Mansoura Engineering Journal, (MEJ), Vol. 35, No. 2, June 2010.

Optimization of Fiber-Reinforced Composite Plate for Maximum Buckling Strength

التصميم الأمثل لألواح المواد المركبة المقواه بالألياف للحصول على أعلى مقاومة إنبعاج

Abdou Abdel-samad[1], N. Fouda[2], M. Hussein[3]

[1]Associate Professor, Production Engineering and Mechanical Design Department, Faculty of Engineering, Mansoura University, Mansoura, Egypt.
[2] Lecturer, Faculty of Engineering, Mansoura University, Mansoura, Egypt.
[3] Demonstrator, Faculty of Engineering, Mansoura University, Mansoura, Egypt.

الملخص العربى

يعتبر من مميزات المواد المركبة عن المواد التقليديه هو سهولة تعديل خصائصها لكى تلائم متطلبات محدده لتطبيق معين. يكون هذا التعديل لخصائص المواد المركبه والوصول لأعلى خصائص ميكانيكية عن طريق تغيير زوايا الألياف المقويه لطبقات الماده والوصول بهذه الزوايا إلى القيمه المثلى. لذلك تم عمل دراسه نظرية الغرض منها أولا: تحديد تأثير التماثل وعدم التماثل للطبقات المكونه للماده وكذلك تأثير العوامل المحيطه على سلوك الإنحناء لألواح المواد المركبه المقواه بألياف الزجاج وذلك يتم بإستخدام شكلين مختلفين من ترتيب الألواح [90/45/−45/0]as و [90/45/−45/0]s وإعتبارهما التصميم الإبتدائى ، ثانيا: الأختيار الأمثل لزوايا الألياف وذلك لزياده حمل الإنحناء الذى تتحمله المواد المركبه المقواه بألياف الزجاج،وأخيرا مقارنة قيم حمل الإنحناء الإبتدائيه وكذلك قيم زوايا الألياف الإبتدائيه بالقيم المثاليه لحمل الإنحناء وكذلك قيم زوايا الألياف المثاليه. الظروف الخارجيه الأربعه في هذه الدراسه هى Clamped–Clamped [CC], Clamped–Pinned [CP], Pinned–Pinned [PP] and Clamped-Free [CF]). وقد أظهرت النتائج أن حمل الإنحناء يتأثر تأثر كبير بتغير العوامل المحيطة ويكون أكبر حمل إنحناء فى clamped clamped boundary condition أما أصغر حمل إنحناء فى clamped free boundary condition.

Abstract:

An advantage of composite materials over conventional ones is the possibility of tailoring their properties to the specific requirements of a given application. The tailoring is mostly achieved by maximizing the mechanical properties as a result of selecting the fiber angles of the layers optimally so A numerical study was carried out, First to determine the effects of symmetric and anti-symmetric laminate configuration and various boundary conditions on the buckling behavior of E/glass-epoxy composite plates using two different initial laminate configurations ($[90/45/-45/0]_{as}$ and $[90/45/-45/0]_{s}$) as initial fiber orientation, Second to optimize the fiber orientation (ply angles) for maximizing the critical buckling load of E/glass-epoxy composite plates, Finally the initial buckling values and initial fiber angles were compared with optimum buckling values and Optimum fiber angles for the same boundary condition. The four boundary conditions in this study are

---

Accepted June 30, 2010.

(clamped–clamped [CC], clamped–pinned [CP], pinned–pinned [PP] and Clamped-Free [CF]). The results mirrored that the buckling load have great effect by changing the boundary conditions. The maximum critical buckling load value is for clamped clamped boundary condition and the minimum value is for clamped free boundary condition. The buckling loads and fiber orientations of the laminated composite were calculated and optimized by ANSYS finite-element computer code.

Keywords: Laminated composites; buckling strength; Finite element analysis; Stacking sequence optimization; fiber orientation optimization.

1 Introduction

Fiber reinforced composites are used extensively in the form of relatively thin plate, and an important failure mode for these structures is buckling under in-plane loading [1]. The in-plane load carrying capacity of these structures can be maximized by using the fiber ply angle as a design variable and determining the optimal angles. Optimization of composite structures with respect to ply angles to maximize the critical buckling load is necessary to realize the full potential of fiber reinforced materials. The load carrying capability of composite plate against buckling has been intensively considered by researchers under various loading and boundary conditions.

B. Okutan Baba and A. Baltaci [2] carried a numerical and experimental study to determine the effects of anti-symmetric laminate configuration, cutout and length/thickness ratio on the buckling behavior of E/glass-epoxy composite plates. They concluded that the buckling loads of anti-symmetrically laminates are higher as compared to symmetric ones. The highest buckling load is provided by the imperforated [90/45/−45/0]as composites under clamped boundary condition for L/t=37.5. The buckling loads for clamped boundary conditions are higher than those for any simply supported conditions.

