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Simulation of the Laser Beam Melting Process – Approaches for an Efficient Modelling of the Beam-Material Interaction

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Abstract

Currently, the main field of application of additive manufacturing processes is shifting from research laboratories to production facilities. Simulation models can foster this transition by providing support in process development and design. This paper introduces approaches to modelling the beam-material interaction in laser beam melting on a level of detail that allows the simulation of the whole build-up process of parts, not only of single laser tracks. Thus both the achievable result accuracy and the needed calculation time are discussed. For this purpose, fundamental correlations to link process characteristics with model parameters are explained. Subsequently, four modelling approaches are analysed. After an introduction of the well-known method of applying a uniform load on a whole layer compound (e. g. [1]), the developed methods are discussed which allow modelling the beam-material interaction on a more detailed level. Thereby, the focus lies on the ability to model load gradients perpendicular to the build direction. This article is completed with a discussion of simulated temperature curves for selected monitoring points using two different modelling approaches.

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Keywords: Laser beam melting; Modelling; Additive Manufacturing

1. Introduction

Additive manufacturing is becoming more and more important to industrial enterprises. Especially the laser beam melting (LBM) process is increasingly utilized for the manufacturing of products [2]. Therefore, a first-time-right process design is ideal to ensure economical fabrication. Simulation models can contribute to this objective by offering the possibility of virtual tests of chosen process parameter combinations in terms of their influence on quality criteria (like resulting temperature fields or distortions). Within this manuscript approaches for an efficient modelling of the beam-material interaction are introduced and their potential is discussed. Finally, simulation results are analysed and future work is derived.

2. Simulation of the laser beam melting process

The LBM process is an additive manufacturing technique to produce almost fully dense metal parts from a powdery feedstock by utilizing a laser beam for the powder solidification. Figure 1 illustrates a schematic setup of a LBM system. The general process procedure consists of three recurring steps:

1. Applying a powder layer (a, i) by the utilization of a coater (b)
2. Local solidifying (caused by f, g) of the powder according to the corresponding layer information in a process chamber which is flooded with inert gas (h)

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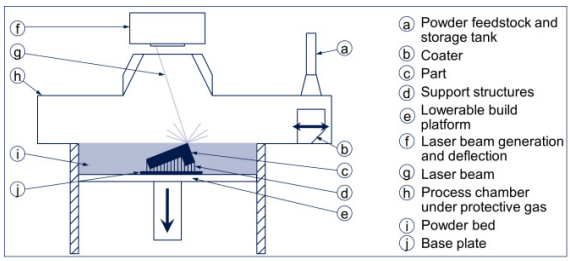

3. Lowering the build platform (e) on which the base plate (j) is mounted consistent with the utilized layer thickness (typically 20 - 50 µm).

Fig. 1. Schematic setting of an LBM system (following [3]).

Throughout the process, parts (c) are built on a base plate (j) ensuring a mechanical connection. This is of importance because the high energy input of the laser causes local temperature gradients which lead to residual stresses. In cases in which a mechanical connection between the part and the base plate is not granted, part layers bend as a result of the temperature gradient mechanism [1] and can thereby cause a collision with the coater (b), even during the part's generation. This could lead to a process interruption. For the same reason overhanging part areas also need to have a mechanical connection with the base plate. This is achieved by utilizing support structures (d).

In order to enhance the understanding of the described process, several models of the LBM process have been developed. On the one hand, there are existent simulation models which take occurring physical effects during powder solidification like Marangoni convection, evaporation etc. into account and aim to simulate the beam material interaction with a high time resolution. This results in a large amount of calculation steps but allows investigating e. g. melt pool dynamics and powder solidification within one laser scan vector (so-called hatch) with a high spatial and time resolution ([4], [5]). Considering today's state of the art computer hardware, it is hardly possible to use such detailed modelling techniques for the simulation of the whole part's structural behaviour (e. g. distortions or the residual stress states). Hence, abstractions are used within current simulation models which lead to a significantly reduced computing time and allow the application on mid-sized workstations (for instance 8 cores, 32 GB working memory). Instead of being able to analyse melt pool dynamics of single hatches (spatial resolution: micrometers, time resolution milliseconds [5]) or layers, the temperature field during the build-up process or the resulting part's structural properties can be simulated in this case (spatial resolution: millimetres, time resolution (milli)seconds ([1], [6])). Within this article approaches for a computing time efficient modelling of the beam-material interaction during the whole build-up process are introduced and discussed (by utilizing the FEA-software ANSYS®). This work is based on previous research results (see [7], [8] and [9]).

3. Methods for modeling the beam-material interaction

3.1. Overview and basics

In literature ([1], [10]) the modelling of the beam-material interaction is often done by applying a heat flux (power per area in [W/m2]) or by prescribing a temperature load for a defined time. The methods introduced in the following are with minor adjustments in the programme code suitable for both ways of load application and are explicitly discussed in order to model layer compounds, not single layers only.

Within the scope of this work, the load is applied as a "load-step" and subsequently the resulting temperature field for a predefined cool down time is calculated within a succeeding load-step subdivided into discrete "sub-steps". Hence, the amount of necessary solution steps $N_{solution,th}$, which decisively defines the calculation time for the thermal simulation, can be determined as a function of the amount of load-steps $N_{load,th}$ for heat input modelling. Assuming that there is a constant ratio between load- and corresponding sub-steps for the cool down times and that the heat input load-step is not subdivided, the amount of solution steps can be estimated by the following equation:

$$N_{solution,th} \approx N_{load,th} + N_{load,th} \cdot N_{sub,th} \quad (1)$$

The amount and timing of sub-steps per load step to model the cool down period $N_{sub,th}$ can be either defined by the user or automatically chosen by ANSYS® using the command "autots". Following the real process chain, a final cool-down time (order of dimension: minutes to hours) should be modelled after the build-up process [1], which does add solution steps once but is neglected in equation 1.

As a weak coupling between thermal and mechanical solution [1] is chosen for this work, the thermal calculation is completed before the mechanical solution is started. The loads for the latter are the transient temperature fields resulting from the load- and sub-steps within the thermal solution. For the best possible result accuracy, the amount of load-steps in the mechanical solution $N_{load,m}$ should equal the sum of load- and sub-steps in the thermal simulation (cf. formula 1 and 2):

$$N_{load,m} \approx N_{load,th} + N_{load,th} \cdot N_{sub,th} \quad (2)$$

Consequently, this leads to a significant increase in solution steps and calculation time needed for the mechanical solution and CAE-engineers should be aware of the correlations described in equations 1 and 2 while developing modelling approaches (load- and sub-steps needed) for the heat input. To reduce the time required for the mechanical solution, it is possible to apply not every temperature field resulting from a thermal load- or sub-step as load for the mechanical solution. This should lead to a reduced calculation time but might also affect the result accuracy.

Figure 2 illustrates the approaches for heat input modelling discussed within this manuscript. The most abstract level to simulate the melting of a layer compound, which is already well-known in literature ([1], [11], [12], [7]), is achieved through the application of a uniform load on the whole layer within one load-step. With this method, no consideration of temperature gradients in X-Y-direction during load application is possible. If these gradients should be taken into