

Stacking Sequence Optimization by an Improved Genetic Algorithm

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Abstract An improved genetic algorithm is used to obtain the stacking sequence of the laminate that reach the maximum strength

Keywords Genetic Algorithm · Laminates · Stacking Sequence

1 Introduction

Fiber-reinforced composites are widely used in automotive, aerospace, shipbuilding, and other branches of engineering because of their high specific strength and stiffness.

Genetic algorithms(GAs) simulate the process of natural evolutionary includes selection, crossover ,and mutation according to Darwin's principal of "survival of the fittest".

According to T Back [?],the selection mechanism is one of the primary means of controlling the GA's convergence rate and its likelihood of finding global optima.

Four evaluation criteria are used. The first is normalized cost per genetic search,

$$C_n$$

cost is determined by the following formula.

$$C_n = N_g P / R$$

where P is population size, R is Apparent reliability.

2 Optimization formulation and solution

Text with citations [?] and [?].

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2.1 Formulation

For the orthotropic lamina, the strain-stress relation as:

$$\begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{bmatrix} = \begin{bmatrix} Q_{11} & Q_{12} & 0 \\ Q_{12} & Q_{22} & 0 \\ 0 & 0 & Q_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma \end{bmatrix} \quad (1)$$

Where Q_{ij} are the stiffnesses of the lamina that are related to the compliance matrix components and elastic constants by

$$\begin{aligned} Q_{11} &= \frac{E_1}{1 - \mu_{12}\mu_{21}} \\ Q_{22} &= \frac{E_2}{1 - \mu_{12}\mu_{21}} \\ Q_{66} &= G_{12} \\ Q_{12} &= \frac{\mu_{21}E_2}{1 - \mu_{12}\mu_{21}} \end{aligned} \quad (2)$$

The transformation of the equation*sof the off-axis coordinates to the principal axis of the material stress tensor as

$$[T] = \begin{bmatrix} \cos^2 \theta & \sin^2 \theta & 2\sin 2\theta \\ \sin^2 \theta & \cos^2 \theta & -2\sin 2\theta \\ -\frac{1}{2}\sin 2\theta & \frac{1}{2}\sin 2\theta & \cos 2\theta \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} N_x \\ N_y \\ N_{xy} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} \\ A_{12} & A_{22} & A_{26} \\ A_{16} & A_{26} & A_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_x^0 \\ \varepsilon_y^0 \\ \gamma_{xy}^0 \end{bmatrix} + \begin{bmatrix} B_{11} & B_{12} & B_{16} \\ B_{11} & B_{12} & B_{16} \\ B_{16} & B_{26} & B_{66} \end{bmatrix} \begin{bmatrix} k_x \\ k_y \\ k_{xy} \end{bmatrix} \quad (4)$$

$$\begin{bmatrix} M_x \\ M_y \\ M_{xy} \end{bmatrix} = \begin{bmatrix} B_{11} & B_{12} & B_{16} \\ B_{12} & B_{22} & B_{26} \\ B_{16} & B_{26} & B_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_x^0 \\ \varepsilon_y^0 \\ \gamma_{xy}^0 \end{bmatrix} + \begin{bmatrix} D_{11} & D_{12} & D_{16} \\ D_{11} & D_{12} & D_{16} \\ D_{16} & D_{26} & D_{66} \end{bmatrix} \begin{bmatrix} k_x \\ k_y \\ k_{xy} \end{bmatrix}$$

$$\begin{aligned} A_{ij} &= \sum_{k=1}^n (\overline{Q_{ij}})_k (h_k - h_{k-1}) \\ B_{ij} &= \frac{1}{2} \sum_{k=1}^n (\overline{Q_{ij}})_k (h_k - h_{k-1}) \\ D_{ij} &= \frac{1}{3} \sum_{k=1}^n (\overline{Q_{ij}})_k (h_k - h_{k-1}) \end{aligned} \quad (5)$$

