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Layup optimization with GA for tapered laminates with internal plydrops

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Abstract

Layup optimization of the maximum strength of laminated composites with internal ply-drops is performed by genetic algorithm (GA). Interlaminar stresses are considered in estimating the strength of laminates and calculated by the stress function based complementary virtual work principle. Out-of-plane stress functions are expanded in terms of harmonic series through the thickness direction and initially satisfied the traction free boundary conditions of laminates automatically. As the number of expansion terms is increased, stress concentration near the dropped plies is predicted with better accuracy. Since the proposed analysis is relatively simple and efficient in the prediction of interlaminar stress concentration near the ply-drops, the layup optimization of composite laminates with dropped plies considering interlaminar strength can be easily performed by GA. In the formulation of genetic algorithm, a repair strategy is adopted to satisfy given constraints and multiple elitism scheme is implemented to efficiently find multiple global optima or near-optima.

Keywords: Internal ply-drops; Interlaminar stress; Genetic algorithm; Repair strategy; Multiple elitism

1. Introduction

To save weight when loads are non-uniform, the composite laminates with tapered thickness have commonly been manufactured by terminating, or dropping internal plies within the laminates. This is an important method of tailoring stiffness in structures made from advanced composite materials. For example, it is

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recommended that there should be ply-drops in aircraft wing skins, in composite flexbeams of helicopter rotor hubs, and near field joints in solid rocket boosters. Tapered composite structures create geometry and material discontinuities near dropped plies of composite laminates, which cause high stress concentration, or singularity. The stress concentration initiates failure of the laminates and thus the prediction of interlaminar stresses at the dropped plies is required in solving the optimization problem of a layup design.

Stress analysis near the dropped plies is similar to that of free-edge problem. Numerous research efforts have been made to resolve serious stress concentration/singularity near the free edges and near the dropped plies of composite laminates. However, since the difficulties occur during the process of obtaining the exact singular elasticity solutions, approximate methods have been pursued which are based on numerical or analytical approaches. Although recently developed numerical methods consist of either finite element methods or boundary integral methods, simple and reliable analytical methods are preferred in the preliminary design stage since they facilitate parametric study. After Pipes and Pagano (1970) proposed free-edge interlaminar stress analysis, linear elastic models and simple regular stress function-based approximation methods have been proposed for interlaminar stress problems with free edges. Present analysis method for tapered laminates is based on the stress function-based variational method of free-edge interlaminar stresses proposed by Cho and Yoon (1999) and Cho and Kim (2000). In the case of the presence of free edge at the boundary, the layup optimization considering bounded uncertainty of material properties were conducted by Cho and Rhee (2003, 2004).

Fish and Lee (1989) showed the delamination effect of interlaminar stresses for laminates with internal ply-drops. To analyze interlaminar stresses, Fish and Lee used 2-D finite element method. Botting et al. (1996) reported the effect of ply-drop by using FEM and experiments. They used 3-D solid finite element to analyze interlaminar stresses. Mukherjee and Varughese (1999) proposed global-local scheme for the reduction of degrees of freedom. However, FEM approach requires large amount of computer resources. Harrison and Johnson (1996) proposed a mixed variational formulation for reliable approximations of interlaminar stresses. A mixed formulation has an advantage in describing displacement-prescribed boundary conditions and displacement continuity conditions at the interfaces between layers but it has too many primary variables. On the other hand, a stress function-based variational method shows simple and efficient approximation in the prediction of interlaminar stresses only with stress variables. The present study is based on complementary strain energy principle with stress variables only. It is essential in the optimization procedure to reduce computing time of objective function which is the strength of laminates in the present study.

In laminated composite structures, the layups of laminates can be arranged for the lightweight and/or high performance of composite structures. In most structural designs using composite laminates, laminates are restricted to some discrete sets of ply orientation angles such as 0°, ±45° and 90°. This practical manufacturing point of view requires the discretized optimization methodology for the layup design problem. Genetic algorithm (GA) is considered as a powerful methodology for the discretized problems in which the gradient of the objective functions is difficult to obtain. A considerable number of researches in design optimization of composite structures have reported the employment of genetic algorithm. Le Riche and Haftka (1993) proposed a genetic algorithm to optimize the stacking sequence of composite laminate for maximum buckling load. A recessive-gene-like repair strategy was introduced by Todoroki and Haftka (1998) to handle given constraints efficiently. Recently, Soremekun et al. (2001) applied the generalized elitist selection (GES) scheme to the problems with many global optima and near-optima showing performance very close to optimal. Because of random nature of GA, they easily produce alternative optima in repeated runs. This property is particularly important in layup optimization because widely different layups can have very similar performance.

In the tapered composite laminates, common design practice is weight minimization of laminates with required stiffness constraints. However, in the present study, we perform the layup optimization for the maximum strength of laminated composites with internal ply-drops by genetic algorithm (GA) with a repair strategy and multiple elitism.