Multi-scale and multi-physical process modeling for additive manufacturing of ceramics through vat photopolymerization

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ABSTRACT

Additive manufacturing (AM) of ceramics through vat photopolymerization (VP) is already recognized as a promising fabrication technique, both for medical and technical applications, due to the high intrinsic resolution and the evanesence of the stresses introduced during the AM process. Nonetheless, feasible product dimensions and the variations in resulting part quality are limiting factors for widespread application of this technique [1].

To advance the (reproducible) part quality and facilitate greater build volumes, an improved process understanding is of key importance. The AM fabrication technique considered consists of multiple steps [1]. This study investigates the printing of the intermediate "green" phase by vat photopolymerization of ceramic powder in a polymer binder.

Within this AM step, the presence of a large volume fraction of ceramic inclusions in the polymer resin constitutes a dominant factor in both the multi-scale and multi-physical nature of the process. Starting with the former, the relevant length scales range from the sub-micron UV wavelength, μm powder dimension, 10's of μm layer thicknesses, to part sizes of multiple centimeters. With respect to the involved physics, the ceramic particles typically possess different optical properties than the resin, which causes the cured profile to be many times broader than the light source profile. In addition to the light scattering, the presence of the inclusions dictates the thermo-mechanical behavior because of profoundly different properties, compared to the polymer matrix material.

Figure 1: Modeling length scales considered in the homogenization scheme. From left to right the macro-, meso- and micro-scale is shown.

To account for the presence of the inclusions without making full part simulation infeasible, this contribution presents a multi-physical and multi-scale modeling framework for AM of ceramics by photopolymerization. Effective mechanical and thermal behavior is accounted for on the micro-scale, whereas the light scattering is evaluated on an intermediate meso-scale [2]. The homogenized results of these analyses are used as input for the simulation of the actual printing process at the macroscopic scale. This multi-scale approach, c.f. Fig. 1, furthers the ability to understand and predict the part quality for variable materials, print process conditions and product geometries.

REFERENCES

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