Comparison of *ex situ* x-ray radiography and *in situ* monitoring to gain control over defects during laser powder bed fusion

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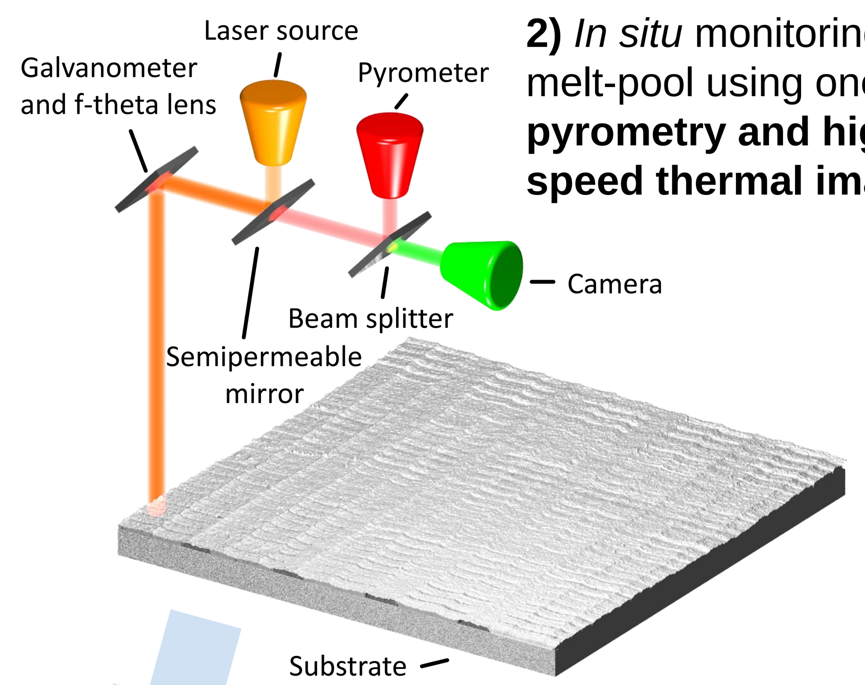
ABSTRACT

As in any other laser welding technique, creation of pores and defects during laser powder bed fusion can lead to component failure and thus cannot be tolerated. Post-build inspection is required to ensure the printed parts are defects-free. These inspections can take time and are complicated particularly for large parts. A solution is to use in situ process monitoring to detect the creation of defects, which could in turn be corrected during the printing itself. However, the relationship between pore creation and in situ monitoring still needs to be understood. In this work, we use **x-ray computed tomography** to detect pores and correlate them to **pyrometry** and **high speed thermal imaging** signals collected during laser welding.

