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Analytical and Experimental Optimization of Nylon Weave Woven Fabrics with Polyester Composite Thick Plates

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Abstract

The study in present paper deals with find the analytical and experimental for optimum of thick composite plate made of nylon weave woven fabrics with polyester (ply angle and stacking sequences) with two optimization strategy (linear programming LP and genetic algorithm GA) for simply supported thick plate with central point load condition tacking in consideration the price and weight of materials in used. A simulation program build with MATLAB to find out the optimum design and finally compare the results using ANSYS then for check the manufacturing quality of plates, the first natural frequencies of prepared plates and ANSYS model is compared.

From this paper results, the maximum difference between the LP and GA optimization with displacement ANSYS results are 5% and 7% respectively, and the maximum difference between the experimental and ANSYS of the first natural frequency results are 18% and 19% LP and GA results respectively.

Key words: optimization, composite materials, thick plates, mechanical properties of nylon weave woven.

Nomenclature

A_{ij} : extensional stiffness matrix. (N / m)
a: width .(m)
B_{ij}: bending extensional coupling stiffness matrix. (N / m)
b : length. (m)
c: thickness. (m)
D_{ij}: bending stiffness matrix. (N / m)
E_1, E_2, and E_3: are principles modulus of elasticity in x, y, and z axes, respectivily. (Gpa)
G_{12}, G_{23}, and G_{13}: are principles modulus of rigidity in x-y, y-z, and z-x planes, respectivily. (Gpa)
K: shear correction coefficient.
n: number of layers.
Q_x, Q_y, and Q_z: are materials stiffness in x, y, and z axes, respectively. (N/ m)
u, v, and w: are displacements of a point in x, y, and z axes, respectively. (m)
υ_{12}, υ_{23}, and υ_{13}: are principles Poisson's ratios in x-y, y-z, and z-x planes, respectively.
Φ_x, and Φ_y : are rotation a transverse, normal about the y and x axes, respectively.

Introduction

The design is the activity in which engineers accomplish the preceding task. The designer task is to create set of specification for making or manufacturing.

Optimization is a technique for improving or increasing the value of some numerical quantity that in practice may take the form of temperature, air flow, speed, pay-off in a game, political appeal, destructive power, information, monetary profit, and the like.

Optimum design of fiber composite plates presents one of the most interesting and yet intricate problems of structural mechanics. In order to optimally design such a plate, it must take in consideration the function, safety, reliability, cost, manufacturability, marketability. Fiber-reinforced composite materials are continuing to replace the conventional metals in primary and secondary aerospace structural elements owing to their best mechanical properties.

Currently not just aerospace companies use composite in most of its work, cars companies, civil construction companies, sport equipments companies, etc. use composite in most of its works and its use efficient and face not significant problems.

The thick plates is widely used in many things such as cars, aircrafts, civil constructions and the use of first-order shear plate theory give very good result in the design and optimization of thick plates and commonly use in all over the world because of the behave of the thick plates that make the neglecting of the effect of normal stress that perpendicular to the plate possible.

At 1977 **D. Philips et al [1],** developed a programming solution using Fortran77 based on linear programming to find the optimal design of thick composite for buckling constraints.

Seung Jo Kim and Nam Seo Goo[2], studied at 1992 the use of Fuzzy Environment to find optimal design of composite thick plates. There goal was minimize weight design for composite laminate plates.

At 1993 **T. Y. Kam et al [3],** published their paper that deals with dynamic programming with finite element method to find the optimum aspect ratio for composite thick plates that give maximum stiffness and low weight and find the natural frequencies for the plates.

Young Shin Lee et al.[4], published their paper at 1994 on optimal design of thick composite plates with static and dynamic constraints and take ply angle and ply thickness as design variables. They use a linear programming method and nonlinear optimization problem for various hybrid rectangular composite thick plates with arbitrary boundary conditions.

