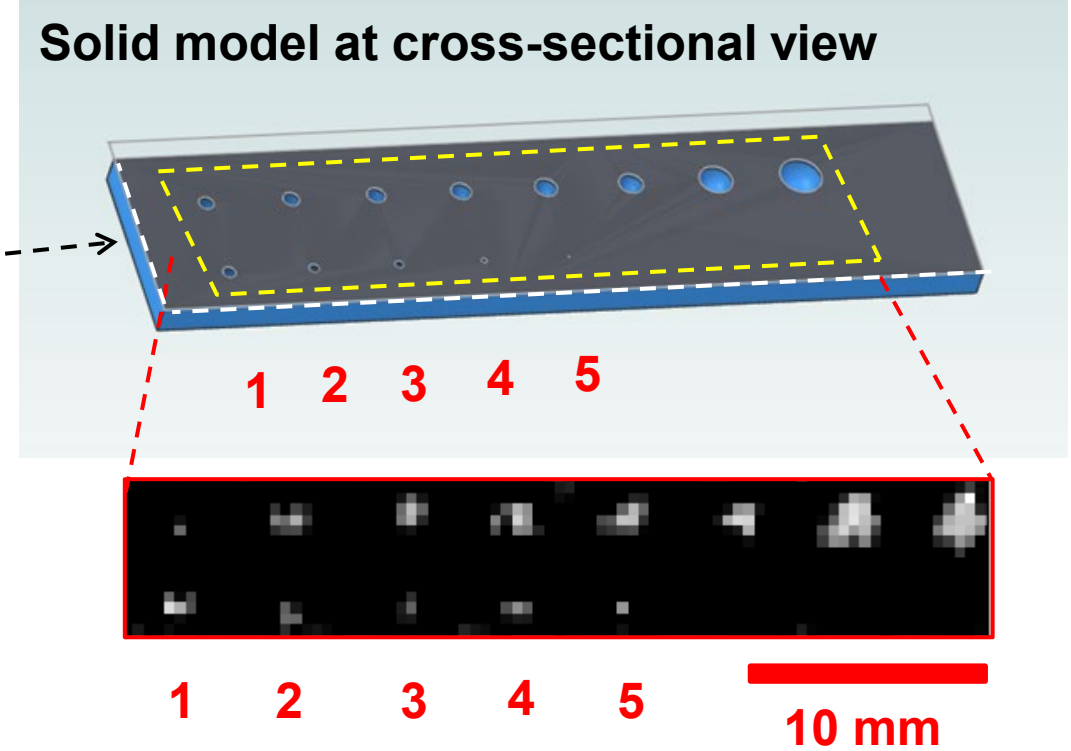
Solid model (line view)

showing internal structure

Photographs of Printed Part

Laser Powder Bed in-Machine Testing - Embedded Voids (p. 2 of 2)





- Successful real-time detection of internal structure.
- Volumetric data will be extracted.
- Defect map matches design

- Real-time internal defect map at the cross-section: 1.65mm below top surface
- Void diameter at cross-section:

  #1 : 0.84 mm. #5: 0.4mm

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Laser Powder Bed in-Machine Testing - Embedded Cylindrical Holes

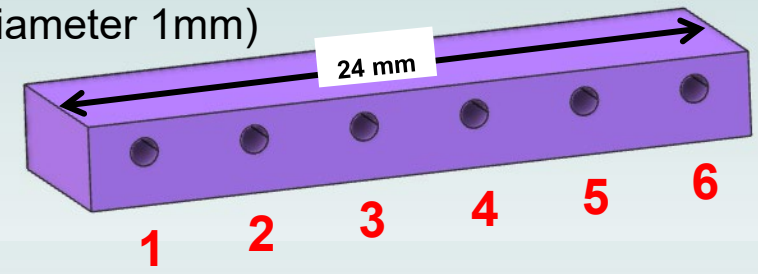
Solid model (fill view)

