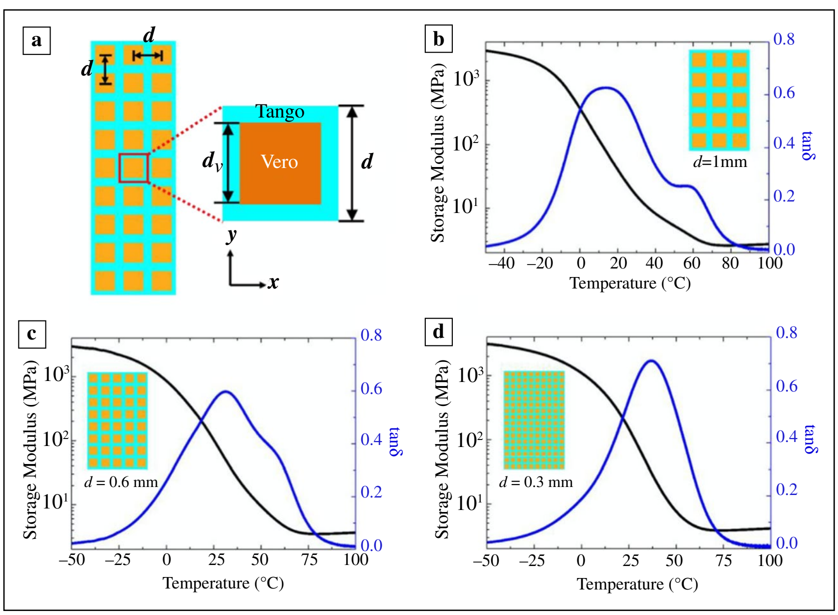
Spatial control through voxel design enables customizable properties in additive manufacturing

Additive manufacturing (AM) has revolutionized fabrication of objects with complex, three-dimensional (3D) geometries. Previous efforts have focused on optimizing the mechanical properties of single material prints by controlling processing parameters such as printing orientation and void density. Unfortunately, for real applications, single-material optimization cannot meet the demands required. To combat these issues, a group of researchers from the Singapore University of Technology, Xi'an University of Technology, and Southern University of Science and Technology has developed a 3D printing process that allows spatial control through voxel design of materials properties within additively manufactured composite structures. They report their findings in a recent issue of *Materials and Design* (https://doi.org/10.1016/j.matdes.2020.109205).

Spatial control of materials properties for 3D printed parts is highly desirable as it can create an endless catalog of customizable materials properties. Instead of focusing on developing new printing or materials systems to improve the properties of AM parts, a new methodology known as digital material printing is gaining momentum. Digital material printing uses 3D units known as voxels to construct heterogeneous structures. Voxels of different materials properties can be assembled to manufacture a part with highly tunable properties. The research group proposed a new voxel design mechanism of constructing digital materials for AM by optimizing the voxel size to directly customize thermomechanical properties throughout a bulk material.

Two photopolymers were used in this work to manufacture these heterogenous structures, Vero and Tango. Vero is a mixture of isobornyl acrylate, acrylic monomer, urethane acrylate, epoxy acrylate, acrylic monomer, acrylic oligomer, and photoinitiator. Tango is polymerized by urethane acrylate oligomer, exo-1,7,7-trimethylbicyclo hept-2-yl acrylate, methacrylate oligomer, polyurethane resin, and a photoinitiator.



Effect of voxel size on the thermomechanical properties of voxel-designed digital materials. (a) Voxel design strategy for constructing digital material. (b–d) Temperature-dependent storage modulus and tanδ of the voxel-designed digital material with voxel size of 1 mm, 0.6 mm, and 0.3 mm, respectively. The volume fraction of Vero (a mixture of isobornyl acrylate, acrylic monomer, urethane acrylate, epoxy acrylate, acrylic monomer, acrylic oligomer, and photoinitiator) is maintained at 50% for all voxel sizes. Credit: *J Materials & Design*.

The strategy uses various sized voxels comprised of Vero inclusions and a Tango matrix. The research team used the Vero inclusion and tango matrix to form a pattern within the *x*–*y* plane to constitute the bulk digital material. This provided the capability to continuously vary the bulk material's property through geometrical design.

It was determined that a voxel size of 0.3 mm was optimal, and reducing voxel size leads to stable glass-transition temperatures. As the researchers elevated the Vero content within the voxel design, the printed polymeric digital material displayed a tunable storage modulus up to three orders of magnitude and a glass-transition temperature ranging from 0°C to 6°C. As a direct consequence, different shape-memory performances were demonstrated by the bulk voxel-designed digital materials. The printed structures displayed enhanced shape recovery with elevated Vero content. This enhanced shape recovery can be utilized within applications for smart structures that can benefit from shape memory.

The researchers' purpose in developing the voxel design is to obtain a large catalog of customized thermomechanical properties that accommodate the requirements of various applications. In doing so, a convenient way of property tailoring needed to be discovered to ensure the voxel design strategy. By reducing the voxel size to 0.3 mm, the researchers were able to reduce the phase separation, allowing a favored, single peak tanδ curve to be obtained. The tanδ curve occurs at the highest temperature and is a good measure of the midpoint between the glassy and rubbery states of a polymer. By varying Vero content, a composite voxel design was achieved leading the way to the possibility to tailor the shape-memory performance of bulk materials.

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