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

BUCKLING OPTIMIZATION OF COMPOSITE STRUCTURES USING A DISCRETE MATERIAL PARAMETRIZATION CONSIDERING WORST SHAPE IMPERFECTIONS

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Key words: *Composite laminate optimization, Composite structures, Discrete material optimization, Nonlinear buckling analysis, Geometric imperfections.*

In the optimum design of lightweight structures, composite materials (here: fiber reinforced polymers) often have desirable properties compared to their metal counterparts. Besides a higher specific stiffness and strength, these properties include the possibility to tailor the layup of the composite material to the specific application. Hence composite materials are often used in the manufacturing of lightweight thin-walled structures. These structures may fail due to buckling prior to material failure if compressive loads are present. For this reason the buckling load for the structure should be assessed, hereby securing the buckling load is not surpassed. This enables the possibility of designing lightweight composite structures without stability issues.

In the papers by Lindgaard and Lund [1–3] geometrically non-linear (GNL) buckling is used for analyzing and optimizing the fiber angles of laminated composite structures. The optimization was conducted using gradient based optimization applying a semi-analytical design sensitivity analysis. One conclusion from the papers is that when comparing the optimized designs using GNL buckling to those employing a linear buckling formulation, the latter is insufficient for design of buckling sensitive structures and will most likely not produce a significant increase in the buckling load when non-linear effects are taken into account. As a consequence we employ a GNL buckling formulation for the analysis and gradient based optimization of the considered composite structures. In this work the laminated composite structures are parametrized using the Discrete Material Optimization (DMO) approach by Stegmann and Lund [4]. This method is used to select the optimum material among a finite set of distinct candidate materials. These candidate materials can consist of e.g., sandwich core materials and fiber reinforced materials aligned at different orientations. Previously the DMO method has successfully been applied to various design optimization problems and will here be applied for geometrically non-linear buckling optimization of composite structures.

Structural optimization is often conducted on the perfect geometry, however, during manufacturing deviations from the perfect geometry will be induced. For e.g., shell structures these imperfections can cause a significant drop in the buckling load. This drop must be assessed by analyzing a structure whereon imperfections are induced. Furthermore, Thompson [5] warns that optimization can be a trigger towards imperfection sensitivity, since performing an optimization the structure will be tailored towards the loading scenario included in the structure. Based on this Thompson claims a deviation from this scenario can lead to a catastrophic failure of the structure. This statement is tested by Lindgaard and co-workers [2], where the "worst" shape imperfections are included into the optimization, hereby introducing a lower bound of the buckling load. This displays the possibilities of conducting structural optimization when imperfections are present in the structure.

The used optimization approach is similar to that in [2], meaning that a two step optimization procedure is applied; 1) the lowest buckling load is maximized using DMO and 2) the lowest buckling load is minimized by shape anti-optimization of the structure. In the structural analysis, the nonlinear equilibrium path is traced using the arc-length solver and the buckling loads are estimated by solving the eigenbuckling problem at a precritical equilibrium point accounting for the deformed geometry. Furthermore, the optimization problems are solved using gradient based methods employing a semi-analytical design sensitivity analysis. To constrain the shape optimization problem an amplitude or volume constraint is applied, and the effect of these constraints is shown through numerical examples.

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