DESIGN OPTIMIZATION OF LAMINATED COMPOSITE CYLINDRICAL SKIRT FOR WEIGHT MINIMIZING BY USING NON-DOMINATED SORTING GENETIC ALGORITHM

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Abstract
Laminated composite construction of panels and other structural elements is currently being used for many applications in aerospace, automotive, civil and defence industries. Laminated composites have several advantages over more traditional materials including greater specific strength, specific stiffness, corrosion and fatigue resistance, and energy absorption among others. Optimization of composite laminates with respect to ply angles to maximize the strength is necessary to realize the full potential of fiber reinforced materials. NSGA-II (Non-Dominated Sorting in Genetic Algorithms) is a non-dominated based genetic algorithm for objective optimization. It is very effective algorithm but has been generally criticized for its computational complexity. A modified version was developed, which has a better sorting algorithm which incorporates archiving better ranked objectives. Modified NSGA-II builds a population of competing individuals, ranks and sorts each individual according to non-domination level, applies Evolutionary Operations (EVOPs) to create new pool of offspring, and then combines the parents and offspring before partitioning the new combined pool into fronts. The NSGA-II then conducts niching by adding a crowding distance to each member. It uses this crowding distance in its selection operator to keep a diverse front by making sure each member stays a crowding distance apart. This keeps the population diverse and helps the algorithm to explore the fitness landscape. The above methodology is applied to the optimization of laminated composite materials. This problem deals with a practical design example of fiber-reinforced composite cylindrical skirt of solid rocket motor of aerospace vehicle are investigated. A skirt is a potential element for weight reduction in rocket motors as it leads to reduction of the total weight of solid rocket motor. Due to its significance for solid rocket motors, it is proposed to optimize the weight of the fiber-reinforced composite cylindrical skirt subjected to a buckling strength constraint and an overstressing strength constraint under aerodynamic torque and axial thrust. This is achieved by arriving at an optimal stacking sequence for the cylinder satisfying all the design constraints and also by employing multiple composite materials. Classical laminate theory combining with elastic stability theory of thin shells is used to arrive at buckling strength and overstressing strength of the fiber-reinforced composite cylindrical skirt. The Tsai-Wu failure criterion is employed to assess the first ply failure. Buckling strength and failure strength of the cylindrical skirt is described by using buckling load factor and overstressing load level factor. Following material combinations such as Graphite/Epoxy & Glass/Epoxy have been used to find the optimal curve. The obtained results show the effectiveness of the proposed methodology for the optimization of composite materials.

Keywords: laminated composite materials, NSGA-II, Tsai-Wu failure criterion, fiber-reinforced composite, rocket motor.

I INTRODUCTION

Genetic algorithms (GAs) have been gaining substantial attention in recent years. GAs are well known for their robustness and ability to search complex and noisy search spaces, phenomena which are frequently encountered in design and optimization problems. Genetic algorithms can be regarded as expensive optimization tools also, sometimes requiring tens of thousands of analyses to achieve convergence. However, there is a large amount of research work being done with GAs and it is continuing to grow, with many new ideas aimed at reducing computational cost. The diversity of applications utilizing GAs in search and optimization is also quite impressive. Fields of study range anywhere from biology and the social sciences to computer science and engineering applications. Composite materials are becoming the material of choice in structural applications today and for the future. Although the high strength-to-weight properties of composite materials are attractive, their greatest advantage is that they provide the designer with the ability to tailor the directional strength and stiffness's of a material to a given loading environment of the structure [1]. For laminated composite structures, which are studied in this work, each laminate has its greatest stiffness and strength properties along the direction that the fibers are oriented in, By orienting each layer at different angles, the structure can be designed specifically for its loading environment. Thus, performance capabilities are usually not constant throughout a composite structure, with areas exposed to high loading conditions possessing the greatest stiffness and strength properties. On the negative side, composite structures are well known for being expensive to fabricate and, Until recently, little was known about fatigue life or repair and maintenance procedures either. Furthermore, a composite structure may run into problems if placed under a load in an unexpected direction in which the strength is low, yielding the potential for structural failure. Such problems are easier to avoid by using isotropic materials such as aluminum or steel, which have uniform material properties in every direction. Designers have been reluctant to use composite materials in aerospace applications where there is a high demand for strong, yet light weight structures, because it is difficult to absolutely determine and design for the range of all possible loading conditions that a structure will encounter. The advantages of using composite materials are somewhat offset by the more complex structural analysis that is required. Composite structures usually involve large, non-convex, integer programming problems that are discrete in nature. Genetic algorithms are ideal optimization algorithms for these type of problems and are simple to implement when compared to other optimization techniques, allowing for their application towards a wide array of problems in this area of study. This paper presents some new ideas aimed at improving the efficiency of GAs in composite structure design, and to explore other areas in their application toward composite structure design and optimization.

