Thermomechanically coupled finite-element-based modelling and simulation of phase transitions during selective laser melting processes

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ABSTRACT

Additive manufacturing exhibits a great potential for innovative and efficient industrial applications. The effect of the associated process parameters on the properties of the final workpiece are, however, still rather vague. Thus, material and structural designs in order to obtain improved properties—in particular with respect to lifetime estimations—are rather based on empirical knowledge. This motivates the need for sophisticated material models and process simulations in the context of additive manufacturing. The characteristics of processes such as the aforementioned laser cladding or selective laser melting render the computer-based modelling and simulation challenging. Not only because the constitutive behaviour of the respective material in its powder, molten and re-solidified form has to be captured appropriately, but also the process itself requires a sophisticated use, control, and extension of global computation schemes such as, e.g., the Finite Element Method (FEM). First FEM-based simulations of additive manufacturing processes were focussed on the temperature problem only. The different states of the material were captured by temperature-dependent quantities such as mass density, thermal conductivity, and elastic stiffnesses. In this sense, the state of the material is directly linked to the temperature in such models. In the present contribution, cf. [1], the thermomechanically fully coupled constitutive framework is based on the definition of energy densities for each possible state of the material. These energy densities define the constitutive behaviour of the related states or, in other words, phases of the material. The overall material model then follows from a mixture rule as well as specific homogenization assumptions, and the temperature-induced change of the material's composition is obtained via energy minimisation and the associated determination of energetically favourable volume fractions of the phases. In this regard, the change of states of the material is treated as a classical phase transformation. The overall constitutive framework also covers dissipative effects caused by the highly viscous elastic behaviour of the molten phase as well as plastic deformation in the solidified phase. Further challenges are related to the FEM-based modelling of the manufacturing process itself, for example in terms of an appropriate modelling of the layer build-up. The overall scientific aim is to establish a physically well-motivated material model which allows accurate predictions of the effective material properties and, e.g., the simulation of process-induced eigenstresses of the manufactured workpiece. The capabilities of the developed modelling framework will be exemplified by numerical examples.

REFERENCES

[1] Bartel, T. and Guschke, I. and Menzel, A. Towards the simulation of Selective Laser Melting processes via phase transformation models. *Computers & Mathematics with Applications* (2018) https://doi.org/10.1016/j.camwa.2018.08.032.