Thermo-Fluiddynamical Modelling of Laser Beam-Matter Interaction in Selective Laser Melting

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Introduction In Selective Laser Melting (SLM) a laser beam is applied to build up a workpiece by melting up powder layer by layer (see Figure 1). In order to extend the applicability of SLM to high melting materials like molybdenum, multi-physical simulations are a versatile tool, as they allow a look into the process.

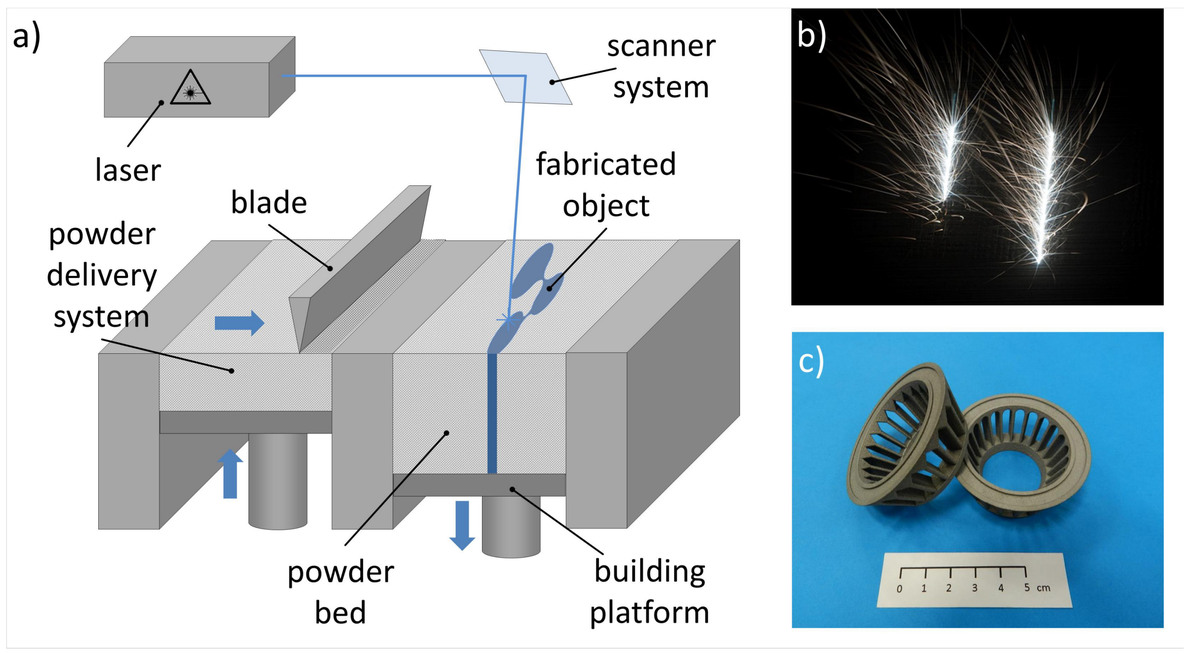

Figure 1. Selective Laser Melting: a) technology principle; b) process during operation; c) molybdenum demonstrator parts.

Simulation Model The multi-physical simulation model for SLM is based on the computational fluid dynamics and the heat transfer module of Comsol Multiphysics. It includes the absorption of laser radiation, conductive and convective heat transfer as well as melting, solidification, evaporation and condensation processes. The model is based on a coupled system of four differential equations. The heat conduction equation

$$\rho\tilde{C}_p\frac{\partial T}{\partial t}+\rho\tilde{C}_p\boldsymbol{u}\cdot\boldsymbol{\nabla}T=\boldsymbol{\nabla}\cdot(k\boldsymbol{\nabla}T)+\Gamma_{top}AQ_{Laser}-\Gamma Q_{rad}$$

T: temperature, ρ: density, $\tilde{C}_p$: effective heat capacity, $\boldsymbol{u}$: velocity, k: thermal conductivity, Γ: interface function, A: absorption coefficient, Q_{Laser}: laser intensity distribution, Q_{rad}:thermal radiation losses

describes the temperature evolution during the process and takes into account latent heats. The multi-phase fluiddynamical description is based on the Navier-Stokes equation

$$\rho\frac{\partial\boldsymbol{u}}{\partial t}+\rho(\boldsymbol{u}\cdot\boldsymbol{\nabla})\boldsymbol{u}=-\boldsymbol{\nabla}p+\mu\boldsymbol{\nabla}^2\boldsymbol{u}+\rho\boldsymbol{g}+\boldsymbol{F}_\sigma,$$

$\boldsymbol{u}$: velocity, ρ: density, p: pressure, μ: viscosity, $\boldsymbol{g}$: gravity constant, $\boldsymbol{F}_\sigma$: surface tension force

the continuity equation

$$\boldsymbol{\nabla}\cdot\boldsymbol{u}=Q_v$$

$\boldsymbol{u}$: velocity, Q_v: source term evaporation

and the Cahn-Hillard equation

$$\frac{\partial\Phi}{\partial t}+\boldsymbol{u}\cdot\boldsymbol{\nabla}\Phi=\boldsymbol{\nabla}\cdot\frac{\gamma\lambda}{\varepsilon^2}\psi+Q_v{}'$$

$$\psi=-\boldsymbol{\nabla}\cdot\varepsilon^2\boldsymbol{\nabla}\Phi+(\Phi^2-1)\Phi.$$