$$\begin{aligned} F_1 &= \frac{1}{X_t} - \frac{1}{X_c}, \quad F_{11} = \frac{1}{X_t X_c} \\ F_2 &= \frac{1}{Y_t} - \frac{1}{Y_c}, \quad F_{22} = \frac{1}{Y_t Y_c} \\ F_{66} &= \frac{1}{S^2} \end{aligned} \quad (6)$$

$$R = \frac{\sigma_{i(\alpha)}}{\sigma_i}$$

where R is the strength ratio, σ_{ia} is allowable stress, σ_i is the stress under loading

substituting Eq. 9 for σ into Eq. 8, we obtain

$$F_1 \sigma_{1(a)} + F_2 \sigma_{2(a)} + F_{11} \sigma_{1(a)}^2 + F_{22} \sigma_{2(a)}^2 + F_{66} \sigma_{6(a)}^2 + 2F_{12} \sigma_{1(a)} \sigma_{2(a)} = 1$$

For orthotropic materials with three planes of symmetry,

$$(F_{11} \sigma_1^2 + F_{22} \sigma_2^2 + F_{66} \sigma_6^2 + 2F_{12} \sigma_1 \sigma_2) R^2 + (F_1 \sigma_1 + F_2 \sigma_2) R - 1 = 0$$

2.2 fitness function

The objective function to be maximized is the strenght of the laminate. the ratio of the component of allowable stress and the stress component under stress.

$$F = \max(\frac{1}{R(i) - 1})$$

Substituting Eq. 9 for R into Eq. 8, we obtain

$$(F_{11} \sigma_1^2 + F_{22} \sigma_2^2 + F_{66} \sigma_6^2 + 2F_{12} \sigma_1 \sigma_2) R^2 + (F_1 \sigma_1 + F_2 \sigma_2) R - 1 = 0$$

2.3 Solution by a genetic algorithm

as required. Don't forget to give each section and subsection a unique label).

3 Results and Discussion

Table 1: AS4C/PEEK Material Properties

Material	Parameter	Value
1	E_x/GPa	141
2	E_y/GPa	9.7
3	G_{xy}/GPa	5
4	X_t/MPa	1732
5	X_c/MPa	832
6	Y_t/MPa	60
7	Y_c/MPa	136
8	S/MPa	113

Table 2: GA-parameters

parameter	value
population size	20
encoding method	float encoding
selection strategy	roulette wheel
crossover strategy	one-point
mutation strategy	mass mutation

Table 3: Anneal Parameters

parameter	value
initial position	(10,10)
initial temperature	25000

Table 4: Random Walk Algorithm

parameter	value
initial position	(10,10)
initial step length	0.5
number of random normalization vector	1

Table 5: Improved Random Walk Algorithm

parameter	value
initial position	(10,10)
initial step length	10
number of random normalization vector	10

