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

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- 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 $f(x) + c_1\phi_1(x) + c_2\phi_2(x) + \cdots + c_n\phi_n(x)$

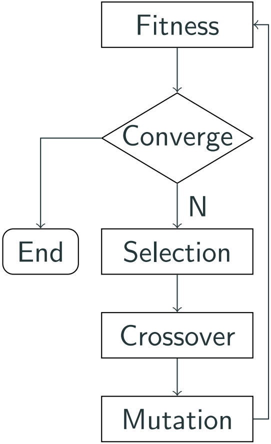


Figure 1: GA process

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 $f(x)$.

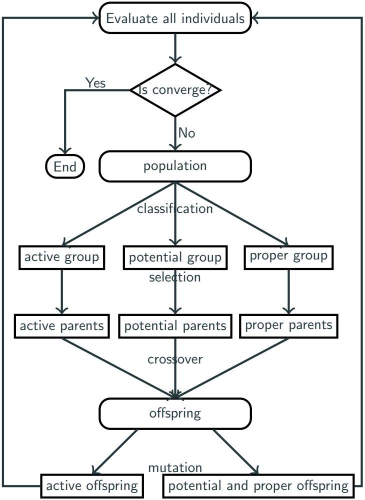


Figure 2: General flowchart of proposed GA model.

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.

Problem I: Example

Table 1: Group Classification,and strength ratio constraint is 2.

Layup	Strength Ratio	Group
$[0_3/90_2]_s$	0.72	Active Individual
$[0_2/90_2]_s$	0.49	Active Individual
$[0_1/90_5]_s$	0.29	Active Individual
$[0_6/90_4]_s$	1.45	Potential Individual
$[0_5/90_3]_s$	1.20	Potential Individual
$[0_9/90_8/\overline{90}]_s$	2.10	Proper Individual

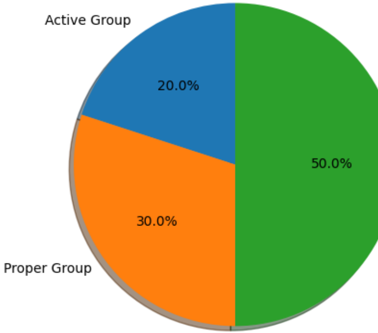
Table 2: Comparison of the carbon/epoxy, graphite/epoxy, and glass/epoxy properties

Property	Symbol	Unit	Carbon/Epoxy	Graphite/Epoxy	Glass/Epoxy
Longitudinal elastic modulus	E_1	GPa	116.6	181	38.6
Traverse elastic modulus	E_2	GPa	7.67	10.3	8.27
Major Poisson's ratio	v_{12}		0.27	0.28	0.26
Shear modulus	G_{12}	GPa	4.17	7.17	4.14
Ultimate longitudinal tensile strength	$(\sigma_1^T)_{ult}$	MP	2062	1500	1062
Ultimate longitudinal compressive strength	$(\sigma_1^C)_{ult}$	MP	1701	1500	610
Ultimate transverse tensile strength	$(\sigma_2^T)_{ult}$	MPa	70	40	31
Ultimate transverse compressive strength	$(\sigma_2^C)_{ult}$	MPa	240	246	118
Ultimate in-plane shear strength	$(\tau_{12})_{ult}$	MPa	105	68	72
Density	ρ	g/cm^3	1.605	1.590	1.903
Cost			8	2.5	1

Problem I: mating pool

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 with one constraint

Figure 4: Model for cross ply laminate

0
90
90
0
90

Example I: result

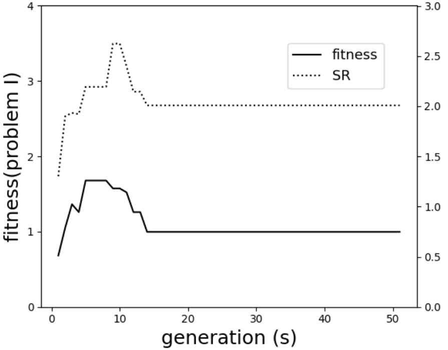


Figure 5: Parents

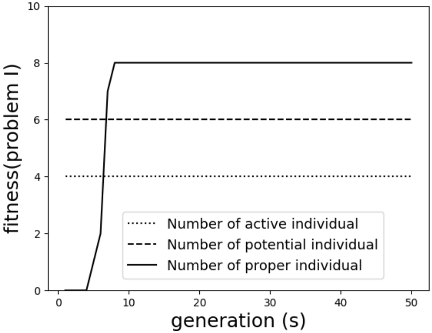


Figure 6: Parents

Example I: universalness

Table 3: The optimum layup for the loading $N_x = 1e^6$ N when changing the length mutation coefficient, the performance of the GA can be improved when the lenght mutation coefficient is smaller.

