Optimization of Composite Plates Based on Imperialist Competitive Algorithm

Hamid Mozafari
Faculty of Mechanical Engineering
Universiti Teknologi Malaysia
Johor, Malaysia

Behzad Abdi
Faculty of Mechanical Engineering
Universiti Teknologi Malaysia
Johor, Malaysia

Amran Ayob
Faculty of Mechanical Engineering
Universiti Teknologi Malaysia
Johor, Malaysia

***Abstract*—Imperialist Competitive Algorithm (ICA) is a new optimization algorithm that inspired by socio-political process of imperialistic competition. In this paper an optimization methodology for the design of composite plates is presented. An imperialist competitive algorithm (ICA) is thus evaluated for its recognition.**

Keywords-composite plates; imperialist competitive algorithm (ICA); minimum weight and cost optimization.

I. INTRODUCTION

Nowadays one of the most important causes for using composite materials in mechanical and material engineering applications was for reducing structural weight due to the high specific stiffness and strength of the composites. However, a change from design for minimal weight to design for cost has become crucial during the recent years [1–3].

Global optimization problems are finding many applications in science and engineering. So far, evolutionary algorithms [4, 5] have been proposed for solving global optimization problems.

Recently, a novel evolutionary algorithm has been proposed by Atashpaz-Gargari and Lucas [6], in 2007 which has inspired from a socio-political phenomenon, called Imperialist Competitive Algorithm. Imperialist competitive algorithm (ICA) is used for optimization of transmission conditions of thin adhesive layer in [7].

In this article, we investigate the optimization of composite plates by using imperialist competitive algorithm (ICA).

II. ANALYSIS OF PROBLEM

The problem is formulated for the plate (see Fig. 1) based on classic theory as [8],

$$\begin{Bmatrix} N \\ M \end{Bmatrix} = \begin{bmatrix} [K_{11}] & [K_{12}] \\ [K_{21}] & [K_{22}] \end{bmatrix} \begin{Bmatrix} \varepsilon' \\ R' \end{Bmatrix} \tag{1}$$

where N and M are the relative stress resultants and moment resultant on the plate, ε' is strain, R' is the middle surface curvatures and $[K_{ij}]$ is extensional stiffness matrixes of composite layers , respectively.

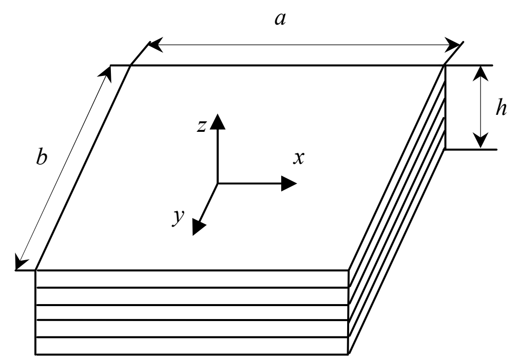

Figure 1. Illustration of specimen plate

$$N = \begin{Bmatrix} N_x \\ N_y \\ N_{xy} \end{Bmatrix} \quad , \quad M = \begin{Bmatrix} M_x \\ M_y \\ M_{xy} \end{Bmatrix} \tag{2}$$

We can rewrite Equation (1) as,

$$\begin{Bmatrix} \varepsilon' \\ R' \end{Bmatrix} = \begin{bmatrix} [K'_{11}] & [K'_{12}] \\ [K'_{21}] & [K'_{22}] \end{bmatrix} \begin{Bmatrix} N \\ M \end{Bmatrix} \tag{3}$$

From Equation (3) can be obtained the values ε' and R' in middle surface. Stress and strain can be calculated in the *xy*-coordinate as,

$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_{xy} \end{Bmatrix}_{R'} = \begin{Bmatrix} \varepsilon'_x \\ \varepsilon'_y \\ \varepsilon'_{xy} \end{Bmatrix} + Z_{R'} \begin{Bmatrix} R'_x \\ R'_y \\ R'_{xy} \end{Bmatrix} \tag{4}$$

Respective stresses can be calculated as,

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_{xy} \end{Bmatrix}_{R'} = \begin{bmatrix} \overline{G_{11}} & \overline{G_{12}} & \overline{G_{16}} \\ \overline{G_{12}} & \overline{G_{22}} & \overline{G_{26}} \\ \overline{G_{16}} & \overline{G_{26}} & \overline{G_{66}} \end{bmatrix}_{R'} . \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_{xy} \end{Bmatrix}_{R'} \quad (5)$$

where $Z_{R'}$ is the height of middle layer and ε' is the middle surface strain.