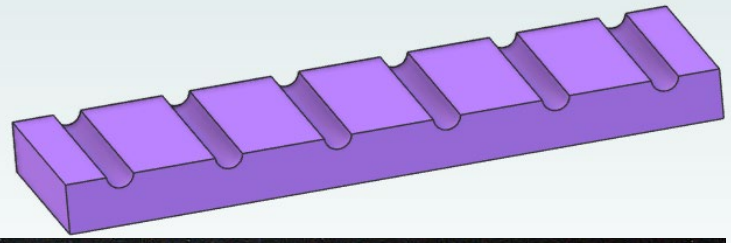
Solid model at cross-sectional view

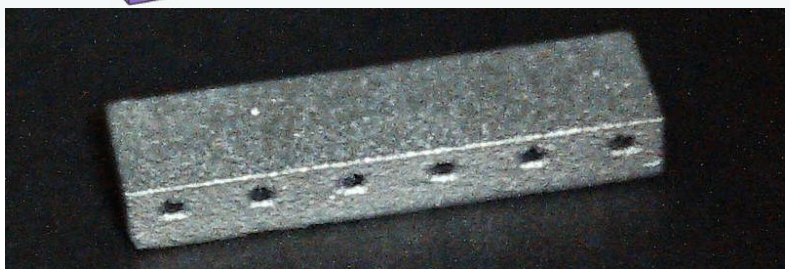
Photographs of Printed Parts

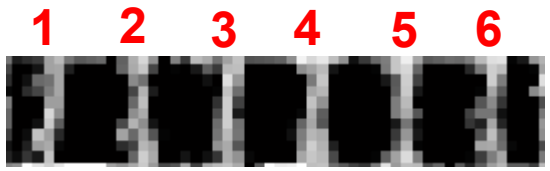
Real-time internal defect map at the cross-section

Equal Size Holes
(Diameter 1mm)

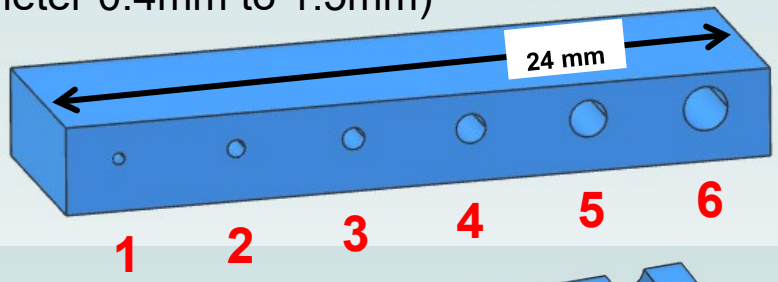


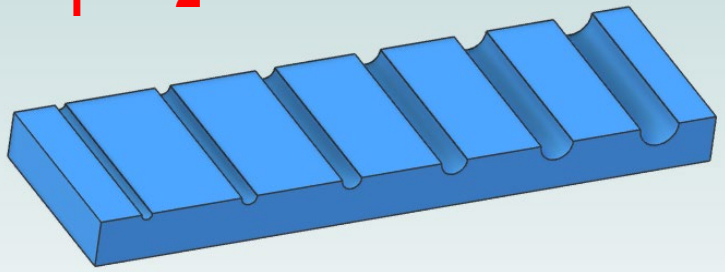


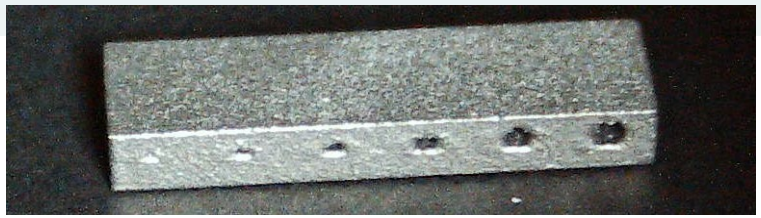


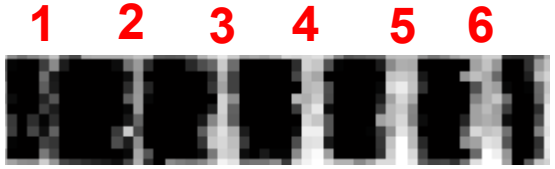


Different Size Holes
(Diameter 0.4mm to 1.5mm)

