Simulation of temperature distribution and mechanical material behaviour in selective beam melting processes

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ABSTRACT

Selective beam melting processes as selective laser melting (SLM) of polymers or selective electron beam melting (SEBM) of metals are additive manufacturing processes. They are used to additively build geometrical complex parts from thin layers of powder material. In the SLM and SEBM process the energy of the laser or electron beam fuses the powder in defined, locally-restricted points in the current layer. Therefore the beam energy causes the powder particles to undergo a phase change from a powder particle to a melt and then to a solid after cooling down. By repeating the fusing procedure for multiple powder layers the part is constructed layer-by-layer additively. Due to the high energy of the beam extreme temperatures and temperature gradients occur. These result in residual stress and distortion of the produced part, which should be avoided.

The goal of this contribution is to predict the transient temperature distribution in the SLM and SEBM process, to simulate the residual stresses and distortion of the produced part. For this purpose a simulation tool is developed. The basis of the tool is a continuous, nonlinear thermomechanical model to simulate the process from a macroscopic point of view. In the model the powder material is not described as single powder particles, but as a continuum. The model is able to capture temperature-dependent material parameters, the effect of latent heat and to distinguish between powder, molten and solid material. Since the material behaviour of the solidified material, e.g. PA12, in the SLM process is not only elastic but also rate-dependent and depends strongly on temperature, a thermo-visco-elastic material model is applied. For similar reasons a thermo-visco-plastic material model is used for the simulation of the titanium aluminium alloy Ti6Al4V in the SEBM process. The finite element method is adopted for the spatial discretization of the model and the implementation is done by using the open-source finite element library deal.II [1]. An implicit Runge-Kutta scheme of second-order accuracy is applied for the time integration. The energy input of the laser and electron beams is modeled as a moving heat source and the amount of energy induced into the powder material is computed by using the beam models from [2] and [3]. An adaptive mesh refinement strategy is adopted to capture the extreme temperature gradients in the area of the beam. The thermomechanical simulation of the SLM and SEBM process is very expensive in terms of computing time. Therefore adaptive mesh refinement, coarsening and dynamic extension of the simulation space are applied.

The developed tool is used to simulate the SLM process for PA12 and the SEBM process for Ti6Al4V. In this context not only the processing of multiple powder layers is simulated, but also the deposition of new powder layers. The numerical results for temperature, residual stress and deformation are discussed in detail and partly compared with experimental data.

References

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