Powder bed operations in the model of selective laser melting process

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Keywords: additive manufacturing, 3D printing, powder bed fusion, selective laser melting, modeling

1. Introduction

Additive manufacturing or 3D printing processes are highly fast-developing industrial fields and require strong scientific accompaniment and support. Additive manufacturing processes can be grouped into several categories (seven categories according to ISO/ASTM52900-15), and one of them collects Powder Bed Fusion (PBF) techniques. Among the different branded processes, Selective Laser Melting (SLM) was chosen to be supported by our research teams for analysis, development, and optimization. During the SLM process, the powder is completely melted by the high-energy laser with consequent solidification manufacturing the final product in a layer-by--layer method. The mechanical properties of the final product are close to those of the products manufactured by the conventional method. The holistic model of the entire SLM process has been developed but its components are still being improved.

The holistic model was developed after analysis of the SLM in three levels: technological, associated physical processes and phenomena, and associated mathematical models. The last with appropriate connections or interfaces are the content (components) of the holistic model. On the first, technological level, SLM can be schematically represented as a cyclic process with powder deposition, pause, laser beam treatment, pause, and powder removal sequence. This sequence can be repeated many times until the product is finished. The following six basic processes are considered on the second level of analysis, and then can be consequently modeled: powder deposition, laser beam heat treatment, melting, liquid flow (free flow of melted material), solidification, and powder removal. The defined processes and phenomena associated with SLM are modeled using the following five submodels: the powder deposition model, the heat transfer model with the laser treatment, the phase transition model, the model of fluid flow with the free surface, and the powder removal model. The work under the model development made some adjustments to the structure of the holistic model and its components. Now, the structure and functioning of the model can be presented by a block diagram (Figure 1) [1]. The diagram has two circuits. The first external circuit contains the powder bed generation (PBG) model, cycle initialization, and its realization (represented by the internal circuit – LBM calculation module) and the powder removal (PR) model.

The PBG and PR models currently communicate between themselves and with the other parts of the main algorithm with the use of files. Consideration of these two models is the main objective of this paper.

The publication is co-financed from the state budget under the programme of the Minister of Education and Science called “Excellent Science” project no. DNK/SP/548041/2022

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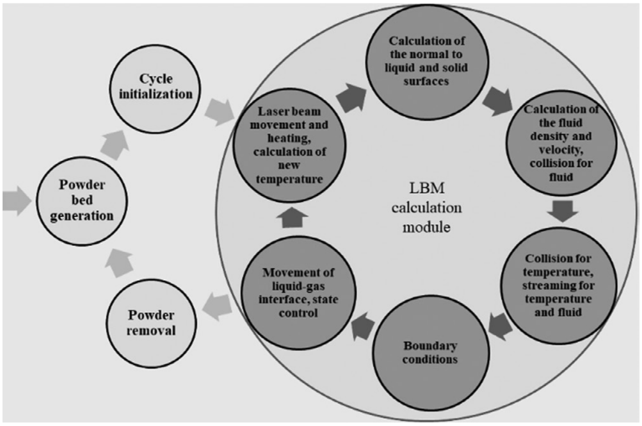

Figure 1. Schematic representation of the main algorithm of the holistic model [1].

2. The powder deposition models

Four variants of the powder deposition model have been developed during the work under the project. The first three variants use a quasi-kinematic approach with a simplified static stability test and are based on a similar algorithm. Shortly, each particle falls to the basement (flat, curved, or arbitrary shape after treatment) or the previously deposited particles. First of all, the first contact of the falling particle is searched, it restricts the first degree of freedom. Then, the particle begins to roll, slide, or rotate over the surface or other particles until it seeks the second contact. After the tests, the algorithm can go further or return to the previous stages. Next, the particle continues to move with a restriction of two degrees of freedom. When the third contact point is found and the last degree of freedom is restricted, the stability of the particle is tested. If the stability conditions are satisfied, the location of the particle is treated as final and the algorithm passes to the next particle. Algorithms of the variants differ in detail depending on the particle's shape and accepted assumptions.

The first variant considers a powder with atomized particles (spherical shape). The algorithm only considers rolling movement. A detailed description of this variant, simulation results, and model verification and validation can be found in the previous publication [2]. Validation confirms high accuracy in terms of packing density. The second variant has been developed for the articles of arbitrary shape), as well as the previous variant uses 2.5 cellular automata, with the particle represented by the rigid cloud of points on the surface of the particles. The particle can be translated (fall or slide) or rotated around an axis fixed by one or two points. Simulation results presented in the papers [3-5] were obtained with this variant of the model. Then, to improve simulation quality, the particles' surfaces were presented in a vector manner by vertices, edges, and faces (triangles). After deposition, the results can be represented in two forms: vector (continuous) and discrete. Simulation results with this variant can be found elsewhere [1]. The next version uses only the vector representation of the particles without the discrete transformation of deposited particles into the basement. During movement (translation and rotation), two types of contacts are analyzed: vertex--to-face and edge-to-edge.

A variant with the use of Unity® is presented here. A database of the particles was created for the previous variants and contains 50 particles, which are modified by random scaling independently in three directions after their rotation; it gives an unlimited number of unique particles. The database was adapted to Unity. Examples of powder deposition with atomized and arbitrary particles are presented in Figure 2.

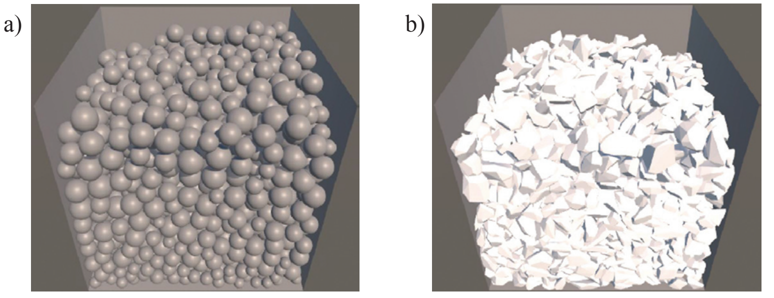

Figure 2. Examples of powder deposition for atomized (a) and arbitrary (b) particles.

After the deposition, particles are transferred to the LBM calculation module, where cycles of the SLM process were simulated. An example of such a simulation is presented in Figures 3a and 3b. Then, results are transferred to the Unity as terrain; and powder deposition is repeated.

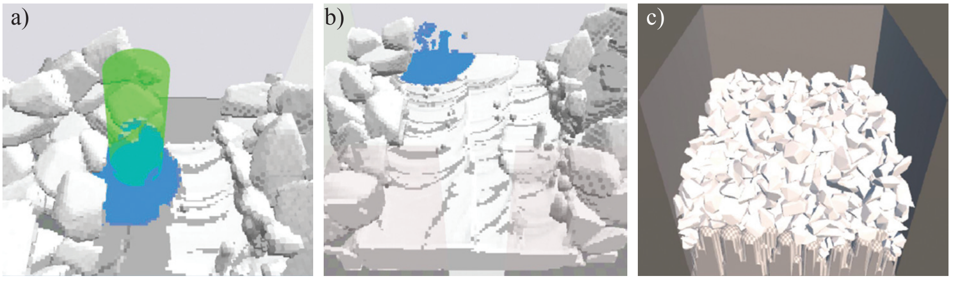

Figure 3. Simulation of SLM process (a and b), deposition of powder with particles of arbitrary shape on the terrain transferred from SLM simulation (c).

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Acknowledgements. This work was supported by the National Science Centre (NCN) in Poland, partly by the projects no. DEC-2013/09/B/ST8/00141) and no. UMO-2018/31/B/ST8/00622.