11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

Combined stacking sequence table and thickness optimization for laminate composite structures

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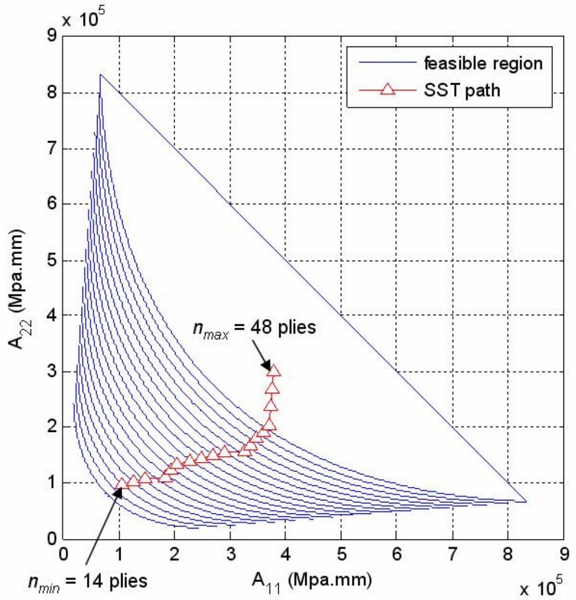
Key Words: *Laminate blending, Stacking Sequence Table (SST), Variable Stiffness, Hybrid Evolutionary Optimization.*

Laminated composite materials are widely used for modern aeronautical structures. Over the last decade, design and manufacturing of large one-shot panels, such as wing-skin panels, has received a growing attention from designers. Detailed design of a large composite structure is usually based on the subdivision of the global problem into local panel design problems. The mass of the structure can be minimized by tailoring the thickness and lay-ups of each panel to the load distribution. For straight-fiber laminates, thickness variations between panels are achieved by adding or terminating plies. Continuity of the plies has to be preserved to obtain one-shot manufacturable structures and avoid stacking sequence mismatch between adjacent panels. The design of laminated structures with ply-drops is commonly referred to as *blending*. A review concerning laminate blending optimization can be found in [1]. In a previous work [2] the authors introduce the concept of Stacking Sequence Table (SST) as a convenient representation of the solutions to solve laminate blending optimization problems. The SST generalizes the concept of guide-based blending [3] by allowing the optimization of the order of the ply drops within the thickness of the laminates. An evolutionary algorithm is specialized to operate on the stacking sequence tables and distribution of number of plies over the constitutive panels of the structure. The subdivision of the structure into panels is a fixed parameter of the optimization. An extensive set of design guidelines representative of the actual industrial requirements is introduced. In particular, two guidelines are directly related to the thickness distribution in order to smooth the load distribution between panels. The *maximum taper slope* is constrained to 7°. The *Δn-rule* constrains the difference of number of plies between connected panels with an upper bound Δn_{max}.

In the present work, SST-based blending optimization is combined with the optimization of thickness distribution in each point of the structure. The subdivision into panels, *i.e.* number and shape and size of the panels, are is a result of the optimization. In order to obtain manufacturable structures, the thickness distribution is constrained by the *Δn-rule* and *maximum taper slope* guideline. The evolutionary algorithm devised in [2] is used to perform the optimization of the stacking sequence tables at the global level. For each stacking sequence table evaluated, a local optimization is performed to improve the thickness distribution over the structure. Indeed, SST-optimization and thickness optimization can be performed separately. A stacking sequence table defines a path in the laminate stiffness space that is a function of the local thickness only (see Figure 1). Thus, a thickness variable is assigned to each element of the finite element mesh of the structure. The density of the mesh defines the number of variables of the local optimization. At the local level, the thickness optimization is performed using a gradient-based method. A specialized constraint handling strategy is devised to handle the design guidelines at both local and global levels and obtain a consistent subdivision of the structure into constant stiffness panels.



n_{min}																	n_{max}
45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
					45	45	45	45	45	45	45	45	45	45	45	45	45
		60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
												30	30	30	30	30	30
45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
										30	30	30	30	30	30	30	30
													30	30	30	30	30
							45	45	45	45	45	45	45	45	45	45	45
90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
								-45	-45	-45	-45	-45	-45	-45	-45	-45	-45
											-30	-30	-30	-30	-30	-30	-30
						-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45
90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
															90	90	90
			-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45
-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45
																90	90
	-60	-60	-60	-60	-60	-60	-60	-60	-60	-60	-60	-60	-60	-60	-60	-60	-60
														-30	-30	-30	-30
-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45
																	0
									-30	-30	-30	-30	-30	-30	-30	-30	-30
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				45	45	45	45	45	45	45	45	45	45	45	45	45	45

Mid-plane of the laminates

Figure 1. An example of stacking sequence table (right) and the plot of the corresponding path in the plane of the longitudinal macroscopic stiffness A_{11} and transverse stiffness A_{22} (left). For each number of plies, the convex hull of the feasible domain in the (A_{11}, A_{22}) plane is given. Even numbers of plies only are represented. In the SST, perfectly symmetrical and balanced laminates are indicated in bold type.

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