At 1994 **C. Huang and B. Kroplin[5],** presented their research that deals with multi-objective function to minimize while satisfying constraints such as the structural deformation and the limits on design variables, and they performed the stiffness analysis by the finite element method for optimal design of a rectangular thick plate.

At 2001 **Pavel Y. Tabakov [6**], use improve genetic algorithm to multi-dimensional design optimization combine with finite element method to find best analysis for stacking laminates and show that the stability of evaluation in direct coding less than for binary coding but the first coding much fast in find solution.

At 2004 **Roberto Brighenti [7],** use genetic algorithm with finite element method to perform the distribution and orientation of the laminates in the composite thick plates to had best distribution for desire bending load.

At 2007, **B. Paluch et al.[8],** combine finite element method with genetic algorithm to optimize composite structures with variable thickness.

Analysis of Composite Thick Plates

The static analyses of orthotropic plates have been topics of continued interest; a variety of analytical and discrete mathematical models based on different theories have been proposed. Generally, the models are based on classical plate theory in which plane sections remain plane and normal to the mid-surface after deformation, and first order shear theory which includes the transverse shear deformation. The classical plate theory can be regarded as a special case of the first order shear theory. According to both theories, the displacements, $u(x,y,z), v(x,y,z)$ and $w(x,y,z)$, at an arbitrary point in the plate can be represented as functions of mid-surface displacements and angular rotations as written in equation (1) in paragraph (2-1).

It is well known that when the aspect ratio of the plate increase, the applicability of the classical plate theory becomes questionable. If, in addition, the plate material is with the magnitude of the transverse shear, the inadequacy of the classical plate theory is even more pronounced **(K. K. Teh et al. [9]).**

As before the analysis of plates using classical laminated plate theory (CLPT) use for thick plate. The define of thick plates is not unique. There's a different standards use by researcher of different countries based on academic relations and actual needs of those countries, but the major characteristic that use to define thin or thick plates is the aspect ratio. This paper use the scale of **Dr. Reddy [10]**,that consider as, thickness ratio greater than ($1/20$) is thick plate.

First–Order Shear Theory for Laminated Composite Plates

In the First–order Shear Deformation plate Theory (FSDT), the **Kirchhoff** hypothesis is relaxed by removing the third part; i.e. the transverse normal do not remain perpendicular to the mid. surface after deformation. This amount to including transverse shear strains in the theory.

$$\begin{aligned} u(x,y,z) &= u^o(x,y) + z\Phi_x(x,y) \\ v(x,y,z,) &= v^o(x,y) + z\Phi_y(x,y) \\ w(x,y,z) &= w^o(x,y) \end{aligned} \quad (1)$$

Where ($u^o, v^o, w^o, \Phi_x, \Phi_y$) are unknown functions to be determined, and (u^o, v^o, w^o) are denote the displacements of a point on plane z = 0, and **[1]**

$$\Phi_x = \frac{\partial u}{\partial z} \qquad \Phi_y = \frac{\partial v}{\partial z} \tag{2}$$

Which indicate that Φ_x and Φ_y are the rotation of a transverse normal about the y and x axes respectively.

Laminate Constitutive Equations

Constitutive equations are that relate the force and moment resultants to the strain of laminate.
First, the resultants direct forces (not transverse) acting on a laminate are obtained by integration of the stresses in each layer of lamina through the laminate thickness.
As before:- **[24]**

$$[N] = \sum_{k=1}^{n} \int_{z_k}^{z_{k+1}} [\sigma] dz \tag{3}$$

So: **[24]**

$$\begin{bmatrix} N_x \\ N_Y \\ N_z \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} \\ A_{12} & A_{22} & A_{26} \\ A_{16} & A_{26} & A_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_x^{(0)} \\ \varepsilon_y^{(0)} \\ \gamma_{xy}^{(0)} \end{bmatrix} + \begin{bmatrix} B_{11} & B_{12} & B_{16} \\ B_{12} & B_{22} & B_{26} \\ B_{16} & B_{26} & B_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_x^{(1)} \\ \varepsilon_y^{(1)} \\ \varepsilon_{xy}^{(1)} \end{bmatrix} \tag{4}$$

