Analytical LPBF Melt Pool Simulation and Experimentation for Metamaterial Lattices

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ABSTRACT

Laser Powder Bed Fusion (LPBF) has emerged as a pivotal additive manufacturing technique, enabling the fabrication of complex geometries with high precision. Metamaterial lattices, characterized by architected periodic structures, have garnered significant interest due to their unique mechanical properties and potential applications across various engineering domains. Sizing of the lattice struts requires accurate prediction of the melt pool geometry. In particular, unsupported overhanging struts, exemplary for auxetic lattice structures, are challenging to fabricate with consistent quality [1]. Traditional finite element analysis are computationally intensive and may not be practical for optimization. Analytical models offer a more efficient approach to predict melt pool characteristics [2-3], yet their application to the fabrication of complex metamaterial lattices remains underexplored.

In this study, we present an analytical model tailored to predict melt pool dimensions specific to the fabrication of metamaterial lattices using LPBF. Our model integrates key process parameters, including laser power, scanning speed and material properties, to estimate melt pool width, depth and length. The model has been validated for stainless steel 316L based on thin-walled structures. To predict the processability of unsupported overhanging structures, the thermal behaviour of consolidating directly on powder has been considered. Results show that in particular the melt pool depth and most significantly the length are influenced.

LPBF experiments have been conducted, in which horizontally overhanging struts are fabricated. The experimental results show agreement with the predictions of our analytical model with deviations within understandable margins. Subsequently, optimal LPBF process parameters were select to successfully fabricate a number of metamaterial lattice structures, including hard-to-print auxetic structures.

Our findings provide valuable insights into the complex relationships between LPBF process parameters and resulting melt pool geometry. The models rapid predictive capabilities make it a valuable asset for selecting optimal parameters, reduce extensive empirical testing and enable the fabrication of high-quality metamaterial lattices.

REFERENCES

[1] W.W. Wits, C. de Vos, M. Montero-Sistiaga, M. de Smit, Laser powder bed fusion process parameters for the fabrication of unsupported overhang structures of metamaterial lattices, *CIRP Annals - Manufacturing Technology*, 2025, DOI: 10.1016/j.cirp.2025.03.003.
[2] A.M. Rubenchik, W.E. King, S.S. Wu, Scaling laws for the additive manufacturing, *Journal of Materials Processing Technology*, 257, 2018, pp. 234-243, DOI: 10.1016/j.jmatprotec.2018.02.034.
[3] M. Letenneur, A. Kreitcberg, V. Brailovski, Optimization of LPBF Processing Using a Combination of Melt Pool Modeling and Design of Experiment Approaches: Density Control. *Journal of Manufacturing and Materials Processing*, 3(1), 2019, 21, DOI: 10.3390/jmmp3010021.