II LITERATURE REVIEW

Fiber reinforced composites are extensively used in many modern engineering applications due to their ability to improve structural performance. Examples include lightweight, strong and rigid aircraft frames, composite drive shafts and suspension components, sports equipment, pressure vessels and high-speed flywheels with superior energy storage capabilities. A reason for the widespread use of laminated composite materials is their inherent tailorability, which enables them to meet specific design objectives for a given application. Several techniques have been reported in the literature for the optimization of laminated composite materials. Venkataraman and Haftka [2] describe genetic algorithms as the most popular method for the combinatorial optimization of laminate stacking sequence. Genetic algorithms (GAs) are contemporary search techniques developed by Holland [3], that mimic the evolutionary principles and chromosomal processing in natural genetics. A GA begins its search with a population of random individuals. Each member of the population possesses a chromosome which encodes, in some fashion, certain characteristics of the individual. In the present case, an individual member of the population corresponds to a particular laminate design and its chromosome consists of the fiber orientations, fiber volume fractions and lamina thicknesses. The algorithm systematically analyses each individual in the population of designs according to set specifications and assigns it a fitness rating which reflects the designer's goals. This fitness rating is then used to identify the structural designs that perform better than others, thereby enabling the genetic algorithm to determine the designs that are weak and must be eliminated using the reproduction operator. The remaining, more desirable genetic material is then utilized to create a new population of individuals. This is performed by applying two more operators similar to natural genetic processes, namely gene crossover and gene mutation [4]. The process is iterated over many generations in order to obtain optimal designs. The evolutionary technique provides major benefits over traditional gradient based optimization routines, such as nominal insensitivity to problem complexity and the ability to seek out global rather than local optima. Several researchers have utilized GAs for the single objective optimization of composite laminates. For example, Le Riche and Haftka [5] and Nagendra et al. [6] optimized the stacking sequence of composite plates to maximize the buckling load. A strategy for the optimal design of composite grid-stiffened cylinders subjected to global and local buckling constraints and strength constraints was proposed by Jaunky et al.[7]. Rajendran and Vijayarangan [8] have demonstrated that it is possible to obtain a significant reduction in weight of a mono-leaf composite spring compared to a seven-leaf steel spring. Park et al. [9] analyzed symmetric composite laminates using a shear deformation theory and the Tsai–Hill failure criterion to obtain optimal designs of symmetric composite laminates subject to various loading and boundary conditions. Messager et al. [10] employed an analytical model of shell buckling coupled to a GA to determine optimized stacking sequences for underwater cylindrical composite structures. The classical lamination theory is utilized to determine the lamina stresses for thin laminates subjected to force and/or moment resultants and the first-ply failure load is obtained using the Tsai–Wu failure criterion. An integer-coded objective genetic algorithm, based on the elitist non-dominated sorting genetic algorithm (NSGA-II) [12,13], is implemented to obtain Pareto-optimal designs for conflicting objectives. A novel feature of our proposed methodology is the incorporation of an automatic termination criterion for objective genetic algorithms. It keeps track of the number of new designs that are added to a historical archive of non-dominated individuals and terminates the algorithm when it reaches the point of diminishing returns. Numerical results are presented for the model problems having various conflicting objectives. In this model problem, the aim is to maximize the failure load while minimizing the mass of a graphite/epoxy laminate subjected to biaxial moments.

