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Prediction of elastic material properties in additively fabricated multimaterials

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Abstract: The use of multimaterial 3d printers allow not to only shape the geometry but also the material properties of the part being designed. The difficulty for the designer is now to anticipate, what the resulting material properties of the mixture might be. Here a continuum mechanical approach is presented, and how this can be applied to currently used multimaterial printers using photopolymers and its use in a digital design process.

I. Introduction

Natural tissues come in great variety each with its individual properties. When replacing or mimicking such materials, e.g. for manufacturing prostheses, it is often hard to find a synthetic material with mechanical properties matching the natural surrounding tissue. Additive manufacturing allows one to create composite materials with unprecedented degree of reproducibility, therefore the understanding of the mechanical properties of such mixtures becomes very important.

PolyJet 3d printers deposit photopolymers layer by layer and cure them via UV radiation. Multiple ways of material mixings are possible, either by depositing droplets of a composition of multiple different photopolymers on each voxel before curing, or by implementing the inclusion geometry in the digital design in a way that the 3d printer places different materials at distinct places, with the possibility to freely choose the geometry of the inclusions.

Advances in the field of continuum mechanics offer various possibilities to predict properties of mixed solid materials, especially focused on elastic properties [1,2]. This approach requires knowledge of the properties of the pure materials [3,4], and allows to predict and therefore adapt the material mixture to the desired target properties. These kind of prediction can be used for mix-material inclusions of different shapes [5–7], various other material properties other than mechanical elasticity [8–11] and with different mixture behavior [12,13]. In this manuscript mathematical models from continuum mechanics are applied to materials printable using PolyJet technology.

II. Methods

II.I Mixing Material Models

Several options now exist for predicting homogenized mixed materials, two of which are well suited of emulating the capabilities of common multi-material 3d printers. The so called Mori-Tanaka scheme assumes a matrix consisting of one material with various inclusions in it [13], while the self-consistent scheme assumes the material to be built up from dispersed aggregations, as it is typical for polycrystals [4,12] (Figure 1). Note that the investigated material has to be larger than the included individual phases [2]. If the length scales of the macroscopic and microscopic geometries are getting closer, the accuracy of the material homogenization will become poorer. In this study both homogenization methods were used to simulate mixed material properties.

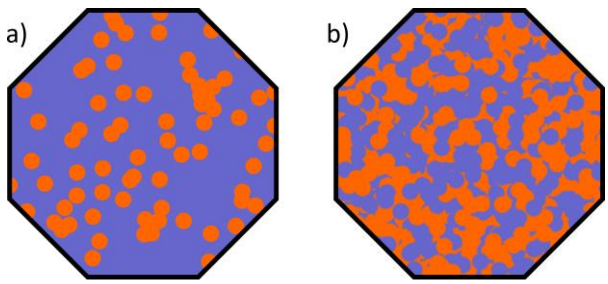

Figure 1: a) Mori-Tanaka scheme with orange inclusions embedded in a blue matrix. b) Self-consistent scheme with overlapping blue and orange phases.

II.II Mixed material property estimation

The simulation combined *Tango+* and *VeroClear* (Stratasys Ltd., Minnesota, USA). From the experimentally determined properties of the pure materials [14–16] the elastic moduli have been derived assuming transversal isotropy (perpendicular to the building direction of the 3d printer). The mix material properties have been calculated following the approach outlined in ref. [1] for all possible bi-material composites. Although these photopolymer mixtures are jetted as small droplets during the fabrication,

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both for the Mori-Tanaka and self-consistent schemes the inclusions were assumed to be perfect spheres. The required Hill tensor was derived in a similar manner as shown in [17] and [18].

III. Results and Discussion

The elastic moduli and the derived Young's Modulus of the mixtures could be calculated for the different mixing proportions using the Mori-Tanaka scheme (Figure 2). According to this simulation, to reproduce the mechanical elasticity of e.g. a tendon (Young's modulus of E_1=1.2 GPa [19]) would demand an inclusion volume fraction of 60% VeroClear within Tango+.

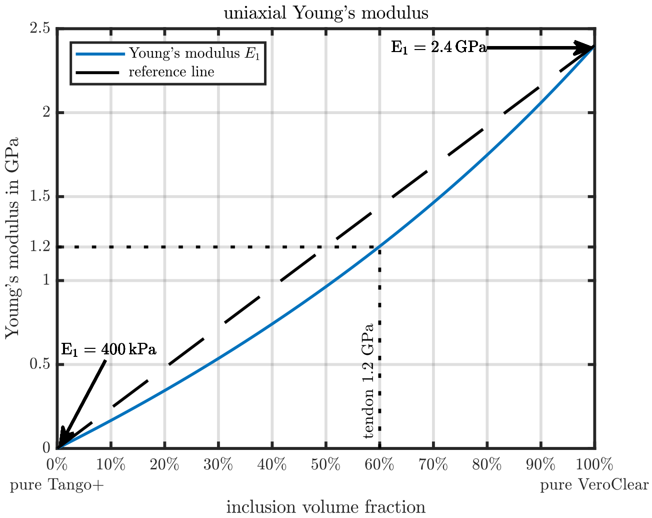

Figure 2: Uniaxial Young's modulus E_1 from Tango+, VeroClear and the mixable bi-materials from these. A material mixture of about 60% VeroClear will show a Young's modulus of E_1=1.2 GPa, corresponding to a human tendon as reported in ref. [19]. The reference dashed line shows a linear interpolation between the pure materials Young's moduli.

Since no analytical solution to the self-consistent scheme exists, a numerical solution was computed. However, this computation did not lead to meaningful results, possibly due to numerical instability arising when the materials elastic properties of the two single constituents are different by orders of magnitude.

IV. Conclusions

Continuum mechanics provide a framework to predict 3d printed multimaterials and may help selecting the optimal material composition. However, careful model selection and experimental validation of these homogenization concepts and their dissimilarity for different applications are required.

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Author's statement

Conflict of interest: none

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