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An Optimization Formulation for Improved Post-Buckling Stability of Laminated Composite Structures

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Abstract
This work presents a novel FEM-based approach for optimal design of laminated composite structures exhibiting complicated buckling and post-buckling behavior, thus enabling design of lighter and more cost-effective structures.
The use of fibre-reinforced polymers has gained an ever-increasing popularity due to their superior mechanical properties. Designing laminated composite structures represents a challenging task since both thicknesses, number of plies, and their relative orientation must be selected. The best utilization of the material can only be gained through a careful selection of the layup. The focus is on optimal design of laminated composite shell structures i.e. with focus on the optimal fiber orientations within the laminate which is a complicated problem due to the many possible design combinations.
Stability is one of the most important objectives/constraints in structural optimization of shell structures, such as wind turbine blades and in many aeronautical applications. It has been shown that optimization of the buckling load without considering the post-buckling response may lead to unstable and thus imperfection sensitive designs. Furthermore, in some applications not only the magnitude of the buckling load is important, but also the response in the post-buckling regime is of interest. If loading beyond the buckling load is allowed, lighter and more effective structures may be achieved. This however requires that the post-buckling structural response is sufficiently stable, i.e. positive slopes of the response curves. Previous efforts on optimization of post-buckling stability include simple analytical one degree-of-freedom problems, simple analytical/heuristic post-buckling models, and FEM-based models with many degree-of-freedoms where the post-buckling response is constrained to pass through certain equilibrium states. None of these methods and formulations are generic and can be applied directly to optimize for post-buckling stability.
The scope of the present work is to develop a generic post-buckling criterion and optimization formulation, which in a FE-framework directly addresses the post-buckling stability of the problem by ensuring positive-definiteness of the tangent stiffness at a post-buckling equilibrium state. This work is a continuation of the work by the authors, see [1,2], in nonlinear buckling load optimization in case of limit load and bifurcation type instability.
The proposed method includes the nonlinear pre-buckling effects by using geometrically nonlinear path tracing analysis by the arc-length method. The nonlinear analysis is stopped at a post-buckling state, and the stability problem is formulated as an eigenvalue problem of the tangent stiffness, where the lowest eigenvalue becomes a measure of post-buckling stability. The optimization formulation is formulated as a mathematical programming problem and solved using gradient based methods. Design sensitivities of the stability measure are obtained semi-analytically by the direct differentiation approach on the eigenvalue problem described by discretized finite element matrix equations.
The proposed optimization procedure is presented together with numerical results obtained by applying the proposed procedure to optimize fiber orientations in laminated composite structures.

Keywords: Post-buckling stability, laminate optimization, composite structures, design sensitivity analysis, geometrically nonlinear.

References
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