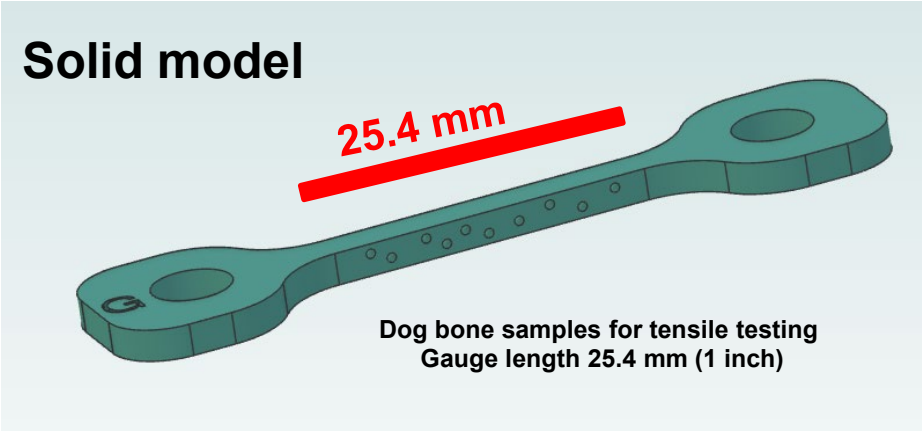


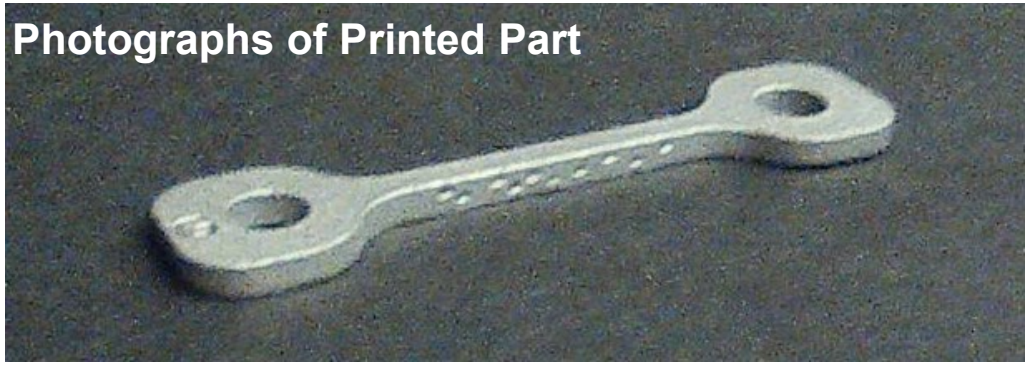






Laser Powder Bed in-Machine Testing - Tensile Testing Parts





- Various samples with and without defects were fabricated
- Prints included various tensile test specimens

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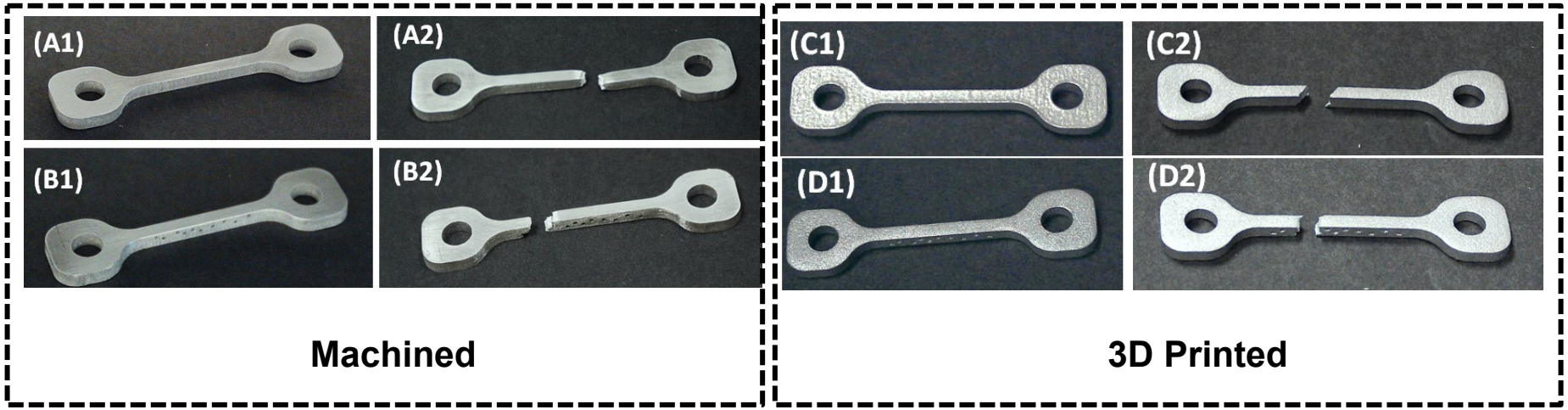
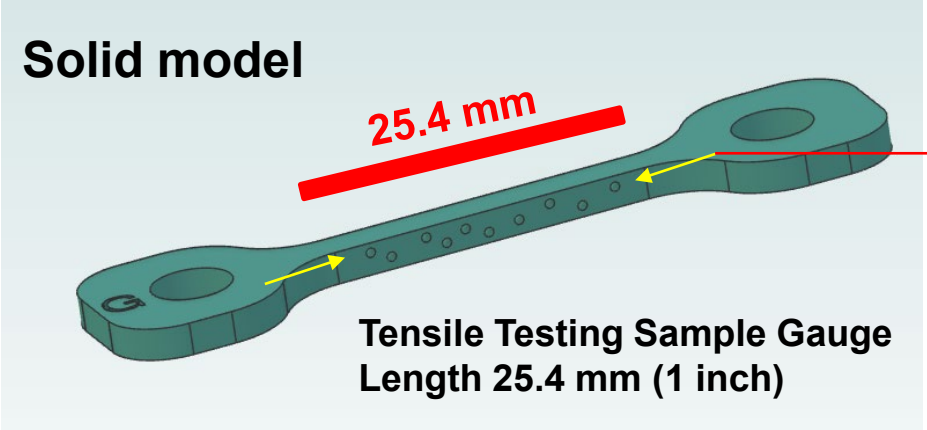
Compare Solid and Additive Manufactured Part Strength

