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Sacrificial templates for manufacturing multidimensional vasculature

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ABSTRACT

Biological systems employ complex, composite architectures that are intimately related to homeostatic functionality. A common necessity underlying many of these systems is the transport of fluids that distribute nutrients, remove waste, and provide thermal regulation. Parallels exist in engineered materials; however, the architectures are comparatively less complex. No single fabrication technique has emerged with the flexibility to create architectures of various size-scale and dimensionality. Esser-Kahn et al. introduced a technique referred to as vaporization of sacrificial components (VaSC) [1]. Poly(lactic acid) PLA fibers are first treated with a catalyst, tin oxalate (SnOx), to lower their depolymerization temperature. The fibers are embedded in a thermoset matrix and then vaporized to leave behind straight channels (1D dimensionality). In this study, we extend the application of sacrificial PLA and VaSC to all levels of spatial dimensionality (0D–3D). Sacrificial PLA templates of each level of dimensionality: 0D-spheres, 1D-fibers, 2D-sheets, and 3D-printed structures are fabricated. Two different tin catalysts (tin oxalate, SnOx, and tin octoate, SnOc) are incorporated into PLA to promote depolymerization at modest temperatures (~200°C). Spheres with diameters averaging 23 μm are fabricated using an emulsion/solvent evaporation technique. Fibers spanning two orders of magnitude in diameter are fabricated using electrospinning (~5 μm) and melt-spinning (~300 μm) techniques. Sheets (~550 μm thick) are hot-pressed and laser cut to form branched planar networks. Fused deposition modeling is used to create a 3D branching tree-like structure. Each template is embedded in epoxy and removed using VaSC (200°C in a vacuum oven, 24–48 h) to reveal the inverse of the template architecture. The effectiveness of VaSC is evaluated using isothermal thermogravimetric analysis (iTGA) at 200°C (ex situ), and by tracking weight of the embedded °C in a vacuum oven (in situ). The templates in epoxy subjected to 200°C choice of catalyst influences the vaporization time with SnOc promoting more rapid removal. Comparison of in situ and ex situ tests reveals a delay in VaSC completion in the embedded state. The structures created using template materials from each level of dimensionality (0D–3D) are evaluated by flow rate testing. Experiments were performed under laminar flow conditions and compared to appropriate predictive models. Structures tested include porous sheets, 1D channels, a 2D-bifurcating network, and a 3D-branched tree-like structure. Flow in porous sheets is compared to Darcy's law using a porosity-permeability correlation, whereas flow in one-dimensional channels is compared to the Hagen–Poiseuille equation. Computational fluid dynamics simulations of flow in both the 2D and 3D structure are performed in ANSYS FLUENT. Experimental data agreed well with modeling/simulation for every level of dimensionality. Sacrificial templates provide a technique to form multiscale, multidimensional, and interconnected vascular and porous networks in thermosetting polymers. Further work in this area will focus on extending the concept to more types of polymers and improving precision and resolution in complex 2D and 3D structures.

REFERENCE

- [1] Esser-Kahn et al.. *Adv. Mater.* 2011, 23, 3654.