Study of the Application of Genetic Algorithm and Artificial Neural Network in Laminated Composite Material

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03-24-2021

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Problem I: constrained optimization of discrete variables

- 1. formulate the objective function, assume it is $f(x)$.
- 2. to satisfy the constraints, adding punishment items $\phi_1(x), \phi_2(x), \cdots, \phi_n(x)$
- 3. reformulate the objective functions as $f(x) + c_1\phi_1(x) + c_2\phi_2(x) + \cdots + c_n\phi_n(x)$

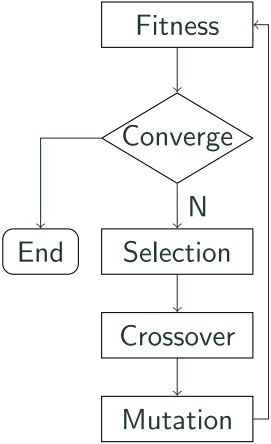


Figure 1: GA process

Problem I: basic idea

- 1. formulate the objective function, assume it is $f(x)$.
- 2. to satisfy the constraints, maintaining different groups in the population
- 3. do not change the objective function $f(x)$.

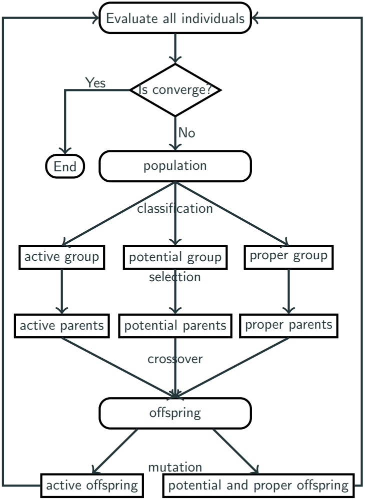


Figure 2: General flowchart of proposed GA model.

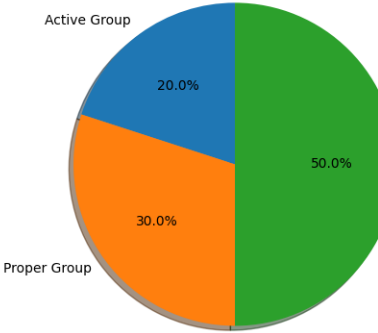
Problem I: Definition

Definition

- An individual is active if it is far smaller than the numerical value of these constraints. A group is consist of active individuals are called as active group.
- An individual is potential if it is close but smaller than the numerical value of these constraints. The corresponding group is refered as potential group.
- An individual is proper if it satisfy all the constraints. Its counterpart group is written as proper group.

Figure 3: Parents

- acitve group: individual is used to increase the diversity of the population
- potential group: individual doesn't fulfill constraint
- proper group: individual meet constraint



Example I: design of cross ply laminate

Figure 4: Model for cross ply laminate

0
90
90
0
90

Example I: result

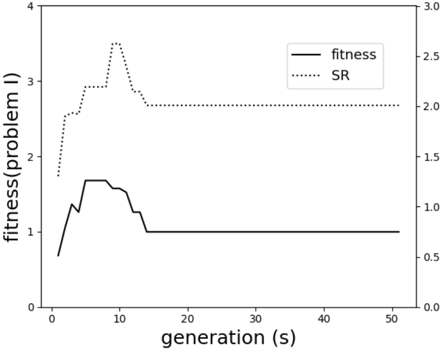


Figure 5: Parents

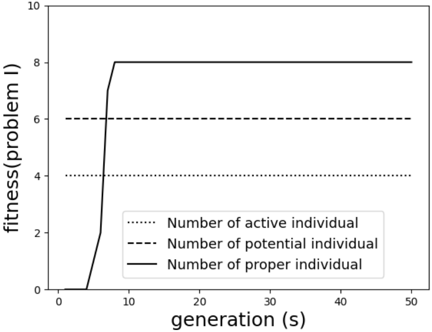


Figure 6: Parents

Example I: comparison with works in other literature

Table 1: The optimum lay-ups for the loading $N_x = 1e6$ N

Cross Ply $[0_M/90_N]$	Choudhury and Mondal's		Current Research	
Material	Glass-Epoxy	Graphite-Epoxy	Glass-Epoxy	Graphite-Epoxy
M	68	17	78	18
N	72	18	28	8
no. of lamina(n)	140	35	106	26
SR	2.01	2.10	2.03	2.16
weight	9.10	1.84	6.89	102.5

Example II: design of angle ply laminate

- Modifying selection strategy: in order to handle the constraint search
- Self-adaptative mutation direction of fiber orientation and laminate thickness: random change the length, and the angle in the laminate.
- The self-adaptative parameters don't refer to parent's proportion, mutation probability.

