Through Thickness Thermal Gradients in Thick Laminates During Cure, Influence on Tg and Modulus

Benjamin Updike/GRC-LERCIP, Sandi Miller/GRC

Michigan Tech 1885

National Aeronautics and Space Administration

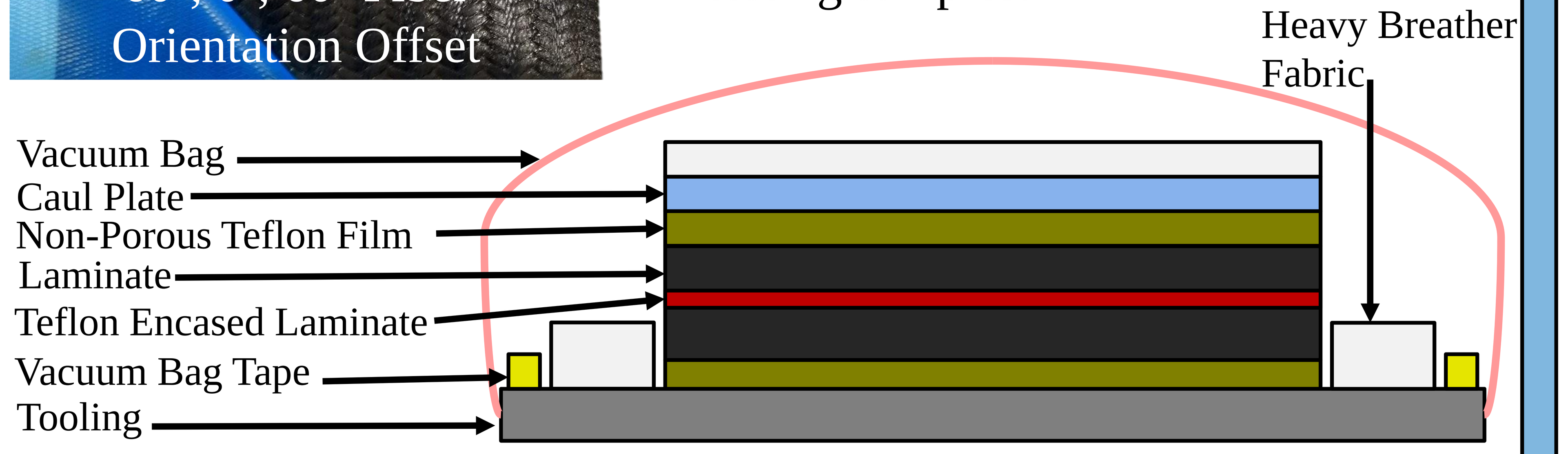
Abstract

Carbon fiber composites are materials of great interest to the aerospace industry because of their light weight and high strength properties. Composite use in high load bearing applications such as roto-craft gearing requires manufacturing parts that are 1.5” thick and beyond. Very thick composite parts (laminates) produce thermal gradients and temperature spikes due to the heat released by resin polymerization and cross-linking during composite cure. It is believed that these thermal gradients will cause internal stresses to build-up inside these ultra-thick laminates during the cure-cycle, yielding parts with non-uniform mechanical properties throughout the thickness of the laminate. The goal of this study is to identify these thermal gradients and determine the magnitude of difference in mechanical properties generated by them.

