Spring-Back Behavior of Thick L-shaped Composite Structures: Cooling Rate and Stacking Sequence Factors of Elastic Recovery Time

Gláucio C. Pereira[1,*,#], Wen S. Chan[2], Peter Lebouluec[2], Wei-Tsen Lu[3], Antônio F. Ávila[4]

[1] Mechanical Engineering Graduate Studies Program, Universidade Federal de Minas Gerais, 6627 Antonio Carlos Avenue, 31270-901 Belo Horizonte, MG - Brazil

[2] Department of Mechanical and Aerospace Engineering, University of Texas at Arlington, Arlington, Texas 76012 - USA

[3] Mechanical and Aerospace Engineering Graduate Studies Program, University of Texas at Arlington, Arlington, Texas 76012 - USA

[4] Mechanical Engineering Department, Universidade Federal de Minas Gerais, 6627 Antonio Carlos Avenue, 31270-901 Belo Horizonte, MG - Brazil

[#]Corresponding author: carleyone@hotmail.com

Abstract

Spring-in behavior of composite materials is the deformation arising from the difference between the cure induced in-plane and out-of-plane residual stresses after curing. While this is a well observed problem, the exact mechanisms for spring-in behavior are not well understood. Furthermore, the industry and academia are seeking innovative solutions for such problem. Companies, in general, try to disregard the spring effect and make compensation in the mold to compensate it as a preset. In general, thermal gradients generated during the composite materials cure process leads to changes in shape, e.g. warping. Therefore, understanding the physics behind this phenomenon it is critical for composite materials manufacturing. The spring-in behaviour of thick L-shaped composite structures observed after fabrication was investigated in this work. In the case of thick composite structures, where the expected spring-in angle is small but the structure is too stiff for subsequent fit-up, the spring-in behaviour becomes a tedious and costly process in fine tuning the tooling design. Several Design of Experiments (DOE) were used : $[0_2]_{ns}$, $[90_2]_{ns}$, $[\pm 45_2]_{ns}$,; and $[0,90]_{ns}$, $[0,30]_{ns}$, $[0,60]_{ns}$, $[30,60]_{ns}$, , $[\pm 45,\pm 30]_{ns}$, where n = [1, 2, 4] and 3 different Cooling Rates of autoclave : 5.0 °F/min (CR 1), 10 °F/min (CR 2) and 20 °F/min (CR 3). The difference of angle measured between two arms of the L-shape laminate have demonstrated quantitatively the spring-in / spring- back effect at different time frames (30, 60 and 109 days) . Digi-Pas DWL-3000 XY and Pro 3600 Digital Protractor were used to measure the deformed angle of each arm of the L-shape laminates. The results were then quantized to determine the effects of the stacking sequence and the autoclave's cooling rate in elastic recovery of the material. The results were : 0.535 ° for $[45,30]_s$ CR 3 (109 days); 0.252 ° for $[30,60]_{2s}$ CR 2 (60 days) and 0.770° for $[90_2]_{4s}$ CR 3 (30 days), categorized by thickness - 4,8 and 16 layers – then determined the optimum choice of manufacturing processing to produce the smallest spring-In.