Thermo-fluid-metallurgical modelling of laser-based powder bed fusion process

Selective laser melting (SLM) is a type of additive manufacturing (AM) technique where the parts are produced in a layer-wised manner. In this process, first a layer of fine metallic spherical particles, with sizes spanning from 20-50 µm, is distributed over a rigid building platform whose elevation can be readily adjusted while the part is being manufactured [1]. When the first powder layer is distributed, a laser with a typical spot size of about 30-100 µm starts scanning it. The input heat imposed from the laser is sufficiently high to melt down and subsequently fuse these discrete particles together. After the first layer has been scanned, the building table (containing the part) moves one increment down and then another powder layer will be distributed with the same coating mechanism. This process is repeated until the final part is manufactured [2].

SLM has many advantages over other conventional production methods such as casting, milling, forging, etc. These are the possibility of complex designs, low material waste and short total manufacturing process time [3]. Although SLM is regarded as a superior technique to some of the existing conventional manufacturing processes, it still needs to be modified to an extent that it becomes more predictable. To address this issue and predict the quality of the parts produced by SLM, one can make use of numerical modelling.

Numerical models, especially if validated with experimental measurements, can be used as an easy and cheap way to predict the feature and quality of the SLM parts. In this respect, different numerical models containing different physics have been developed for the SLM process, ranging from pure thermal models [4], [5] to thermo-mechanical models [6] and the more advanced meso-scale thermo-fluid models [7], [8]. Consideration of just the conductive heat transfer is a proven and well-tested way of SLM modelling. In this type of models, a moving heat source or heat flux, resembles the laser-material interaction. On the other hand, thermal models including the fluid flow, despite incurring much more computational time, will give detailed information about the actual melt pool thermal history, its morphology and even its eventual microstructure [7], [9].

In this work, a thermo-fluid-metallurgical model of the SLM process for a titanium alloy has been developed to analyze the thermal and fluid behavior of the molten metal inside the melt pool. The model takes into account the Marangoni effect caused by the change in shear stresses. To thermally and fluid-mechanically model the solidification phenomenon, the enthalpy-porosity method and solidification drag forces in the porous medium are implemented respectively. Furthermore, an additional microstructural model has been developed and subsequently coupled to the mentioned model to investigate the solidification behavior of the melt pool. In this respect, the important solidification data, such as solidification cooling rate, morphology factor, growth velocity and solidification thermal gradient are calculated during the solidification as well.

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