Doctoral Thesis

Evolutionary design of laminated composite structures

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Evolutionary Design of Laminated Composite Structures

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presented by
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Abstract

This dissertation investigates methods for the automated design and optimization of laminated composite structures. Optimal design of laminated composite structures is challenging due to the possibility to locally adapt the material system to the mechanical situation. Automated structural design on a computer is enabled by a combination of numerical simulation and optimization algorithms. The finite element method provides the possibility to predict mechanical properties of virtual candidate solutions. Numerical optimization algorithms then adapt the structure’s attributes in order to meet specific demands formulated on the aforementioned simulated properties. Evolutionary algorithms are a group of biologically inspired optimization algorithms which have repeatedly and successfully been applied to optimal design problems with laminated composites. This thesis focuses on methods to compose evolutionary algorithms for the specific traits of laminate optimization problems. A special focus is set on the variation state of a canonical evolutionary algorithm. This state is particularly influenced by the genetic representation of a candidate solution, i.e. the way the adjustable attributes are translated to machine readable entities. The aim of the thesis is to develop and examine genetic representation schemes to concurrently evolve a structure’s topology, shape, and laminate properties.

An overview of structural optimization and evolutionary computation illustrates the state-of-the-art. In variable-length representations, the dimensionality of the search space is a variable to optimize. The importance of variable-length representations in evolutionary topology and laminate optimization is exemplified. A weakness of established variable-length crossover operators is the treatment of length constraints. Based on existing concepts a split-and-splice variable-length crossover operator respecting length constraints is introduced.

In order to improve the solution quality of a real-encoded evolutionary algorithm, a gradient-based local search is embedded in the variation state of the algorithm. The algorithm intrinsic parallelization is extended to the variation state in order to cope with different runtimes of deterministic and stochastic operators. A parallelization of the variation state requires abandoning of synchronization points. Hence, the population is replaced by a pool of individuals where distributed breeder processes continuously draw samples for mating and insert offspring to replace parents. A lifetime concept is developed to keep the pool size approximately constant. A niching strategy focuses the stochastic component of the algorithm to unexplored regions.
of the search space. This hybrid, parallel, asynchronous evolutionary algorithm outperforms a conventional, sequential algorithm in test functions with a moderate number of local optima.

This algorithm is then applied on ply angle optimization problems. The ply angles are parameterized following the concept of global plies. Thus, the global cohesion of the structure is guaranteed. In simple academic benchmark problems the algorithm is capable to repeatedly find global optimal solutions. Two examples illustrate the applicability of the method to typical engineering problems.

A structured representation scheme aimed at the optimization of locally varying laminate properties on geometrically partitioned structures is proposed. It employs graph operations to generate connected reinforcement patches. Gradient information is used in genetic variation operations of the shape of reinforcements and ply angles. The method surpasses existing approaches in convergence and the results of repeated applications on the same problem show considerably lower spread. A case study illustrates a possible application of the method.

An arrangement-based representation for the optimization of topology attributes is investigated. The method employs a set of spline curves for the partition of the Euclidean plane into faces of different shape. An assignment of void and material on these faces then represents the structure's topology. Graph operations are used to ensure a connected load path. The method is investigated in a cantilever problem and compared to a homogenization approach. Although a feasible result is achieved, the performance is not competitive. The robustness of geometric operations and automated meshing are identified as sources of inefficiencies. Experiments to avoid numerical difficulties in geometric operations by exact computation have been bring no remedy. Shape healing and repair algorithms and mesh checks are employed instead.

The arrangement-based representation is then simplified and an alternative meshing strategy enhances the robustness of the method. In order to allow for a combined laminate and topology optimization, the face properties are realized by the before introduced laminate optimization method. In a simple academic example the method outperforms the laminate optimization on a predefined partition of the structure. But the numerical requirements and the spread in the results is considerably increased. The same representation is extended by the possibility to optimize shape parameters as well. Therefore, the arrangement is projected on a parameterized shape. Numerical examples demonstrate the method’s ability to concurrently optimize shape and laminate properties. Although enabled by the representation, topological changes in the form of void regions are not observed. Dependencies between the shape
and topological level of the genetic encoding and inside the shape representation itself induce difficulties to create beam-like structural members.

The thesis investigates representation schemes along a path of increasing complexity. Hybrid and problem-specific variation operations are able to improve properties of existing methods despite of this increasing complexity. This is demonstrated in ply angle and laminate optimization problems. More complex genotype concepts reduce the number of optimization variables. At the same time the induce dependencies between these, which – like in the arrangement-based topology optimization – affect the solution of the problem. The arrangement-based encoding of shape attributes reveals not to be powerful enough for a combined topology and shape optimization of laminated composite structures.
Zusammenfassung


Um die Lösungsqualität eines reellwertig codierten evolutionären Algorithmus zu verbessern, wird eine gradientenbasierte, locale Suche im Variationsschritt eingebettet. Die dem Algorithmus innewohnende Parallelität wird auf den Variationsschritt ausgeweitet um der unterschiedlichen Laufzeit deterministischer und stochastischer Operatoren gerecht zu werden. Die


Die Arrangement-basierte Repräsentation wird in der Folge vereinfacht und eine alternative Vernetzungsstrategie verbessert die Robustheit der Methode. Um die kombinierte Optimierung von Laminat und Topologie zu ermöglichen, werden Flächeneigenschaften mittels der vorher entwickelten Laminatoptimierungsmethode erstellt. In einem einfachen, akademischen Beispiel