Matrix of $[\overline{G}]_{R'}$ is obtained as,

$$[\overline{G}] = [T]^{-1}.[G].[T]^{-T} \quad (6)$$

where $[T]$ is transformation matrix as,

$$[T] = \begin{bmatrix} \cos^2\theta & \sin^2\theta & 2\sin\theta.\cos\theta \\ \sin^2\theta & \cos^2\theta & -2\sin\theta.\cos\theta \\ -2\sin\theta.\cos\theta & 2\sin\theta.\cos\theta & \cos^2\theta - \sin^2\theta \end{bmatrix}$$

III. IMPERIALIST COMPETITIVE ALGORITHM

Imperialist competitive algorithm (ICA) is a new progressive algorithm for optimization, and the flowchart of ICA is shown in Fig. 2.

This algorithm starts with an initial population. Each population in ICA is called country.

Some of the best countries in the population are selected to be the imperialists and the rest form the colonies of these imperialists. In this algorithm the more powerful the imperialists, the more they have colonies. When the competition starts, the imperialists attempt to achieve more colonies and the colonies start to move toward their imperialists. So during the competition the powerful imperialists will survive and the weak ones will be collapsed. At the end just one imperialist will remain. Further details about this algorithm are described in [6].

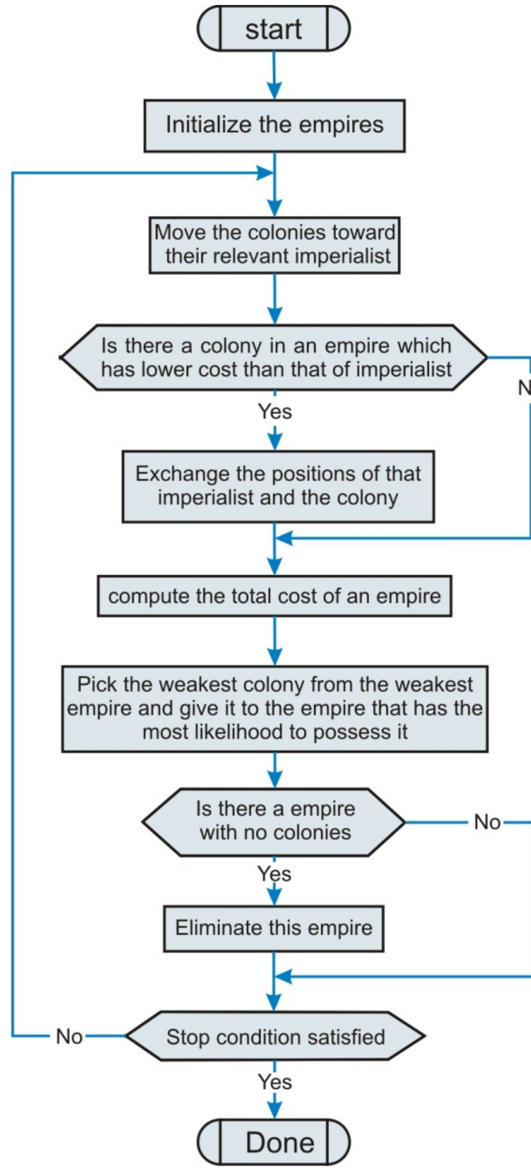

Figure 2. Illustration of imperialist of competitive algorithm (ICA)

A. Cost function

Minimization of the structure weight of the composite plate and the fabrication costs are the design objectives. Therefore, cost functions for weight and fabrication cost ψ_1, ψ_2 are considered to be minimized in this articleUnits

$$\psi_1 = \left(1 + \frac{W}{W^*}\right) \qquad \psi_2 = \left(1 + \frac{C}{C^*}\right) \quad (7)$$

where W^* and C^* are maximum weight and fabrication costs of the composite plate, respectively.

B. Design variables

The design variables of problem are the thickness of plate and the angle of layers of composite plates as,

$$t_{low} \leq t_i \leq t_{up} \qquad i = 1, 2, 3, \ldots, k$$

$$\theta_{low} \leq \theta_i \leq \theta_{up} \qquad i = 1, 2, 3, \ldots, k$$

where k is the number of the respective plate layers.

To obtain an optimal design which considers both weight and fabrication costs of composite plates, the objective functions is defined as follows,

$$f_1 = \psi_1 + \psi_2 \qquad (8)$$
$$f_2 = \psi_1$$

When the weight of the composite plate is more important than fabrication costs, the selection is f_2 and by considering f_1 both weight and fabrication costs will be optimized simultaneously.

