MECHANICAL METAMATERIALS BY DLP PRINTING

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Mechanical metamaterials, with designs typically containing mesoscale features, are under increasing investigation due to their ready fabrication using additive manufacturing techniques such as digital light processing (DLP). However, applications with demanding weight and size limitations require material formulations with lower densities and higher moduli and which are not readily available. Here, we present an effort to fuse resin formulations, characterization, and error compensation approaches to enhance the performance of these mechanical metamaterial structures. First, a design map for mechanical metamaterial performance based on analytical and finite element models is created in order to provide directional predictions for material formulations that maximize performance. Based on these predictions, an open-source acrylate-based photopolymer resin is filled with hollow glass microspheres to reduce the formulation density and to increase the modulus. A rule of mixtures relationship between volume fraction fillers and density is verified. The volume fraction fillers is maximized to reduce density while maintaining sufficient flow for re-coating the DLP window between each layer through viscosity modification, dispersants, and agglomeration prevention. This novel formulation is able to reduce density by over 30% and increase the modulus by 85%, thereby increasing the metamaterial performance metric of modulus-to-density ratio a factor of 2.7. This metric value has not been reached in previously reported DLP resin formulations. The structures are characterized in order to validate performance and to provide a feedback loop for improved formulations and future prints. Details of defects – both geometric (i.e., feature dimensions) and – are measured by microscopy and Computed Tomography. The data are analyzed to modify the additive manufacturing process for error correction. These data will form the basis for future machine-learning efforts to identify significant processing characteristics and minimize defects. Finally, mechanical metamaterial modeling indicates multi-material printing will provide a step-change increase in performance. Initial efforts to produce these multi-material structures will be presented.

Figure 1 – A printed mechanical metamaterial using novel resin formulation. (left) A 5 x 5 unit cell structure produced by DLP printing. (middle) An optical micrograph of the unit cell structure for big data analysis. (right) A partial analysis of the geometric features for the unit cell shown in the middle image. Key feature dimensions are collected and fed into machine learning algorithms to improve the printing process.