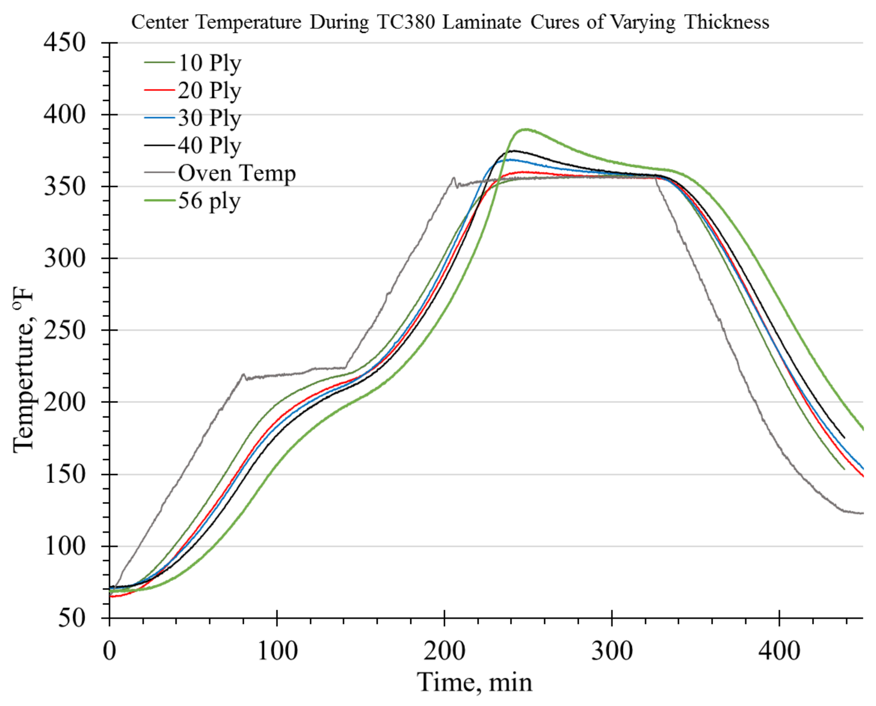
Materials and Methods

Tencate[TM] TC380 2D Braided Prepreg

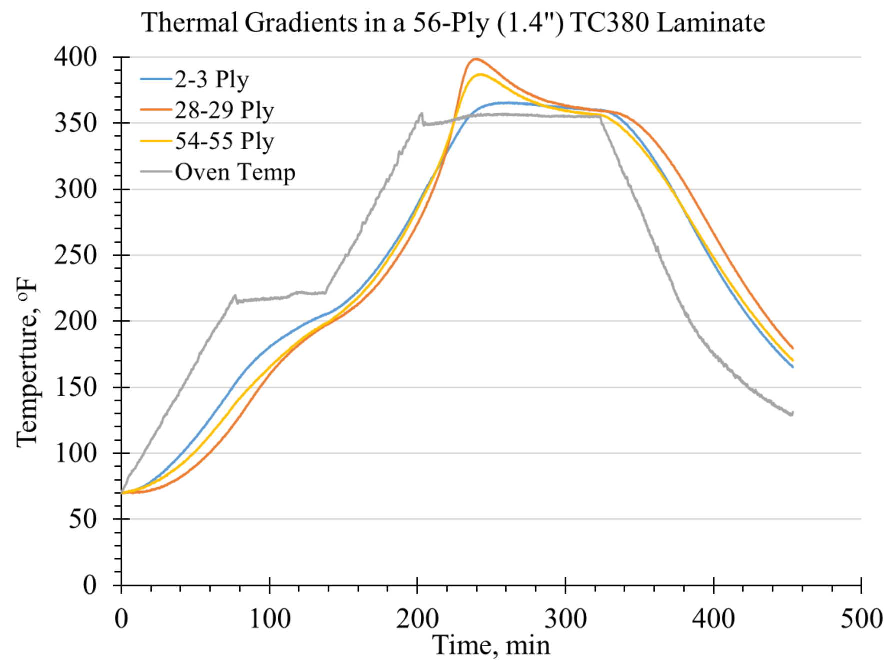
Autoclave-style vacuum bag layup procedure using both aluminum and steel tooling. Teflon non-porous paper is put inside the laminate to isolate sections of interest for mechanical testing or thermal gradient analysis. Vacuum bagging helps consolidate laminates (remove voids) and produce good mechanical testing samples.



Thermal Gradients Analysis



- Comparison between center temperature in varying thickness (0.25”-1.4”) TC380 laminates and oven air temperature during cure cycle to show effect of laminate thickness on thermal lag
- Thermal lag in center of composite increase significantly with large number of plies, going from 150 minutes to reach 225 F in a 10 ply laminate to nearly 180 minutes to reach 225 F in a 56 ply laminate