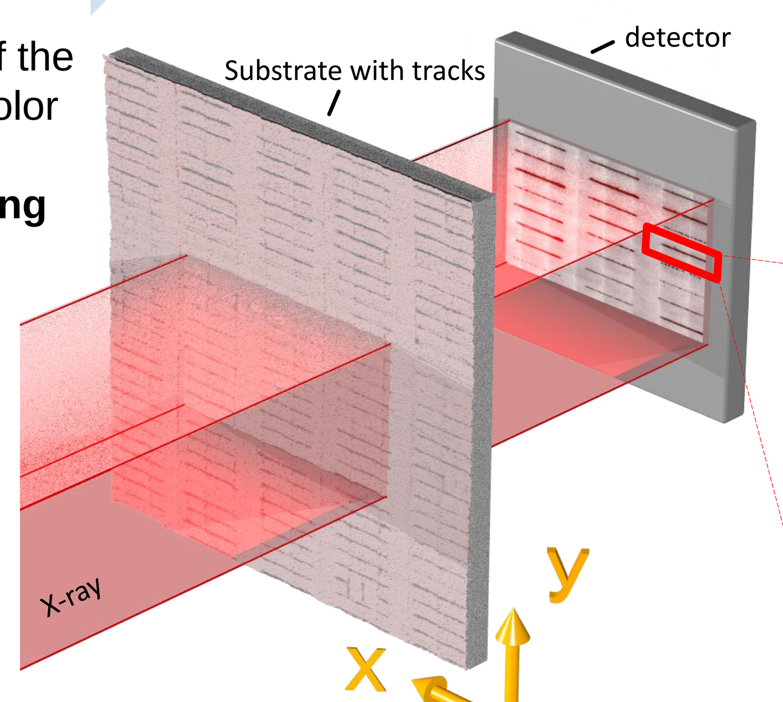
EXPERIMENTAL APPROACH

1) Laser welding of single tracks on stainless steel powder bed with varying parameters

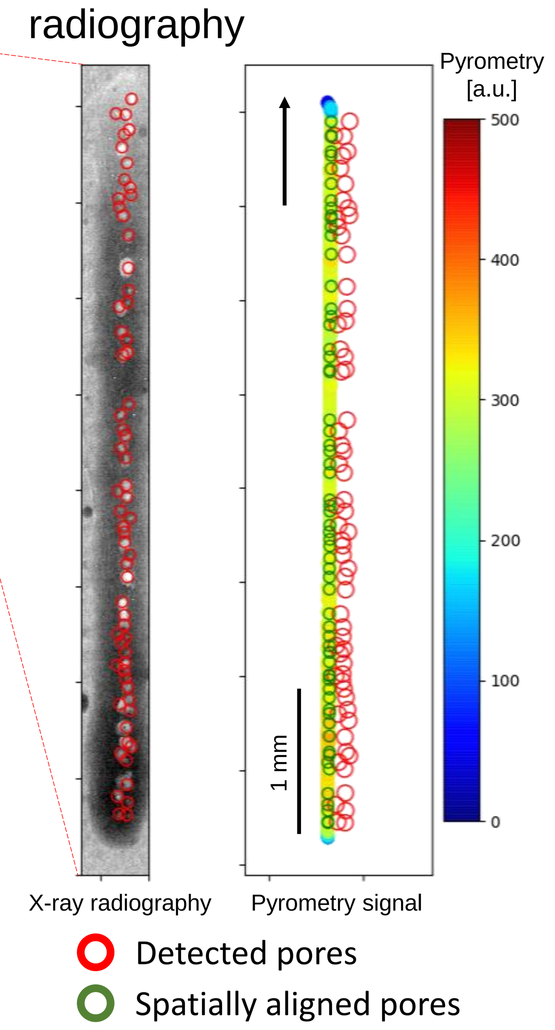
2) *In situ* monitoring of the melt-pool using one color **pyrometry and high speed thermal imaging**



