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# Automated fiber placement of multifunctional fiber-reinforced composites

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**AUTOMATED FIBER PLACEMENT OF MULTIFUNCTIONAL FIBER-REINFORCED COMPOSITES**

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Multi-functional composite materials, in which additional functions exist beyond the primary structural function, offer broad scope for system-level performance enhancements. Key functions targeted for composite structures include thermal management, self-healing, and structural health monitoring capabilities. Aerospace and other advanced fiber-reinforced composites applications, which will benefit from these capabilities, are increasingly being manufactured via Automated Fiber Placement (AFP); however, the lack of (1) available material systems suitable for AFP and (2) the lack of processing knowledge regarding their deposition and compaction hinder the automated manufacture of these multifunctional features. Here, we present efforts to create functional pre-preg materials suitable for AFP processing and to characterize the processing-performance relationships of the resulting multifunctional structures. Specifically, the material systems explored include sacrificial filament carbon-fiber pre-pregs, microcapsule-based pre-pregs, and carbon nanotube (CNT)-containing pre-pregs. These materials are targeted for microvascular- based, self-healing, and interlaminar toughening coupled to resistivity-based heating of composites, respectively. This investigation of processing requirements for automated fiber placement is novel, in that knowledge-driven AFP processing is systematically investigated to translate these high-profile functional materials from small, hand laid-up specimens to scalable, automated fabrication of relevance to modern fiber-reinforced composites manufacturing. The specific tasks to investigate these processing-performance relationships are pursued by custom-designed functional tow pre-preg materials that are laid-up into structures with an Electroimpact 7-axis gantry-style AFP machine at Aurora Flight Science's facility. Sacrificial filaments, which degrade in a post-cure cycle to embed hollow synthetic microvascular networks within a composite structure, are extruded in continuous lengths suitable for spooling onto uni-directional carbon fiber pre-pregs. The effects of filament diameter and position with respect to contact with the AFP add-roller or passive-roller are studied to determine the quality of filament lay-up. Compaction pressures and temperatures, as well as fiber orientation of the adjacent layers, are shown to have substantial effects on the cross-sectional shape, surface roughness, and flow resistivity within the embedded microvascular networks. Microcapsules containing solvents and other healing agent components are used for self-healing applications. AFP-related parameters, such as feeding and roller pressures, are correlated with capsule survivability and ultimate healing functionality. Finally, vertically aligned carbon nanotubes (VACNTs) are transferred from wafers and continuous spools of VACNTs onto AFP-ready pre-preg for interlaminar toughening and resistive heating applications. The mechanical impact of VACNTs on interfacial bonding near embedded functional features is investigated with double cantilever beam geometry tests. The maintenance of vertical CNT orientation during AFP processing is investigated as a function of automated placement processing parameters. These aims and tasks directly address the CALL topical areas of structural and functional composite materials.