Finite Element Simulation of the Thermomechanical Material Behaviour in the Electron Beam Melting Process for Ti6Al4V

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ABSTRACT

The electron beam melting process is used to additively build geometrical complex parts from thin layers of metal powder material. The energy of the beam fuses the powder in defined, locally-restricted points in the current layer to melt the powder into the already fused and recongealed material of the previous layers. 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. By repeating the fusing procedure for multiple vertically stratified 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 deformation of the produced part, which are both undesirable effects.

The aim of this contribution is to predict the residual stress, deformation and detoriation by means of a simulation tool to optimize the mechanical properties of the produced part by adjusting the parameters of the process, e. g. beam scan path or beam power. The basis of the tool is a continuous, nonlinear thermomechanical model to simulate the process from a macroscopic point of view. The model describes the powder material not 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 in the electron beam melting process the material behavior of the solidified material is plastic and strongly depends on temperature, a thermo-elasto-plastic material model is developed. The spatial discretization of the model is done with the finite element method and for the implementation the open-source finite element library deal.II [1] is used. For the time integration an implicit Runge-Kutta scheme is applied. The energy input of the electron beam is modeled as a moving heat source and the amount of energy induced into the powder material is computed by using a semi-empirical electron beam model [2]. To capture the extreme temperature gradients in the area of the beam an adaptive mesh refinement strategy is adopted. As the thermomechanical simulation of the electron beam melting process is very expensive in terms of computing time [3], adaptive mesh coarsening and dynamic extension of the simulation space are applied.

The developed tool is used to simulate the electron beam melting process for Ti6Al4V metal powder. 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 compared with experimental data and an approach for improving the developed material model by using homogenization methods is presented.

REFERENCES

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