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Mass and buckling criterion optimization of stiffened carbon/epoxy composite cylinder under external hydrostatic pressure

Abstract

In this manuscript, stiffened carbon / epoxy composite cylinders under external hydrostatic pressure will be examined to minimize mass and maximize buckling pressure. The new approach proposed in this paper is single objective optimization of stiffened composite cylindrical shell under external pressure by genetic algorithm (GA) in order to obtain the reduction of mass and cost, and increasing the buckling pressure. The objective function of buckling has been used by performing the analytical energy equations and Tsai-Wu and Hashin failure criteria have been considered. Single objective optimization was performed by improving the evolutionary GA. Optimization have been done to achieve the minimum weight with failure and buckling constraints. Finally, optimal angles pattern of layers and fiber orientations are provided for cylinder under external hydrostatic pressure.

Keywords

Criterion optimization, buckling, Hydrostatic pressure, Composite cylinder, Genetic algorithm.

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1 INTRODUCTION

For decades, buckling of laminated cylindrical shells has been considered in the field of mechanical engineering, marine science, civil, chemical and aerospace engineering. Thin shells are very effective structures that can bear high buckling loads. In recent decades, the use of composites instead of metal materials had constant growth in engineering due to their lightweight, high strength and many advantages. The significant increase in carbon fiber composites in various industries, show the importance of the mechanical properties of these materials. This increased use of carbon fiber composites is due to its high strength to weight, stiffness to weight ratio, and appropriate properties in their fatigue loads. Therefore, the optimization of the buckling loads is a very importance issue. Until now, many researches have been done whether in theoretical or experimental areas in the field of cylindrical shells under external loading. But there are few researches in terms of minimization of mass and optimization of composite shells. In the following, some of these research in this field that have been done as analytical, numerical and experimental methods, will be mentioned.

The optimization of laminated composite cylindrical shell under different load and pressure has already been highly regarded in literature (Haftka and Riche, 1993; Onoda, 1985; Abdi et al., 2012; Koide and Luersen, 2013; Almeida and Awrucha, 2007; Topal, 2011; Raju and Rao, 2015). In these researches, mass and cost of shell, strength and stiffness, frequency and stability can be function for optimizing. All of these functions may be as an objective or constrain which researchers have investigated about them. (Yang and Hu, 2007; Topal, 2009; Lund, 2009; Sadeghifar et al., 2010)

Pelletier and Vel (2006) presented a methodology for the multi-objective optimization of laminated composite materials for strength, stiffness and minimal mass that is based on an integer-coded genetic algorithm (GA). They can maximize the load carrying capacity and minimize the mass of a graphite/epoxy laminate that is subjected to biaxial moments.

Sofiyev and Karaca (2009) studied the free vibration and buckling of laminated homogeneous and non-homogeneous orthotropic shells under lateral and hydrostatic pressures. Gillet et al. (2010) evaluated the influence of a number of parameters within the context of composite structure optimization. They used GA to optimize elementary plates and structures modeled using finite element methods. Arian Nik et al. (2012) examined the simultaneous optimization of stiffness and buckling load of a composite laminate plate with curvilinear fiber paths. They integrate surrogate modeling into an evolutionary algorithm to reduce the high computational cost required to solve the optimization process.

Hwang et al. (2014) find possible combinations by using GA with new operator called the elite comparison, which compares and uses the differences in the design variables of the two best solutions. Deveci et al.(2016) optimize buckling of composite laminates using a hybrid algorithm under Puck failure criterion constraint. They proposed an optimization method to find the optimum stacking sequence designs of laminated composite plates in different fiber angle domains for maximum buckling resistance. Civalek (2016) worked on buckling analysis of composite shells with different material properties by discrete singular convolution (DSC) method. They achieved a numerical solution for static buckling problem of circular cylindrical panels, conical panels, conical shells and circular cylindrical shells under axial load. Isotropic, laminated composite, functionally graded material (FGM) and carbon nanotube (CNT) stiffened functionally graded cases are taken into consideration.

Ghasemi and Hajmohammad (2017) investigated multi-objective optimization of composite cylindrical shell under external hydrostatic pressure. They considered parameters of mass, cost and buckling pressure as fitness functions and failure criteria as optimization criterion. Multi-objective optimization was performed by improving the evolutionary algorithm of NSGA-II. The GA as an evolutionary approach is a suitable method for discrete optimization problems. Many researchers reported that GA has a good performance in discrete optimization problems such as composite structures (Kim and Kang, 2005; Kim et al., 2014; Herath et al., 2014; Sekulski, 2010; Ghasemi and Hajmohammad, 2015).

As mentioned before, there is no research focused on mass minimization and buckling maximization with failure criteria of stiffened composite laminated shells, simultaneously. In this paper, stiffened carbon/epoxy composite cylinders under external hydrostatic pressure will be examined to minimize mass and maximize buckling pressure. The new approach proposed in this manuscript is criterion optimization of stiffened composite cylindrical shell under external pressure by GA in order to obtain the reduction of mass and cost, and increasing the buckling pressure. According to the results in the optimization of buckling, the best response is obtained.

2 Problem formulation

In this section, the objective functions and the design variables of stiffened composite cylindrical shell are investigated. The design variables are quantity of the layers, layers orientation, number of stiffeners and quantity of layers stiffeners. The stiffener is considered for this problem consists of a multilayer composite cross section that connected circumferential to the shell as shown in Figure 1. This stiffener is the most used type of stiffeners in composite cylinders.

