Measuring Porosity in Ti-6Al-4V Laser Powder Bed Fusion Samples

ENGINEERING HONORS PROGRAM
UNIVERSITY OF MICHIGAN

Wei-Ling (Winnie) Hung (Honors Capstone)
Advisor: Dr. Jerard Gordon

Background

Metal additive manufacturing (metal AM), or metal 3D printing, is a promising manufacturing process that allows for unprecedented design freedom and eliminates the need for custom tools compared to traditional methods of metal manufacturing. Laser powder bed fusion (LPBF) is a form of metal AM that produces parts by melting and fusing metal powder layer by layer on a platform. This project analyzes and compares the formation of pores in Ti-6Al-4V (or Ti64) LPBF samples printed under different laser settings to better understand and predict defects in the future.

Objectives

1. Based on the defect structure process map (DSPM) from a previous research project by Dr. Gordon, print 16 cubic samples of 1 cm^3 under different combinations of laser power and speed of interest
2. Perform optical microscopy on the samples to measure porosity
3. Compare experimental results to the DSPM to verify the predictive model

Methods

- Defect Structure Process Map (DSPM): The Rosenthal Equation uses material parameters to predict the melt pool depth for the LPBF process. Based on this and other melt pool geometric dimensions, a model was developed to predict LOF porosity in the Ti64 samples.
- LPBF Sample Printing: 16 1 cm^3 samples of Ti64 were printed using the TRUMPF TruPrint 1000 under different combinations of laser powers and speeds selected based on the predictive model.
- Optical Microscopy and Analysis: Each sample was observed under an optical microscope and processed using ImageJ to obtain the actual porosity, which is then compared to the DSPM.

Defect Structure Process Map (DSPM)

Based on the melt pool dimensions and layer thickness of the TRUMPF TruPrint 1000, the LOF defect boundary was mapped as part of Dr. Gordon's research. Along with the boundary for keyhole defects, which occurs when gas is trapped during the printing process, a process window was identified for the commonly desired printing outcome of higher density parts, as shown in Figure 1.

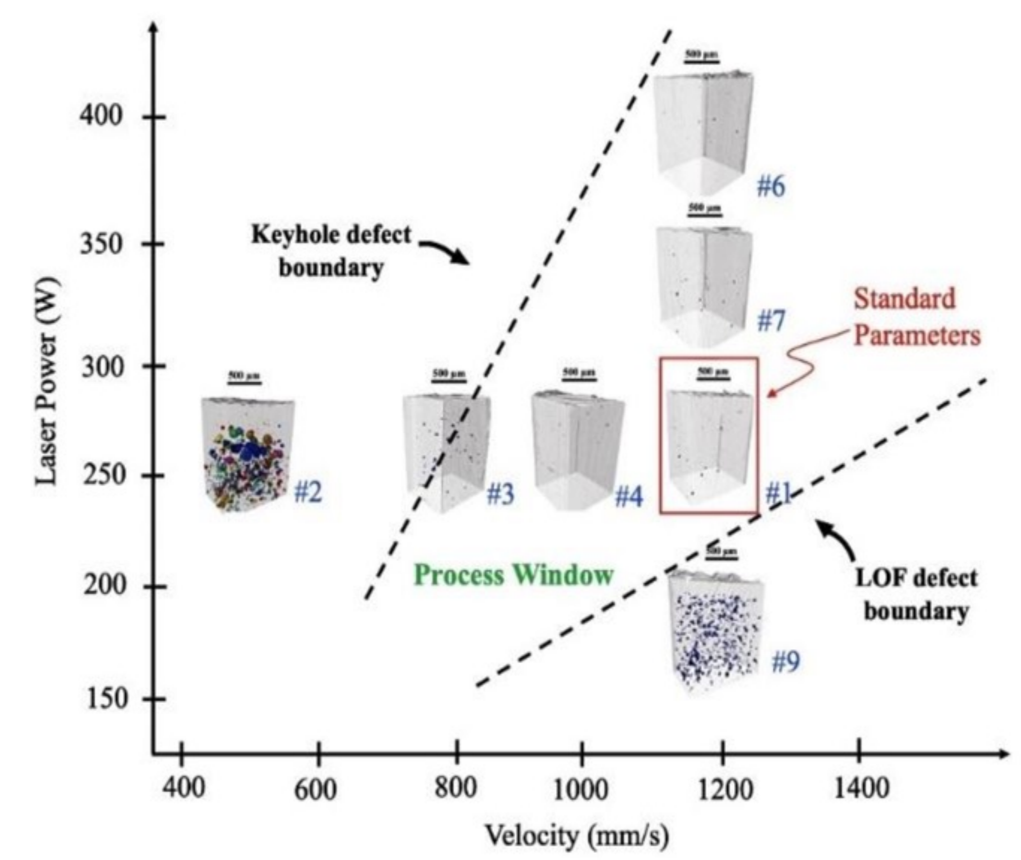

Figure 1: Defect structure process map of LPBF Ti64 samples. LOF pores are expected to form when the printing parameters are beyond the LOF defect boundary.

Optical Microscopy Results

After being printed by the TRMUPF TruPrint 1000, the samples were cut off the baseplate using wire EDM. They were then prepared for optical microscopy through a series of grinding and polishing processes from coarse grit P400 sandpaper to fine 1 μm diamond solution. The samples were then imaged using an optical microscope and analyzed with ImageJ to calculate their porosities. In addition, the images also show distinct differences between LOF defects (large, irregular pores) and keyhole defects (small, round pores). The results for two out of the 16 samples are shown below in Figure2 and Figure 3.