Where $\varepsilon^{(0)}$ and $\varepsilon^{(1)}$ are vectors of the membrane and bending strains:**[24]**

$$\begin{bmatrix} \varepsilon_x^{(1)} \\ \varepsilon^{(1)}{}_y \\ \gamma_{xy}^{(1)} \end{bmatrix} = \begin{bmatrix} \dfrac{\partial \Phi_x}{\partial x} \\ \dfrac{\partial \Phi_y}{\partial y} \\ \dfrac{\partial \Phi_x}{\partial y} + \dfrac{\partial \Phi_y}{\partial x} \end{bmatrix} \tag{5}$$

For moments it is not different from above so,

$$\begin{bmatrix} M_x \\ M_y \\ M_{xy} \end{bmatrix} = \begin{bmatrix} B_{11} & B_{12} & B_{16} \\ B_{12} & B_{22} & B_{26} \\ B_{16} & B_{26} & B_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_x^{(0)} \\ \varepsilon^{(0)}{}_y \\ \gamma_{xy}^{(0)} \end{bmatrix} + \begin{bmatrix} D_{11} & D_{12} & D_{16} \\ D_{12} & D_{22} & D_{26} \\ D_{16} & D_{26} & D_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_x^{(1)} \\ \varepsilon^{(1)}{}_y \\ \gamma_{xy}^{(1)} \end{bmatrix} \tag{6}$$

A_{ij} is called extensional stiffness matrix, B_{ij} the bending-extensional coupling stiffness matrix and D_{ij} is bending stiffness matrix.

A_{ij}, B_{ij} and D_{ij} matrices can be written as:-**[10]**

$$A_{ij} = \sum_{k=1}^{n} \overline{Q}_{ij}^{(k)} (z_{k+1} - z_k)$$
$$B_{ij} = \frac{1}{2} \sum_{k=1}^{n} \overline{Q}_{ij}^{(k)} (z^2{}_{k+1} - z_k{}^2)$$
$$D_{ij} = \frac{1}{3} \sum_{k=1}^{n} \overline{Q}_{ij}^{(k)} (z^3{}_{k+1} - z_k{}^3) \tag{7}$$

Where (n) is the number of layers and ($\overline{Q}_{ij}$) is the materials stiffness of the K^{th} lamina
Now equations (4) and (6) can be written in a compact form as:-**[10]**

$$\begin{bmatrix} [N] \\ [M] \end{bmatrix} = \begin{bmatrix} [A] & [B] \\ [B] & [D] \end{bmatrix} \begin{bmatrix} [\varepsilon^{(0)}] \\ [\varepsilon^{(1)}] \end{bmatrix} \tag{8}$$

And the transverse force resultant across the lamina of thickness h be as:-**[10]**

$$\begin{bmatrix} Q_x \\ Q_y \end{bmatrix} = \int_{-\frac{h}{2}}^{\frac{h}{2}} \begin{bmatrix} \tau_{xz} \\ \tau_{yz} \end{bmatrix} dz \tag{9}$$

Since the transverse shear strains are represented as constant through the laminate thickness, it follows that the transverse shear stresses will also be constant. In composite thick plates, the transverse shear stresses vary at least quadratically through layer thickness. This discrepancy between the actual stress state and the constant stress state predicted by the (FSDT) is often corrected in computing the transverse shear force resultants (Q_x, Q_y) by multiplying the integrals in equation (10) with a parameter K, called shear correction coefficient, so:**[10]**

$$\begin{bmatrix} Q_x \\ Q_y \end{bmatrix} = K \int_{-\frac{h}{2}}^{\frac{h}{2}} \begin{bmatrix} \tau_{xz} \\ \tau_{yz} \end{bmatrix} dz \tag{10}$$