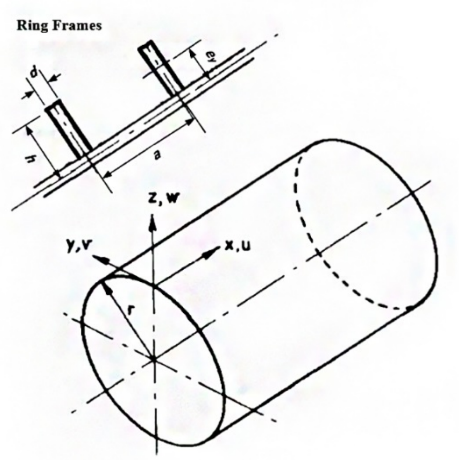

Figure 1 *Environmental stiffener and their properties.*

By considering as case study in order to run the optimization process, a shell with 3m in length, 75 cm in internal diameter and 0.2 mm in per shell thickness has been considered. In order to show the optimization procedure made for finding the optimal design, the material properties are mentioned in Table 1.

Table 1 *Material properties of a unidirectional orthotropic lamina1*

property	E1 (GPa)	E2=E3 (GPa)	G12=G13 (GPa)	G23 (GPa)	$\nu_{12} = \nu_{13}$	ν_{23}	Density (kg/m^3)
Carbon/Epoxy	181	10.3	7.17	4.2	0.3	0.7	1600

2.1 Mass objective function

The final mass function is sum of the weight function of composite cylindrical shell and weight function of circumferential stiffener of the shell. As shown in Figure 1, a is the distance between the stiffeners and e_y is the distance from the middle plane to the center of stiffener. Also according that the cross of stiffener is considered rectangular, h and s are considered as stiffener height and stiffener width, respectively. By assuming that stiffener surrounded all around the shell from the inside, and the mass function of the stiffener is calculated as follows:

$$M_{ring} = \mathrm{S}_{\mathrm{ring}} \times L_{\mathrm{ring}} \times \rho_{\mathrm{ring}} \tag{1}$$

$$L_{\mathrm{ring}} = 2\pi (D_{in} + \frac{h}{2}) = \pi (D_{in} + h) \tag{2}$$

$$\mathrm{S}_{\mathrm{ring}} = h \times d \tag{3}$$

So the final mass function will be as follows:

$$M_{ring} = M_{ring} + M_{shell} \tag{4}$$

2.2 Constraints

2.2.1 Geometric constraints

Range of constraints is determined in Table 2. To determine the lower and upper limits of each of these constraints, buckling pressure in different conditions and desired ranges is achieved.

Table 2 *Range of variables for stiffened cylinder*

	Upper bound	Lower bound
Number of stiffeners	3	1
Number of layers of the shell	80	80
Number of layers of the stiffeners	50	20
Angle of layer of the shell	90	-90
Angle of layer of the stiffener	90	-90

2.2.2 Buckling constraint

The eqs. (5) and (6) is used to calculate the buckling pressure (Smith, 1991). The λ coefficient in buckling pressure will be calculated from the eq. (7). And also to calculate the elements of matrix a and stiffness matrix will be used from eqs. (8) to (9).

$$P_{cr} = \lambda \Big/ \left(\frac{\alpha^2 R}{2} + \frac{n^2}{R} - \frac{1}{R} \right) \tag{5}$$

$$\lambda = a_{33} + \frac{2a_{12}a_{13}a_{23} - a_{11}a_{23}^{\ 2} - a_{22}a_{13}^{\ 2}}{a_{11}a_{22} - a_{12}^{\ 2}} \tag{6}$$

$$
\begin{aligned}
a_{11} &= \alpha^2 A_{11} + \beta^2 A_{66} \\
a_{12} &= \alpha\beta\left(A_{12} + A_{66}\right) \\
a_{13} &= -\alpha\left(\frac{A_{12}}{R} + \alpha^2 B_{11}\right) \\
a_{22} &= \beta^2 A_{22} + \alpha^2 A_{66} + \left[2\beta^2 \frac{B_{22}}{R} + \beta^2 \frac{D_{22}}{R^2} + \alpha^2 \frac{D_{66}}{R^2}\right] \\
a_{23} &= -\beta \frac{A_{22}}{R} - \beta B_{22}\left(\beta^2 + \frac{1}{R^2}\right) - \left[\alpha^2 \beta \frac{D_{12}}{R} + \beta^3 \frac{D_{22}}{R} + 2\alpha^2 \beta \frac{D_{66}}{R}\right] \\
a_{33} &= \alpha^4 D_{11} + 2\alpha^2\beta^2\left(D_{12} + 2D_{66}\right) + \beta^4 D_{22} + \frac{A_{22}}{R^2} + 2\beta^2 \frac{B_{22}}{R} \\
\alpha &= {}^{m\pi}\!/_{L} \quad , \quad \beta = {}^{n}\!/_{R}
\end{aligned}
\tag{7}
$$

$$
\begin{aligned}
& A_{11} = A_x \;\; , \;\; A_{12} = \nu_y A_x \;\; , \;\; A_{22} = A_y + \frac{A_{sy}}{a} \;\; , \;\; A_{66} = \frac{G_{xy}}{h} \\
& B_{22} = e_y \frac{A_{sy}}{a} \;\; , \;\; B_{11} = B_{12} = B_{66} = 0 \\
& D_{11} = D_x \;\; , \;\; D_{12} = \nu_y D_x \\
& D_{22} = D_y + {\left(D_{sy} + A_{sy} e_y{}^2\right)}\!\Big/ a \\
& D_{66} = \frac{G_{xy} h^3}{12} + \frac{1}{2}\left(\frac{D_{Ty}}{a}\right)
\end{aligned}
\tag{8}
$$

$$
\begin{aligned}
& A_x = {E_x h}\Big/{\left(1 - \nu_x \nu_y\right)} \;\; , \;\; A_y = {E_y h}\Big/{\left(1 - \nu_x \nu_y\right)} \\
& D_x = {E_x h^3}\Big/{\left[12\left(1 - \nu_x \nu_y\right)\right]} \;\; , \;\; D_y = {E_y h^3}\Big/{\left[12\left(1 - \nu_x \nu_y\right)\right]}
\end{aligned}
\tag{9}
$$