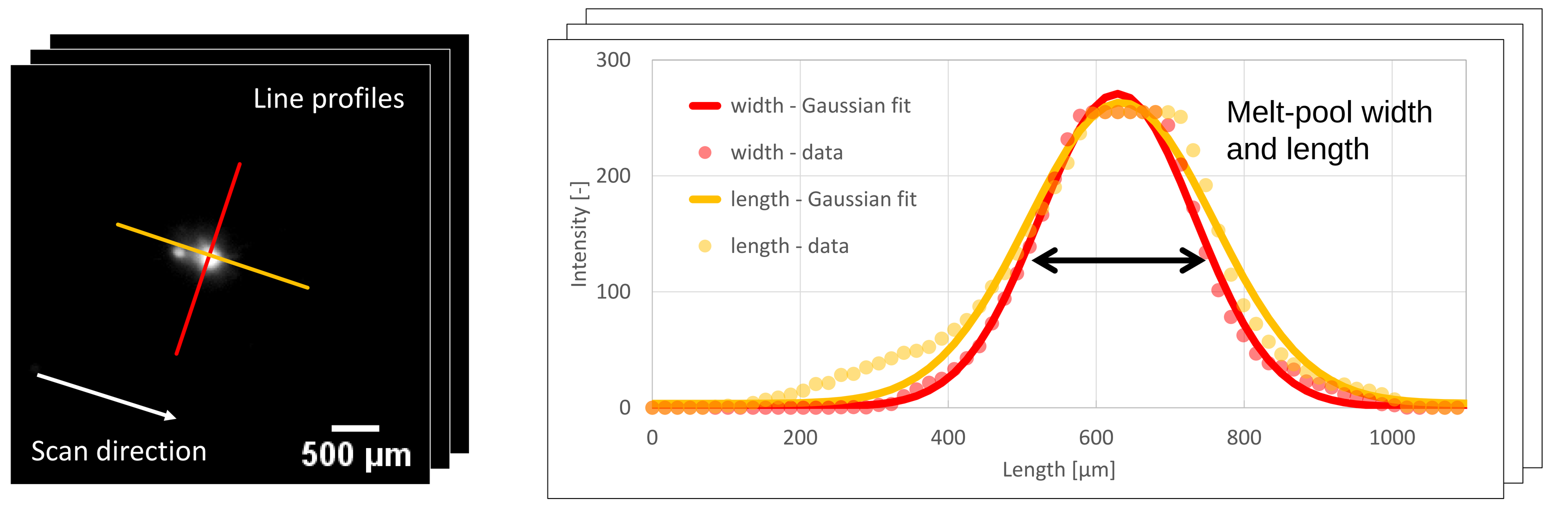
3) *Ex situ* **x-ray radiography**



4) Image processing and pores detection using x-ray radiography

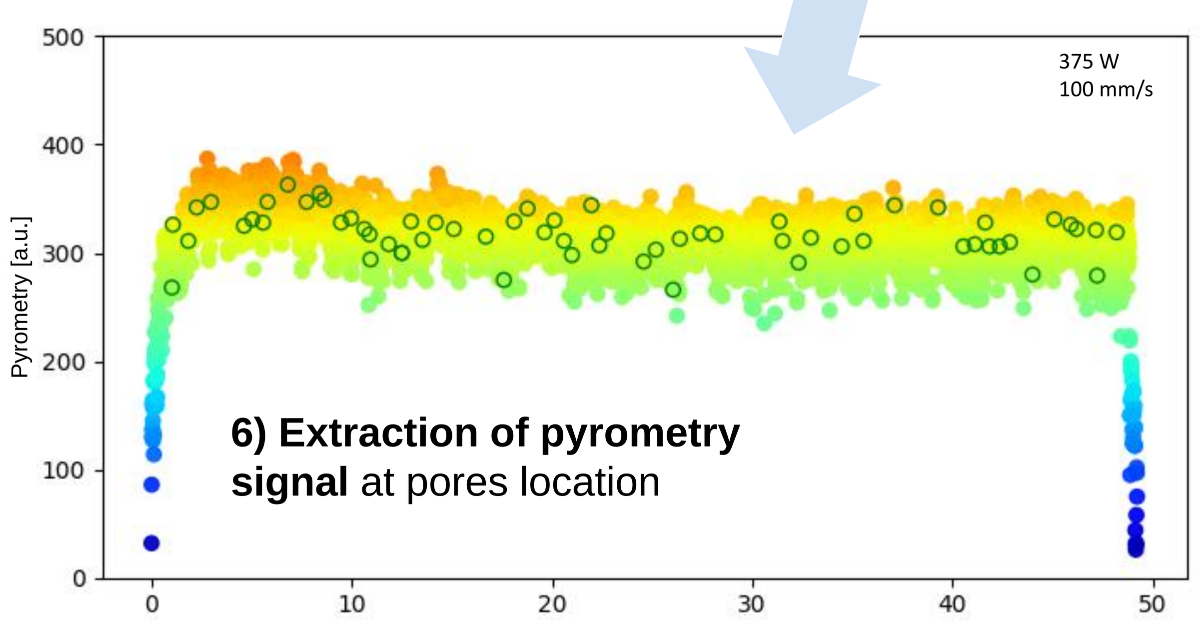


7) Characterization of **melt-pool geometry** via profile fitting



5) Spatial alignment of detected pores with pyrometry signal

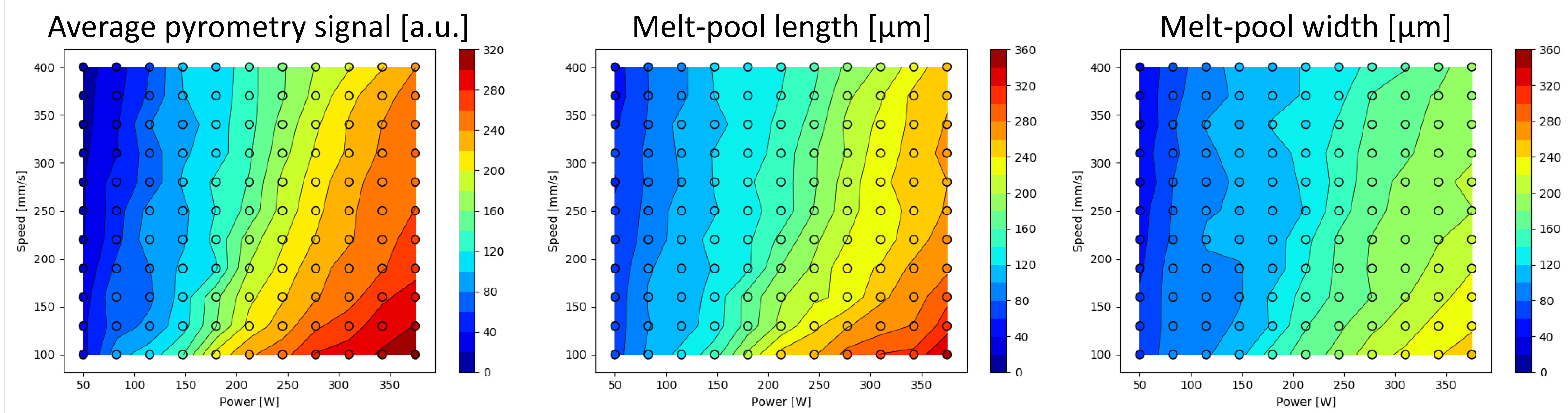
Print parameter	Value
Materials	SS316L
Layer thickness	50 um
Laser power	[50-350] W
Laser speed	[100-400] mm/s
Monitoring parameter	
Pyrometer acquisition rate	100 kHz
- sampling time	10 µm
- spectral range	[1580-2200] nm – [500-2000] K
High speed acquisition rate	1 kHz
- sampling time	1 ms
- spectral range	[400-800] nm
- resolution	17 µm/pixel