These amounts to modifying the plate transverse shear stiffness. The factor K is computed such that the strain energy due to transverse shear stresses in equation (11) equals the strain energy due to the true transverse stresses predicted by the three-dimensional elasticity theory. The constitutive equation for transverse shear forces be**:[10]**

$$\begin{bmatrix} Q_x \\ Q_y \end{bmatrix} = K \begin{bmatrix} A_{44} & A_{45} \\ A_{45} & A_{55} \end{bmatrix} \begin{bmatrix} \dfrac{\partial w_o}{\partial y} + \Phi_y \\ \dfrac{\partial w_o}{\partial x} + \Phi_x \end{bmatrix} \qquad (11)$$

Navier's Solution

Navier present a solution of bending of simply supported thick plates by double trigonometric series. For simply supported thick plate with (FSDT) analysis **(Fig.(1)).**The boundary conditions are satisfied by the following excretions:**[24]**

$$\begin{aligned} u_o(x,y) &= \sum_{n=1}^{\infty}\sum_{m=1}^{\infty} U_{mn} \cos\alpha x \sin\beta y \\ v_o(x,y) &= \sum_{n=1}^{\infty}\sum_{m=1}^{\infty} V_{mn} \sin\alpha x \cos\beta y \\ w_o(x,y) &= \sum_{n=1}^{\infty}\sum_{m=1}^{\infty} W_{mn} \sin\alpha x \sin\beta y \\ \Phi_x(x,y) &= \sum_{n=1}^{\infty}\sum_{m=1}^{\infty} X_{mn} \cos\alpha x \sin\beta y \\ \Phi_y(x,y) &= \sum_{n=1}^{\infty}\sum_{m=1}^{\infty} Y_{mn} \sin\alpha x \cos\beta y \end{aligned} \qquad (12)$$

where $\alpha = m\pi/a$ and $\beta = n\pi/b$

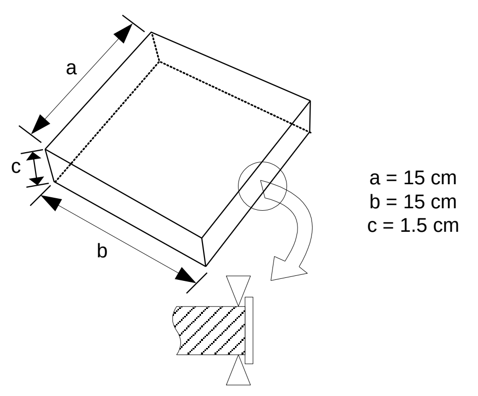

Fig. (1) Simply supported thick plate.

The mechanical load are also expanded in double Fourier sine series**:[24]**

$$q(x,y) = \sum_{n=1}^{\infty}\sum_{m=1}^{\infty} Q_{mn} \sin\alpha x \sin\beta y \qquad (13)$$

where :

$$Q_{mn}(t) = \frac{4}{ab}\int_0^a\int_0^b q(x,y)\sin\alpha x \sin\beta y \, dxdy \qquad (14)$$

The final form express be**:-[24]**

$$\begin{bmatrix} \hat{S}_{11} & \hat{S}_{12} & 0 & \hat{S}_{14} & \hat{S}_{15} \\ \hat{S}_{12} & \hat{S}_{22} & 0 & \hat{S}_{24} & \hat{S}_{25} \\ 0 & 0 & \hat{S}_{33} & \hat{S}_{34} & \hat{S}_{35} \\ \hat{S}_{14} & \hat{S}_{24} & \hat{S}_{34} & \hat{S}_{44} & \hat{S}_{45} \\ \hat{S}_{15} & \hat{S}_{25} & \hat{S}_{35} & \hat{S}_{45} & \hat{S}_{55} \end{bmatrix} \begin{bmatrix} U_{mn} \\ V_{mn} \\ W_{mn} \\ X_{mn} \\ Y_{mn} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ Q_{mn} \\ 0 \\ 0 \end{bmatrix} \qquad (15)$$

where:

