A B S T R A C T

This lecture describes a new manufacturing platform technology that allows for near net-zero energy fabrication of structural polymers and composites. The approach is predicated on the exploitation of a self-propagating polymerization reaction occurring in a system undergoing reaction and diffusion of its components. The system uses the exothermic release of energy to provide a positive feedback to the reaction. In turn, this stimulates further exothermic energy release, and a self-propagating reaction front that rapidly moves through the material – a process called frontal polymerization. The frontal ring opening metathesis polymerization of endo-dicyclopentadiene using a thermally activated ruthenium catalyst exhibits the high energy density, high reactivity, and low viscosity required for the synthesis of high-performance thermosets. The resulting polydicyclopentadiene is a cross-linked thermoset polymer suitable for the fabrication of durable resin and fiber-reinforced composites. Composite parts are fabricated in less than 5 min by frontal ring opening metathesis polymerization of woven carbon fibers infused with monomer solution. The total energy to create a 30x30 cm panel is 50 J compared to approximately 500 MJ by conventional autoclave curing – a seven order of magnitude decrease in required energy. Tuning the resin chemistry allows access to a range of rheological profiles between low-viscosity liquid and free-standing elastomeric gel – all of which frontally polymerize upon thermal activation. The gel is amenable to 3D printing by extruding from a print head and frontally polymerizing immediately upon exiting the nozzle, thereby allowing for the simultaneous freeform printing and curing of thermostet polymers. Frontal polymerization enables the manufacture of complex architectures, in situ fabrication of vascular networks and the seamless addition of functional additives not possible with traditional processing approaches.

Reaction-diffusion processes are versatile, yet underexplored methods for manufacturing that provide unique opportunities to control the spatial properties of materials, achieving order through broken symmetry. The mathematical formalism and derivation of equations coupling reaction and diffusion were presented in the seminal paper by Alan Turing [Phil. Trans. R. Soc. Lond. B 237, 371952], which describes how random fluctuations can drive the emergence of pattern and structure from initial uniformity. Inspired by reaction-diffusion systems in nature, this talk describes a new manufacturing platform technology predicated on the exploitation of a self-propagating polymerization reaction occurring in a system undergoing reaction and diffusion of its components. The system uses the exothermic release of energy to provide a positive feedback to the reaction. In turn, this stimulates further exothermic energy release, and a self-propagating reaction “front” that rapidly moves through the material – a process called frontal polymerization. The self-sustained propagation of a reaction wave through the material gives rise to entirely new ways of manufacturing high performance composites using rapid, energy efficient methods at greatly reduced costs, including 3D printing of thermostsetting polymers and composites. Controlling the reaction wave by simple thermal perturbations gives rise to symmetry breaking events that can enable complex, emergent pattern formation and control over growth, topology, and shape.
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