Φ: phase function, $\boldsymbol{u}$: velocity, γ: mobility, λ: mixing energy density, ε: capillary width, $Q_v{}'$: source term evaporation

Depending on the temperature, the actual two-phase description distinguishes between solid, liquid and vapor phase state within the metal phase. The solid is treated as a high viscous fluid and the surface tension is restricted to the liquid phase. The density change during evaporation is taken into account by source terms in the continuity and the Cahn-Hillard equation:

$$Q_v=\dot{m}\cdot\Gamma\cdot\left(\frac{1}{\rho_{vap}}-\frac{1}{\rho_{met}}\right)$$

$$Q_v'=\dot{m}\cdot\Gamma\cdot\left(\frac{1-\Phi}{\rho_{vap}}+\frac{\Phi}{\rho_{met}}\right)$$

$\dot{m}$: evaporation rate, Γ: interface function, Φ: phase function, ρ_{vap}: vapor density, ρ_{met}: metal density

Results Based on the model a material specific comparison of SLM of steel and molybdenum was performed (see Figure 2). Whereas for steel a long melt pool and a significant amount of evaporation is found, for molybdenum the melt pool is restricted to the size of the laser beam and no evaporation is observed.

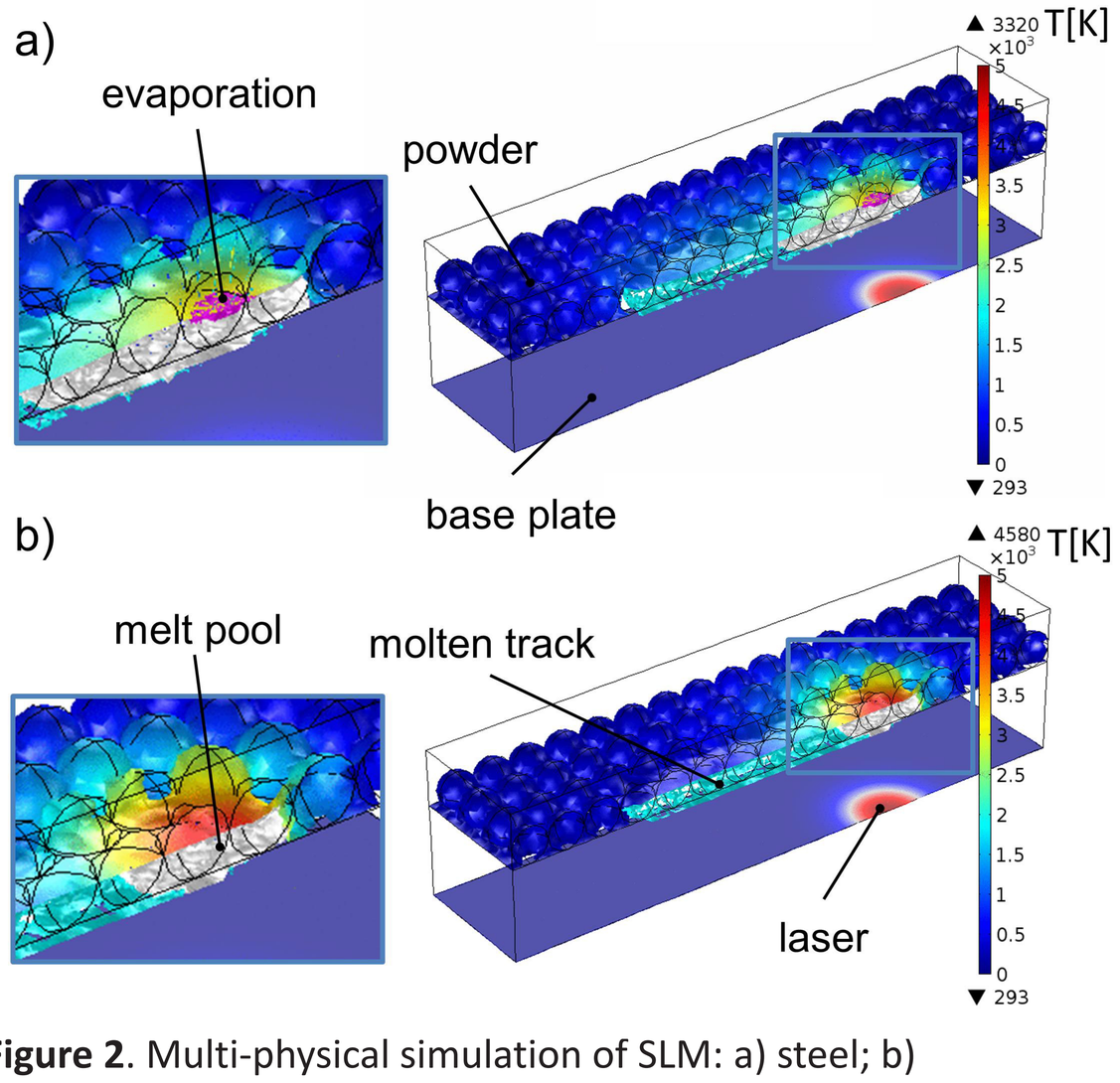

Figure 2. Multi-physical simulation of SLM: a) steel; b) molybdenum.

Conclusions The presented simulation approach is able to describe the process dynamics of SLM as well as its material specific process characteristics. As the core of the model is the description of the laser beam-matter interaction, its applicability is not restricted to SLM. It can easily be adopted for a simulation of other laser based manufacturing processes.

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