III GENETIC OPTIMIZATION OF COMPOSITE STRUCTURES

It has been established that stacking sequence design of composite laminates requires discrete programming since ply thicknesses and orientation angles are restricted to a discrete set of values. This restriction is due to manufacturing limitations because plies are fabricated at certain thickness values. Furthermore, a majority of composite structures are still manually constructed and it is often to difficult to accurately hand-lay plies at odd orientation angles. Design procedures discussed in the previous section with continuous design variables have several disadvantages. First, composite laminate design and optimization problems possess non-linear functions of the number of plies, ply thicknesses, and orientation angles and substantial effort is required for transformation to a linear problem. Second, composite laminate design often involves many local optimum designs because their performance is characterized by a number of parameters which is typically smaller than the number of design variables. Sequential linearization is a standard approach to solving non-linear problems but can often get trapped in local optimum design areas [14]. Thirdly, rounding off design variables when using continuous optimization methods haven shown to produce sub-optimal or even unfeasible designs [15]. Continuous optimization and branch-and-bound algorithms may not be well suited to complex composite structures either because they exhibit an exponential dependence on the number of design variables [5].In recent years, genetic algorithms have been successfully applied to large, non-convex, integer programming problems. Thus, it was obvious that GAs would be well suited for the design and optimization of laminated composite plates

IV OPTIMUM DESIGN OF LAMINATED COMPOSITE CYLINDRICAL SKIRT

Multi-layer and sandwich construction also offer many opportunities for analysts and designers to tailor their properties to the specific requirements of a given application. The tailoring is mostly achieved by optimizing the mechanical properties, thereby increasing the load carrying capacity of the structure. Optimization of composite laminates with respect to ply angles to maximize the strength is necessary to realize the full potential of fiber reinforced materials. Figure.1 shows a laminated fiber-reinforced composite cylindrical shell of length L, radius R (from the center to the mid-surface of the shell), and total thickness h under aerodynamic torque T and axial thrust F. The shell has a symmetric lay up consisting of K layers of equal thickness t. The shell has balanced laminates.The composite cylindrical skirt is subjected to aerodynamic torque T and axial thrust F leading to failure by buckling [19], the force (Nx,Ny,Nxy) and moment resultants (Mx,My,Mxy) can be written as

$N_x = \frac{F}{2\pi R}$ $\quad N_{xy} = \frac{T}{2\pi R^2}$ $N_y=M_x=M_y=M_{xy}=0$ … 1

When the applied aerodynamic torque and axial thrust are greater than or equal to the critical values, buckling or overstressing will occur.

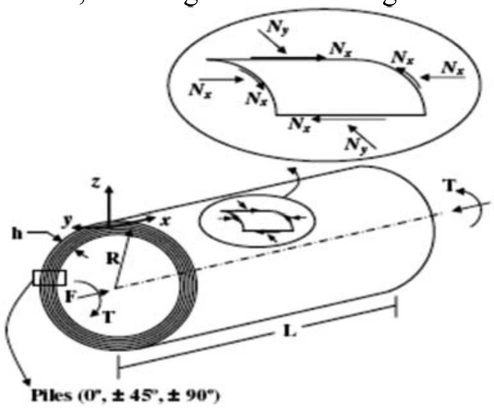

Fig. 1 laminate composite cylindrical skirt

SA is generally more reliable in finding global optimum and unlike GA, simulated annealing algorithm uses single individual to perform the search. Several researchers while solving other combinatorial problems [9,10] have established that simulated annealing outperforms GA both in computational performance and also in finding the global optimum solutions.

- A skirt is a key element of a rocket motor and is in cylindrical shape.
- The skirt of solid rocket motor is commonly subjected to aerodynamic torque and axial thrust during operation.
- Hence, buckling due to combined loads and failure due to overstressing are two major concerns in the safe and reliable design of the skirt.