Example II: mutation operator

$\text{md} = [CT_1, \cdots, CT_{n-1}, CT_n] - [ICV_0, \cdots, ICV_{n-1}, ICV_n]$

- md means mutation direction.
- CT_i denotes the i-th constraint, such as weight, safety factor.
- ICV_i denotes individual's i-th constraint value, such as, weight, safety factor of current individual.

Example II: mutation operator

- length mutation $=$

$$\begin{cases} LMC * [0, \sum_{i=1}^{N} md_i] & \text{if } \sum_{i=1}^{N} md_i > 0 \\ LMC * [\sum_{i=1}^{N} md_i, 0] & \text{if } \sum_{i=1}^{N} md_i < 0 \end{cases}$$

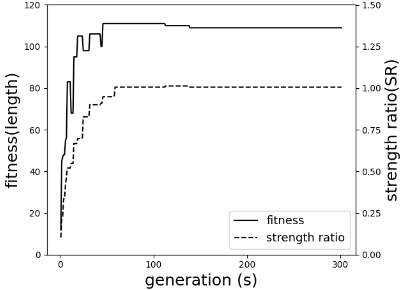
  LMC stands for length mutation coefficient, it's a positive integer.

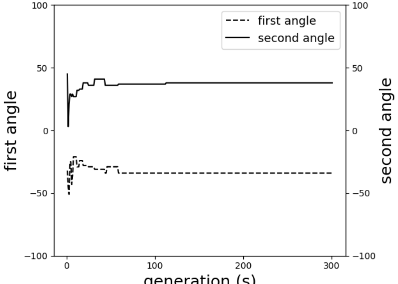
- angle mutation $=$

$$\begin{cases} AMC * [0, \sum_{i=1}^{N} md_i] & \text{if } \sum_{i=1}^{N} md_i > 0 \\ AMC * [\sum_{i=1}^{N} md_i, 0] & \text{if } \sum_{i=1}^{N} md_i < 0 \end{cases}$$

  AMC stands for angle mutation coefficient, it's sign is unclear.

Example II: Experiment: $N_x = 10, N_y = 5$ MPa m





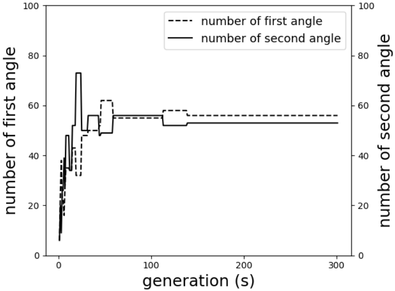


Figure 7: Two distinct angles in the laminate

Table 2: Comparison with the results of DSA

Loading	**Akbulut and Sonmez's Study**				**Present Study**			
$N_x/N_y/N_{xy}$ (MPa m)	Optimum lay-up sequences	laminate thickness	TW	MS	Optimum lay-up sequences	laminate thickness	TW	MS
10/5/0	$[37_{27}/-37_{27}]_s$	108	1.0068	1.0277	$[33_{29}/-39_{25}/-\overline{39}]_s$	109	1.0074	1.0246
20/5/0	$[31_{23}/-31_{23}]_s$	92	1.0208	1.1985	$[33_{22}/-31_{24}]_s$	92	1.0055	1.2065
40/5/0	$[26_{20}/-26_{20}]_s$	80	1.0190	1.5381	$[29_{18}/-21_{23}/-\overline{21}]_s$	83	1.0034	1.7350
80/5/0	$[21_{25}/-19_{28}]_s$	106	1.0113	1.2213	$[-20_{27}/21_{25}/\overline{25}]_s$	105	1.0029	1.2063
120/5/0	$[17_{35}/-17_{35}]_s$	140	1.0030	1.0950	$[-18_{34}/17_{36}]_s$	140	1.0000	1.0898

Problem II: calculation of strength ratio

It follows a two-step procedure:

- 1. calculate relationship between stress and strain according to classical lamination theory.
- 2. obtained strength ratio based on related failure criterion.

Paper 3: Angle ply laminate

$+\theta$
$-\theta$
$\cdots$
$-\theta$
$+\theta$

Figure 8: Model for Angle ply laminate

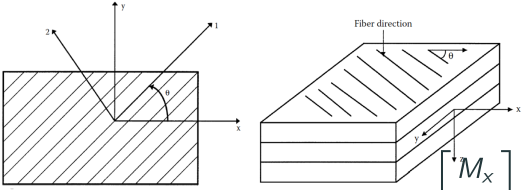


Figure 9: Composite Material

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

$$\begin{bmatrix} M_x \\ M_y \\ M_{xy} \end{bmatrix} = \begin{bmatrix} B_{11} & B_{12} & B_{16} \\ B_{12} & B_{22} & B_{26} \\ B_{16} & B_{26} & B_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_x^0 \\ \varepsilon_y^0 \\ \gamma_{xy}^0 \end{bmatrix} + \begin{bmatrix} D_{11} & D_{12} & D_{16} \\ D_{11} & D_{12} & D_{16} \\ D_{16} & D_{26} & D_{66} \end{bmatrix} \begin{bmatrix} k_x \\ k_y \\ k_{xy} \end{bmatrix} \tag{1}$$

