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Maximum fundamental frequency and thermal buckling temperature of laminated composite plates by a new hybrid multi-objective optimization technique

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A B S T R A C T

In this paper, a hybrid method for simultaneously maximizing fundamental natural frequency and thermal buckling temperature of laminated composite plates is developed. This method is a new combination of the differential quadrature method (DQM), non-dominated sorting genetic algorithm II (NSGA-II) and Young bargaining model. The governing equations are obtained within the framework of the first-order shear deformation theory (FSDT) of plates and are discretized using the DQM. Then, the DQM is linked with the NSGA-II optimization model and the trade-off between the objectives with respect to fibers orientations is obtained. Finally, by applying Young bargaining model the best fibers orientations which maximize the objectives of laminated composite plates with different boundary conditions, thickness-to-length and aspect ratios are obtained.

1. Introduction

Due to proper performance and high strength to weight ratio, laminated composites are widely used in various types of structures and optimum design of these structures is of interest in different fields of engineering. Among design parameters, fibers orientations play an important role in single or multi-objective optimization problems. In multi-objective optimization problems two or more criteria should be optimized [1–15].

To date, there have been a number of researches on multi-objective optimization of laminated composite structures with fibers orientations as design variables. The multi-objective optimization problem can be solved in different ways which are mentioned in the following part.

In the first type of multi-objective optimization problems, a function as a weighted sum of the objectives is defined and the problem is transformed to a single-objective one. Abouhamze and Shakeri [5] maximized a weighted sum of natural frequency and buckling load of laminated cylindrical panels by applying the finite element method, genetic algorithms and neural network. Topal and Uzman [6] maximized weighted sum of biaxial compressive and thermal buckling loads of laminated composite plates using the finite element method and modified feasible direction method as an optimization technique. Topal [7] used the finite element and feasible direction optimization method to maximize a weighted sum of buckling load and frequency of laminated cylindrical shells. Sadeghifar et al. [8] combined the genetic algorithms optimization method and Rayleigh–Ritz energy procedure to optimize a weighted sum of weight and axial buckling load of stiffened cylindrical shells.

In the second type of multi-objective optimization problems, optimization techniques employ to obtain Pareto front or trade-off curve of the objectives and then from the Pareto front the optimum result is obtained. Almeida and Awruch [9] minimized the deflection and weight of composite laminated plates using the finite element method and genetic algorithm. They found the minimum weight and the related optimum deflection from the obtained Pareto front. Lee et al. [10] used the parallel/distributed evolutionary algorithm and a commercial finite element software to minimize the deflection, weight and cost of multi-layered structures. Madeira et al. [11] used the direct multi-search optimization technique and finite element method to maximize loss modal factor and minimize weight of laminated composite plates by obtaining the Pareto front of the objectives. Pelletier and Vel [12] applied the simplified micromechanics equations to maximize load carrying capacity and minimize the mass of laminated

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composite materials by an integer-coded genetic algorithm from Pareto front of the objectives. Rahul et al. [13] combined the finite element method and genetic algorithm optimization technique to minimize cost and weight of laminated composite plates subject to impact load using the Pareto front. Abachizadeh and Tahani [14] employed the ant colony optimization technique and analytical solution for maximizing fundamental natural frequency and cost minimization of laminated composite plates.

In the third type of multi-objective optimization problems, objectives have the same importance and bargaining models such as game theory, Taguchi's method and so on can be employed to obtain the optimum result from the Pareto front of the objectives. Spallino and Rizzo [15] combined the closed form solution, genetic algorithms and game theory to maximize frequency and buckling load of laminated composite thin plates, simultaneously.

From the above mentioned review and to the best of author's knowledge, it has been shown that there are no publications on the maximizing fundamental natural frequency and thermal buckling temperature of laminated composite plates, simultaneously. So, in this paper a hybrid method for the maximizing fundamental natural frequency and thermal buckling temperature of moderately thick laminated composite plates is presented. The free vibration and thermal buckling governing equations of laminated composite plates are obtained within the framework of the first-order shear deformation plate theory. The governing equations and the related boundary conditions are discretized using the differential quadrature method. The DQM solution procedure is linked with the non-dominated sorting genetic algorithm II optimization technique and the trade-off curve between the objectives with respect to fibers angles as design variables is carried out. Then, Young bargaining model is employed to find the best fibers orientations on the basis of the obtained trade-off. The reliability and applicability of the presented method is demonstrated through different examples.

