Development of holistic scaling laws for melt pool characterization in laser additive manufacturing

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ABSTRACT

Laser additive manufacturing is a key enabler to manufacture complex structures such as biomimetic designs or cellular structures. Both require a fundamental understanding of underlying melting process mechanisms to manufacture reliable and dense parts. Particularly, for very thin-walled cellular structures such as lattices the melt pool width which is defined by the process parameters is directly used to realize a desired strut thickness. It is thus determinant for the lattice geometry which directly correlates with the elasto-plastic properties. Further, a dedicated melt pool understanding also engenders information on part porosity and thermally induced stresses and can thus be applied to dense parts. From literature authors mostly carry out experimental work or numerical simulations for single melt tracks that bear extensive calculation effort and can hardly be applied for part design.

In this contribution we deliver a simple scaling law using the dimensional analysis according to the Buckingham Π-theorem and validate that it works independent of chosen material and machine type. The theorem yields a defined amount of dimensionless parameters as reduced output depending on the dimensional number of input parameters as well as the considered dimensional system. Here a dimensional system consisting of length, mass, time and temperature is regarded taking only material and process specific quantities as input parameters into account. The dimensionless parameters denote relations between fundamental physical mechanisms that underlie the melting process. By that approach we reduce the quantities needed to describe the process which decreases the effort in experimental design significantly. The experimental data together with the theory is summarized in characteristic maps yielding information on the physical phenomena occurring during melting as well as the interaction between process and material quantities with the desired melt pool width. The presented model is holistic in a way that it works independent from considered machine and material and can be used for designing thin-walled cellular structures such as lattices.