Joint Special Interest Group meeting between euspen and ASPE
Advancing Precision in Additive Manufacturing
KU Leuven, Belgium, September 2023
www.euspen.eu

Benchmarking of an Open Architecture Polymer Laser Powder Bed Fusion system

Christian L. Budden[1], Magnus B. Kjer[1], Aakil R. Lalwani[1], Venkata K. Nadimpalli[1], and David B. Pedersen[1]

[1]*Technical University of Denmark, Institute of Civil and Mechanical Engineering, Denmark*

clebu@dtu.dk

Abstract
This study aims to benchmark a fibre laser powered Open Architecture Polymer Laser Powder Bed Fusion (LPBF) system, which has been developed to offer complete process control. It enables researchers to investigate the process and materials development for the Polymer laser powder bed fusion process by providing control over critical parameters during the additive manufacturing process. To verify the solution, a benchmark study was conducted to investigate the system's capabilities. The investigation involved manufacturing a known benchmarking geometry that challenges the polymer powder additive manufacturing process. The results indicate that the Open Architecture Polymer LPBF system can reproduce the benchmarking geometry successfully. The findings of this study demonstrate the potential of the Open Architecture Polymer laser powder bed fusion system for research and development in the field of additive manufacturing.

Open-source, laser powder bed fusion, L-PBF, open-architecture, polymer, Selective laser sintering, sls

1. Introduction

Additive manufacturing of plastic components employs various methods, with laser powder bed fusion of polymers being one of the most widely used. It selectively melts polymer powder layer-wise with a laser to create 3D objects. An Open Architecture laser powder bed fusion system for polymers has been developed to enhance user control and allow research into fibre lasers. Traditionally, CO2 lasers were used for polymer powder processing, but this work implements an optical absorber in a powder mix to enable consolidation using a fibre laser. [1-4]

This work presents the capabilities of a laser powder bed fusion system for polymers developed at the Technical University of Denmark by producing a benchmark geometry with intricate details and complex geometries. The work is part of a joint collaboration with the authors of benchmarking of an open architecture metal laser powder bed fusion system. This work utilises the same method and benchmarking geometry, with the major difference being the material and processing system presented in the work.

2. Methodology

The benchmark geometry was manufactured on the Open Architecture polymer laser powder bed fusion system developed at the Technical University of Denmark [2]. The system utilises a fibre laser with a spot size of 150 µm. The system is a repurposed 3D Systems binder jetting machine (Projet 4500) now capable of laser powder bed fusion of polymers.

Table 1 Process parameters used to manufacture the benchmark

	Feedrate	Power	Hatch	Layer
Hatch	3000mm/s	55W	150µm	40µm
Contour	1500mm/s	35W		

2.1. Benchmark manufacturing

The benchmark was manufactured using a blend of white and black PA11 Ultrasint polymer powder from BASF. The powder mix consisted of 95% white powder and 5% black powder, as detailed in a previous publication [2]. The process parameters utilised are listed in Table 1. The manufacturing strategy involved hatch and contour scanning, with a 10-second temperature stabilisation period after each recoating.

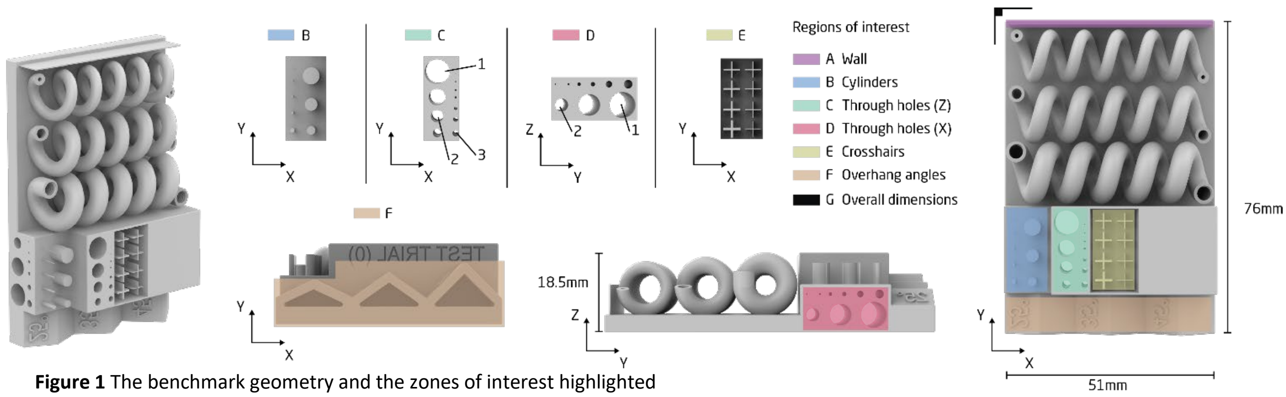

Figure 1 The benchmark geometry and the zones of interest highlighted

	A	A1	A2	B	C	C1	C2	D	D1	D2	E	F	G1	G2
Insp.														
Feat.				1	1.5			2						
μ [mm]		0.66	6.32			5.61	2.68		5.50	2.47			76.44	50.55
σ [mm]		0.0093	0.0085			0.0009	0.0028		0.0022	0.0063			0.0003	0.0003
Nom. [mm]		0.3	7			6	3		6	3			76	51
Δ [mm]		0.364	-0.683			-0.394	-0.315		-0.503	-0.525			0.438	-0.455
Δ [%]		121.2	-9.761			-6.573	-10.52		-8.389	-17.51			0.576	-0.892
R [mm]		-	-			0.226	0.197		0.4063	0.3271			-	-
σR [mm]		-	-			0.002	0.001		0.0015	0.0266			-	-