4 Concluding Remarks

5 Acknowledgements

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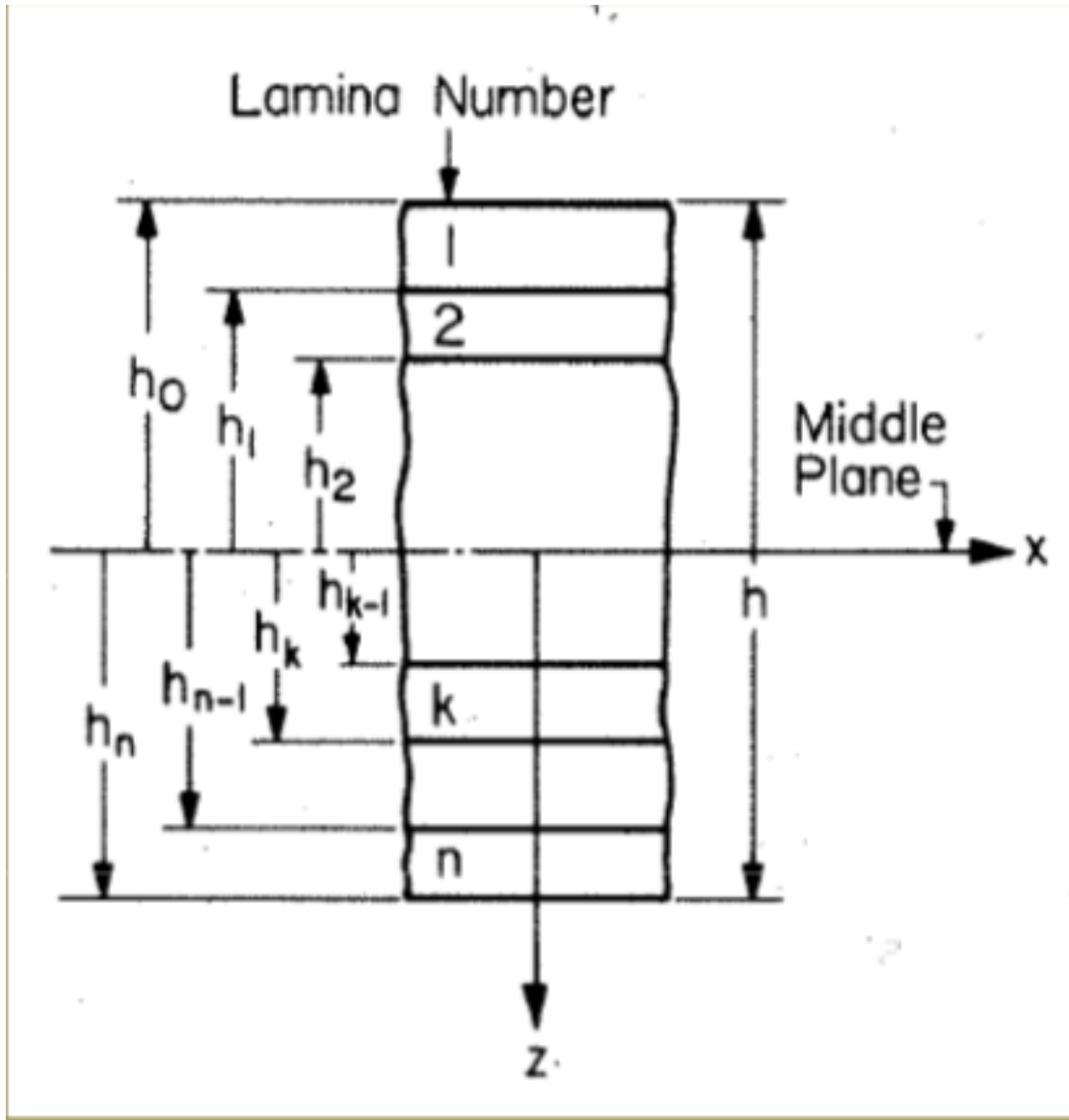


Fig. 1: Stacking Sequence Optimization

The target function is

$$p = \begin{cases} 1 & E(x_{new}) < E(x_{old}) \\ \exp\left(-\frac{E(x_{new}) - E(x_{old})}{T}\right) & E(x_{new}) > E(x_{old}) \end{cases} \quad (7)$$

$$f(r) = \sin(r)/r + 1$$

$$\text{where } r = \sqrt{(x - 50)^2 + (y - 50)^2} + 2.71828$$

For orthotropic materials with three planes of symmetry,

$$F_1 \sigma_1 + F_2 \sigma_2 + F_{11} \sigma_1^2 + F_{22} \sigma_2^2 + F_{66} \sigma_6^2 + 2F_2 F_2 = 1 \quad (8)$$

we define R is the strength ratio,

$$R = \frac{\sigma_{i(\alpha)}}{\sigma_i} \quad (9)$$

where $\sigma_{i\sigma}$ is allowable stress and σ_i is the stress under loading, R is the ratio of the component of allowable stress and the stress component under stress. substituting $\sigma_{i(\alpha)}$ for σ_i into Eq. 8, we obtain

$$\begin{aligned} F_1 \sigma_{1(\alpha)} + F_2 \sigma_{2(\alpha)} + F_{11} \sigma_{1(\alpha)}^2 + F_{22} \sigma_{2(\alpha)}^2 \\ + F_{66} \sigma_{6(\alpha)}^2 + 2F_{12} \sigma_{1(\alpha)} \sigma_{2(\alpha)} = 1 \end{aligned} \quad (10)$$

