Parameter-free optimization of material orientation for high performance composite shell structures

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ABSTRACT

Thin plate structures such as shells, folded plates have been widely utilized in various industrial products. From an economic point of view, weight reduction is strictly required, especially in the structural design of vehicles. The usage of composite materials such as carbon-fiber-reinforced plastics (CFRP) is one of the solutions to meet the requirement since they have higher specific strength or specific stiffness. Recently, new technologies such as automated fiber placement have enabled the manufacture of curvilinear-distributed material orientation of a composite structure. The arbitrary optimal material distribution can develop the potential of CFRP, or design a high performance shell structure [1][2].

In this study, we present a parameter-free optimization method for designing the optimum free material-orientation of a thin plate structure consisting of orthotropic materials. Solutions to stiffness and strength design problems are provided. We introduce the compliance and the maximum value of the Tsai-Hill failure criterion as the objective function, and minimize them under the equilibrium equation constraint. The distributed material orientation is taken as design variable. The optimum design problems are formulated as distributed-parameter optimization problems, and the sensitivity (or gradient) functions with respect to the material-orientation variation are theoretically derived based on the variational method. The optimum orientation variation is determined by the modified H^1 gradient method for these problems from the original one [3], where the sensitivity function is not used directly to determine the material orientation but instead is transferred to the distributed heat supply. This approach makes it possible both to reduce the objective functional of the large scale optimization problem and to maintain the smooth material orientation, i.e., the regularity of the material orientation, simultaneously. The positive definiteness of the thermal conductivity matrix has an important role for this gradient method. The potential (i.e., temperature) field obtained in this pseudo-thermal conductivity analysis is used to update the distribution of the material-orientation. With the proposed method, we can conventionally obtain the arbitrary optimal distributions of the material orientations of all layers of complicated large-scale shell structures while maintaining the regularity of the design variable field. The optimum design examples show that the proposed optimization method can effectively obtain the optimum material orientation with the smooth curvilinear distribution and maximize the stiffness or the strength of composite shell structures.

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