In the above equations, A_{sy}, D_{sy}, D_{Ty} and e_y are axial rigidity of longitudinal stiffeners, buckling rigidity of stiffeners around the middle axis, torsional rigidity of stiffener and distance of the center of stiffener from middle plane of the shell. Parameters E_x, E_y, G_{xy}, υ_x and υ_y including the elastic parameters as the elastic modulus in direction of fibers, elastic modulus in perpendicular direction of fibers, in-plane shear modulus, major Poisson's ratio and minor Poisson's ratio, respectively. The parameters L, h, R, m and n are the length, thickness and average radius of the shell and number of longitudinal half-waves and number of circumfrential waves, respectively.

By calculating the buckling pressure according to the above eqs., the fitness function is calculated as a combination of final mass function and buckling pressure.

2.2.3 Failure constraints

In this study, the failure of the first layer is considered and the failure constraints is defined accordingly. The definition of multilayer failure criterion is required as one of the important constraints in the optimization.

The most general polynomial failure criterion for composite materials, is tensor polynomial criterion that is provided by Tsai-Wu. Tsai-Wu failure criterion is obtained based on the definition of total strain energy (Kaw, 2010). In this study, all three criteria including Tsai-Wu failure, maximum strain and Hashin are considered as failure constraints in the design and optimization.

By considering Tsai-Wu failure theory based on the total strain energy, a lamina is considered to be safe if

$$F_{11}\sigma_{11}^2 + 2F_{12}\sigma_{11}\sigma_{22} + F_{22}\sigma_{22}^2 + F_{66}\sigma_{12}^2 + F_1\sigma_{11} + F_2\sigma_{22} \le 1 \tag{10}$$

Where F_i , F_{ij} , σ_i and σ_j are quadratic strength parameters and stress components, respectively.

Also, to determine the mode of failure in matrix or fiber, Hashin (1980) has presented the failure criteria which can be obtained from Eqs. (11)-(14). These relations in Eqs. (11)-(14) have been used to determine the tensile fiber mode, compressive fiber mode, tensile matrix mode and compressive matrix mode, respectively.

$$\sigma_{11} \ge 0 \;\rightarrow\; \left(\frac{\sigma_{11}}{X^T}\right)^2 + \left(\frac{\sigma_{12}}{S^L}\right)^2 \le 1 \tag{11}$$

$$\sigma_{11} < 0 \;\rightarrow\; \frac{\sigma_{11}}{X^C} \le 1 \tag{12}$$

$$\sigma_{22} \ge 0 \;\rightarrow\; \left(\frac{\sigma_{22}}{Y^T}\right)^2 + \left(\frac{\sigma_{12}}{S^L}\right)^2 \le 1 \tag{13}$$

$$\sigma_{22} < 0 \;\rightarrow\; \left(\frac{\sigma_{22}}{2S^T}\right)^2 + \left[\left(\frac{Y^C}{2S^T}\right)^2 - 1\right]\frac{\sigma_{22}}{Y^C} + \left(\frac{\sigma_{12}}{S^L}\right)^2 \le 1 \tag{14}$$

Where X^T , Y^T, X^C , X^C , S^L and S^T are longitudinal tensile strength, transverse tensile strength, longitudinal compressive strength, transverse compressive strength, longitudinal shearstrength and transverse shear strength, respectively. The ultimate failure stresses of the carbon/epoxy are presented in Table 3.

***Table 3** Ultimate strength of the carbon/epoxy*

Ultimate strength	σ_{1T}^U (MPa)	σ_{1C}^U (MPa)	σ_{2T}^U (MPa)	σ_{2C}^U (MPa)	σ_{12}^U (MPa)	σ_{23}^U (MPa)
Carbon/Epoxy	2231	-1082	29	-100	60	32

3 Optimization procedure

In this section, the optimization of composite cylindrical shell under external hydrostatic pressure is investigated. Optimization was designed by GA evolutionary algorithm method and the results of each these methods has been compared with others. Optimization have been done to achieve the minimum weight with failure and buckling constraints. Finally, optimal angles pattern of layers is provided for cylinder. In Fig. 2, optimization flowchart is provided for optimizing.

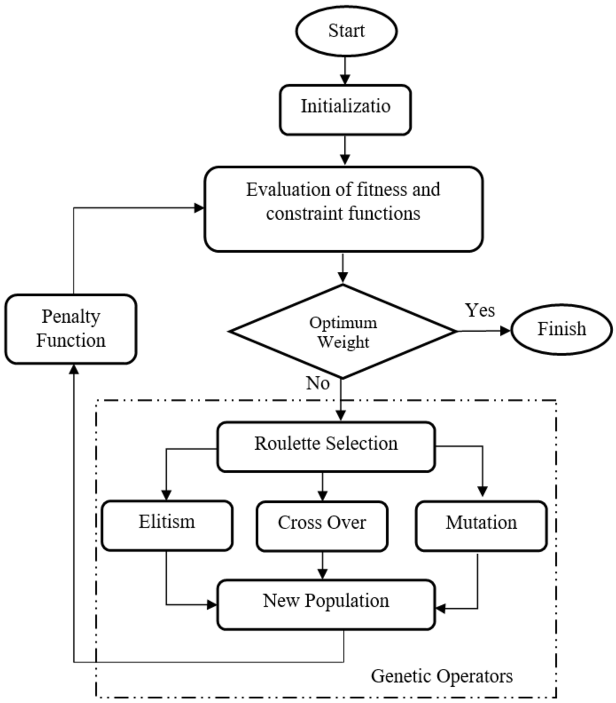

Figure 2 *Optimization flowchart*

In the GA, random mode usually is used to select parent chromosomes. But in this algorithm, applied selection of roulette wheel is used. In this way parent chromosome fit with higher fitness, will be elected more probably and all chromosomes will participate with their presence chance in roulette wheel.