V COMPOSITE CYLINDRICAL SKIRT FOR WEIGHT MINIMIZATION

The Mathematical model of the problem is taken as follows

OBJECTIVE FUNCTION

The objective of this problem is to minimize the weight

Minimize F1

Where F1=weight

CONSTRAINTS

1) Tsai-Wu factor should be less then or equal to one ($\zeta \leq 1$) It is used as the design constraint in the proposed staking sequence optimization of cylindrical skirt

2) Combined buckling load factor should be greater than one ($\lambda \geq 1$). Serves as another restriction on the optimization design problem in this work

MATERIALS USED

The materials used for calculation are graphite/epoxy and glass/epoxy with the following material properties are given in Table 1.

Material Properties:

Table 1: Materials properties of Graphite, Glass Epoxy

Property	Graphite-epoxy	Glass-epoxy
Long.Modulus,E1	181.0 Gpa	38.6 Gpa
Transverse modulus,E2	10.3 Gpa	5.27 Gpa
In-plane shear modulusG12	7.17 Gpa	4.141 Gpa
Poisson ratio,v12	0.28	0.26
Density	16.054kN/m^3	19.929kN/m^3

Thickness, t	0.000127m	0.000127m
Cost factor ,C	8	1
Long. tensile strength, F1lt	1447.0 Mpa	1280.0 Mpa
Long. comp strength, F1lc	1447.0 Mpa	690.0 Mpa
Trans. Tensile strength, F2tt	51.7 Mpa	49 Mpa
Trans. comp	206.0 Mpa	158 Mpa
In-plane shear	93.0 Mpa	69.0 Mpa

CLASSICAL LAMINATE THEORY FOR COMPOSITE CYLINDRICAL SKIRT

The classical laminate theory is used in the present work to describe the behavior of a laminate composite cylindrical skirt with a particular laminate configuration. Since the shell of the composite cylindrical skirt is a symmetric laminate with respect to the mid-surface and is balanced, the bending-extensional coupling stiffness matrix [B] can be neglected, and the constitutive equation for the fiber-reinforced composite cylindrical skirt can be rewritten as

$$\{N\}_{xy} = [A]\{\varepsilon\}_{xy} \qquad \{M\}_{xy} = [D]\{K\}_{xy} \qquad \ldots 2$$

where $\{N\}_{xy}$ is the force resultant tensor, $\{M\}_{xy}$ the moment resultant tensor, $\{\varepsilon\}_{xy}$ the strain tensor, $\{K\}_{xy}$ the curvature tensor. The extensional stiffness matrix [A] and the bending stiffness matrix [D] are given as

$$A_{ij} = \sum_{i=1}^{k} Q_{ij}\,(h_i - h_{i-1})$$

$$D_{ij} = \frac{1}{3}\sum_{i=1}^{k} Q_{ij}\,({h^3}_i - {h^3}_{i-1}) \qquad \ldots 3$$

Where hi is the thickness of the ith lamina and Q denotes the reduced stiffness of the layers of the laminate. The extensional stiffness matrix and bending stiffness matrix, which are functions of design variables, are the major factors that influence the stability and strength design of the fiber reinforced composite cylindrical skirt. These matrices will be used in buckling and failure analysis of the skirt.

VI FAILURE CRITERIA

The Tsai-Wu failure criterion is employed here to assess the capability of the composite cylindrical skirt to withstand failure due to overstressing. A strength failure load factor is used to identify the characteristics of the first-ply failure of the cylindrical skirt. Based on the Tsai-Wu failure criterion, the strength level factor ζ is defined as

$$\xi = k^{max}\{F_{11}\left(\sigma_L{}^{(k)}\right)^2 + F_{22}\left(\sigma_T{}^{(k)}\right)^2 + F_{66}\left(\sigma_{LT}{}^{(k)}\right)^2 + 2F_{12}\sigma_L{}^{(k)}\sigma_T{}^{(k)} + F_1\sigma_L{}^{(k)} + F_2\sigma_L{}^{(k)}\} \qquad \ldots 4$$

