Out-of-Autoclave Manufacturing of Complex Shape Composite Laminates

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Introduction
Out-of-autoclave (OOA) prepreg processing is becoming an increasingly viable alternative to traditional autoclave manufacturing of high performance composites. The size and complexity limitations for composite parts manufactured with autoclave together with the associated high costs can be overcome with OOA processing.

The general objective of this research is to evaluate the effect of important design and processing parameters on the quality of complex shape composite laminates manufactured by OOA processes. The present study aims to better understand the mechanism that governs the compaction of complex shape laminates using OOA materials and to develop guidelines for their manufacturing.

Materials

Methodology
A1. Processing of L-shape laminates with various radii and thicknesses:

A2. Characterization of L-shape laminates:

B1. Processing of “U”-shape laminates with various flange lengths:

B2. Characterization of “U”-shape laminates:

Results
A. L-shape laminates:
12 L-shape laminates with 5 different tools (2 convex tools, 3 concave tools).
5 different tool radius, R=1/4, R=3/8 (convex) and R=1/2, R=5/8, R=1 (concave).
5 nominal thicknesses, from t=0.07 in (5 plies) to t=0.25 in (18 plies).
1 thickness profile and the void content are characterized for each L-shape laminates.

Thickening is observed on both convex and concave L-shape laminates. The maximum thickness deviation is lower than 5% for convex laminates and higher than 22% for concave laminates. Maximum void content measured is slightly higher than 1%. Micro-void contents are negligible.

For concave L-shape laminates, thickness deviation is more sensitive to tool radius with increasing laminate thickness and less sensitive to laminate thickness with increasing tool radius. Thickness deviation is inversely proportional to tool radius and seems to be proportional to laminate thickness for L-shape laminates manufactured on concave tools.

Larger radius leads to smaller thickness deviation (concave angle)

B. “U-shape” laminates:
3 “U-shape” laminates with 3 different flange lengths (2 in, 8 in, 14 in).
2 thickness profiles are characterized for each “U-shape” laminates (s1, s2).
1 nominal thickness, t=0.07 in (5 plies) & 2 concave angles, R=0.77 in.

Angle relative thickness, trel (angle), is the average of relative thickness in positions 5, 6, 7, 11, 12, 13.
Large thickness deviations (up to 65%) are observed in the corner regions of these “U-shape” laminates. Voids are concentrated in the corner regions. Void contents in the corner regions of “U-shape” laminates are slightly higher than for L-shape laminates with similar radius.

Larger flange length leads to larger thickness deviation (concave angle)

Conclusion
Design parameters such as tool radius, laminate thickness or flange length have a key role on the compaction mechanisms that occur in complex shape composite laminates. Thickness deviations are expected in the corner regions. In the case of concave L-shape laminates, a smaller radius, a bigger thickness or a longer flange length lead to a larger thickness deviation. Thickness deviations are partly explained by compaction pressure differences in corner regions (lower pressure for concave angle, higher pressure for convex angle) due to surface area differential between top and bottom of laminates. Theoretical expectations were thickening for concave laminates and thinning for convex laminates. But thickening is observed on both convex and concave L-shape laminates. Friction and shear mechanisms between plies, which prevent slippage, have therefore a key role in the compaction of complex shape composite laminates and request further investigations.

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