Length mutation coefficient	Material	case	Stacking sequence	Strength ratio	Mass	Cost	Layer
1	glass-epoxy	worst	$[0_{40}/90_{26}]_s$	2.010	8.58	132	132
		best	$[90_{24}/0_{38}/\bar{90}]_s$	2.078	8.12	125	125
		average		2.012	7.83	123	123
	graphite-epoxy	worst	$[0_9/90_4/\bar{0}]_s$	2.17	1.41	68	27
		best	$[0_9/90_1/\bar{0}]_s$	2.15	1.10	53	21
		average		2.018	1.47	70	28
5	glass-epoxy	worst	$[0_{36}/90_{32}]_s$	2.009	8.84	136	136
		best	$[0_{36}/90_{26}/\bar{90}]_s$	2.003	8.12	125	125
		average		2.008	8.55	131	131
	graphite-epoxy	worst	$[0_9/90_{12}]_s$	2.006	2.20	105	42
		best	$[0_8/90_3/\bar{0}]_s$	2.001	1.20	57	23
		average		2.022	1.54	73	29

Example I: comparison with works in other literature

Table 4: 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 with two constraints

- 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 =

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

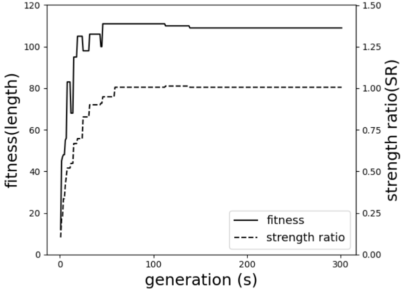
  LMC stands for length mutation coefficient, it's a positive integer.

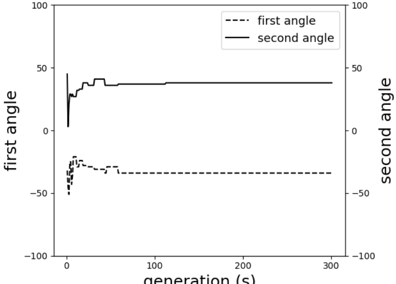
- angle mutation =

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

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

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





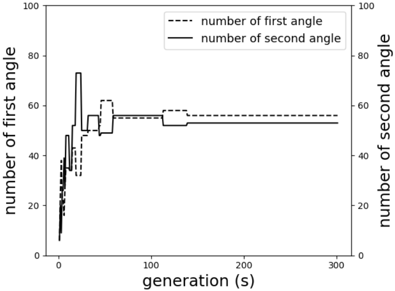


Figure 7: Two distinct angles in the laminate

Example II: comparison with works in other literature

Table 5: 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	$[37_{27}/\text{-}37_{27}]_s$	108	1.0068	1.0277	$[33_{29}/\text{-}39_{25}/\text{-}\bar{3}9]_s$	109	1.0074	1.0246
20/5/0	$[31_{23}/\text{-}31_{23}]_s$	92	1.0208	1.1985	$[33_{22}/\text{-}31_{24}]_s$	92	1.0055	1.2065
40/5/0	$[26_{20}/\text{-}26_{20}]_s$	80	1.0190	1.5381	$[29_{18}/\text{-}21_{23}/\text{-}\bar{2}1]_s$	83	1.0034	1.7350
80/5/0	$[21_{25}/\text{-}19_{28}]_s$	106	1.0113	1.2213	$[\text{-}20_{27}/21_{25}/2\bar{5}]_s$	105	1.0029	1.2063
120/5/0	$[17_{35}/\text{-}17_{35}]_s$	140	1.0030	1.0950	$[\text{-}18_{34}/17_{36}]_s$	140	1.0000	1.0898

reviewer's comment

- "no one uses unsymmetric laminate stacking sequences" argued by reviewer.
- "Furthermore, the authors have not included the ply properties used in the study and have not stated whether they used first ply failure or last ply failure" argued by reviewer.
- "In Table 3 - the strength ratio differences are not statistically significant given the variation in strength properties of the input layers."

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.

Problem II: two-step procedure

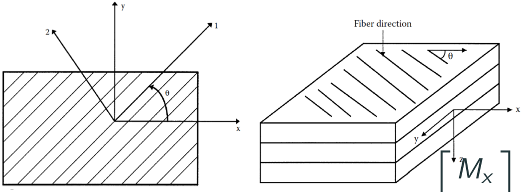


Figure 8: Composite Material

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

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

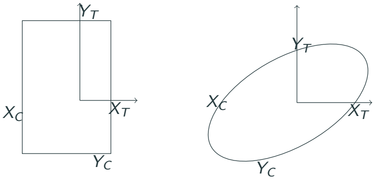


Figure 9: Schematic failure surfaces for maximum stress and quadratic failure criteria

- Maximum stress failure

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

- Tsai-wu failure theory

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

Table 6: 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

Example: angle ply laminate

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

Figure 10: Model for Angle ply laminate

Example: neural network structure

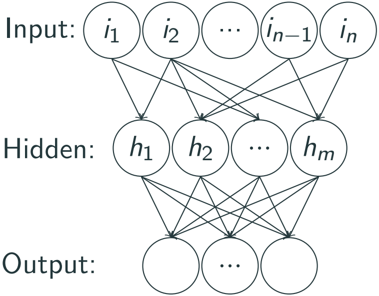


Figure 11: Neural Network Model

Example: preparation of trainging data

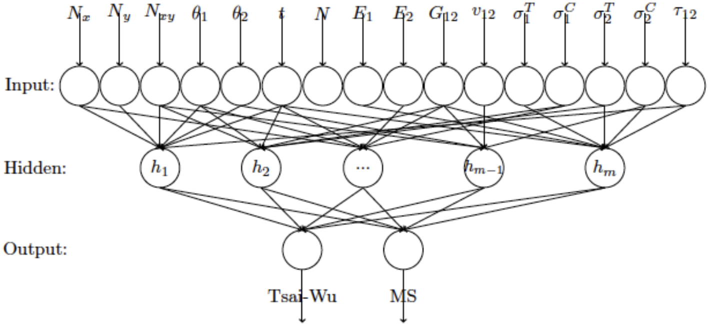


Figure 12: General Neural Network for CLT

Example: prediction

Table 7: 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