$$\begin{aligned} \hat{S}_{11} &= (A_{11}\alpha^2 + A_{66}\beta^2) \\ \hat{S}_{12} &= (A_{12} + A_{66})\alpha\beta \\ \hat{S}_{14} &= (B_{11}\alpha^2 + B_{66}\beta^2) \\ \hat{S}_{15} &= (B_{12} + B_{66})\alpha\beta \\ \hat{S}_{22} &= (A_{66}\alpha^2 + A_{22}\beta^2) \\ \hat{S}_{24} &= \hat{S}_{15} \\ \hat{S}_{25} &= (B_{66}\alpha^2 + B_{22}\beta^2) \\ \hat{S}_{33} &= K(A_{55}\alpha^2 + A_{44}\beta^2) \\ \hat{S}_{34} &= KA_{55}\alpha^2 \\ \hat{S}_{35} &= KA_{44}\beta \\ \hat{S}_{44} &= (D_{11}\alpha^2 + D_{66}\beta^2 + KA_{55} \\ \hat{S}_{45} &= (D_{12} + D_{66})\alpha\beta \\ \hat{S}_{55} &= (D_{66}\alpha^2 + D_{22}\beta^2 + KA_{44}) \end{aligned}$$

Optimization

Optimization is a field of applied mathematics consisting of a collection of principles and methods used for the solution of quantitative problems in many disciplines, including physics, biology, engineering, economics, and business, evolutionary methods, and control. The operation uses the calculation of weight of plates, cost and

Navier's solution as evaluation criterion. The calculations made by equation (13).

The methods that used in this research are divided into two main types, first, approximation methods, and that achieved by using linear programming with random equations sets, and the second type represents in knowledge-based information systems or Evolutionary computing algorithms are designed to mimic the performance of biological systems, and that the Genetic Algorithms. Genetic Algorithm or (GA) use a techniques derived from biology and rely on the application of Darwin's principle of survival of the fittest. When a population of biological creatures is allowed to evolve generations, individual characteristics that are useful for survival tend to be passed on to future generations, because individuals carrying them get more chances to breed. In biological populations these characteristics are stored in what called chromosomal strings. The mechanics of natural genetics is based on operations that result in structured yet randomized exchange of genetic information between the chromosomal strings of the reproduction parents and consists of reproduction, crossover, occasional mutation and inversion of the chromosomal strings. A program written with MATLAB use linear programming associated with probabilistic equations to achieve best optimized laminated plate. The input data (mechanical properties and dimensions) taken from experimental work and desired design **(Fig.(2))** show the flow chart.

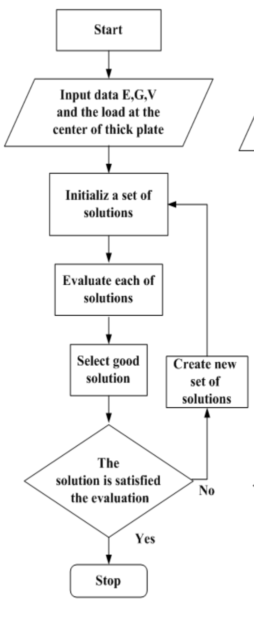

Fig.(2) Flow linear chart of programming optimization.

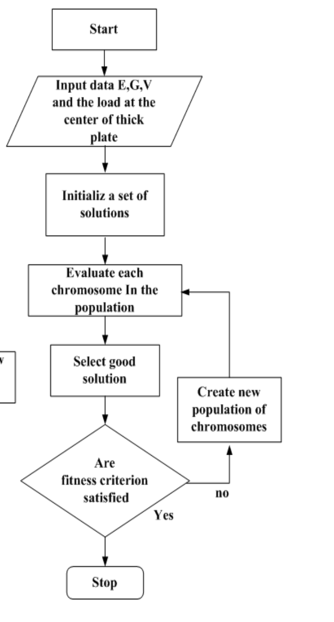

Fig.(3) Flow chart of real coding GA optimization technique.

Experimental Works

Structural optimization is a process by which the optimum design is aimed while satisfying all the defined constraints. In recent years, using thick composite materials in fabrication of mechanical, aerospace, marine and machine industries are of major concern, due to their high strength and light weight.