The optimum laminate configurations are anti-symmetric of long laminated composite cylindrical shells subjected to combined loads of axial compression and torsion [3]. Umut Topal and Ümit Uzman [4, 5] presented optimal design of simply supported laminated composite plates with and without central circular hole subject to given in-plane static loads for which the design objective is the maximization of the buckling load and the design variable is considered as the fiber orientation. The critical buckling loads are higher for laminates without a hole than those for laminates with a hole. As the number of layer increases, the differences of critical buckling load between with and without a hole decrease. The optimum fiber orientations are the same for laminated plates with a hole for all number of layers. H.-T. Hu and B.-H. Lin [6] maximized the buckling resistance of symmetrically laminated plates with a given material system and subjected to uniaxial compression with respect to fiber orientations by using a sequential linear programming method together with a simple move-limit strategy. The optimal fiber angles and the optimal buckling loads of thin square composite plates with a central circular cutout are influenced significantly by the end conditions. For thick square composite plates with a central circular cutout, the results of optimization of plates with two simply supported ends and two fixed ends are the same as those of plates with four fixed ends. M. G. Joshi and S. B. Biggers, Jr [7] modeled Isotropic plates and composite laminated plates using variable thickness, shear deformable, finite plate elements. The method of feasible directions is used to determine optimal thickness distributions over the plates that yield maximum uniaxial and biaxial buckling loads. Optimization produces increases in uniaxial buckling loads of over 200% for isotropic plates compared to uniform plates. Much smaller improvements are possible when biaxial compressive loads are present. Composite materials also allow for increased efficiency in the redistribution of loads and stiffnesses. M. Walker [9,10] presented a Finite element solutions for the optimal design of symmetrically laminated rectangular plates with central circular cut-outs subject to a combination of simply supported, clamped and free boundary conditions. The design objective is the maximization of the biaxial buckling load by determining the fiber orientations optimally with the effects of bending-twisting coupling taken into account. The results show that the difference in the buckling loads of optimal and non-optimal plates could be quite substantial, emphasizing the importance of optimization for fiber composite structures. B. Liu et al. [12] investigated a continuous variable optimization approach based on lamination parameters for the maximization of buckling loads for composite laminates and have compared its results with the combinatorial design of the stacking sequence via a genetic algorithm. It is shown that only for very thin panels with low aspect ratios is there a significant difference between the continuous and discrete solutions. O. Erdal and F.O. Sonmez [13] presented a method to find globally optimum designs for two-dimensional composite structures subject to given in plane static loads for which the critical failure mode is buckling. The aim is to maximize the buckling load capacity of laminated composites.

The results presented in literature indicate that the interaction among stacking sequence on the buckling behavior of laminated composites is needed to investigate in more detail. The aim of this study is to identify the effects of boundary conditions and to assess the impact of changing from a symmetric laminate to the anti-symmetric laminate on the buckling response of laminated composites and to maximize the buckling strength by changing the stacking sequence and the fiber ply angle for symmetrically and anti symmetrically laminated composite for different boundary conditions. Numerically predicted and optimized results are presented using a powerful and widely used commercial finite element software ANSYS and APDL (Ansys Parametric Design Language) is used to build the parameterized finite element model necessary for the optimization loop. The results obtained from this study will be beneficial to further studies about buckling characteristics of symmetric and anti-symmetric plates. Especially, it will be used to provide a comparison for new theoretical investigations.

2 Problem description

Two different initial laminate conFigurations ($[90/45/-45/0]_s$ and $[90/45/-45/0]_{as}$) were considered in this study, in order to investigate The buckling loads (P_{buc}) of E-glass/epoxy rectangular composite plates under uniaxial compressive loads. Although most laminates in use today are symmetric, the anti-symmetric laminated composites are also occasionally used to achieve the design requirements in special structure applications. Therefore, the symmetric and anti-symmetric laminated plates were selected in this study. The geometry of the E-glass/epoxy composite plate used in this study was shown in Fig. (1) the plate length, width and thickness were defined as L, W and t, respectively. The model used is a rectangular laminate of constant thickness 2 mm and constant width 25 mm with the 0^0 ply fiber axis Perpendicular to the length. The ratios of length to thickness (L/t) are chosen as 75. Eight-layered composite plates under clamped–clamped (CC), clamped–pinned (CP), pinned–pinned (PP) and Clamped-Free (CF) boundary conditions were considered as shown in Fig. (2) The thickness of each layer is 0.25 mm. The material considered in this paper is E/glass-epoxy with the following mechanical properties E1=39(Gpa), E1=E2=8.2(Gpa), G12=G23=G13=2.9 (Gpa),v12=v23=v13=0.29.

