PHOTODIODE BASED MONITORING AND QUALITY ASSURANCE PARADIGMS FOR LASER POWDER-BED FUSION: A SYSTEMATIC APPROACH

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AMSC event, December 8, 2021
Contents

• Brief overview of Multi-Scale Additive Manufacturing (MSAM) Lab of the University of Waterloo

• A systematic approach to in-situ photodiodes monitoring and analytical/machine learning defect detection algorithms

• Defect healing using an intermittent controller

• Conclusions and Outlook
University of Waterloo

- Most Innovative University in Canada for the last 32 years
- First in Canada and #22 in the World, based on 2021 Pitchbook Top 50 colleges for founders
Multi-Scale Additive Manufacturing (MSAM) Lab

Comprehensive Research Programs

World-class Additive Manufacturing Equipment

Advanced Characterization Equipment

http://msam.uwaterloo.ca
Additive Manufacturing: A Paradigm Shift

• “Today, additive manufacturing is achieving economies of scale in a variety of ways— and doing so without sacrificing economies of scope”.

• Like all conventional techniques, in-situ monitoring and quality assurance procedures/tools for AM are of the utmost importance in aiding manufacturers in quality management and certification to confidently step into low- and high-volume manufacturing.

• In-situ monitoring and its impact on the process health monitoring call for the development of standards.
Challenges with In-situ Monitoring and Quality Assurance for LPBF

- Most in-situ monitoring technologies for LBPF are not yet advanced enough to detect process disturbances reliably with high level of confidence.
- Many developments have been carried on in-house developed systems, making it hard to replicate.
- Too many intrinsic and extrinsic parameters involved in LPBF, causing major nonlinear, non-harmonic disturbances during the process.
- Requirement to an adaptive calibration platform due to temperature dependency of intrinsic parameters.
- Not adequate resolution, accuracy and sampling frequency in monitoring devices to count for small size defects (<50 micron).
- Lack of model-based monitoring and quality assurance platforms.
PHOTODIODE BASED MONITORING AND QUALITY ASSURANCE PARADIGMS FOR LASER POWDER-BED FUSION (LPBF): A SYSTEMATIC APPROACH TOWARDS THE DEVELOPMENT OF BEST PRACTICES
Project Goal

LPBF

Decrypted data

Correction factors

On-line data analysis

Analytical & ML algorithms

Layer-wised defect detection

CT-Scan

Validation/Calibration

Laser power correction map

Intermittent controller

Rule-based controller

Voxelization

Project Goal

Intermittent controller

Rule-based controller

Voxelization
Analytical and ML Methods Applied to Decrypted Datasets

Absolute Limits

\[ \frac{1}{n} \sum_{i=0}^{n-1} \text{intensity signal}(i) \]

Signal Dynamics

moving average(intensity) – mean value(intensity)

Short Term Fluctuations

(80 – 120)% of moving average(intensity)

Unsupervised methods

Supervised methods
Systematic Approach: Parts with Intentional Defects

- Mimic lack of fusion by creating intentional voids embodied in the design.
- Vertical and horizontal notches were incorporated into design for data registry and matching with CT.
- A periodic change in the height of the intentional cylindrical defects was considered in some samples.
- The inclusion of spheres with different diameters was devised in some samples.

Void ranging from 100 to 350 micron

CT-Scan result
Systematic Approach: Design of Experiments

Set 1
Set 2
Set 3
Set 4
Set 5
Set 6
Set 7
Set 8

Argon gas flow direction
Re-coater direction

Top view of the arrangement (effect of position/orientation on the signal)

Note: Parts are printed at different process parameters.
Material tested: HX and Ti64
Cross section of one individual part, showing 9 intentional defects

Side view
Analysis is done on capping layer
Footprint of intentional defects is major in the capping layer, while being faded in the successive layers.
Learning Points

1- Absolute Limits (AL) (threshold 10000-22000 and window length 5-30)
2- Signal Dynamics (SD) (threshold 20-1000, and window lengths 5-30)
3- Short Term Fluctuations (STF) (threshold 65-140 and window length 5-20)

Randomized Porosity: Tailored Voxelization

Detection algorithm based on the confusion matrix concept

Evaluation of model based on the calculated labels

Accuracy = \frac{TP+TN}{total\ population}

TP= True positive         TN= True negative

Volume slice n
Volume slice n-1
Volume slice n-2

Volume slice i+2
Volume slice i+1
Volume slice i

With 120\,\mu m overlap

With 60\,\mu m overlap

Without overlap
Results: MSAM Detection Algorithm vs. CT-Scan

~75% prediction rate for pores larger than 120 micron
Preliminary results of intermittent controller

Pores smaller than 120 µm was filtered out from the CT-Scan results

Density= 97.96
Density= 98.90
Conclusions and Outlook

1. The threshold levels and sampling windows obtained through the systemic approach, applied to printed parts with intentional pores, facilitate a model-based detection platform to identify randomized pores.

2. The successful detection is limited to pores larger than 120 micron.

3. Level of confidence in the detection is more than 75%.

4. With new technical development and improving the hardware resolution and frequency, the detection of finer pores is on horizon.

5. A work item (ASTM WK76983) has recently been registered in ASTM to craft a best practice under “In-situ Defect Detection and Analysis” and collect feedback from peers on the developed approach.
Thank you for your attention