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A new multi-scale optimisation strategy for designing variable angle tow composites by integrating manufacturing constraints

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In this work a multi-scale two-level (MS2L) optimisation strategy for optimising variable angle tow (VAT) composites is presented. In the framework of the MS2L methodology [1], [2], [3] the design problem is split and solved into two steps. At the first step the goal is to determine the optimum distribution of the laminate stiffness properties over the structure (macroscopic scale), while the second step aims at retrieving the optimum fibres-path in each layer meeting all the requirements provided by the problem at hand (mesoscopic scale).

The MS2L design strategy is characterised on the one hand by the refusal of simplifying hypotheses and classical rules usually employed in the framework of the design process of laminates, and on the other hand by a proper and complete mathematical formalisation of the optimum design problem at each characteristic scale (meso-macro).

The MS2L strategy relies on the use of the polar formalism (extended to the case of higher-order theories [4], [5]) for the description of the anisotropic behaviour of the composite. The real advantage in using the Verchery's polar method is in the fact that the elastic response of the structure at the macro-scale is described in terms of tensor invariants, the so-called *polar parameters*, having a precise physical meaning (which is linked to the elastic symmetries of the material) [4]. On the other hand the MS2L strategy relies on the use of a particular genetic algorithm (GA) able to deal with a special class of huge-size optimisation problems (from hundreds to thousands of design variables) defined over a domain of variable dimension, i.e. optimisation problems involving a *variable number* of design variables [6].

The MS2L strategy has been improved in order to integrate all types of requirements (mechanical, manufacturability, geometric, etc.) within the first-level problem [3]. Several modifications have been introduced in the theoretical and numerical framework of the MS2L design procedure at both first and second levels [2], [3]. At the first level (laminate macroscopic scale) of the procedure, where the VAT laminate is modelled as an equivalent homogeneous anisotropic plate whose mechanical behaviour is described in terms of polar parameters (which vary locally over the structure), the major modifications focus on: 1) the utilisation of higher-order theories (First-order Shear Deformation Theory (FSDT) framework [4], [5] for taking into account the influence of the transverse shear stiffness on the overall mechanical response of VAT composites; 2) the utilisation of B-spline surfaces for obtaining a continuous point-wise variation of the laminate polar parameters; 3) a proper mathematical formalisation of the manufacturability constraints linked to the AFP process in the framework of the B-spline representation and in terms of laminate polar parameters. Regarding the second-level problem (laminate mesoscopic scale, i.e. the ply level) the main modifications is the utilisation of B-spline surfaces for obtaining a continuous point-wise variation of the fibres-path within each ply.

Accordingly, the second-level problem (the lay-up design) can now be formulated as an unconstrained minimisation problem as all the requirements (geometrical, technological, mechanical, etc.) are satisfied since the first step of the MS2L strategy. All of these modifications imply several advantages for the resolution of the related optimisation problems (both at first and second level of the strategy) as detailed in [3]. The effectiveness of the MS2L strategy is proven through a numerical example on the maximisation of the first buckling factor of a VAT plate subject to both mechanical and manufacturability constraints.

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