2. The governing equations

A symmetric laminated composite plate with N_L perfectly bonded orthotropic layers of length a, width b and total thickness h is considered (see Fig. 1). According to the first-order shear deformation theory (FSDT) the free vibration and thermal buckling governing equations for the laminated composite plates subjected to uniform temperature rise can be stated as [16],

I. Free vibration

$$A_{55}\frac{\partial \varphi^x}{\partial x} + A_{45}\frac{\partial \varphi^x}{\partial y} + A_{45}\frac{\partial \varphi^y}{\partial x} + A_{44}\frac{\partial \varphi^y}{\partial y} + A_{55}\frac{\partial^2 w}{\partial x^2} + 2A_{45}\frac{\partial^2 w}{\partial x \partial y} + A_{44}\frac{\partial^2 w}{\partial y^2} = I_{00}\frac{\partial^2 w}{\partial t^2} \tag{1}$$

$$-A_{55}\frac{\partial w}{\partial x} - A_{45}\frac{\partial w}{\partial y} + D_{11}\frac{\partial^2 \varphi^x}{\partial x^2} + 2D_{16}\frac{\partial^2 \varphi^x}{\partial x \partial y} + D_{66}\frac{\partial^2 \varphi^x}{\partial y^2} + D_{16}\frac{\partial^2 \varphi^y}{\partial x^2} + (D_{12}+D_{66})\frac{\partial^2 \varphi^y}{\partial x \partial y} + D_{26}\frac{\partial^2 \varphi^y}{\partial y^2} - A_{55}\varphi^x - A_{45}\varphi^y = I_{22}\frac{\partial^2 \varphi^x}{\partial t^2} \tag{2}$$

$$-A_{45}\frac{\partial w}{\partial x} - A_{44}\frac{\partial w}{\partial y} + D_{16}\frac{\partial^2 \varphi^x}{\partial x^2} + (D_{12}+D_{66})\frac{\partial^2 \varphi^x}{\partial x \partial y} + D_{26}\frac{\partial^2 \varphi^x}{\partial y^2} + D_{66}\frac{\partial^2 \varphi^y}{\partial x^2} + 2D_{26}\frac{\partial^2 \varphi^y}{\partial x \partial y} + D_{22}\frac{\partial^2 \varphi^y}{\partial y^2} - A_{45}\varphi^x - A_{44}\varphi^y = I_{22}\frac{\partial^2 \varphi^y}{\partial t^2} \tag{3}$$

II. Thermal buckling

$$A_{55}\frac{\partial \varphi^x}{\partial x} + A_{45}\frac{\partial \varphi^x}{\partial y} + A_{45}\frac{\partial \varphi^y}{\partial x} + A_{44}\frac{\partial \varphi^y}{\partial y} + A_{55}\frac{\partial^2 w}{\partial x^2} + 2A_{45}\frac{\partial^2 w}{\partial x \partial y} + A_{44}\frac{\partial^2 w}{\partial y^2} + N^T_{xx}\frac{\partial^2 w}{\partial x^2} + 2N^T_{xy}\frac{\partial^2 w}{\partial x \partial y} + N^T_{yy}\frac{\partial^2 w}{\partial y^2} = 0 \tag{4}$$

$$-A_{55}\frac{\partial w}{\partial x} - A_{45}\frac{\partial w}{\partial y} + D_{11}\frac{\partial^2 \varphi^x}{\partial x^2} + 2D_{16}\frac{\partial^2 \varphi^x}{\partial x \partial y} + D_{66}\frac{\partial^2 \varphi^x}{\partial y^2} + D_{16}\frac{\partial^2 \varphi^y}{\partial x^2} + (D_{12}+D_{66})\frac{\partial^2 \varphi^y}{\partial x \partial y} + D_{26}\frac{\partial^2 \varphi^y}{\partial y^2} - A_{55}\varphi^x - A_{45}\varphi^y = 0 \tag{5}$$

$$-A_{45}\frac{\partial w}{\partial x} - A_{44}\frac{\partial w}{\partial y} + D_{16}\frac{\partial^2 \varphi^x}{\partial x^2} + (D_{12}+D_{66})\frac{\partial^2 \varphi^x}{\partial x \partial y} + D_{26}\frac{\partial^2 \varphi^x}{\partial y^2}$$

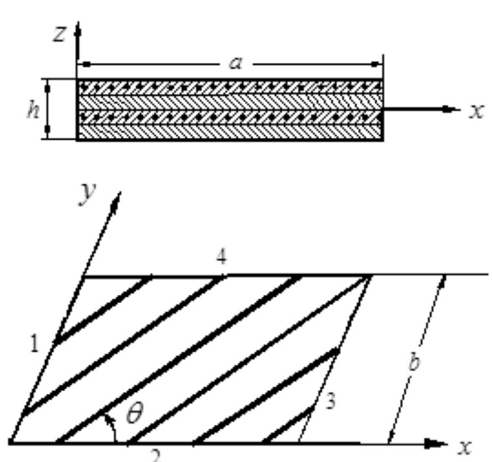

Fig. 1. The geometry of the plate.