In Eq. (4), each stress component of the kth layer ,$\sigma_L{}^{(k)}$,$\sigma_T{}^{(k)}$,$\sigma_{LT}{}^{(k)}$ in the material direction can be calculated by

$$\{\sigma\}^{(k)}{}_{LT} = [T][Q]^{(k)}[A]^{-1}\{N\}_{xy} \qquad \ldots 5$$

Where $\{N\}_{xy}$ is the resultant tensor $[N_x,N_y,N_{xy}]T$, defined in Eq. (1); $[A]^{-1}$ the inverse of the extension stiffness matrix [A], given in Eq. (3); Q is the reduced stiffness of the kth layer of the laminate; and the strength parameters F_{11}, F_{12}, F_{22}, F_{66}, F_1 and F_2 are given by

$$F_{11} = \left(\frac{1}{\sigma_{LU}{}^T\sigma_{LU}{}^C}\right), \qquad F_{22} = \left(\frac{1}{\sigma_{TU}{}^T\sigma_{TU}{}^C}\right)$$

$$F_{66} = \left(\frac{1}{\sigma_{TLU}{}^2}\right)$$

$$F_1 = \left(\frac{1}{\sigma_{LU}{}^T} - \frac{1}{\sigma_{LU}{}^C}\right), \qquad F_2 = \left(\frac{1}{\sigma_{TU}{}^T} - \frac{1}{\sigma_{TU}{}^C}\right) \ldots 6$$

$$F_{12} = -\left(\frac{1}{2}\right)\left(\frac{1}{\sqrt{\sigma_{LU}{}^T\sigma_{LU}{}^C\sigma_{TU}{}^T\sigma_{TU}{}^C}}\right)$$

Where $\sigma_{LU}{}^T, \sigma_{LU}{}^C, \sigma_{TU}{}^T$,and $\sigma_{TU}{}^C$ are the tensile and compressive strengths of the composite material in the longitudinal and transverse directions, and $\sigma_{LU}{}^T$ is the in-plane shear strength.

In order to ensure that first-ply failure does not occur in the cylindrical skirt, the following condition must be satisfied

$$\xi \leq 1 \qquad \ldots\ldots (7)$$

Eq. (7) is used as a design constraint in the proposed stacking sequence optimization of cylindrical skirt.

BUCKLING LOADS

The fiber-reinforced composite cylindrical skirt is subjected to torque due to aerodynamics and axial compression due to thrust, during operation. The skirt will buckle and, thus, the rocket will fail if these loads exceed critical values. To ensure stability of the skirt, it is necessary that the critical buckling load must be higher than the actual load in the fiber-reinforced composite cylindrical skirt.

A buckling load factor, λ is used to identify pre-buckling of the fiber-reinforced composite cylindrical skirt and is defined as $\lambda = N_1/N_a$ …… (8)

The buckling characteristics of the cylindrical skirt can be defined using the buckling load factor, λ as follows:

(i) Buckling of the cylindrical skirt will occur at the actual load Na, when 0 ≤ λ < 1.

(ii) Buckling is incipient under the actual load Na, when λ = 1.

(iii) Buckling will occur at a load level higher than the actual load Na, when λ > 1.

AXIAL BUCKLING LOADS

Buckling of the shell of a cylindrical skirt constructed of a symmetrical and balanced laminate under axial thrust F is governed by the following system of equations [19]

$$A_{11}u_{xx} + A_{12}\left(v_{xy} + \frac{w_x}{R}\right) + A_{66}\left(v_{xy} + u_{yy}\right) = 0$$

$$A_{66}\left(v_{xx} + u_{xy}\right) + A_{12}u_{xy} + A_{22}\left(v_{yy} + \frac{w_y}{R}\right) = 0 \quad \text{……. 9}$$

$$D_{11}w_{xxxx} + 2(D_{12} + 2D_{66})w_{xxyy} + A_{12}\frac{u_x}{R} + A_{22}\left(\frac{v_y}{R} + \frac{w}{R^2}\right) + D_{22}w_{yyyy} = Fw_{xx}$$