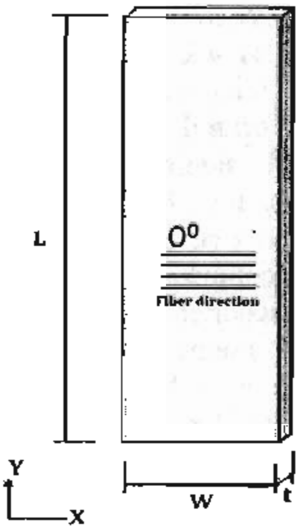
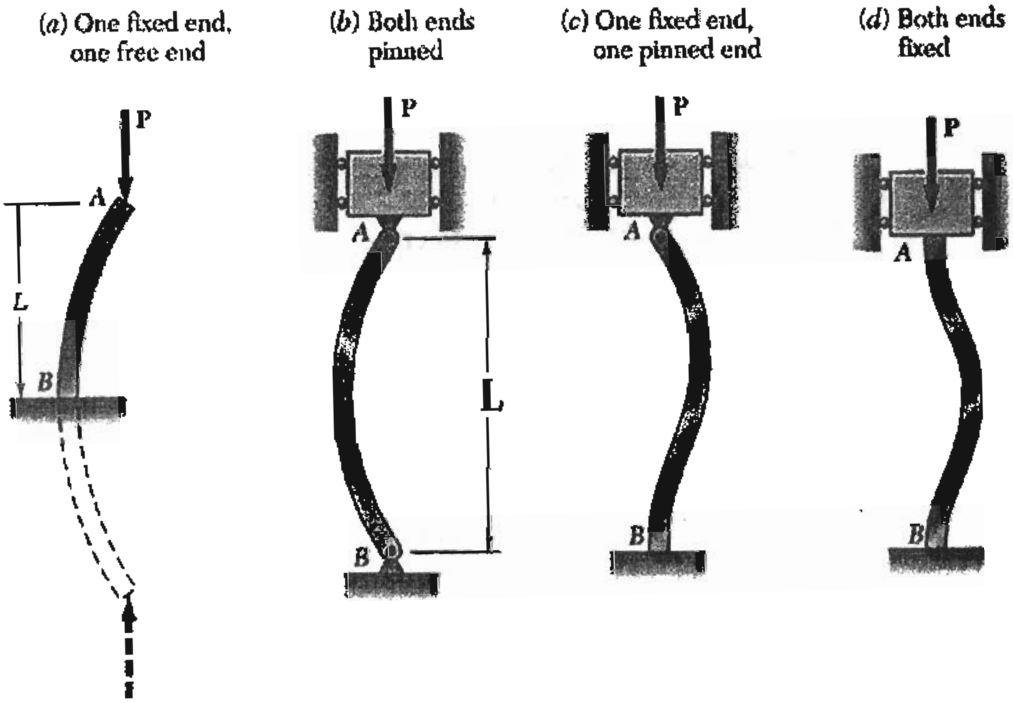


Fig. (1). Rectangular plate configuration for this study

3 Finite Element and Optimization Modeling

Buckling behavior of composite plates was investigated using finite element method. Ansys commercial software package were used to analyze the rectangular plate. Fig. (3) Shows boundary conditions and typical finite element meshes employed for the plates. The plate elements lie in the xy plane and z axis is the plate normal. To simulate clamped loaded edges, the displacements u, v, w and the rotations ϕ_x, ϕ_y, ϕ_z of all nodes at edges were set equal to zero and, to simulate pinned edges, the displacements u, v, w along the edges were constrained. The plates were subjected to axial compressive load acting downward. The plates were modeled using eight noded multilayered shell elements (SHELL 91), having six degrees of freedom at each node (translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes) .


(*a*) One fixed end, one free end

(*b*) Both ends pinned

(*c*) One fixed end, one pinned end

(*d*) Both ends fixed

Fig. (2) Various boundary conditions

The optimization problem considered is to find the optimal fiber ply angles and stacking sequence of the laminated composite plate to have the maximum buckling strength. Therefore the objective of this optimization problem is to maximize the buckling strength and the fiber orientations are taken as design variables.

4 Numerical Results and Discussions

Numerical results were presented to illustrate the changing parameters such as anti-symmetric and ply angles. The finite element analysis and optimization procedure are carried out to study the critical buckling load of laminated composite plate. The initial stacking sequence for E-glass/epoxy rectangular composite plates is ($[90/45/-45/0]_s$ and $[90/45/-45/0]_{as}$) then optimization is used to maximize critical buckling load through changing the ply angles.