The design variables are ply angle and stacking sequence so the optimization made on finding high strength with low price. The laminate analysis based on (FSDT) so it is widely used for the analysis of thick plates and recommended in many papers and research. The analysis should have a known input and known output, in other words, it may be used a quantity of something can be easily measured and control in input data and the effect as well as before, so this research use Navier's solution in analysis of square plat had area (a*b*c) equal to (15*15*1.5) cm^3,and use constraint load act in the middle of the plate.

The aim of this section is to find mechanical properties of laminated in used to form the thick plates in study.

Preparing Testing Samples

First of all programs needs mechanical properties database of chosen material that needed or be desired to use in constructing thick composite plates so preparing testing samples with different angles of fibers according to ASTM specimens, to find out mechanical properties.

The materials that used in this study are polyester resin and nylon weave woven fibers. Polyester resin (NCS 942) that made by SRBS Company. The mixture need 24 hours or more (according to environmental conditions) to solidification, and the mixture done by 1 unit volume of hardener to 100 unit volume of resin. The reinforcement of thick composite plates should contain at least two different types of reinforcements. It is commonly use in Iraqi's markets and consider cheap comparing with other type of reinforcements that used in composite structures manufacturing. Fiber nylon weave woven has many advantages, such as, good physical properties, high strength to weight ratio, good resistance to chemical agents and it's relatively not costly. The samples made by using hand lay p method; cutting samples as ASTM chart D638 and test it with tensile test apparatus **(Fig.4)** associated with strain gage to find out mechanical properties, and are listed in **Table (1)** below.

Fig. (4) Tensile test device

Table (1) Mechanical properties of composite reinforcement experimentally results.	
Nylon weave woven \ polyester properties	
E_1(GPa)	21.8
E_2(GPa)	4.6
E_3(GPa)	4.6
υ_{12}	0.32
υ_{23}	0.38
υ_{13}	0.32
G_{12}(GPa)	3.1
G_{23}(GPa)	2.72
G_{13}(GPa)	3.1

Optimization programs give the results that shown below and according to these results, eight layers (0^o – 90^o) and (45^o / - 45^o) plates constructed with hand lay - up methods and supported with the device that shown in **Fig. (5).**

Fig.(5) Vibration test equipments.

It's used to find the first natural frequency, comparing its results with ANSYS V(11) results. **Tables (2), and (3)** with **Figure**s **(6)** a**nd (7)** show the results.

Table (2) LP programs results for eight layers (0^O / 90^O).

Load value (N)	**Load condition**	**Area (cm^2)**	**LP test displacement (m)**	**ANSYS displacement w(m)**
100	Central Load	22.5	0.20e-6	0.21e-6
300	=	=	0.382 e-6	0.39e-6
600	=	=	0.824e-6	0,84e-6
1000	=	=	1.4e-6	1.42e-6

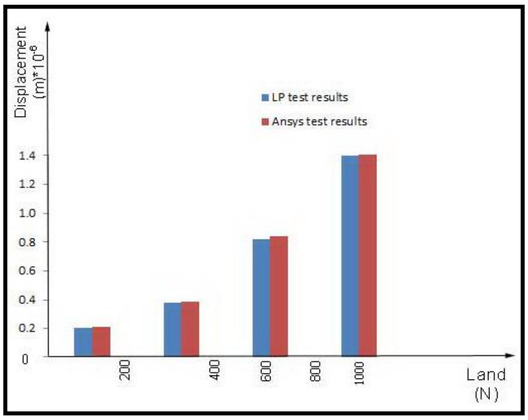

Fig. (6) Load versus displacement for LP and ANSYS tests results (ply angle 0°/90°).

Table (3) GA programs results for eight layers (45^O / - 45^O).

