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Towards Local Design Criteria in Discrete Material Optimization

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ABSTRACT

Design of modern multi-layered composite shell structures such as wind turbine blades is highly complex due to conflicting requirements of high strength and stiffness at low weight and cost. In the development of such products, design optimization methods have become an increasingly important tool in aiding the designer at obtaining rational designs. Compared to analysis of structural response the inverse process of design optimization is a step up in complexity due to the possibly large number of iterations required to obtain a feasible design.

Designing optimal laminate lay-ups is complicated due to the non-convexity of strength and stiffness objectives if ply thickness and orientation are used as design variables. Alternatively, the lay-up design problem may be formulated as a material choice problem using another parametrization, and in this paper the so-called Discrete Material Optimization (DMO) approach is applied. This approach is based on ideas from multi-phase topology optimization where the material stiffness is computed as a weighted sum of candidate materials. So far, this methodology has been applied successfully to problems involving global criteria functions such as compliance and buckling load factors, see e.g. [1] and [2].

Including criteria on the local strength should lead to designs that perform well not only from a stiffness point of view but also have sufficient strength in terms of satisfaction of some failure criterion depending on the allowable strains or stresses of the different candidate materials. Initial investigations in [3] have shown the use of a local strain criterion in a DMO parametrization with orthotropic materials having the same stiffness and strength properties however oriented at different directions. The approach taken there was to minimize the maximum principal strain in the structure without taking strength or directionality of the orthotropic candidate materials into account.

In this paper we discuss and show a formulation of local strength criteria suitable for use in DMO parametrized design problems. In general, DMO allows using multiple (orthotropic and isotropic) materials that possibly have different strength properties in terms of allowable strains and/or stresses. To care for the treatment of such multi-

criteria material design problems the material allowables are included in the problem formulation in order to obtain normalised measures of failure.

The material choice problem is addressed for multiple isotropic candidate materials with different stiffness and strength properties. Such problems give rise to the question of how to interpolate the strength of mixed intermediate density materials during optimization. For power-law materials that fail according to a von Mises criterion Duysinx and Bendsøe [4] proposed to scale strength by the same factor as stiffness is scaled in SIMP interpolation. This approach is extended to the multi-material formulation used in DMO allowing us to solve optimum material choice problems involving materials of different stiffness and strength.

The method proposed is developed for laminated composite shell structures where the overall thickness of the structure is unchanged and the objective is to distribute the candidate materials optimally within the fixed domain. First, the approach is applied to a sandwich beam like 2D continuum structure on a fixed domain with two isotropic candidate materials having different stiffness and strength properties. Next, several multi-layered laminated plate and shell structures are considered with the same candidate materials where the parametrization varies both layerwise and within each layer. The approach is investigated with respect to the ability to obtain a unique choice of material everywhere in the design domain, the realistic number of design variables and local criteria functions to take into account, and mesh dependence.

Future lines of research are indicated by outlining how the formulation described above may be extended to handle strength design involving orthotropic materials taking the strength directionality into account.

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