Introduction: Failure Theory

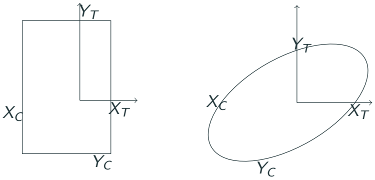


Figure 10: Schematic failure surfaces for maximum stress and quadratic failure criteria

- Maximum stress failure

$$SF^k_{MS} = \text{min of} \begin{cases} SF^k_X = \begin{cases} \frac{X_t}{\sigma_{11}}, & \text{if } \sigma_{11} > 0 \\ \frac{X_c}{\sigma_{11}}, & \text{if } \sigma_{11} < 0 \end{cases} \\ SF^k_Y = \begin{cases} \frac{Y_t}{\sigma_{22}}, & \text{if } \sigma_{22} > 0 \\ \frac{Y_c}{\sigma_{22}}, & \text{if } \sigma_{22} < 0 \end{cases} \\ SF^k_S = \left\{ \frac{S}{|\tau_{12}|} \right. \end{cases} .$$

- Tsai-wu failure theory

$$\begin{aligned} &H_1\sigma_1 + H_2\sigma_2 + H_6\tau_{12} + H_{11}\sigma_1^2 + H_{22}\sigma_2^2 \\ &\quad + H_{66}\tau_{12}^2 + 2H_{12}\sigma_1\sigma_2 < 1 \end{aligned}$$

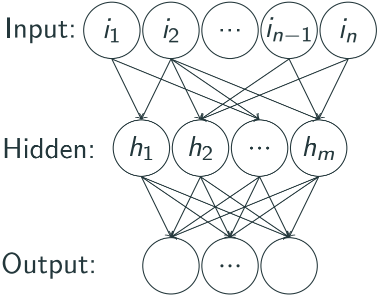


Figure 11: Neural Network Model

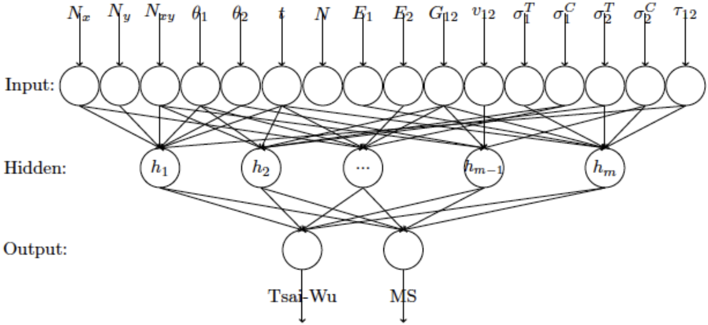


Figure 12: General Neural Network for CLT

Paper 3: Trainging data preparation

Table 3: Part of train dataset

Input				Output	
Load	Laminate Structure	Material Property	Failure Property	MS	Tsai-Wu
-70,-10,-40,	90,-90,4,1.27,	38.6,8.27,0.26,4.14,	1062.0,610.0,31,118,72,	0.0102,	0.0086
-10,10,0,	-86,86,80,1.27,	181.0,10.3,0.28,7.17,	1500.0,1500.0,40,246,68,	0.4026,	2.5120
-70,-50,80,	-38,38,4,1.27,	116.6,7.67,0.27,4.173,	2062.0,1701.0,70,240,105,	0.0080,	0.0325
-70,80,-40,	90,-90,48,1.27,	38.6,8.27,0.26,4.14,	1062.0,610.0,31,118,72,	0.0218,	0.1028
-20,-30,0,	-86,86,60,1.27,	181.0,10.3,0.28,7.17,	1500.0,1500.0,40,246,68,	0.6481,	0.9512
0,-40,0,	74,-74,168,1.27,	181.0,10.3,0.28,7.17,	1500.0,1500.0,40,246,68,	1.3110,	3.9619

Table 4: Comparsion between practical and simulation

Input				Output			
Load	Laminate Structure	Material Property	Failure Property	CLT MS	CLT Tsai-Wu	ANN MS	ANN Tsai-Wu
-10,40,20	26,-26,168,1.27	116.6,7.67,0.27,4.17	2062.0,1701.0,70,240,105	0.342	0.476	0.351	0.492
20,-70,-30	10,-10,196,1.27	181.0,10.3,0.28,7.17	1500.0,1500.0,40,246,68	0.653	0.489	0.612	0.445
60,-20,0	82 -82,128,1.27	181.0,10.3,0.28,7.17	1500.0,1500.0,40,246,68	1.663	0.112	1.673	0.189

Paper 3: Prediction

1) paper1: journal of reinforced plastic and composites
2) paper2: journal of thermoplastic composite
3) paper3: which journal?