Substituting $\sigma_{i(\sigma)} = R\sigma_i$ into Eq. 8, we obtain

$$\begin{aligned} (F_{11} \sigma_1^2 + F_{22} \sigma_2^2 + F_{66} \sigma_6^2 + 2F_{12} \sigma_1 \sigma_2) R^2 \\ + (F_1 \sigma_1 + F_2 \sigma_2) R - 1 = 0 \end{aligned} \quad (11)$$

This is a quadric equation about R , the value of $(R - 1)$ is the multiples that the stress can be increased. The objective function to be maximized is the strenght of the laminate.

$$F = \max\left(\frac{1}{R(i) - 1}\right) \quad (12)$$

where i is the layer number

References

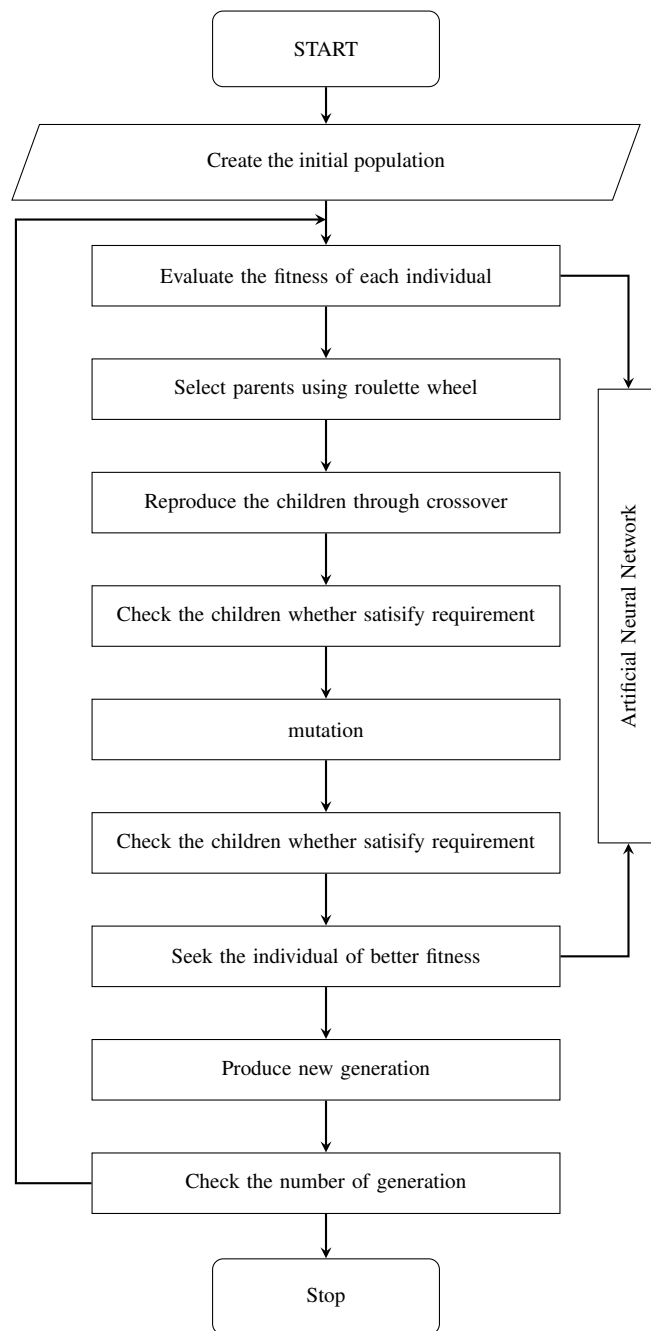


Fig. 2: the flowchart of Genetic Algorithm