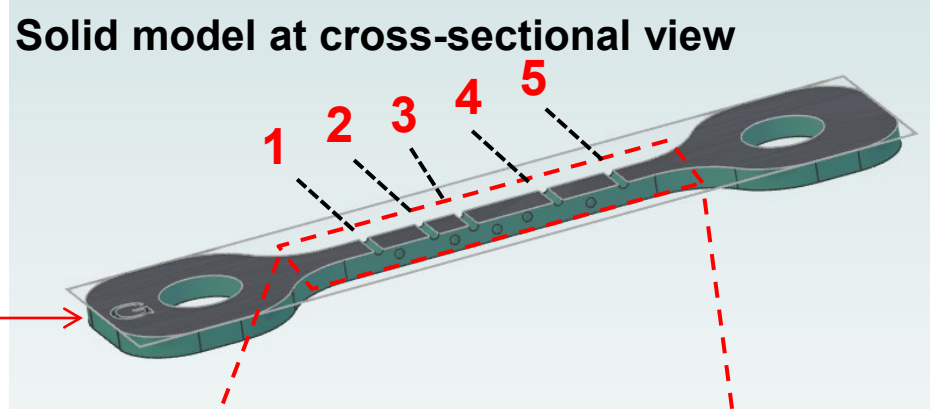
- Strength were compared between real-time AM inspection and machined parts.
- Machined sample (*6061-T6 Aluminum*) defects are similar to 3D printed samples (*AlSi10Mg – Aluminum*)
- Real-time NDE of 3D printed parts in the powder bed machine
- Performed tensile testing of machined and 3D printed samples