Given that the number of layers is one of the optimization variables, so the number of chromosomes of each member is variable. This point led to the modified combined operator is been designed for children. In Fig. 3, modified combined operator (modified cross over) is shown. According to this operator, considering the cutoff point m, there will be two modes for children. In this figure, parent 1 and parent 2 are the first and second parent, and also offspring 1 and offspring 2 are the first and second child. This initiative has a significant impact on optimization process and till now such work has not been done.

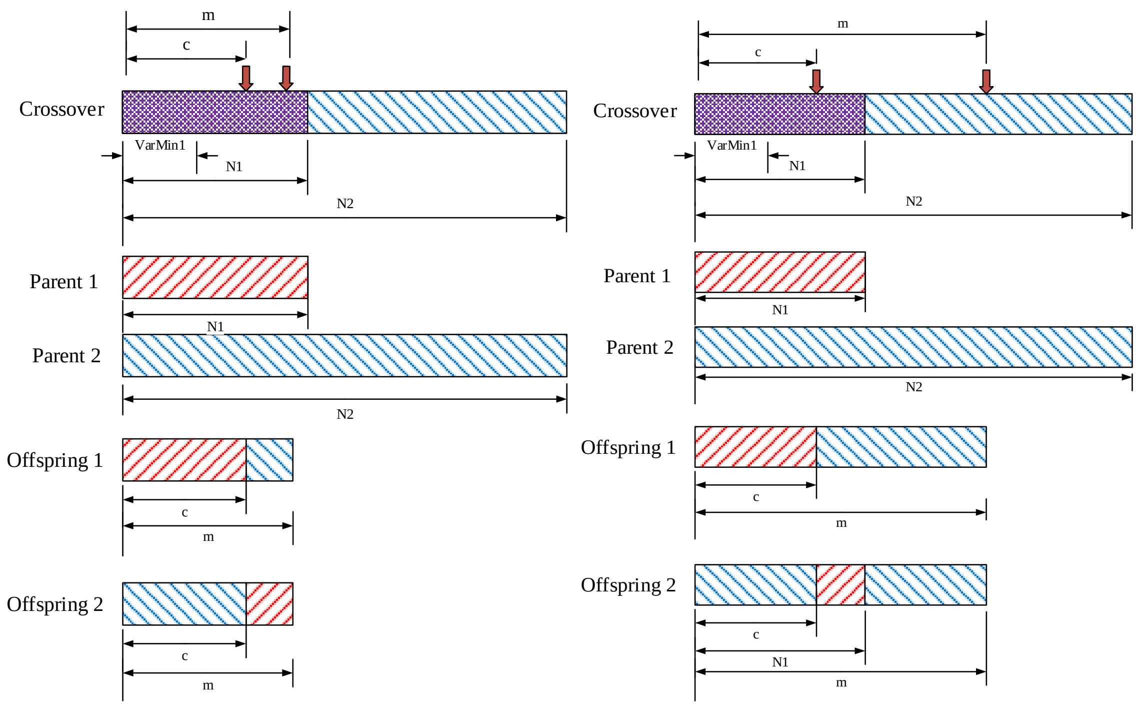

Figure 3 *Modified combined operator*

Gaussian mutation was used for mutation operations which is one of the strongest mutations. For this operator, considering that design variables range is different, two Gaussian mutation are defined. In the first case, only the angles will be mutated and in the second case other variables (thickness of each layer, number of layers, etc.) become mutated.

4 Determine the fitnss function

In this part, objective function is a weight function. Function weight depends on the density of composite material, thickness and number of the layers and it is not dependent on the angle of the layers which is an important parameter for determining the buckling pressure. So, in order to influence the angle of the fitness function, buckling function must be defined as a constraint function and as part of the fitness function. If weight function is defined alone as fitness function, achieved minimum weight is not the optimal point, and it is possible that by changing angles and satisfying buckling constraint, another optimum points exist.

Therefor choose of a fitness function has an important role in achieving the optimal response. Since both mass and buckling function play a major role in the fitness function, the combination of these two functions should be such that mass function direct relationship with the fitness function and buckling function has inverse relationship with the fitness function.

The reason for this is that by minimizing the fitness function, mass reduce and buckling increase. The Eqs. (15)-(18) are defined as the fitness functions to optimize composite cylinder.

$$F_1 = 1000 \times \frac{M}{P_{cr}} \tag{15}$$

$$F_2 = M^* + P^* = 1000 \times \left(\frac{M - M_{\min}}{M_{\max} - M_{\min}} + \frac{1/P_{cr} - 1/P_{\min}}{1/P_{\max} - 1/P_{\min}} \right) \tag{16}$$

$$F_3 = \frac{\dfrac{M - M_{\min}}{M_{\max} - M_{\min}}}{\dfrac{P_{cr} - P_{\min}}{P_{\max} - P_{\min}}} \tag{17}$$

$$F_4 = M^* + P^* = \frac{M - M_{\min}}{M_{\max} - M_{\min}} + \frac{1/\log\left(P_{cr}\right) - 1/\log\left(P_{\min}\right)}{1/\log\left(P_{\max}\right) - 1/\log\left(P_{\min}\right)} \tag{18}$$

In above eqs., $M_{\min}$, M_{max}, P_{min}, P_{max}, M and P are the minimum mass, maximum mass, minimum buckling pressure, maximum buckling pressure, mass and buckling pressure of desired member, respectively. As in Eqs. (15)-(18) is specified, the function F_1 is defined without considering map and other functions have been defined with considering mas and buckling map.