Due to the mid-surface symmetry of the shell, the bending-extension coupling matrix [B] does not appear in Eq. (9). For a simply supported shell, the boundary conditions are given as

w=0,v=0 at x=0,L. … 10

The solution to the system of Eq. (9) which satisfies the simply supported boundary conditions given in Eq. (10) is obtained by assuming displacements in the form

$$u = u_{mn}\cos(mx)\cos(ny) \qquad v = v_{mn}\sin(mx)\sin(ny) \qquad w = w_{mn}\sin(mx)\cos(ny) \quad \text{…11}$$

Where m= $m\pi/L$, n = n/R ; m and n are numbers of half waves in the buckle pattern in the axial and circumferential direction,; u_{mn}, v_{mn} and w_{mn} are the buckling displacement amplitude coefficients. The buckling load factor λa corresponding to these wave numbers is obtained as an eigen value of the linear system of equations obtained by substituting Eq. (11) into Eq. (9) and also combining Eqs. (8) and (1). This can be written as

$$\lambda_a(m,n,\theta) = \frac{2R}{\pi F}\left(\frac{L}{m}\right)^2 \frac{\begin{vmatrix} c_{11} & c_{12} & c_{13} \\ c_{21} & c_{22} & c_{23} \\ c_{31} & c_{32} & c_{33} \end{vmatrix}}{\begin{vmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{vmatrix}} \quad \text{…12}$$

$c_{11} = A_{11}m^2 + A_{66}n^2$ $\quad c_{22} = A_{22}n^2 + A_{66}m^2$

$c_{33} = D_{11}m^4 + 2(D_{12} + 2D_{66})m^2n^2 + D_{22}n^4 + \frac{A_{22}}{R^2}$

$c_{12} = c_{21} = (A_{12} + A_{66})mn$ $\quad c_{23} = c_{32} = \frac{A_{22}}{R}$ $\quad c_{13} = c_{31} = \frac{A_{12}}{R}\, m$

The buckling load due to axial thrust is calculated using Eq. (12). The critical buckling load factor λ_a^{cr} is calculated from

$$\lambda_a^{\ cr} = \min \lambda_a(m,n,\theta) \quad \text{… 13}$$

TORSIONAL BUCKING LOAD

For the symmetrical shell, the critical torsion buckling load is given by Vinson [19] as

$$T_{cr} = 21.75(D_{22})^{5/8}\left(\frac{A_{11}A_{12} - A^2{}_{12}}{A_{22}}\right)^{3/8}\left(\frac{R^{5/4}}{L^{3/2}}\right) \quad \text{…14}$$

Subject to the condition that

$$\left(\frac{D_{22}}{D11}\right)^{5/6}\left(\frac{A_{11}A_{2\,2} - A^2{}_{12}}{12A_{22}D11}\right)^{1/2}\left(\frac{L^2}{R}\right) \geq 500 \quad \text{…15}$$

Substituting Eq. (14) into Eq. (8) and combining this with Eq. (1), the critical torsion buckling load factor λ^{cr} for the symmetrical skirt shell under aerodynamic torque T can be obtained and it can be written as

$$\lambda_T^{\ cr} = \frac{T_{cr}}{T} = \frac{21.75}{T}(D_{22})^{3/8}\left(\frac{A_{11}A_{12} - A^2{}_{12}}{A_{22}}\right)^{3/8}\left(\frac{R^{5/4}}{L^{1/2}}\right) \quad \text{…16}$$

BUCKLING DUE TO COMBINED AXIAL THRUST AND AERODYNAMIC TORQUE

In the design of the fiber-reinforced composite cylindrical skirt, a combined buckling load factor k is employed to describe the buckling of a cylindrical shell subjected to combined axial thrust and aerodynamic torque.λ can be determined by [31]

$$\frac{1}{\lambda} = \frac{1}{\lambda_a^{\ cr}} + \frac{1}{\lambda_T^{\ cr}} \quad \text{…17}$$