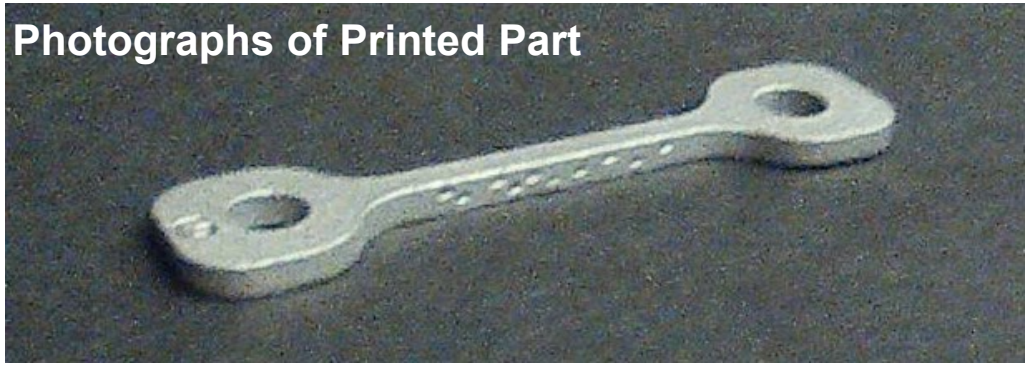


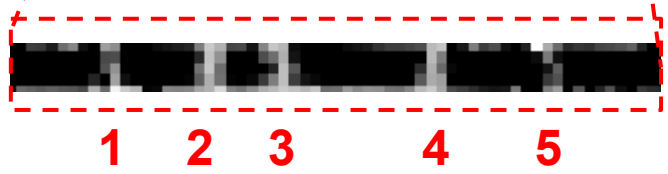
Sample	Type	Yield Strength (MPa)	Ultimate Strength (MPa)
Machined (A)	No Defects	276	310
Machined (B)	With Defects	186	214
3D printed (C)	No Defects	269	400
3D printed (D)	With Defects	179	223

Laser Powder Bed in-Machine Testing - Tensile Testing Parts









Real-time internal defect map at one of the cross-section

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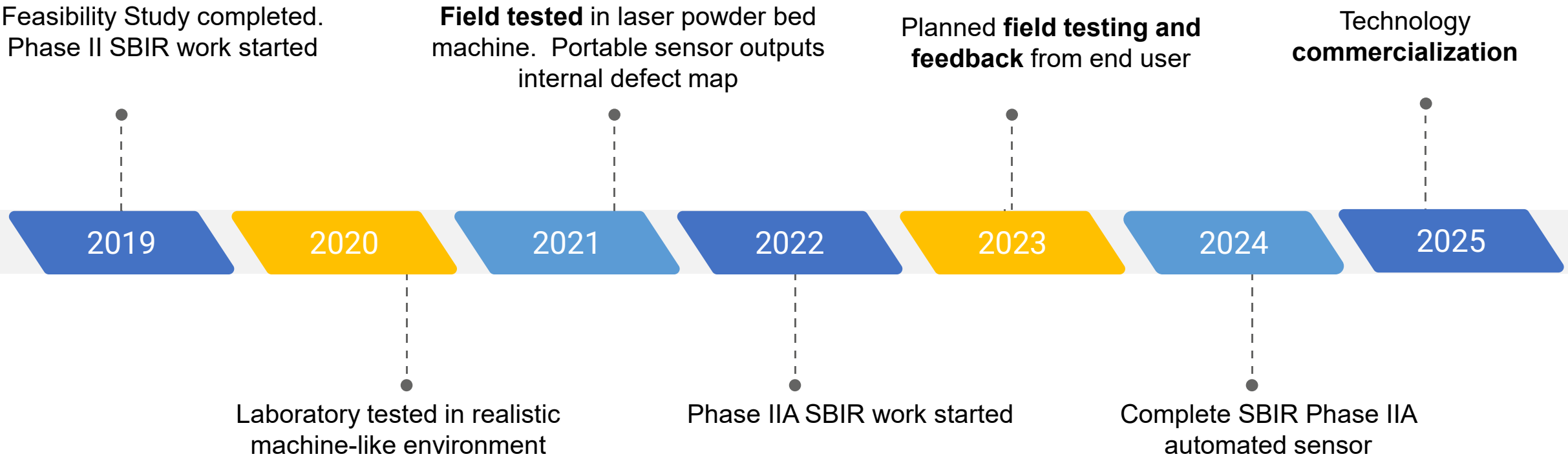
Roadmap



Summary

- AM SS316, Inconel 718 and Aluminum samples were made with intentional defects and NDE screened successfully
- Defect map was quantified to reveal parameters such as position of the defect, defect size, defect surface area, overall defect count, percentage of the surface that is defective.
- High degree of correlation between actual and detected defect values.
- Testing of AM Real time Aluminum tensile test samples showed strong correlation with detected defects which were introduced in the AM process.

Recap

- LER Technologies' sensor provide **a real-time, in-situ, non-destructive sensor** to detect surface/sub-surface defects during **3D printing of metal parts which can be applicable to 3D printer Service Providers and Original Equipment Manufacturers (OEMs).**
- Our customers are currently limited to destructive, post-production defect detection. Quality, cost and throughput are at risk.
- LER Technologies provides a solution by producing **real-time, high resolution defect maps** allowing **immediate corrective action** on critical, precision outputs (i.e. nuclear components). This can **decrease build time** (early-detection) and **cost** (labor and scrap).
- Our sensor is portable, machine agnostic and require less system downtime than alternative solutions.

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THANK YOU

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