Energy Efficient Morphogenic Manufacturing of Composite Materials in Space and on Earth

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Abstract

Bio-inspired manufacturing research aims at providing economic benefits and energy savings of structural materials with minimal environmental impacts. In this talk, I will present our efforts using frontal polymerization (FP) for space and terrestrial morphogenic manufacturing of carbon fiber reinforced composites. FP uses poly-dicyclopentadiene (pDCPD), a stiff and tough thermosetting polymer capable of energy-efficient "self-propagation and self-curing".

In space, I will describe our progress towards "Mission Illinois": the first on-orbit carbon fiber composite manufacturing space experiment planned for launch in 2026. This mission will enable the manufacturing of extremely large, mass-efficient, and precise structures on-orbit. We introduce reactive extrusion of CFRP (RE-CFRP), where two rollers provide localized heat and pressure to sustain the curing reaction and the consolidation of a continuous carbon fiber tow pre-impregnated with DCPD. We study the effect of the extrusion speed, temperature, and compaction force on the properties of the produced CFRP. Mechanical testing confirms that the resulting fiber volume fraction and the elastic modulus are similar to bulk cured tows. A homogenized thermo-chemical model is developed to study the effect of the process parameters on the polymerization reaction. The process produces hollow woven composite tubes directly via extrusion and in situ curing. Overall, this process offers advantages in curing, tooling, speed, and energy.

Next, I will describe growth printing, an additive manufacturing (AM) process harnessing this spatially propagating FP reaction to produce 3D polymer parts 1000 times faster and twice as energy efficient than the faster stereolithography. In contrast with existing 3D printing, this morphogenic process is inspired by biological "growth and form" due to the self-directed propagation of the polymerization reaction. Growth printing is triggered when a heated initiator contacts the uncured liquid resin in an open container. The initiator nucleates the frontal polymerization reaction and the radial propagation of the growth front. During the front propagation, the initiator is simultaneously moved up across the free surface of the resin, pulling the cured object out of the uncured resin. The vertical motion of the initiator with respect to the free resin surface controls the growth morphology of the 3D part. We developed an inverse design algorithm to produce 3D part geometries by modeling the reaction-diffusion-driven solidification process. Various bio-inspired geometries achieved using this process demonstrate substantial energy and data savings and high printing speeds. I will describe experiments and modeling to enable the potential use of this disruptive technology.

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