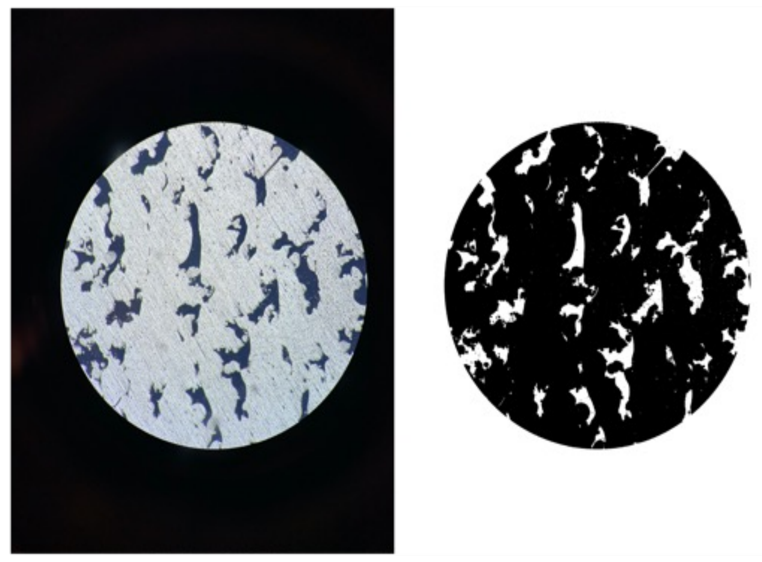

Figure 2: Optical image of sample 4 at 5X magnification (left) and its ImageJ processed result (right). This sample has mainly large irregularly shaped LOF pores and its porosity is calculated to be 13.731%.

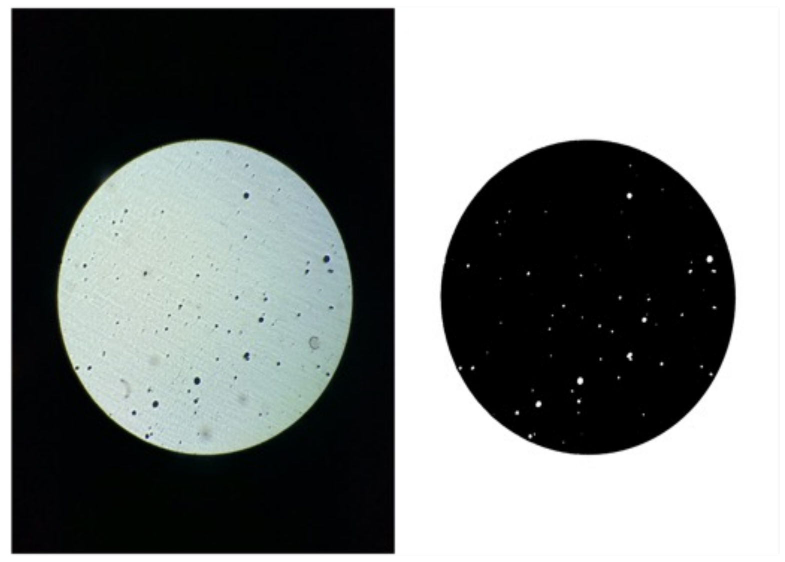

Figure 3: Optical image of sample 16 at 5X magnification (left) and its ImageJ processed result (right). Only small keyhole defects are observed in this sample and its porosity is calculated to be 2.131%.

Sample Analysis

The printing parameters and calculated porosity of the 16 Ti64 LPBF sample are summarized below in Table 1. A linear regression line was plotted between the LOF criteria and the porosity (R^2 = 0.575). Experimental results are generally consistent with the model with the exception of sample 11, which is observed to have LOF defects despite being printed at high power and low velocity. The cause of this deviation from the DSPM is unclear.

Table 1: Parameters and results of the 16 LPBF samples.

Sample	Power (W)	Velocity (m/s)	LOF Criteria	Porosity	LOF?
1	60	0.1	0.10010697	0.456%	
2	60	0.3	0.30032092	9.112%	x
3	60	0.5	0.50053486	12.061%	x
4	60	0.75	0.70074881	13.731%	x
5	60	1	0.90096275	13.763%	x
6	90	0.1	0.06673798	0.385%	
7	90	0.3	0.20021394	1.22%	x
8	90	0.5	0.33368991	7.079%	x
9	90	0.75	0.46716587	5.876%	x
10	90	1	0.60064183	15.636%	x
11	120	0.1	0.05005349	8.95%	x
12	120	0.3	0.15016046	0.899%	
13	120	0.5	0.25026743	5.992%	x
14	120	0.75	0.3503744	5.969%	x
15	120	1	0.45048138	2.993%	x
16	80	0.2	Nominal	2.131%	

Acknowledgement

This project would not have been possible without the guidance and previous research done by Dr. Jerard Gordon. It also would not have been possible without the support of Michael Stryk, Audrey Yung, and Daniel Rubio-Ejchel. Furthermore, my appreciation goes to Dr. Amit Misra's lab for letting me use their microscope. Thank you all!

References

Gordon, Jerard, et al. "Defect Structures Process Maps for Laser Powder Bed Fusion Additive Manufacturing." *Additive Manufacturing,* vol. 36, 2022, pp. 101552. https://doi.org/10.1016/j.addma.2020.101552.