Load value (N)	**Load condition**	**Area (cm^2)**	**GA test displacement (m)**	**ANSYS displacement w(m)**
100	Central Load	22.5	0.34e-6	0.366e-6
300	=	=	0.428e-6	0.437e-6
600	=	=	0.901e-6	0.9232e-6
1000	=	=	1.622e-6	1.653e-6

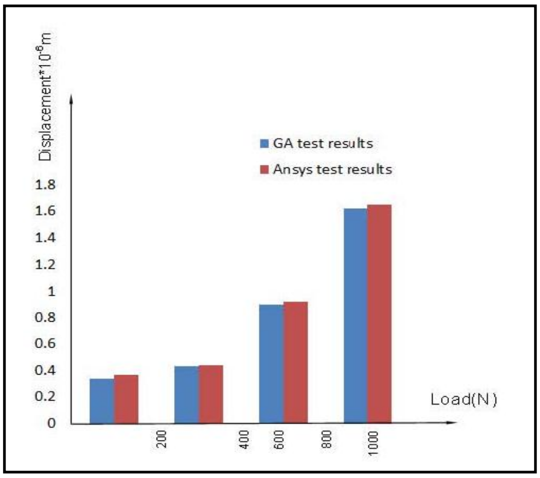

Fig.(7) Load versus displacement of GA and ANSYS tests results (ply angle 45°/ -45°).

Tables (4) and **(5)** with **Figures (8)** and **(9)** show the first natural frequency experimentally and ANSYS by two optimizations strategy results.

Table (4) First natural frequency results of LP optimized thick plates for ten layers.

Ω Experimentally Results (Hz)	Ω with ANSYS Analysis Results (Hz)	Layers
1900	2242	(0°/ 90°)
3100	3443	(45°/-45°)
3200	3532	(30°/60°)
4800	4239	(Random)

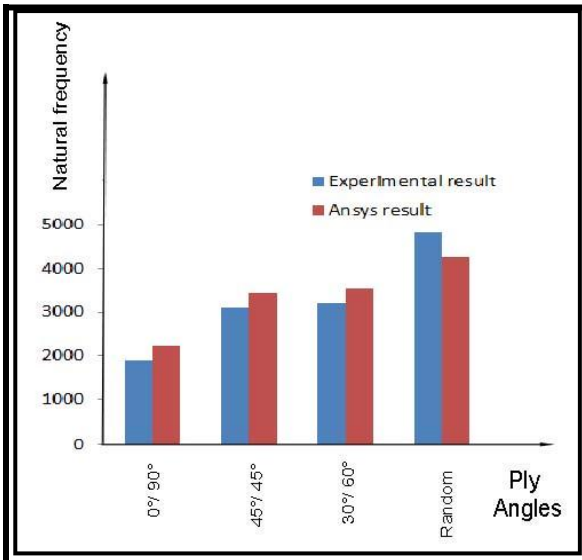

Fig.(8) Ply angles versus first natural frequency for experimental and ANSYS results of LP optimized plates. (10 layers).

Table (5) First natural frequency results of GA optimized thick plates for eight layers.

Ω Experimentally Results (Hz)	Ω with ANSYS Analysis Results (Hz)	Layers
2900	3453	(0°/ 90°)
5000	5345	(45°/-45°)
3900	4458	(30°/60°)
2800	3097	(Random)

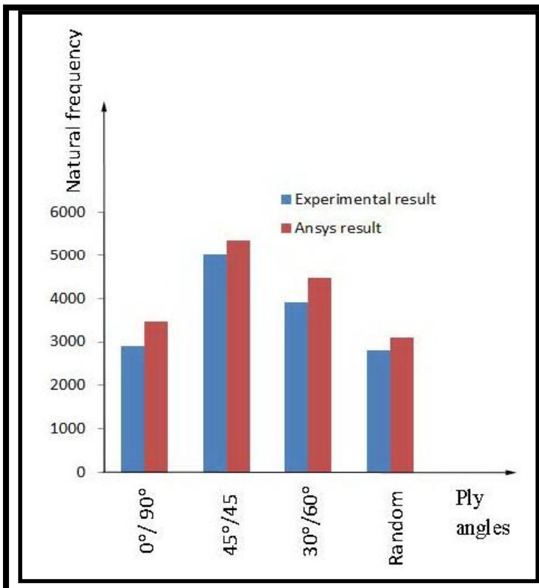

Fig.(9) Ply angles versus first natural frequency for experimental and ANSYS results of GA optimized plates. (8 layers).