Where λ_T^{cr} is Torsional buckling load
λ_a^{cr} is Axial buckling load

To ensure that the fiber-reinforced composite cylindrical skirt subjected to the combined loads does not buckle, the combined buckling load factor k cannot be less than one. That is,

$$\lambda \geq 1 \qquad \ldots 18$$

VII RESULTS AND DISCUSSION

The solutions obtained with the proposed simulated algorithm has been compared with the solutions obtained for the same problem, with other algorithms, as reported in table

Table 2: comparison of modified NSGA-II results with published values values

S.no	F=10E4	T=10E3	WEIGHT 1 (PUBLISHED)	WEIGHT 2 (PRESENT STUDY)
1	70	70	33.64	**29.685**
2	70	80	36.68	**36.44**
3	70	90	36.68	**34.58**
4	70	100	48.72	**38.298**
5	80	70	44.98	**36.44**
6	80	80	44.98	**31.673**
7	80	90	44.98	**34.456**
8	80	100	48.72	**38.298**
9	90	70	44.98	**33.528**
10	90	80	44.98	**37.37**
11	90	90	48.72	**39.225**
12	90	100	48.72	**37.37**
13	100	70	44.98	**37.37**
14	100	80	48.72	**38.298**
15	100	90	48.72	**41.215**
16	100	100	48.72	**38.298**

Table 3: comparison staking sequence of modified NSGA-II results with published values for various axial force and torque

S.No	F=10E4	T=10E3	SEQUENCE 1 (PUBLISHED)	SEQUENCE 2 (PRESENT STUDY)
1	0	70	[2/3/3/2/1/4/3/4/3/2/1]s	**[1/8/1/4/8/6/1]s**
2	70	80	[4/3/3/2/5/2/3/4/4/3/2/3]s	**[2/1/5/2/7/3/1/4/3]s**
3	70	90	[4/3/4/4/3/2/3/3/2/1/2/1]s	**[4/3/1/4/1/1/4/2/2]s**
4	70	100	[2/2/3/2/3/4/4/3/3/4/4/3/2]s	**[3/4/8/5/3/3/2/8/7]s**
5	80	70	[4/4/3/2/2/3/4/4/3/3/4/4/3/2]s	**[3/2/3/6/2/2/7/1/4]s**
6	80	80	[3/3/2/3/2/1/2/3/4/4/3/4]s	**[2/4/1/2/3/6/4/2]s**
7	80	90	[2/3/4/4/3/4/3/4/3/2/1/2]s	**[6/6/4/4/8/1/8/3]s**
8	80	100	[2/3/2/2/1/4/4/3/2/3/4/3/4]s	**[8/8/8/1/3/1/8/4/4]s**
9	90	70	[4/3/2/1/1/4/3/4/3/2/3/2]s	**[2/8/2/2/8/7/3/1]s**
10	90	80	[3/4/3/3/2/2/1/4/3/4/3/2]s	**[1/8/7/1/3/4/3/4/6]s**
11	90	90	[4/3/4/3/3/2/3/3/2/3/2/1/4]s	**[2/8/2/5/2/5/7/5/3]s**
12	90	100	[3/3/2/2/1/2/3/4/4/3/4/3/2]s	**[5/1/6/8/3/2/3/3/2]s**
13	100	70	[4/3/4/3/3/4/1/2/3/2/3/2]s	**[2/6/3/6/3/5/2/1/4]s**
14	100	80	[3/2/5/2/3/2/2/3/4/8/3/4/1]s	**[1/7/1/2/3/6/8/3/6]s**
15	100	90	[4/4/3/3/4/3/4/3/2/2/1/2/3]s	**[1/7/7/1/3/4/4/5/2/4]s**
16	100	100	[3/4/3/4/3/2/3/3/2/1/4/3/2]s	**[1/1/2/8/1/5/6/4/8]s**

It can be seen from the table that the modified NSGA-II (Present study) approach has found a better solution than that ever reported before. It should also be pointed out that for this problem, that the objective function values are far better than MSGNS algorithm.

CONCLUSIONS

Hence the suitability of plant fiber composites for various The result for weight minimization of cylindrical skirt using modified NSGA-II approach is found to be better than those results obtained by using other optimization algorithms multiple start guided neighbour-hood search (MSGNS) algorithm

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