

MICROVASCULAR COMPOSITES FABRICATED FROM SACRIFICIAL FIBERS

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ABSTRACT

Self-healing microvascular material systems have attracted attention for their ability to achieve multiple healing cycles in response to mechanical damage [1]. Current microvascular fabrication methods are limited in their ability to integrate microvascular networks into commercial composite materials. In order to extend self-healing materials to commercial applications, we have developed an approach that is compatible with large-scale composite manufacturing [2,3]. Sacrificial fibers are woven into 3D fiber composites and embedded in a matrix (e.g. epoxy). The sacrificial fiber depolymerizes when heated, resulting in a vaporization of fiber material, while the application of a vacuum allows controlled removal of the depolymerized gaseous monomer from the matrix. The hollow channels produced are high-fidelity inverse replicas of the original fiber's diameter and trajectory (Fig. 1).

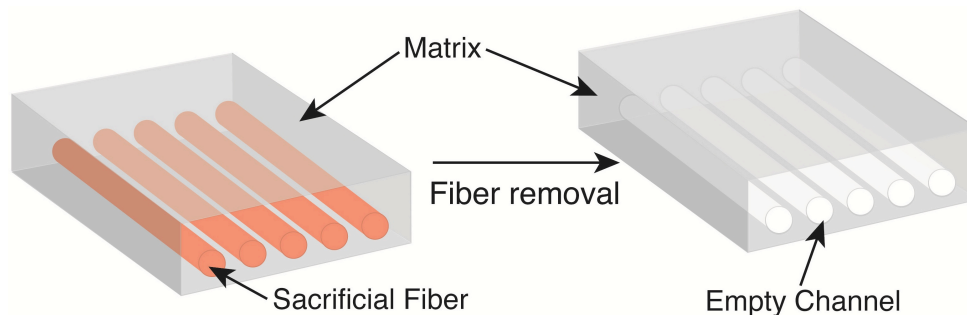


Figure 1: Schematic images of sacrificial fibers embedded in a matrix and subsequent fiber removal resulting in microvascular networks in the matrix.

The degradation behavior of poly(lactic acid) (PLA) has attracted widespread interest because of its bioabsorbable and environmentally-benign degradation products. We explore the possibility of constructing high-aspect ratio microchannels by embedding commercial PLA fibers in an epoxy matrix and then triggering thermal depolymerization (Fig. 2). The uncatalyzed thermal depolymerization of PLA is realized by heating above 280 °C which results in the formation of gaseous lactide monomer. Chemical modification of the fiber is explored to initiate depolymerization at temperature amenable to matrix manufacturing. The depolymerization temperature is lowered by the addition of a variety of Lewis acid catalysts (Fig. 2). We employ a solvent assisted impregnating

technique to infiltrate the sacrificial PLA fiber with catalyst. Catalyst-treated fibers convert to gas at temperatures ca. 100 °C lower than the unmodified ones as measured by thermal gravimetric analysis (TGA). Various processing parameters are optimized to produce fibers that are efficiently removed from an epoxy matrix. This sacrificial fiber vascularization technique creates fiber-reinforced microvascular composites, in forms as large as one meter whose channels can subsequently be filled with self-healing agents and are expected to demonstrate autonomous healing response.

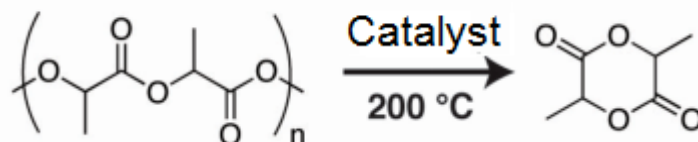


Figure 2: Sacrificial fiber chemistry: the catalyzed depolymerization reaction of PLA fiber.

The method of infiltrating commercial PLA fiber with catalyst has its merit of easy processability and scalability, but faces a serious problem which causes incomplete sacrificial fiber removal by introducing imperfections (plugs, necks, etc.) that block the microchannels. For the complete removal of sacrificial fiber in a composite, an alternative fiber manufacturing method is explored. The new method combines the preparation of viscous PLA solution mixed with metal catalysts and the traditional dry fiber spinning technique. With enriched catalyst content and better catalyst dispersion, the sacrificial fibers produced via fiber spinning show promising advantages over the infiltration of commercial PLA fibers in term of depolymerization rate and imperfections in microchannels. This fiber spinning method is likely to be the best method for microvascular composite fabrication.

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