Table 2 Featured inspected visually (ie. A) features measured by DeMeet (ie. A1)

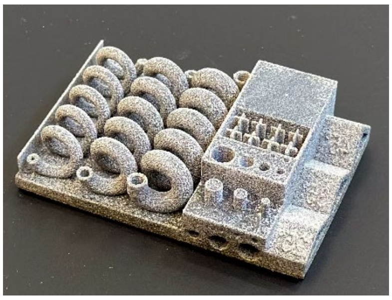

Figure 2 Benchmark geometry

Originally designed for metal powder bed fusion [3], [4], the benchmark geometry was reconfigured and modified for polymer powder laser processing. The entire geometry was shelled to a thickness of two mm, and holes were incorporated into the large flanges to minimise bloating and reduce gas entrapment. None of the benchmark features were modified during this adaptation. The build job was created using Netfabb Premium (Autodesk, USA), and the geometry was shrinkage compensated by 2% in both the X and Y directions, based on a trial run of the geometry with no compensation included. The Netfabb build file was then converted to a custom G-code-inspired syntax compatible with the system controller.

2.2. Benchmark measurements

The benchmark components underwent evaluation on two tracks. Firstly, an overall inspection was conducted to identify the minimum feature within each geometrical category (Figure 2) and detect possible surface defects. Secondly, selected features were measured using a DeMeet 220 (Schut Geometrical, Netherlands), 3D CNC coordinate measuring machine to compare their dimensions with the CAD file's nominal values. The parts were inspected in their as-printed state, with only loose powders removed prior to measurement.

3. Results

The manufactured parts demonstrated the system's capability to produce mm-sized features with expected accuracy. Visual inspection and measured results are presented in Table 2, where green indicates passed features and red indicates missing or damaged features. The inspection window shows the minimum feature size of failed geometries, reflecting the system's capabilities, considering the material and process. Measured features, including mean (μ), standard deviation (σ), nominal parameter (nom.), absolute (Δ) and relative (Δ) deviation, roundness (R), and roundness standard deviation (σR), are shown below the inspected features. The wall (A) was structurally stable but oversized, which was clear from the mean of A1. Cylinders (B) were within an expected range, with a minimum feature size of 1 mm. Z-direction holes (C) exhibited roundness issues due to uncontrolled part growth in the heated build environment. X-direction holes (D) showed decreased roundness, resulting in oval-shaped holes. Crosshairs (E) were all present, and overhang angles (F) displayed good capabilities without surface defects. Overall dimensions (G) closely matched nominal values, correlating with the utilised shrinkage factor but lacking full compensation. The Z direction lacked shrinkage compensation, exacerbating the oval effect for features perpendicular to it. The system successfully produced intricate details in geometry.

4. Analysis

The benchmark geometry was reproduced successfully, showcasing many of the fine intricate features. The system could not reproducible all the pillars in B with the breakdown level being less than 1.5mm. The majority of the holes were well formed in both the X and Z direction. The minimum feature size for the through holes travelling the length of the part is 2mm for X and 1.5mm for Z. Enhancing the thermal process control of the build volume temperature and homogenising the black optical absorber, can improve the results further, which is planned for future work.

5. Summary and conclusion

The benchmark component was produced successfully, producing the majority of the intricate features. Despite the low energy absorption in the polymer at fibre laser wavelengths. The smallest features were impossible to produce due to the process and material limitations. For robust features to be produced by polymer laser powder bed fusion, larger features are needed in order to consolidate the powder particles. Laser irradiation in very small areas leads to too little energy delivery, not melting the particles fully. Aided by the very high energy density required for consolidating the major geometries. This, in conjunction with large wait times between successive scanning in small feature areas, cause the minimum feature size to be in the mm range. The mechanism is inverted for holes with small holes growing over because of too high heat intensity in this area, not leaving behind unsintered particles. The main hypothesis of utilising a fibre laser to obtain finer detail resolution is not fully met. However, it is clear that fine details can be produced, with a potential for further optimising the material and optical absorber.

References

[1] T. Wohlers, I. Campbell, O. Diegel, R. Huff, J. Kowen, and W. A. (Firm), *Wohlers report 2023: 3D printing and additive manufacturing global state of the industry*. Wohler Associates Inc., Fort Collins, CO, 2023.

[2] C. L. Budden, A. R. Lalwani, K. Æ. Meinert, A. E. Daugaard, and D. B. Pedersen, "Process optimisation of PA11 in fiber-laser powder-bed fusion through loading of an optical absorber," *Proceedings of the 33rd Annual International Solid Freeform Fabrication (sff) Symposium*, pp. 75–86, 2022.

[3] M. Moshiri, G. ; Tosello, and S. Mohanty, "A new design for an extensive benchmarking of additive manufacturing machines," *Proceedings of the 18th International Conference of the european Society for Precision Engineering and Nanotechnology*, 2018.

[4] M. Moshiri, D. B. Pedersen, G. Tosello, and V. K. Nadimpalli, "Performance evaluation of in-situ near-infrared melt pool monitoring during laser powder bed fusion," *Virtual Phys Prototyp*, vol. 18, no. 1, 2023, doi: 10.1080/17452759.2023.2205387/SUPPL_FILE/NVPP_A_2205387_SM5236.DOCX.