Results

Table (2) and **(3)** with **Figures (6)** and **(7)** show the results for plates by both methods, genetic algorithm and linear programming. Genetic algorithm more efficient than linear programming as shown. The test of natural frequency done by initiating fully controlled sine wave formed by MATLAB program then delivering it using interfacing device to simply supported thick plate (as shown in **Fig. (5)**). The mechanical properties tacking directly from actual measurement from samples of prepared plate to ensure the mechanical properties, but the defect caused by using hand lay-up preparing method, such as air bubbles and material clustering could be propped with comparing first natural frequencies of ANSYS and experimental results, as shown in **Table (4)** with **Figure (8)** for LP optimization, and **Table (5)** with **Figure (9)** for GA optimization**.**

Discussion

Linear programming was less efficient than genetic algorithm, while genetic algorithm need processing and computational ability (that is less important in 21th century) and this difference can be tested with how much genetic algorithm program consumes of processor and memory of computer. The results of ANSYS and MATLAB programs are with no significant differences ,so the mathematical modeling nearly the same the real model. The maximum error of natural frequency experimentally and numerically (using ANSYS) difference near 19%, and that caused from defects during preparation, but it's not big enough difference, so it can be regarded trough to be said that the preparation was good enough. The maximum first natural frequency is found when the composite layers are randomly for LP optimization of ten layers, as shown in **Table (4),** and is found in (45^o / - 45^o) composite layers for GA optimization of eight layers, as shown in **Table (5)**.

Conclusions

1. Using genetic algorithm better than oldest method of optimization such as linear programming, and hand lay-up method of preparing practically accepted.

2. The maximum difference between the LP and GA optimization with displacement ANSYS results are 5% and 7% respectively.

3. For the same materials, number of layers, cross sectional area of composite plates, and for same central load values,, the maximum displacements for (45^o/-45^o) layers arrangement are greater than that for (0^o/90^o) layers arrangement.

4. The maximum difference between the experimental and ANSYS of first natural frequencies results are 18% and 19% for LP and GA optimization respectively.

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المثالية التحليلية والعملية للألواح السميكة المصنعة من المواد المتراكبة المدعمة بألياف طويلة من نسيج النايلون المغمور بالبولي أستر

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الخلاصة

البحث الحالي يدرس تحليليا وعمليا مثالية المواد المتراكبة المدعمة بالألياف الطويلة المصنعة من ألياف نسيج النايلون المغمور بالبولي استر حيث استعملت إستراتيجيتان وهما البرمجة الخطية والحساب الجيني للتصميم (على أساس التتابع الطبقي وزوايا الميلان) للصفائح السميكة البسيطة التثبيت تؤثر عليها قوه متمركزة وسطيا مع الأخذ بنظر الاعتبار مسألة السعر والوزن للمواد المستعملة. كتب برنامج نمذجة ال MATLAB لإيجاد التصميم الأمثل ومقارنة النتائج مع ال ANSYS وللتأكد من جودة عملية تصنيع الصفائح فان الترددات الرنينية حسبت عمليا وباستعمال ال ANSYS وتمت المقارنة بين النتائج.

وقد وجد من خلال نتائج هذا البحث أن أقصى اختلاف بين نتائج الإزاحات المستخرجة من مثالية إستراتيجيتا البرمجة الخطية والحساب الجيني مع نتائج ال ANSYS كان 5% و 7% على الترتيب, كما وجد أن أقصى اختلاف بين نتائج التردد الطبيعي الأول العملية بالمقارنة مع ال ANSYS هي 18% و 19% لأستراتيجيتا البرمجة الخطية والحساب الجيني على الترتيب.