B01

Simulation of the Selective Laser Melting (SLM) Process for the Additive Manufacturing of Steel Parts

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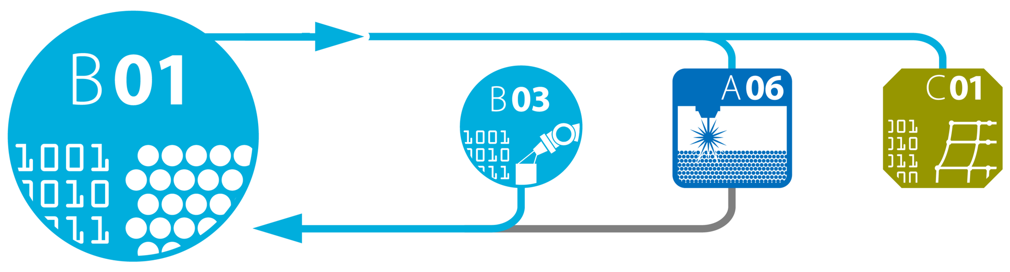
Summary



Selective laser melting is a process involving several length scales, fluid and solid mechanics. Project B01 provides a model and related computational framework for simulation of the SLM process, from the micro-scale (powder bed) to the meso-scale (mm range). To that end, local melting, flow, and solidification are simulated using the Lattice-Boltzmann method (LBM), considering more and more physical phenomena. By coupling the LB simulation to a solid mechanics Finite Element (FE) simulation residual stresses are predicted. Upscaling leads to effective material properties and state of material for use in macroscopic simulations (e.g. C01).

Research Questions

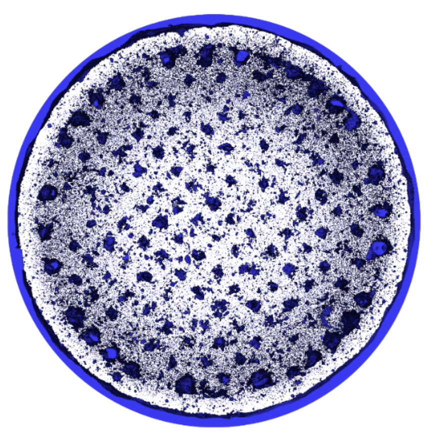
The quality of 3D printed metal parts depends on a number of process parameters. Project B01 employs modeling and simulation to predict the effect of

- laser power and velocity
- scanning strategy and
- powder size distribution and recoating system

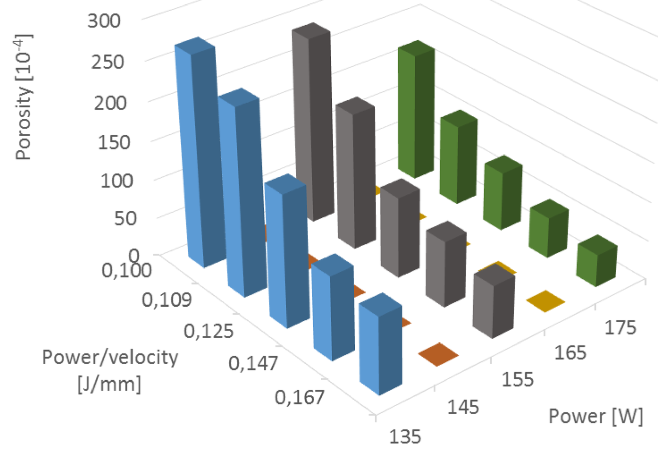
on

- porosity and pore distribution
- surface roughness
- macroscopic mechanical properties (elastic constants, hardness, fracture toughness) and
- thermal and stress state.

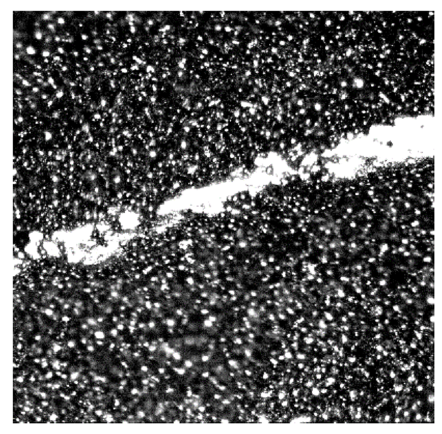
With a predictive model at hand, the process parameters can be optimized (A06) and effective properties are available to macroscopic simulations (C01).



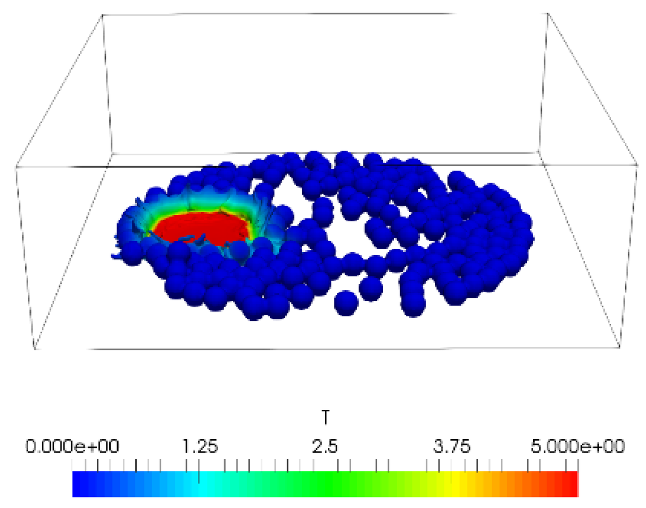
Distribution of pores (blue) in a SLM printed cylinder (view from top). Total porosity 0.4%.



Effect of power density and power on the porosity of AlSi10Mg printed parts.



SLM on the micro-scale: single laser trail on the powder bed.



Local melting of spherical particles by inbound laser radiation (color = normalized temperature).

Preliminary Work

Experiments have been conducted to identify major parameters of influence and effects. Examples can be found in the figure above. Concerning porosity, one observes a concentration of pores close to the outer contour as well as pores in the mesh loops. The total porosity decreases with increasing power density and increasing power (velocity). Single laser tracks exhibit different track width and continuity depending on power density.

On the modeling and simulation side, powder beds have been generated by the discrete element method (DEM, software LIGGGHTS). Melting and flow of the material as result of inbound laser radiation (see rightmost figure) have been simulated using the Lattice-Boltzmann method (LBM, software VirtualFluids, Institute for Computational Modeling in Civil Engineering (B03)).

At this point, the DEM - LBM simulation framework - with limited number of physical effects considered - is operational.

Methods

This project combines state-of-the-art numerical methods from fluid and solid mechanics to achieve a comprehensive, computationally efficient description of the selective laser melting process:

- Simulation of the powder bed generation / recoating systems uses the discrete element method, appropriate for the rigid and mildly adhesive spherical particles;
- The fluid mechanics simulation, describing melting, flow, and solidification of the material, is Lattice-Boltzmann based. A phase field formulation is used to distinguish gas and liquid/solid phases, with an addition liquid fraction field. An increasing number of physical phenomena is implemented: heat transfer by conduction, convection, and radiation; temperature dependent material properties; state dependent laser absorptivity; cooling rate dependent mechanical properties.
- Coupling of the fluid mechanics simulation with a finite element simulation for the solid thermo-mechanical process enables prediction of residual stresses;
- Upscaling by homogenization leads to effective material properties, along with thermal and stress state, on representative volumes in the mm range. The data are used in macroscopic simulations (A06, C01).

Major challenge is the computational complexity of the process, spanning several time and length scales, as well as the large number of physical phenomena to be taken into account.