5 Single objective optimization of stiffened composite cylindrical shell by GA

In this algorithm, probability cross-over and probability mutation parameters are set to 8.0 and 5.0, respectively. Also the number of initial population is 50 and the number of its iteration is 150. The number of repetitions in the second stage is 200, and the constraint of 30 members with the same fitness function is defined to exit the loop optimization. The fitness function is F_1, F_2, F_3 and F_4 as the previous section. As mentioned earlier, F_1 function is directly used from the mass and buckling function and other functions are as mass and buckling map crime in the range of zero to one. The results of the optimization process in each generation is provided in Fig. 4 for each fitness function.

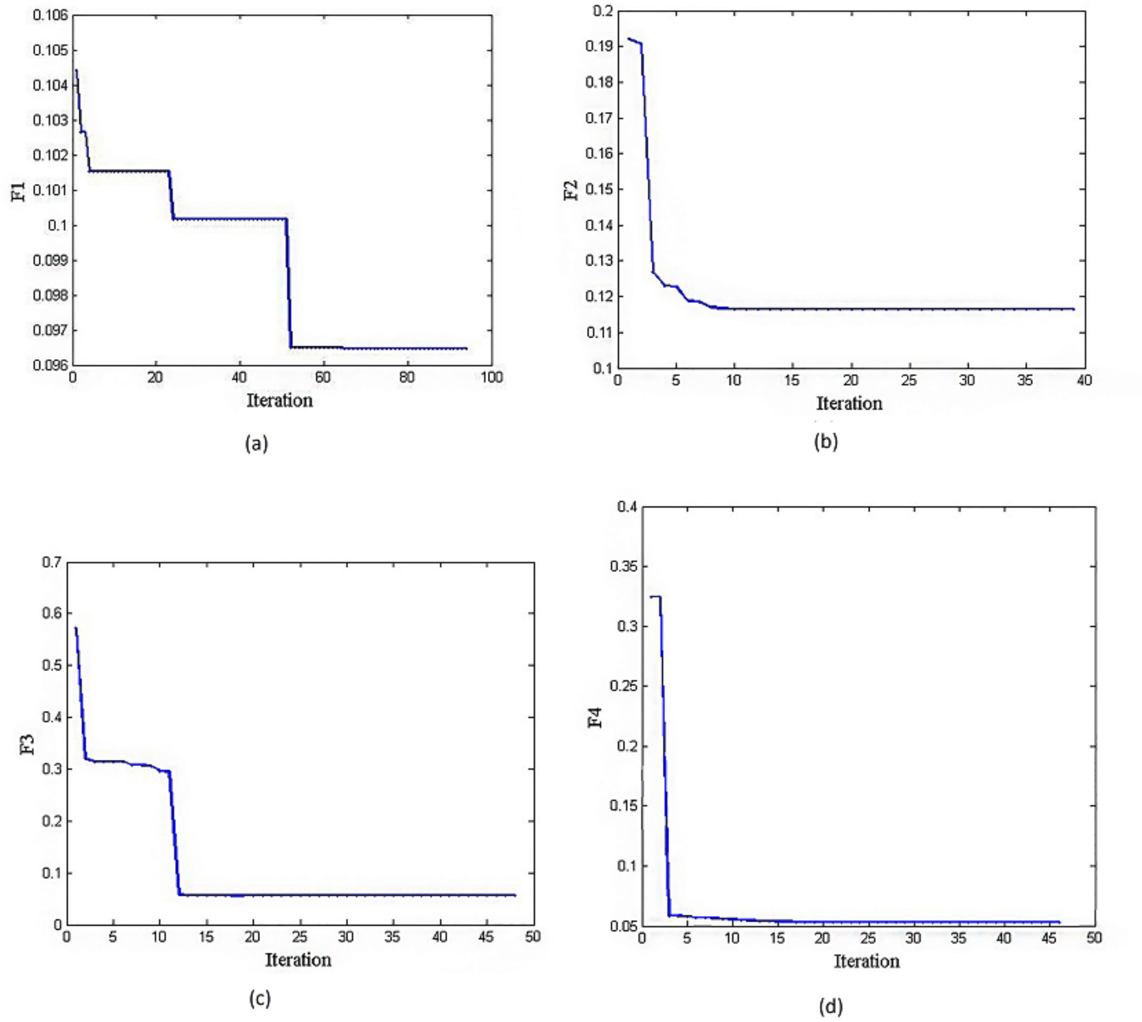

***Figure 4** Fitness function curves based on each generation of optimization of stiffened composite cylinders with a GA. a) F_1, b) F_2, c) F_3 and d) F_4*

Mass and pressure buckling curve while minimizing the fitness function is shown in Figs. 5, 6 and 7. According to these figures, reducing the number of layers leads to reduce the mass and consequently buckling pressure is reduced after reducing the number of layers. In this way the quantity of individuals have been changed in some way to increment buckling pressure in the coveted number of layers, with a specific end goal to limit the fitness function. This process is continued until reaching the convergence condition.

