Multiphysical modeling of the additive manufacturing process for ceramics

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Additive manufacturing (AM) is a potential breakthrough technology. However, before large scale adoption by industry different challenges need to be tackled: increasing the monolithic part density, increasing feasible product size and wall thickness and avoiding the formation of cracks [1]. A better understanding of the AM process for ceramics (as depicted in Fig. 1), is considered key in overcoming these problems [2]. This is pursued here through the development of a (micro-scale) multiphysical numerical finite element framework that focuses on the AM process, as illustrated in the following.

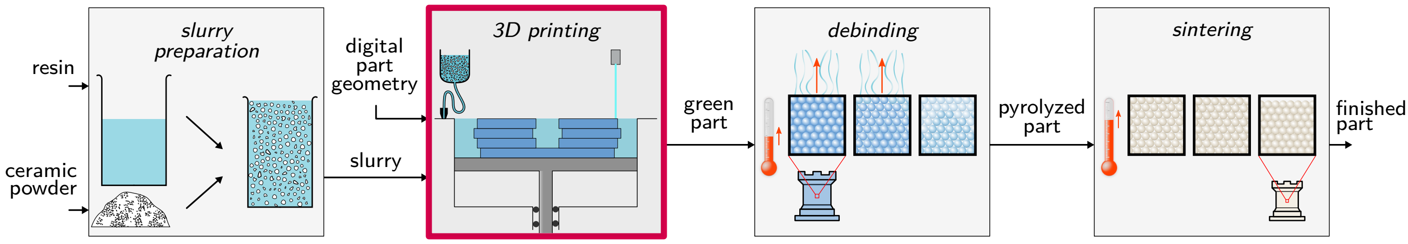
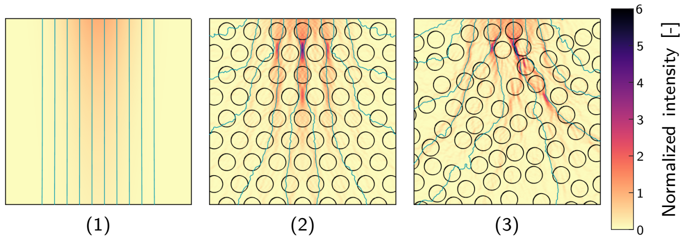


Figure 1: Overview of the considered additive manufacturing process for ceramics. The project focus is on the highlighted box.

Light propagation modeling using a wave (electromagnetic) description

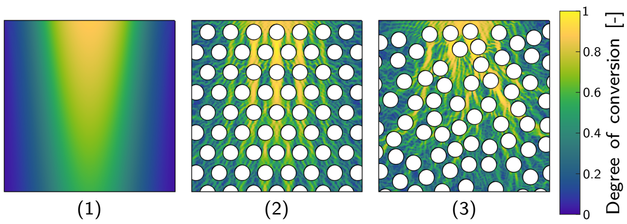
The ceramic slurry, i.e. a suspension with ceramic inclusions in a photo-active monomer solution, is subjected to UV light (400 nm) to initiate a photopolymerization reaction. The propagation and homogeneity of the light through the matter is highly dependent on the inclusions. The figures show the response to a Gaussian shaped, pulsed light source with the intensity normalized by the maximum applied intensity. The considered geometries are 11 × 11 μm^2 with or without ceramic inclusions (⌀ 1 μm).



Intensity

Photopolymerization kinetics

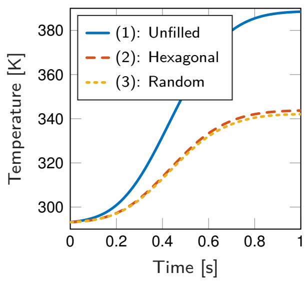
The inclusions clearly induce an inhomogeneous conversion.



Reaction rate

Thermal balance equation

The combined effect of the exothermic polymerization reaction and the absorption of light cause the temperature in the sample to increase. Temperature is homogeneous in the considered domain.

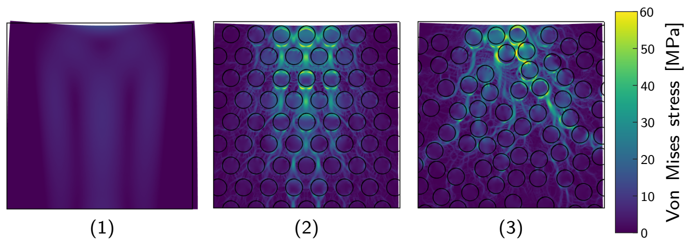


Degree of conversion

Temperature

Linear elastic thermo-chemical-mechanical modeling

The project focus lies on relating process conditions and material properties to the build-up of residual stress and deformation. These effects result from the combined effect of solidification, thermal expansion and conversion shrinkage. When the bottom edge is assumed constrained in the vertical direction, the numerical results for stress and deformation (multiplied by a factor 2) are shown. An important conclusion from these simulation results is the more inhomogeneous cure when a ceramic filled polymer is considered, with more significant internal stresses.



References: [1] Zocca et al. (2015), J. Am. Ceram. Soc. 98(7) [2] Huang et al. (2015), J. Manuf. Sci. Eng. 137