

GLOBAL COMPOSITES EXPERTS WEBINAR SERIES



Control of Reaction Fronts

for Rapid Energy-Efficient Manufacturing of Multifunctional Polymers
and Composites

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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 thermoset 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, 37,1952], 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 thermosetting 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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B I O

Nancy Sottos holds the Maybelle Leland Swanlund Endowed Chair and is Head of the Department of Materials Science and Engineering at the University of Illinois Urbana Champaign. She is leader of the Autonomous Materials Systems (AMS) group at the Beckman Institute for Advanced Science and Technology and director of the University of Illinois spoke of the BP International Center for Advanced Materials. Sottos is also a co-founder of Autonomous Materials Inc. (AMI). Inspired by autonomous function in biological systems, the Sottos group develops polymers and composites capable of self-healing and regeneration, self-reporting, and self-protection to improve reliability and extend material lifetime. Her current research interests focus on new bioinspired methods to manufacture these complex materials. Sottos' research and teaching awards include the ONR Young Investigator Award, Scientific American's SciAm 50 Award, the Hetényi Best Paper Award in Experimental Mechanics, the M.M. Frocht and B.J. Lazan Awards from the Society for Experimental Mechanics, the Daniel Drucker Eminent Faculty Award, the IChemE Global Research Award, and the Society of Engineering Science Medal. She is a member of the National Academy of Engineering, a Fellow of the Society for Experimental Mechanics and the Society for Engineering Science.