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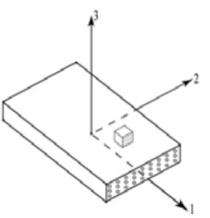

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Manufacturing and Through-Thickness Mechanical Characterization of Thick-Section Composites

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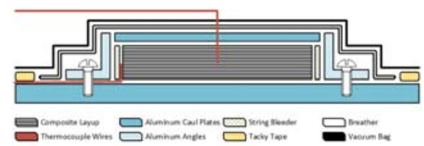
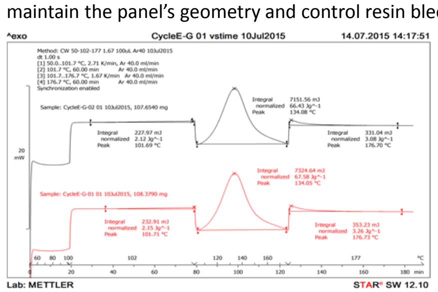
While methods for testing and analysis of the mechanical properties of structural composites are well-defined, the through-thickness (3-direction) properties are difficult to obtain and to properly characterize. The determination of through-thickness properties generally involves the manufacture and testing of thick-section composites (TSC), parts with a high thickness to span ratio (usually ≥ 1" thick). Difficulties in the manufacture of TSC parts yield inconsistent part quality and, therefore, process dependent test results. This study aims to identify and understand the influential factors associated with TSC consolidation, secondary machining, and experimental methodology. The through-thickness mechanical properties of an aerospace-grade carbon fiber and fiberglass system will then be correlated with ply direction angle and temperature of the environment in order to define failure envelopes for design engineers.

Material Fabrication

In order to make a 1" thick laminate, 68 plies of carbon and 110 plies of fiberglass are required, respectively. The primary concern during layup is introducing voids between plies. Voids are reduced by debulking the part frequently (every 5 plies). Debulking removes air pockets from between the plies and reduces the unconsolidated thickness of the panel. Due to its exceptional thickness, the vacuum bag for this part requires tall, stiff dams to maintain the panel's geometry and control resin bleed.



Schematic of dam and vacuum bag setup to be used to obtain the desired final panel geometry.



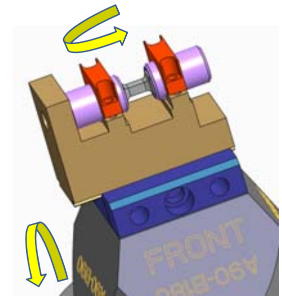
DSC output generated using 7781 fiberglass prepreg samples showing peak heat generation during ramp.

Cure Cycle Development

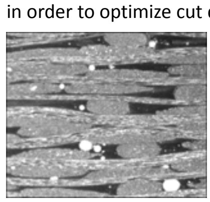
The kinetics of the resin cure are multifaceted, with flow and wet-out dependent on viscosity, devolatilization being a function of partial pressures, and crosslinking dependent on temperature, a unique recipe must be developed to address and control each effect simultaneously. In addition, an uncontrolled exotherm could cause the panel to cure from the inside out, causing severe process-induced residual stresses. To identify and control the peak heat generation, a series of DSC tests are being performed for different potential cure schedules. The experiment, along with Rheology and DMA data, will reveal which isothermal hold and ramp rate combination will best serve to decrease the exothermic peak, and when to introduce pressure and vent vacuum. Embedded thermocouples will be used to monitor heat generation and drive the cure.

Secondary Machining

Once the panels are cured, they must be machined down to individual specimens. A diamond saw will be used to cut the panels into strips, then custom angle blocks will be used to cut the strips into prismatic test specimens at one of six investigated angles. To ensure failure in a prescribed location within the specimen, the tensile specimens must be "waisted" in the middle, where each specimen will be bonded to pull stubs and machined using a 5-axis CNC mill. In order to identify the appropriate tooling and process parameters for this complex operation, an investigation into the resulting surface roughness and topology will be performed in order to optimize cut quality.



Model of specimen (gray) with pull tabs (purple) machining fixture.



Sample microscopy image showing void content.

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Quality Control and Analysis

A critical factor in obtaining accurate material properties and characteristics is producing a high-quality test specimen. To quantify the quality of the specimens produced by the layup and machining process, the resin content, void content, and surface finish will all be evaluated. The mechanical properties being measured are matrix-dominated, therefore it is critical to relate them to the resin content in the composite systems. Voids in the matrix induce stress concentrations which cause the material to fail prematurely. Similarly, secondary machining induced cracking or geometric irregularities could initiate and/or facilitate the propagation of damage during loading, also influencing failure.

Mechanical Testing and Characterization

Testing in both tension and compression will be performed to characterize the material in the through-thickness direction. Testing parameters such as sample geometry and load application rate are described in ASTM D7291. The ply angle (θ) will be systematically varied from 0° to 45° with respective sample populations to induce more or less shear and compressive interaction between plies. An electromechanical load frame will be used to load the samples in displacement control. The surface strain on the specimen will be directly measured using strain gages and digital image correlation (DIC). The thermal effects on the respective properties will then be investigated to define the temperature dependent failure envelopes in a thermally controlled testing environment.

Coordinate system for testing

Goals and Analysis

The goal of this project is to develop a failure envelope for these structural composite materials. This study will also provide the necessary data and insight for finite element model validation and verification . Additionally, the optimized process parameters defined in this study may be applied to the future manufacture and characterization of TSCs.

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