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Multi-Material Topology Optimization of Geometrically Nonlinear Multi-Layered Composite Shell Structures

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ABSTRACT

The use of laminated composite structures with Glass or Carbon Fiber Reinforced Polymers (GFRP/CFRP) is popular for lightweight constructions due to their superior strength and stiffness characteristics. In order to fully exploit the weight saving potential of these multilayered structures, it is necessary to tailor the laminate layup and behavior to the given structural needs. This calls for the use of advanced structural optimization tools.

An example of a challenging lightweight structure made of multi-material laminates is a wind turbine blade. It typically consists of several materials including GFRP/CFRP along with foam materials, balsa tree and birch wood, bonded together by a resin and stacked in a number of layers and groups. In order to obtain a cost effective design, it is desirable to have a general computer aided tool that can generate a high performance topology in the initial design phase. Thus, the design problem considered in this work consists of optimal distribution of these different materials in multi-layered composite shell structures, taking different structural performance criteria into account.

The design problem is formulated using the so-called Discrete Material Optimization (DMO) approach based on ideas from multi-phase topology optimization (see Sigmund and Torquato, 1997) where the material stiffness (or density) is computed as a weighted sum of candidate materials. In this way the discrete problem of choosing the best material (with the correct orientation of the fibre angles) is converted to a continuous formulation where the design variables are the scaling factors (or weight functions) of each candidate material. In this way standard techniques for design sensitivity analysis and mathematical programming can be used to solve the design optimization problems. The DMO approach has been successfully applied for maximum stiffness design, eigenfrequency design, and buckling design using as many as 12 candidate materials at each point and several hundred thousands of design variables in total, see Stegmann & Lund (2005), Lund & Stegmann (2005), and Lund (2007).

In this work the DMO approach is extended to geometrically nonlinear problems. In case of wind turbine blades the structure may exhibit tip displacements in flapwise bending up to 25% of the blade length before collapse due to local buckling on the

compressive side of the blade, and thus geometric nonlinearities may play a significant role in the structural response.

The shell structures are modelled using 9 node isoparametric shell finite elements based on equivalent single layer theory, and the materials are assumed to behave linearly elastic. The geometrically nonlinear analysis problems are solved using iterative Newton-Raphson methods, design sensitivity analysis is done analytically, and the optimization problems are solved using the Method of Moving Asymptotes by Svanberg (1987).

Several different multi-material topology optimization problems are considered for a generic wind turbine blade with the aim of investigating the importance of geometric nonlinearities. In all cases the candidate materials are FRP materials together with foam and wood materials, and cost constraints are taking into account, either by a weight constraint or by constraints on the allowed amounts of the individual materials. The optimization cases included for linear and geometrically nonlinear problems are:

- Maximum stiffness (minimum compliance) design of the blade
- Buckling optimal design taking global bending stiffness constraints into account

The examples illustrate the potential of the DMO approach for multi-material topology design of complicated design problems with conflicting criteria involved, and furthermore the influence of taking geometric nonlinearities into account is discussed.

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