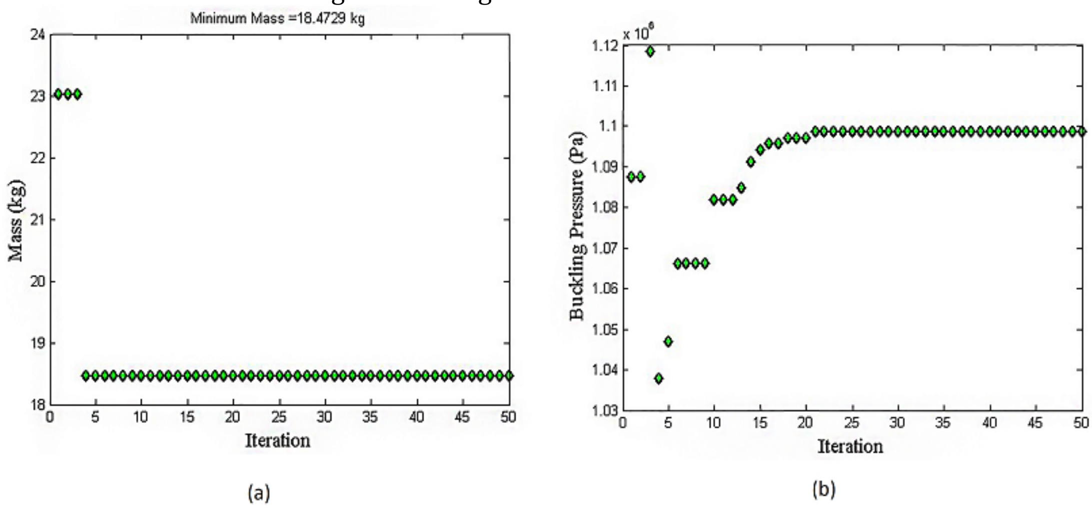

***Figure 5** Mass and pressure buckling curve of fitness function F_1*

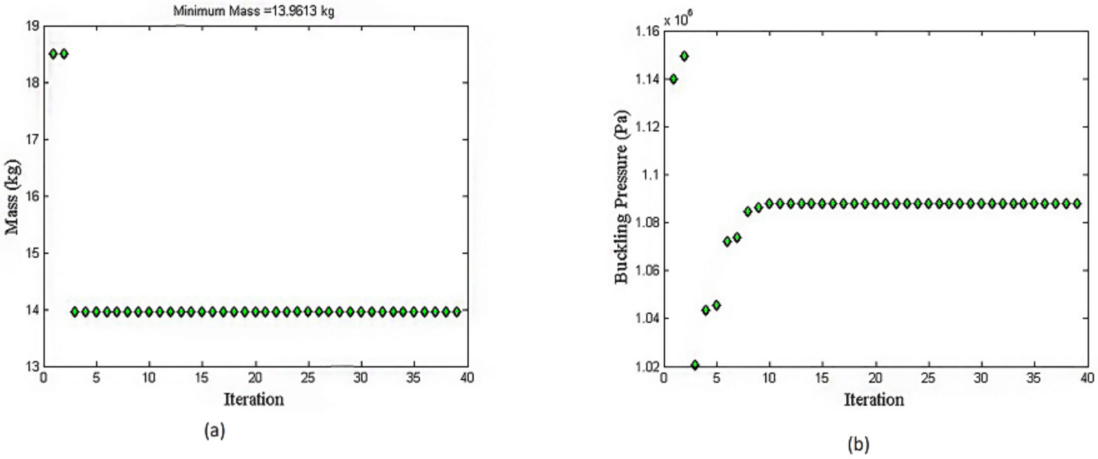

Figure 6 *Mass and pressure buckling curve of fitness function F_2*

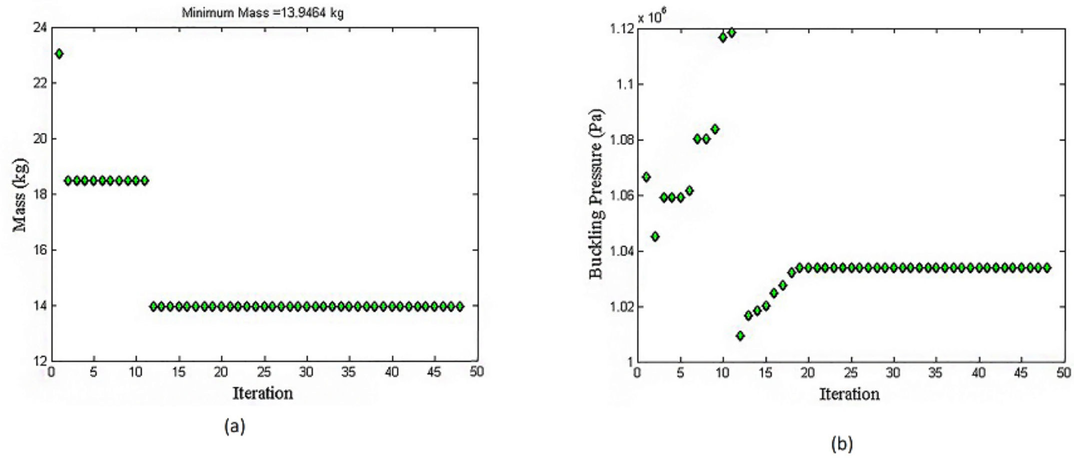

Figure 7 *Mass and pressure buckling curve of fitness function F_3*

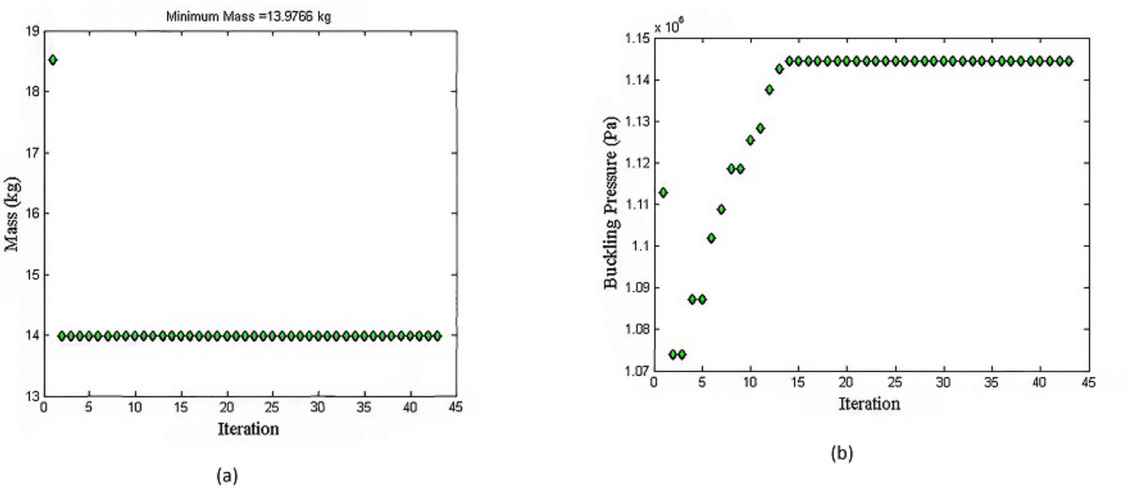

Figure 8 *Mass and pressure buckling curve of fitness function F_4*

As the results show in Figure 4 to Figure 8, F_1 function has less ability to achieve minimum mass. Its reason is, as mentioned earlier, mas and buckling mapping in a common range which makes the impact of the mass and buckling functions in the fitness function is quite different.

The results of optimization, which consists of a number of layers and optimized sample mass is presented in Table 4.

Table 4 Results of single-objective constrained optimization of composite cylinder by GA

