ABSTRACT

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Title: Cost-Effective Prepreg Manufacturing for High-Volume Applications

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In this doctoral thesis work, the impacts of alternative constituent material's impact on low-cost prepreg manufacturing for high volume applications will be considered. Unidirectional prepregs offer the potential for significant increase of specific-properties and thereby weight savings. Hence the automotive industry is seeking to utilize composite components in their design, in order to meet new fuel economy ratings and global emissions targets imposed by governments. New resin formulations to achieve 3-minute cycle times or low-cost carbon fiber manufacturing have been created to address the needs of the automotive and other cost-sensitive industries, however these innovations have led to challenges in the composites manufacturing process. Quality control issues may include variations in resin saturation of the fiber bed, consolidation, porosity, and fiber volume fraction. These quality issues arise in the part forming step or from the initial resin infiltration during prepregging.

Some low-cost carbon fiber has a kidney-bean shaped cross-section which has implications on the compaction and permeability of the fiber bed. The kidney-bean shaped fibers were shown in this work to follow a different compaction trend compared to circular fibers. Furthermore, these fibers required an order of magnitude larger force to compact than circular fibers to achieve similar fiber volume fraction, which had implications on the infiltration and consolidation step. A shape correction factor based on the fiber cross-sectional aspect ratio was proposed to extend the existing compaction model to fibers with irregular cross-sectional shapes. Additionally, permeability simulations were performed on the kidney-bean shaped carbon fiber in various fiber packing unit cells. Since the kidney-bean shaped fiber had some degree of asymmetry, there are two valid hexagonal packing arrangements. At a minimum, the hexagonal packed unit cell orientation caused a 17% reduction in permeability for the same unit cell and fiber volume fraction between the ±90° and 0° orientations. In the most extreme case, a 47% reduction in the permeability was observed between the ±90° and 0° orientations. Depending on the fiber orientation, comparable

permeabilities to circular fibers were attained or up to a 74% reduction in permeability. This means a selection of low-cost carbon fiber could cause the infiltration time to be up to 3.86 longer than for a traditional carbon fiber.

The low-cost carbon fiber was paired with a rapid cure epoxy resin which contained internal mold-release to further improve part cycle times to 3-minutes and reduce part costs. The effect of polar and non-polar internal mold-release was studied for its potential influence on cure kinetics. The polar internal mold-release caused a 20 second delay in the 3-minute part cycle, which increased the cycle time by 10% and would therefore influence part production schedules. This prepreg system was reported to have prepreg quality issues related to solids filtering during infiltration. A hot-melt prepregging process was modeled for S-wrap and nip-roller configurations. The S-wrap process was found to better suited for prepregging multi-phase resins since lower pressures were used. Additionally, a general rule was established when working with multi-phase resins was established, particle diameters should not exceed fiber radii.

The general design principles from the thermoset hot-melt prepregging were used to develop a thermoplastic prepreg tape line. Thermoplastic composites lend themselves to efficient manufacturing processes such as hybrid overmolding which is suitable for the automotive industry. polyamide-66/Kevlar® prepreg tapes were manufactured at various line tensions. Neat, rubber toughened, and glass bead filled polyamide-66 based resins were considered. The neat polyamide-66 resin provided a baseline and was able to consistently saturate the fiber bed up to 400μm regardless of manufacturing conditions. The addition of rubber particles did reduce the infiltration distances from the base resin by 20% with significant a significant 50% reduction when the fiber volume fraction reached 0.70. While the addition of glass particles significantly reduced the infiltration distances by up to 70% across all manufacturing conditions. The reduction in flow distance resulted in poor infiltration in thicker fiber beds.