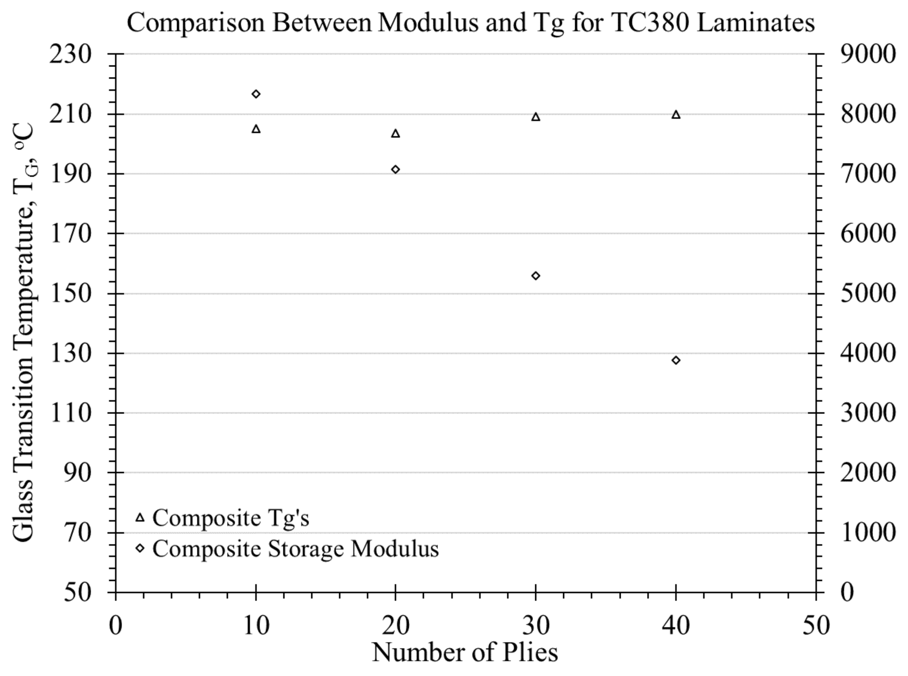


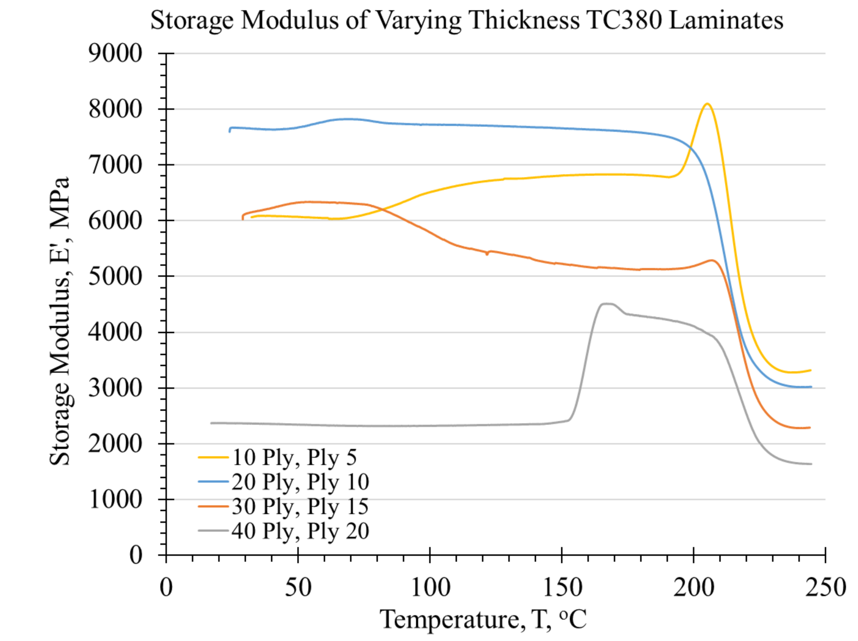
- Plot of temperatures inside a 56-ply laminate from three thermocouple locations, Ply 1 is located next to the tooling and Ply 56 is located beneath the caul plate
- Note how the plies closest to the tooling (1-3) see an exotherm that is 35 F lower than the center plies

Thermal Gradient Data from TC380 Composite Part Cures Up to 1" Thick								
Number of Plies	Exotherm °F (Overshoot of T_C)	Average Temperature Lag to 225 °F (°F)	Observed Composite Ramp Time to 225 °F (min)	Observed Composite Ramp Rate to 225 °F (°F/min)	Average Temperature Lag to 356 °F (°F)	Observed Composite Ramp Time to 356 °F (min)	Observed Composite Ramp Rate to 356 °F (°F/min)	Average Temperature Lag to 122 °F (°F)
10	0	34.5	151	1.04	34.3	90	1.46	33.0
20	3	42.9	160	0.98	40.9	74	1.77	48.3
30	9	48.0	157	0.98	45.5	68	1.93	48.4
40	18	51.7	162	1.02	46.8	64	2.05	62.8

- Data gathered from 0.25” to 1.0”laminates shows that number of plies in laminate significantly effects observed ramp rates during cure
- Exotherm above cure temperature increases dramatically as thickness of laminate increases while holding ply size constant

Preliminary Mechanical Testing





- Plots of basic mechanical properties (T_g and E') by varying number of plies from 10-40 (0.25”-1.0”) as well as storage modulus in aforementioned laminates as a function of temperature
- No major correlation between T_g and number of plies, but storage modulus drops linearly with increasing number of plies
- Increase in storage modulus before drop-off near the end of the temperature range could indicate parts of the laminate are not fully cured
- Mechanical testing carried out using a DMA Q800 setup for dual-cantilever multi-frequency strain testing

Future Work

- Increase the size of sections isolated in the composite for mechanical testing from 1” x 2” to 4” x 8” to be used in ASTM testing for more reliable data
- Take thermal gradients data at alternate locations in 40 and 56 ply laminates to get a more complete thermal profile of ultra-thick composites during the cure
- Experiment with pitch and other thermally conductive fibers added in during layup to improve heat transfer and degree of cure
- Move to laminates that are 2” thick and beyond and also experiment with more eccentric ply geometries