Minimum mass (kg)	Number of stiff-ener	Thickness of stiffener (mm)	Number of layers	Fitness function	Arrangement of layers
18.47	3	9.4	8	F_1	$\left[\pm\theta_{(1)},\ldots,\pm\theta_{(n/2)}\right]$
13.96	3	9.8	6	F_2	
13.94	3	9.6	6	F_3	
13.98	3	10	6	F_4	

According to the results, the lowest mass related to the functions F_2, F_3, F_4 and is equal to 13.96 kg. The optimum number of layers will be equal to 8 layers and is provided in accordance with Table 5.

In the second step, optimization objective function is changed and buckling pressure is defined as the objective function.

As a result, in the second step, optimization implemented for optimal response of first step, optimal fiber angles and minimum number of layer can be obtained as the optimal mode. The results of this optimization in the second step are provided in accordance with Figure 9.

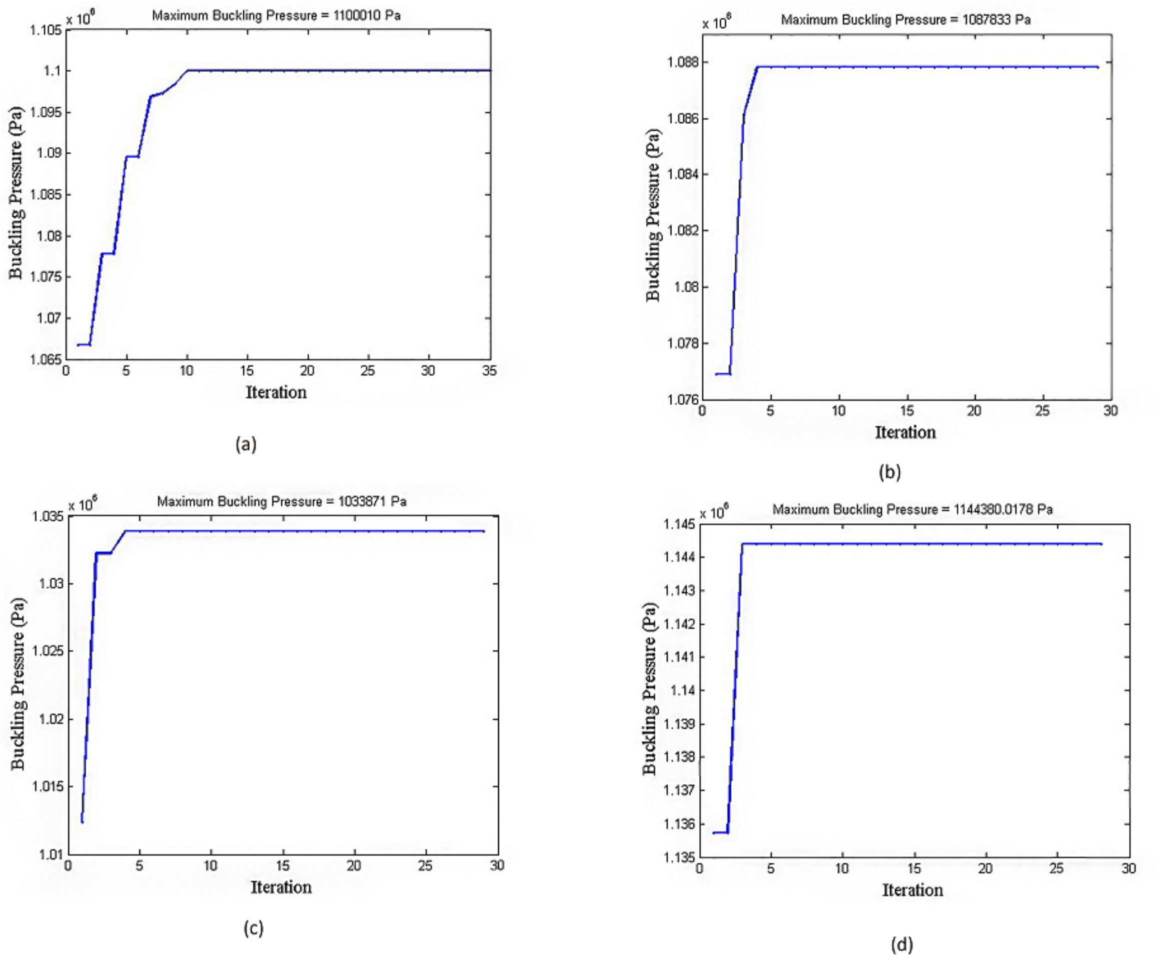

Figure 9 Buckling optimization curve based on each generation of optimization by GA for optimal results in first step for F1-F4

