Multi-scale Reliability Based Optimization of Laminated Composite Structures Based on Fiber Volume Fractions with Genetic Algorithm

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ABSTRACT

Fiber reinforced composites are extensively applied as important components in aircraft, marine and vehicles due to their proficiency to improve structural reliability. Several techniques have been reported for the optimization of laminated composite materials. However, current researches scarcely ever study the effect of uncertainties in micro-scale. Parameters on micro-scale, such as fiber volume fractions and fiber distributions of each layer, may have more optimization capacities on reliability of laminated composite structures.

We present a multi-scale optimization methodology of laminated composite structures which takes the design of fiber volume fraction (FVR) and ply orientation into consideration. The objection is to design a composite configuration with minimum weight while the reliability index of the composite is larger than a certain value, as:

Find $\quad V_f(i)\,,\ \ \theta(i)\,,\ \ i=1,2,...,H$

Minimize $\quad m_s\,,\ \ m_s=\sum_{i=1}^{H}[\rho_f\cdot V_f(i)+\rho_m\cdot(1-V_f(i))]$

Subject to $\quad \beta \geqslant 3.0$

Where H is the layer umber of the laminates, ρ_f and ρ_m are respectively the density of the graphite and matrix. The minimum mass of the laminates m_s is set as the objective function, FVR and fiber orientation of each layer V_f and θ are set as the design variables, β is the reliability index of the composite. Since symmetric laminate is widely used in modern industry, here the optimization is limited to symmetric laminate.

It is known that the FVR lays a significant influence on the lamina stiffness and strength, therefore if the composite reliability in the meso-scale (ply scale), the relationship between lamina mechanical properties and FVR should be derived beforehand. Here the strength and modulus of the lamina is derived by Huang's micro-mechanical model, which is heavily dependent on FVR.

The statics of ply mechanical properties is investigated taking graphite-fiber/ epoxy-matrix (AS/3501-5) as instance. With Huang's micromechanical model, the mechanical properties of unidirectional fiber reinforced composite (UD) is derived.

The first order reliability method (FORM) is used to calculate the reliability of the lamina and interval estimate method is used to predict the laminate reliability based on result of FORM. Fiber parameter E_{f11}, E_{f22}, G_{f12}, υ_{f12}, σ_{fu} and matrix parameter E_m, υ_m, E_{mT}, σ_{mu}, σ_{my}, τ_{mu} and fabrication FVR are the random variables. X is the vector of these variables under normalization and reliability index $\beta=(x^{*T}\cdot x^{*})^{1/2}$. The limit state equation is set by Tsai-Hill failure criterion:

$$G = 1 - \left(\frac{\sigma_1^2}{X_T^2} + \frac{\sigma_2^2}{Y_T^2} - \frac{\sigma_1\sigma_2}{X_T^2} + \frac{\tau_{12}^2}{R^2}\right)$$

The first ply failure (FPF) theory is used to determine the failure of the laminate system. The failure probability of the laminate (P_f^s) is estimated by the maximum ply failure probability (P_f^k).

Genetic algorithms (GAs) are contemporary search techniques that mimic the evolutionary principles and chromosomal processing in natural genetics. A GA begins its search with a population of random individuals, with sort, crossover, mutation and some other procedures, get an optimized result. The procedure of GA on optimal design of laminate composites is shown in figure 1.

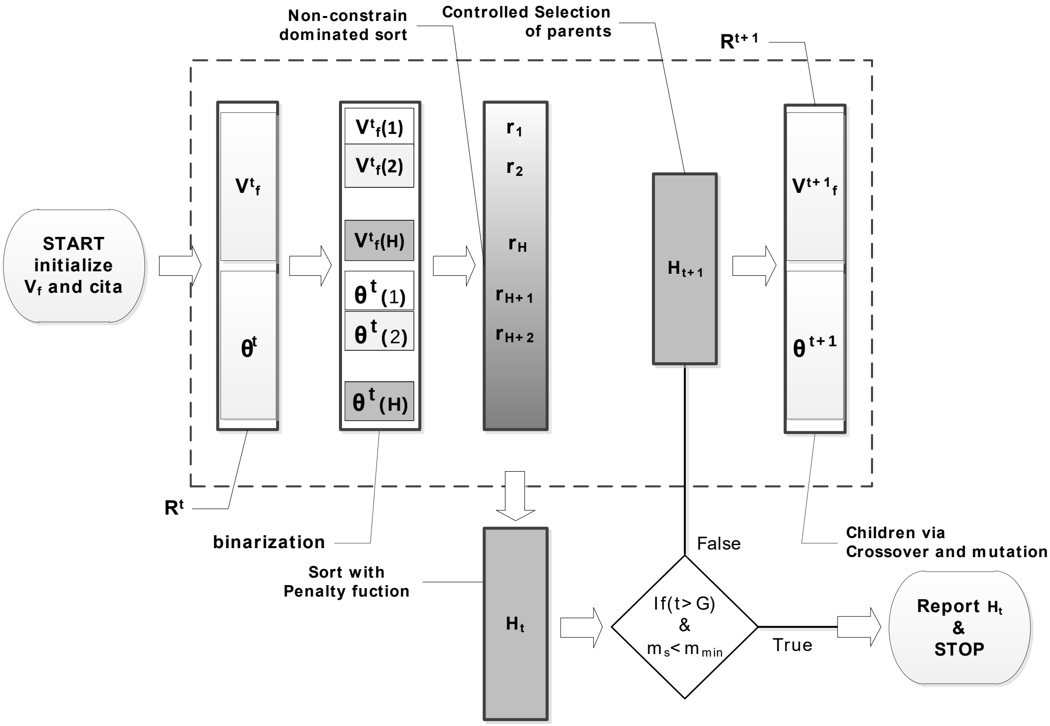

Figure 1: Procedure of GA on optimal design of laminate composites

To evaluate the impact of FVR on optimal design of composites, this work compares the result under the circumstances of the variables with and without the fiber volume fractions. Results shows that fiber volume fractions have impressive improvements in reliability of laminated composite structures and optimize the quality and thickness design of composite under reliability constrains.