IV. OPTIMIZATION RESULTS

The minimum of the objective functions weight and cost were determined using the imperialist competitive algorithm (ICA). The ICA was carried out with the parameters shown in Table 1. The maximum weight, cost, simple tensile loading in *x*-direction and simple tensile loading in *y*-direction are defined to be 3.76 kg, 66.35 $, 950 N/mm and 870 N/mm, respectively. The range of variation of design variables are presented in Table I.

TABLE I. THE RANGE OF VARIATION OF DESIGN VARIABLES

Design variable	Bottom range	Up range
t (mm)	0.6	30
Θ (degree)	0	±60

The optimum design was investigated for seven layers angles 0, ±15°, ±30° and ±60°.

The optimum designs obtained as well as their weight and cost are summarized with monotonic tensile loading in the *x*-direction in Table II. The composite objective functions f_1 and f_2 were minimized using the ICA.

TABLE II. OPTIMUM DESIGN OF MINIMIZATION OF THE COMPOSITE OBJECTIVE FUNCTION (*X*-DIRECTION)

	f_1	f_2
***t* (mm)**	$[20.51\ 0.6\ 9.85\ 10.72]_s$	$[10.72\ 9.85\ 8.03\ 0.6]_s$
***Θ* (degree)**	$[-30\ 0\ 30\ 60]_s$	$[60\ 30\ -60\ 0]_s$
Mat.	$[1\ 1\ 1\ 1]_s$	$[1\ 1\ 2\ 2]_s$
N_x (N/mm)	53	49
***W* (kg)**	0.618	0.31
***C* ($)**	2.42	3.05

Optimum solutions are obtained under simple tensile loading in *x*-direction which is shown in Table III.

TABLE III. OPTIMUM SOLUTION OF THE COMPOSITE PLATE (*X*-DIRECTION)

Uniform loading (N/mm)	Weight (kg)	Cost ($)
49	0.31	2.42

Table IV is shown the optimization of weight and cost under simple monotonic tensile loading in *y*-direction of composite plate based on imperialist competitive algorithm (ICA). The optimum solutions of the composite plate in the y-direction are presented in Table V.

TABLE IV. OPTIMUM DESIGN OF MINIMIZATION OF THE COMPOSITE OBJECTIVE FUNCTION (*Y*-DIRECTION)

	f_1	f_2
***t* (mm)**	$[18.32\ 4.2\ 0.6\ 3.28]_s$	$[3.28\ 0.6\ 18.32\ 4.2]_s$
***Θ* (degree)**	$[-60\ 30\ 0\ 60]_s$	$[60\ 0\ -60\ 30]_s$
Mat.	$[1\ 1\ 2\ 2]_s$	$[1\ 1\ 1\ 1]_s$
N_x (N/mm)	48	43
***W* (kg)**	0.518	0.34
***C* ($)**	3.51	4.17

TABLE V. OPTIMUM SOLUTION OF THE COMPOSITE PLATE (*Y*-DIRECTION)

Uniform loading (N/mm)	Weight (kg)	Cost ($)
43	0.34	3.51

V. CONCLUSION

In this paper, an imperialist competitive algorithm (ICA) procedure has been developed for optimum design of composite plates. The new ICA introduced here to design variables and to supply multi-objective functions. This evolutionary optimization strategy has shown good performance in optimal design on composite plates.

REFERENCES

[1] Thuis HGSJ, Biemans C. Design, fabrication and testing of a composite bracket for aerospace applications. Compos Struct 1997;38:91–8.

[2] Barlow D, Howe C. Preliminary study on cost optimization of aircraft composite structures applicable to liquid moulding technologies. Compos Struct 2002;57:53–7.

[3] Hinrichsen J, Bautista C. The challenge of reducing both airframe weight and manufacturing cost. Air Space Eur 2001;3(3–4): 119–21.

[4] H. Sarimveis and A. Nikolakopoulos. Computers & Operations Research, 32(6):pp.1499–1514, 2005.

[5] H. Muhlenbein, M. Schomisch, J.Born. Proc. Int. Conf. Genetic Algorithms, University of California, San diego, pp. 270-278,1991

[6] E. Atashpaz-Gargari and C. Lucas, "Imperialist Competitive Algorithm: An Algorithm for Optimization Inspired by Imperialistic Competition", IEEE Congress on Evolutionary Computation (CEC 2007).pp 4661-4667, 2007.

[7] H. Mozafari, B. Abdi, Amran Ayob. Int. J. Com. Sci. Eng. Vol. 02, No. 07, 2010, 2486-2490

[8] R. M. Jons. Mechanics of Composite Material. (1975).