As indicated in Fig. 9, angle of layers is optimized for optimal result in the first step as a variable, and buckling pressure is maximized. Table 5 represents the result of buckling optimization for optimum results in the first step of optimization with fitness functions F_1, F_2, F_3 and F_4.

***Table 5:** The results of the second step optimization to maximize buckling pressure of composite cylinder with GA*

Optimal angles	The maximum buckling pressure (Pa)	Number of layers	Fitness function in first step	Arrangement of layers
$[90_2/\pm15/90_4]$	1100010	8	F_1	$\left[\pm\theta_{(1)},\ldots,\pm\theta_{(n/2)}\right]$
$[90_3/\pm15/90]$	1087833	6	F_2	
$[90/\pm15/90_3]$	1033871	6	F_3	
$[90_2/\pm15/90_2]$	1144380	6	F_4	

According to the results in the buckling optimization, it is clear that the best obtained response is related to the arrangement $[90_2/\pm15/90_2]$. This result has been achieved in the final optimization that has fitness function F_4 in its first step. From the results of optimum angles in optimization in the second step can be concluded that the optimal angles pattern at this step of optimization is somehow that the external and internal angles are close to 90 degree and intermediate angles are about 15 degree. The results have been approved by comparing with Messager et al. (2002) research which represents the optimal angles of the cylinder under external hydrostatic pressure. They proved that "the stability limits of $[90_3/15_2/90_2]$ optimized tubes are 40% higher than those of the $[55]_N$ reference cylinders".

The optimization process has been run for some laminated composite cylindrical shells and the optimum pattern of orientation under external hydrostatic pressure has been investigated. Buckling pressure has been considered as target function and failure criteria of Hashin and Tsai-Wu have been considered as optimization. Then the optimization results for different proportions of length to diameter have been examined for 12 number of layers. In each state, optimization algorithm has been conducted several times and finally the optimum result of pattern has been presented. In Table 6, the results of optimum orientation with 12 layers for proportions of length to diameter of 1.5 have been presented.

***Table 6:** Optimum angles for maximum buckling pressure for laminated composite cylindrical shells with constant mass*

Optimum angles	Buckling pressure (MPa)	Length (m)	L/D
$[90_4/\pm15_3/90_2]$	0.2882	0.3	1.5
$[90_4/\pm15_2/90_4]$	0.0778	0.5	
$[90_4/\pm15_3/90_2]$	0.03451	0.7	
$[90_4/\pm15_2/90_4]$	0.01804	0.9	

According to the results in the optimization of other examples, it could be concluded that the optimal angles pattern at this step of optimization is somehow that the external and internal angles are close to 90 degree and intermediate angles are about 15 degree.

By comparing the results with other similar researches which a composite shell has been optimized under external pressure, the optimal fiber orientation have been obtained and compared with each other. The comparison results have been presented in Table 7.

***Table 7:** Comparison results of optimal design for composite cylindrical shell*

Refrences	Failure criteria	Optimization method	Number of layers	Optimal angles
Smerdov (2000)	-	Gradient-based algorithms	4	$[90/19_2/90]$
Messager et al. (2002)	Tsai–Wu criterion	Genetic algorithm	7	$[90_3/15_2/90_2]$
Matsuzaki, and Todoroki (2007)	-	Fractal branch-and-bound method	12	$[90_5/0_2/90_5]$
Muc and Muc-Wierzgoń (2012)	Maximum strain	Evolution strategy	24	$[90_{12}/0_2/90_{10}]$
Lee et al. (2013)	Tsai–Wu criterion	Micro-genetic algorithm	16	$[90_4/\pm25_4/90_4]$
Current study	Tsai–Wu and Hashin criterion	Constraned genetic algorithm	6	$[90_2/\pm15/90_2]$

As shown in Table 7, all of the mentioned researches investigated on optimization of composite cylindrical shell under external pressure and determined the optimal design of fiber orientations. It is important that the shells with different dimensions have similar form of optimal design. Also the form of optimal design in the researches is similar to optimum fiber orientation obtained in this study. Although in the current study, constrained optimization with failure criteria (Tsai-Wu and Hashin criterion) and modified operator has been used. So the results have a good conformity with the other researches.

6 Conclusion

In this paper, stiffened carbon/epoxy composite cylinders under external hydrostatic pressure will be examined to minimize mass and maximize buckling pressure. Optimization was designed by GA evolutionary algorithm method. Optimization have been done to achieve the minimum weight with failure and buckling constraints. Also in the optimization of composite cylinders, in order to influence the angle of the fitness function, buckling function must be defined as a constraint function and as part of the fitness function. Finally, optimal angles pattern of layers is provided for cylinder. From the results of optimum angles in optimization can be concluded that the optimal angles pattern at this step of optimization is somehow that the external and internal angles are close to 90 degree and intermediate angles are about 15 degree.

Acknowledgments

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