Optimal Design of Composite Structures by Advanced Mixed Integer Nonlinear Optimization

Authors: Konstantinos Marmaras, Mathias Stolpe

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We consider optimal lay-up design of laminated composite structures. Our aim is to solve both minimum compliance mass constrained and minimum weight compliance constrained problems to global optimality by modern special purpose global optimization methods and heuristics. The design variables are, in our case, binary and represent locally presence or absence of a material in the structure from a list of pre defined isotropic and orthotropic candidate materials. In their primal formulation, these problems are stated as non-convex mixed integer problems. We use different reformulation techniques to state them as mixed integer convex problems with special properties. This way we can make use of general robust and efficient methods and heuristics developed for solving this type of problems.

The continuous relaxation of the mixed integer problem is being solved by an implementation of a modern primal-dual interior point method for nonlinear programming. This method is chosen for its robustness and its ability to react swiftly to changes of scale in the problem. An efficient heuristic technique for obtaining a discrete feasible solution then applied. The heuristic consists of solving a sequence of 0-1 linear mixed integer programs, based on the solution to the continuous relaxation of the original mixed integer optimization problem. The numerical experiments indicate that for many problem instances, the heuristic provides us with close to optimal solutions.

Based on the principles of decomposition, outer approximation and relaxation, we have developed a framework that provides us with globally optimal solutions. We propose a combination of the convergent Outer Approximation and Local Branching algorithms to perform the global optimization. Outer approximation is a method that consists of solving a sequence of nonlinear programming sub problems and relaxed versions of a mixed-integer linear master program. The Local Branching algorithm alternates between a sequence of high-level strategic branching to define the solution neighborhoods, and low-level tactical branching to explore them.

The numerical experience of our methods and heuristics are reported on a set of discrete material optimization problems. Minimum compliance and minimum weight designs for constant stiffness laminated composite plates are obtained for both in-plane and out of plane loadings. The ability of our framework to perform multi-material optimization is examined and we are considering both single and multiple load cases. The obtained results are in good agreement with previous studies performed on the same examples. Our implementation outperforms existing methods for optimal design of laminated composite structures. Several of the problem instances were solved to global optimality.

The obtained results indicate the importance of including manufacturing and stress constraints in the design problem. For the purpose of this presentation we have not taken such constraints into consideration. The inclusion of such constraints poses several theoretical and computational challenges that have to be overcome before they can be included in practical lay-up design problems of laminated composite structures with many design variables. The presentation will include ideas on how manufacturing constraints can be included as linear constraints in the problem formulations and the methods. Some promising preliminary results will be demonstrated.