Numerical Simulation of Additive Manufacturing Processes in the Framework of the Multi-Level $hp$-adaptive Finite Cell Method

Name: Ali Özcan  
E-Mail: ali.oezcan@tum.de  
Supervisor: Prof. Dr. rer. nat. Ernst Rank  
Chair for Computation in Engineering  
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Overview
Additive manufacturing (AM) has emerged as a very promising technique for creating highly complex and customized solid structures on the basis of digital models. It is achieved by successively joining layers of material of different shapes. One additive manufacturing process is selective laser melting (SLM), which is illustrated in Fig. 1, where metal powder is fused together with the help of a laser. In order to use these parts in industries such as, aerospace or medical orthopedics, the mechanical performance of the end product should be deeply understood. Therefore, the SLM process needs to be simulated to compute the dimensional accuracy and residual stresses of the part.

Numerical Simulation Model
One of the major advantages of AM is the possibility to produce arbitrarily complex geometric shapes. However, the definition and generation of a transient geometric discretization (e.g. by finite elements) is a challenge.

In order to tackle this, the Finite Cell Method (FCM) (Düster et al., 2008), which is a high-order immersed-boundary approach, is employed.

Another challenge is the different scales involved in the nature of the problem. The first one is the macro-scale of the artifact, where shape and internal (residual) stress state of the artifact are desired and which is used to predict the mechanical behavior of the product. The second one is the meso-scale, where the laser beam induces phase change from powder to fluid to solid. This is overcome by use of the multi-level $hp$ adaptivity proposed by Zander et al. (2014).

SLM constitutes a multi-physics problem where the center of interest lies on the moving area of phase.
What has to be taken into account, too, are global effects, namely heat diffusion as well as the thermo-mechanical process of residual stress evolution. The phase changes between powder, liquid and solid states are simulated by the model introduced by Celentano et al. (1994).

Fig. 1: Selective Laser Melting process.

Results
Preliminary results are computed for a SLM process with multiple layers. Ti-6Al-4V alloy is chosen as the material since it is commonly used in SLM for aerospace and biomedical applications.

Fig. 2: Temperatures during the process.

Fig. 2 shows the temperature distribution during the SLM process. Longitudinal residual stresses after the process is finished and the artifact is cooled down are illustrated in Fig. 3.

Fig. 3: Longitudinal residual stresses after cooling.

References
