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Optimal design of composite structures with design rules and manufacturing constraints, based on continuous design variables

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ABSTRACT

The problem of identifying the optimal stacking sequence in laminates, has been investigated for a long time. In most practical applications, the candidate materials are restricted to -45°, 0°, 45° and 90° plies, which are the conventional orientations used in aeronautics. In order to propose solutions which are relevant for industrial applications, the optimal stacking sequences must satisfy specific design rules (Figure 1), such as the laminate must be balanced and symmetric, there must be no more than N_{max} successive plies with the same orientation in the laminate (N_{max} is often equal to 3 or 4), the transition between two plies must be of at most 45°, that is [0/90] and [45/-45] sequences are forbidden, and finally, minimum and maximum percentages of each possible orientation must exist (Figure 2). Blending of plies (i.e. the ply compatibility/continuity between the adjacent regions in a variable thickness and stiffness composite structure) is another requirement reflecting practical manufacturing considerations.

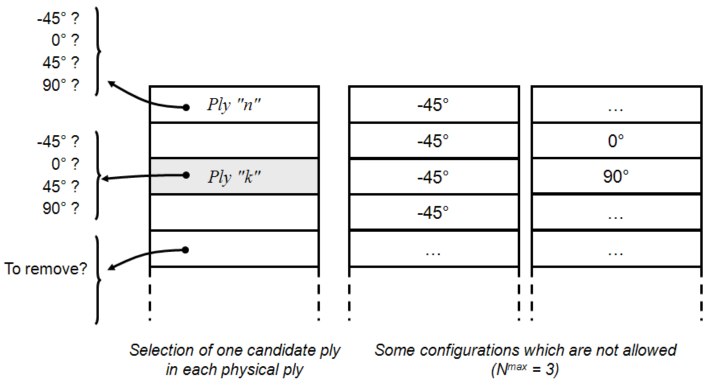

Figure 1: the ply selection problem

In this paper, an optimization procedure based on multi-phase topology optimization is developed to determine the optimal stacking sequence of laminates made up of conventional plies oriented at -45°, 0°, 45 and 90°, taking into account the design rules and the ply continuity constraint. The formulation relies on a parameterization in which the discrete optimization problem is replaced by a continuous approach with a penalty to exclude intermediate values of the design variables. This specific parameterization is called SFP – Shape Functions with Penalization [1]. In this approach, the material stiffness of each physical ply is expressed as a weighted sum over the stiffness of the candidate plies corresponding to -45°, 0°, 45 and 90° orientations.

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(R1) Minimum percentage of each orientation
(R2) Balanced lay-up (same number of plies at 45° and -45°)
(R3) Symmetric laminate
(R4) No more than N_{max} successive plies with the same angle
(R5) Maximum gap between two adjacent (superposed) plies is 45°

Figure 2: set of design rules taken into account in this work

The design rules are expressed in terms of the new parameterization [2]. A specific formulation addresses the ply continuity manufacturing constraints, insuring the blending of the plies between regions of different thicknesses. The methodology is demonstrated on two applications, and it is illustrated how the different design rules can affect the solution. The first application tackles the optimal design of a composite plate of constant thickness submitted to buckling. In the second application, the plate is divided into 2 regions of different thicknesses, and the ply continuity constraint is taken into account. Figures 3 and 4 provide some optimal stacking sequences obtained with the new approach. A gradient-based optimizer is used to solve the optimization problems [3].

Design rules	Iterations	Relative λ_1	Stacking sequence
R1,R3	45	1.00	$[45_4/-45_2/0/90/./.]_S$
R2,R3	23	0.99	$[45_4/-45_4/./.]_S$
R1,R2,R3	32	0.95	$[45_3/-45_2/90/0/-45/./.]_S$
R1,R2,R3,R4,R5	32	0.95	$[45_3/0/-45_3/90/./.]_S$

Notation "/./": the corresponding ply is removed from the stacking sequence

Figure 3: optimal stacking sequences for a plate under buckling, for different design rules

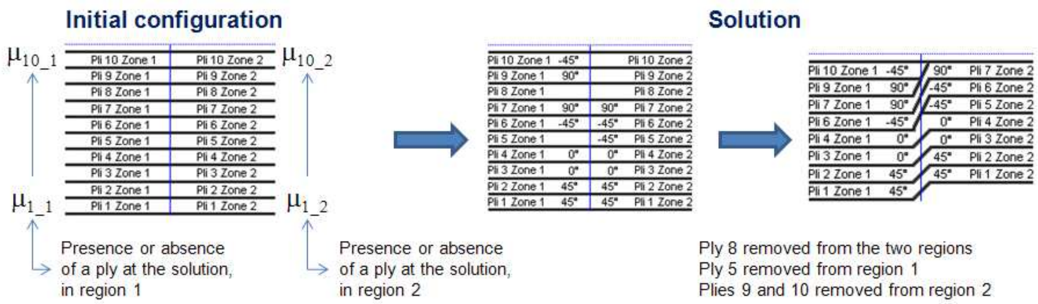

Figure 4: optimal stacking sequence for a plate under an uniform pressure, with design rules

Acknowledgement

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