6) Extraction of pyrometry signal at pores location

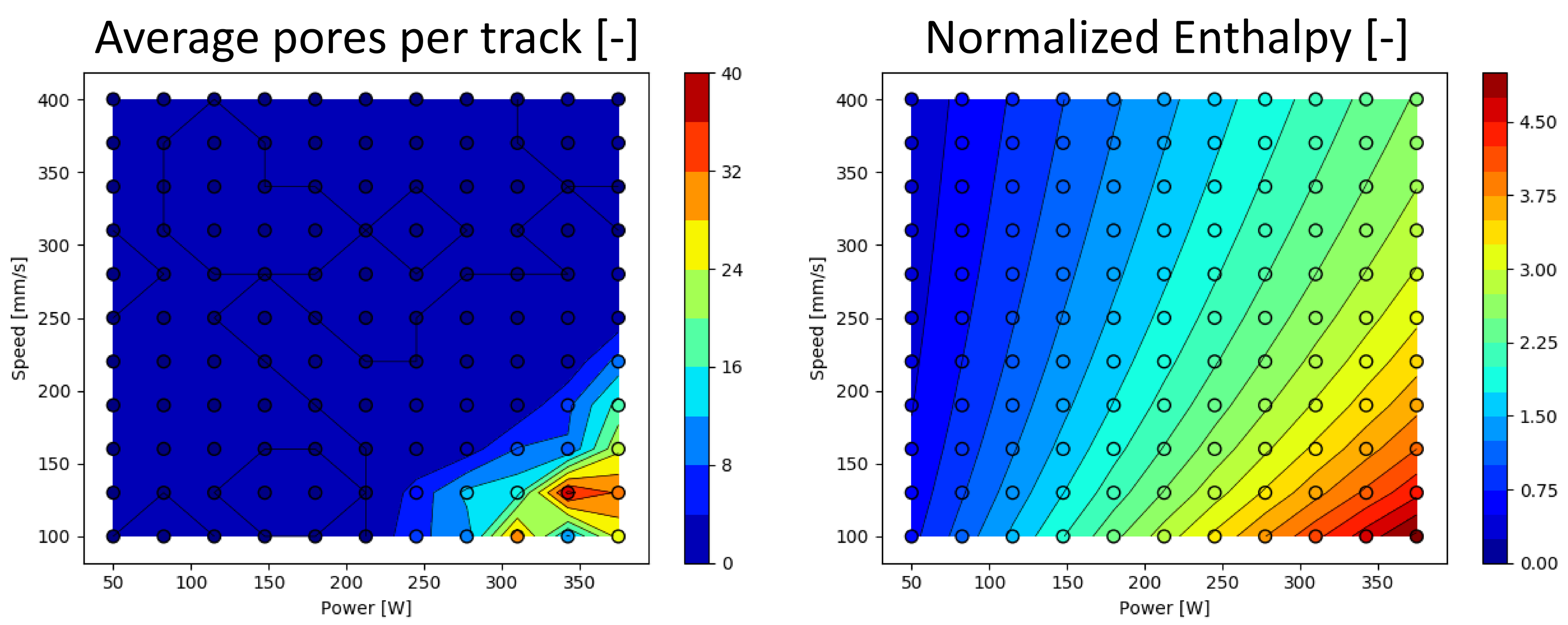
RESULTS

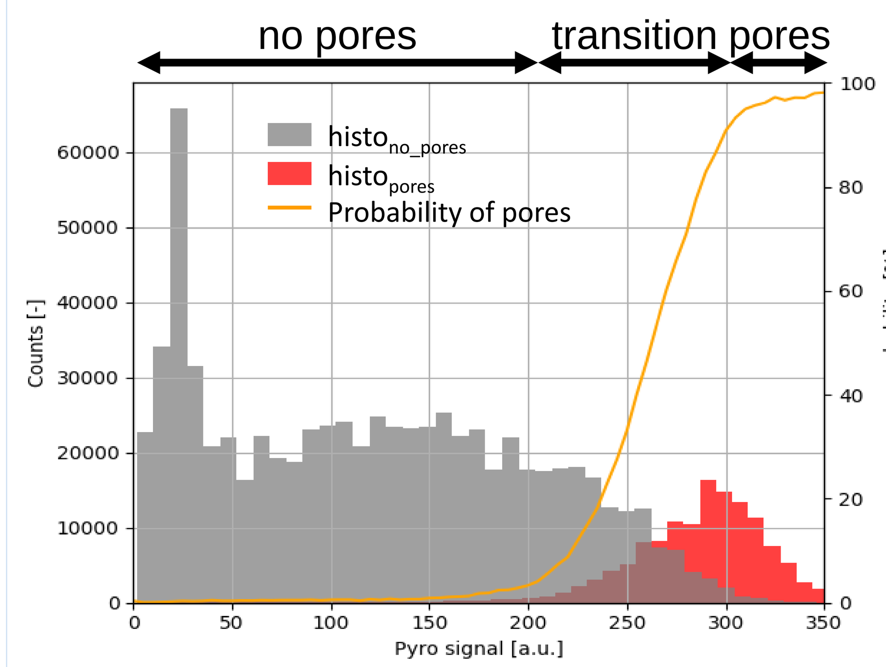
Pyrometry and high-speed imaging are carried out to monitor thermal radiation variation at the surface of the melt-pool as well as length and width changes at different laser power and speed. Both *in situ* monitoring reveal similar variation in their results at almost same rate. The lowest and highest values are obtained at high speed-low power and low speed-high power respectively, following the change of deposited energy.



