Study of the powder deposition in Laser Powder Bed Fusion Additive Manufacturing processes

Ph.D. Thesis by P. Avrampos

Abstract

During the 40 years since the conception of Additive Manufacturing, Powder Bed Fusion processes have been a very important sub-category of AM, mostly due to their ability to produce metal parts of promising quality. Extensive research has been performed in order to ascend PBF processes from their initial prototype-developing status to fully industrial, large-production processes. However, despite the efforts being made, due to their high complexity, PBF processes still have not reached their potential. This work aims to contribute in this direction, and more specifically, to powder deposition. The aspect of powder deposition is of paramount importance to all PBF processes, since the quality of the deposited layer is directly connected to the mechanical properties of the finished part.

The first chapter of this thesis presents an overview of AM processes, their historical background and the development status of PBF processes. The second chapter provides a thorough analysis of the connection between powder spreading process parameters, powder layer quality and finished part quality in terms of mechanical properties. The process parameters of powder deposition are recorded and possible ways that each one affects the other are identified. Then, the quality criteria of the deposited powder layer are identified, and methods of monitoring them, both in-line and off-line, are presented. The ways in which the process parameters are deemed to affect the layer quality criteria are presented too. Subsequently, the mechanical properties that serve as quality criteria of the finished part are analyzed. Finally, the ways in which the powder layer quality criteria are deemed to affect the finished part quality criteria are explained. Extensive use of tables has been made, in order to simplify the navigation and make it easier for future researchers to use this literature review as general guidelines for optimizing the powder spreading process in their projects.

The third chapter presents a robust statistical analysis and comparison of all the powder deposition methods found in literature via Analytic Hierarchy Process. The comparison is performed by defining criteria and grading each method based on its performance with regard to each specific criterion as compared to the other methods. The importance of each criterion is subjective and the weights can be altered based on each researcher's priorities. The comparison proved that mechanical deposition is preferable with regards to other, innovative methods. Then, a prototype Powder Deposition/Recoating System is designed. The innovative design is divided in two groups, the doser/sieving group and the recoating group. Each of these groups is compared via AHP to the respective group of a commonly used powder deposition system embedded in a commercial SLM machine. The criteria based on which the comparisons will be performed are defined in advance. The AHP comparison proved superiority of the suggested design.

The fourth chapter of this thesis presents the modelling of powder in Discrete Element Method (DEM) simulations and the optimization of doctor-blade facilitated, vibration-assisted mechanical spreading via Taguchi DoE and subsequent ANOVA. Initially, a method to model particle size distribution given by D90, D50 and D10 via a lognormal distribution is presented. Then, the available contact models are presented and the best-suited one is selected by Tabor parameter comparison. It is proven that Hertz-Mindlin with JKR is the most suitable model. Modelled powder rheological behaviour is evaluated via cross-check between experiments and simulations using angle of repose and angle of avalanche tests. The simulations that followed examined the spreading conditions (spreading speed, vibrational frequency and amplitude of the blade and relief angle of the blade) by specific layer quality criteria (layer thickness deviation, surface coverage ratio, surface roughness and true packing density) and proved that vibration assists deposited layer evenness and homogeneity. Weighted means analysis of the surface roughness, surface coverage ratio and layer thickness deviation proved that the surficial skewness and kurtosis can serve as equivalent layer quality indicators, for layers created by spherical powder particles. It was shown that the lower the recoating speed, the better the surface quality. True packing density remained constant despite parameter level changes.

The fifth chapter of this thesis evaluated the sieving process via DEM simulations of the same powder as the one modelled in the fourth chapter. The sieving was evaluated by the duration of the linear phase, the mass flow during this phase and the mass sieved during this phase. The sieving parameters were the frequency and amplitude of the sieve's vibration, the taper angle of the sieve's apertures and the level of the powder inside the sieve prior to sieving. The level combinations that maximize powder flow, linearity duration and mass deposited during linearity were identified. Then, the effect of different aperture shapes was evaluated for these optimum level combinations. Finally, the quality of the deposited powder layer via sieving alone, in a recoater-less powder deposition process, was examined. It was proven that it is possible, by calibrating the amount of powder fed into the sieve and the sieving parameters, to achieve level quality superior to that of the vibration-less doctor blade powder spreading, but still inferior to the vibration-assisted doctor blade powder spreading.

The sixth chapter of this thesis presents a novel method for the deposition of multi-material powder layers based on the dual contour-gauge design. The method is mathematically defined and the problem is solved numerically via a C-code. The results are presented schematically for a layer of 5 border curves that define material transitions within the mosaic-patterned layer. The method's viability is proven via an experimental jig and DEM simulations. The simulations used the sieving and spreading optimized parameters that were defined in the fourth and fifth chapter of this thesis. Both experiment and simulation achieved very good approximation of the borders of the developed pattern. The DEM simulations achieved good layer evenness and homogeneity, comparable to the vibration-assisted, doctor blade powder deposition. Overall conclusions and suggestions for future work are presented in the seventh chapter.