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Additive production processes modelled with high-order embedded domain methods

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In the past few years additive manufacturing (also named 3D-printing) has evolved to one of the most promising techniques for creating solid structures of virtually any shape on the basis of digital models. 3D-printing is achieved by successively generating layers of material of different shapes and often also of varying material properties. Applications for additive manufacturing range across virtually all fields in mechanical engineering, from non-load bearing architectural models for mere visualization of designs to parts under severe loads as in lightweight components for the automotive or aerospace industry. Furthermore, additive manufacturing is used on a day to day basis in medical applications, e.g. to produce patient specific implants for teeth or bone or even to print tissue. For an overview on applications we refer to [3]. The vast impact additive manufacturing on economy and society is discussed e.g. in [4],[5].

Until today, there have been suggested dozens of different additive manufacturing processes, see e.g. [1],[2] for a review. A large cluster of processes is formed by laser metal sintering, selective laser sintering or stereolithography. While the production processes are different in detail, they share a common overall pattern: material is added in powder or liquid form, an infusion of external energy causes the material to change its state, and the material evolves obeying a process specific, energy-time-space dependent development process.

While the elastic modulus evolves in time and space, the laser energy causes a local increase in temperature which leads to an expansion of the material. A sintering process or the polymer-reaction, to the contrary, causes the material to shrink. The local temperature then decreases by thermal diffusion causing the now hardened material to shrink. This sequence of processes may lead to undesired residual strains/stresses such that the resulting products can significantly deviate from the intended shape. A simple example demonstrating the generation of one layer only is given in Figure 1.

There have been numerous attempts to numerically model such processes, see e.g. [6] for stereolithography or [7] for selective laser melting. While the simplest of these models rely on voxel finite element simulations, more advanced techniques use phase-field models to gain more insight into these multi-physical processes.

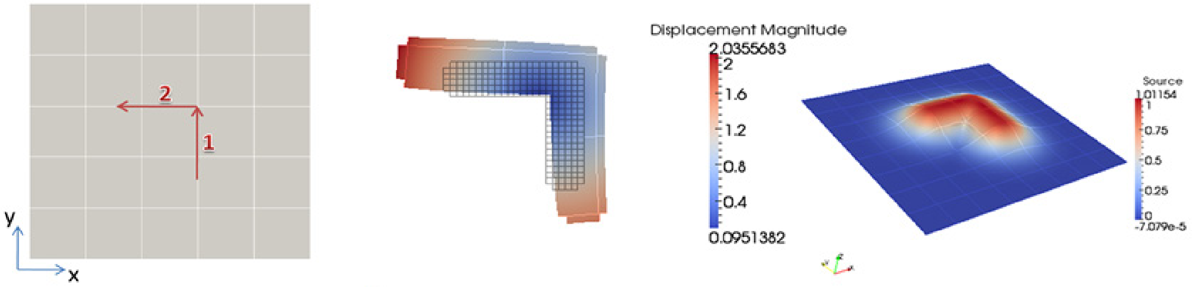

Figure 1: Simulation of a simple additive manufacturing process
left: laser path, middle: intended shape vs. simulated shape: right: total laser energy

This contribution gives a quick introduction into the topic of additive manufacturing and possible computational models. It will then focus on high-order embedded domain methods such as the Finite Cell Method as a computational tool for the prediction of strain/stress fields in parts produced by additive processes. One major advantage of this approach is the possibility to circumvent any mesh generation, which could be extremely involved due to the transient evolution of the structure. We will investigate the computational modelling of the entire process itself rather than only of the finished product and will take a macroscopic point of view. We will present a three-field embedded domain formulation in which a thermo-elastic model is enhanced by a state-field describing the evolving structure. Finally, we will demonstrate that the presented model is able to capture path dependencies, i.e. the effect different laser paths have on the resulting stress/strain field of the final product.

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