X-ray radiography provided projection images of the weld tracks with enough contrast to make possible the detection of pores. The resulting average number of pores is negligible for a large part of laser parameters, namely any laser power above 250mm/s and any laser speed below 200W in this experiment.

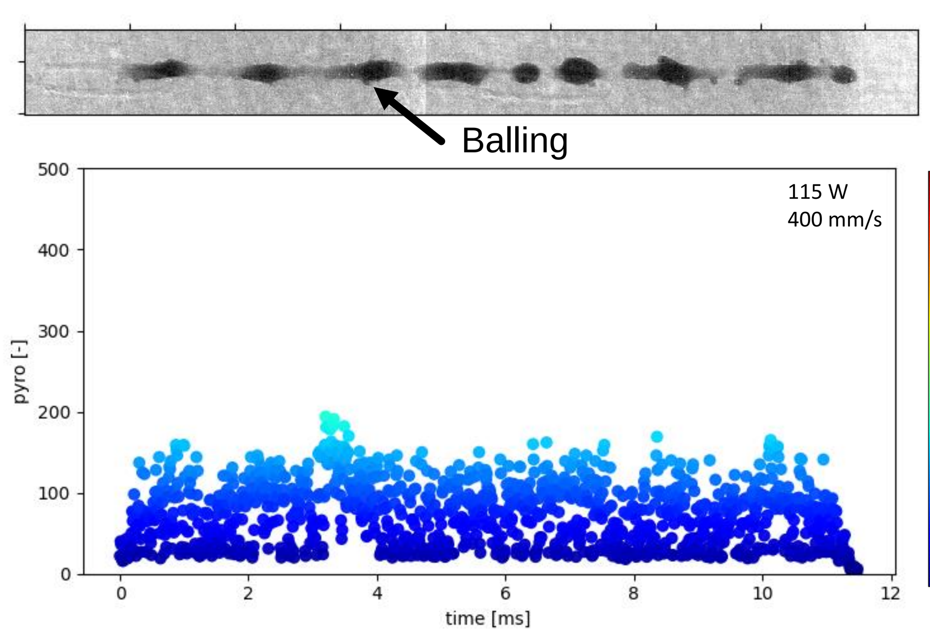
Alignment of x-ray projection of the build plate with pyrometry maps enable to extract thermal radiation information of the melt-pool at the pores location.





Pores probability define as:

$$P_{pores} = \frac{histo_{pores}}{histo_{pores} + histo_{no\ pores}}$$



Comparison of pyrometry data and corresponding x-ray images shows that low yet continuous signal is observed when local discontinuities are present in the melt-pool.

SUMMARY

Conclusions

- Average pyrometry signal as well as melt-pool length and width vary accordingly with regards to normalized enthalpy.
- X-ray imaging enables to retrieve pores presence within the weld and the average number of pores per laser parameters increases with normalized enthalpy above a threshold.
- Alignment of pyrometry maps and x-ray projections enable to extracted thermal radiation information at the pores location. Histogram of pyrometry signal distribution at pores location and in the rest of the welds help to define a confidence range about pore presence in single track.
- The balling effect occurring due to surface tension and high viscosity of the melt is not detectable using pyrometry.
- X-ray radiography is a fast method to look at pores in single layer laser welding sample (~450 tracks printed in and x-ray radiography in 4 hours).

Future Work

- Extract balling information from x-ray radiography.
- Investigate pore correlation with additional *in situ* diagnostics (e.g. height sensors, acoustics).
- Develop *feed-forward / control* approaches to defect mitigation in collaboration with modelers.

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