Thermal behaviour of the melt pool produced in Laser Powder-Bed Fusion (L-PBF): numerical and experimental study

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ABSTRACT

Laser Powder Bed Fusion (L-PBF) is one of the most utilized additive manufacturing (AM) technologies, since it can work with a wide range of metallic materials. Fabricating a part via L-PBF with satisfactory geometrical accuracy and adequate mechanical properties is not an easy task, due to the complex influence of process parameters, such as material properties, powder characteristics, laser intensity, scanning strategy, process kinematics. Their interplay is currently matter of intensive research in both academic and industrial field. The numerical modelling of the thermal behaviour of the melt pool produced in L-PBF involves complex non-linear phenomena. An effective way to make the computational cost of the analysis affordable is to model powder and molten metal as continuous media, wherein all the heat transfer modes occurring in the liquid are simulated as lumped fictitious heat conduction. The augmentation factor used to enhance the thermal conductivity of the liquid is calibrated through experimental estimations of the melt pool size. The present work is aimed at devising a robust method for the calibration of such thermal parameters. Different modelling strategies to efficiently perform thermal analyses at the microscopic scale and to devise several experimental approaches for fine-tuning of the thermal properties to be input into the numerical models are investigated. Specifically, both anisotropic and isotropic enhanced thermal conductivity approaches are evaluated in combination with a laser source modelled either as a 2D or 3D heat source, respectively. The thermal properties, i.e. enhancement factor λ and laser penetration depth, are deduced from experimental measures of the melt pool size. For this purpose, a 3-factor, 3-level Design of Experiment (DoE) is conducted using a Renishaw L-PBF machine employing a pulsed laser beam irradiating a Ti-6Al-4 V powder bed. The DoE comprises the following machine process parameters: laser power, hatch distance, time exposure. Post-process characterization focuses on the width and height of the laser scans studied using a scanning electron microscope (SEM) and a 3D contact profiler. In this way, the calibration of the thermal properties is made less sensitive to the uncertainty affecting the melt pool size measurements. The range of applicability of the thermal model is explored over a broad spectrum of L-PBF parameters. The outcomes of the DoE experiments provide a more robust calibration, compared to methods where the thermal properties are calibrated from a single set of L-PBF machine parameters. The experimental analysis of the surface topology of pieces fabricated via L-PBF and the analysis of the correlation between experimentally determined 3D roughness and numerically estimated size of the melt pool represents a specific point of novelty of the paper. The proposed approach predicts with good accuracy the roughness of L-PBF parts and suggests a way for calibration strategies based on roughness measurements.

REFERENCES

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