All optimized buckling values are greater than initial one, as illustrated as the following.

1- The critical buckling loads of Clamped Clamped boundary condition are shown in Fig. (4). It is shown that for Symmetric plate the critical buckling load increased from 392 N in initial design $[90\ 45\ -45\ 0]_s$ to 1287 N in optimal design and for anti-symmetric plates the critical buckling load increased from 677 N in initial design $[90\ 45\ -45\ 0]_{as}$ to 1295 N in optimal design.

2- The critical buckling loads of Clamped Pinned boundary condition are shown in Fig. (5). It is shown that for

Symmetric plate the critical buckling load increase from 192 N in initial design to 490 N in optimal design and for anti-symmetric plate the critical buckling load increased from 332 N in initial design to 536 N in optimal design.

3- The critical buckling loads of Pinned Pinned boundary condition are shown in Fig. (6) It is shown that for Symmetric plate the critical buckling load increase from 91N in initial design to 285 N in optimal design and for anti-symmetric plates the critical buckling load increased from 156 N in initial design to 259 N in optimal design.

4- The critical buckling loads of Clamped Free boundary condition are shown in Fig. (7) It is shown that for Symmetric plate the critical buckling load increased from 23 N in initial design to 75 N in optimal design and for anti-symmetric plate the critical buckling load increased from 40 N in initial design to 66 N in optimal design.

The comparison between initial and optimal buckling loads for symmetric and anti-symmetric plates with different boundary conditions compiled in Table (1) which represents also the optimal fiber ply angles in symmetrically and anti-symmetrically laminated plates for all boundary conditions.

The result indicate that the greatest buckling load is for anti-symmetric plate under CC boundary condition for initial and optimal design and the lowest buckling load is for symmetric plate under CF boundary condition for initial and optimal design as shown in Fig. (8)

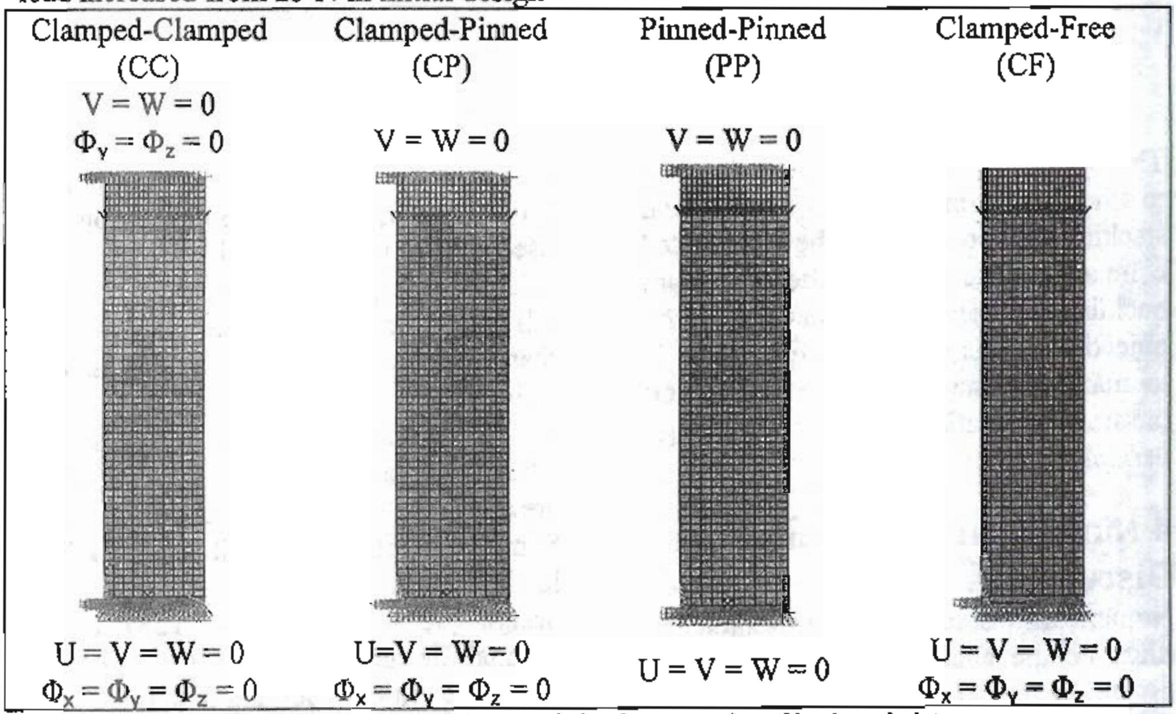


Fig. (3) Boundary conditions and finite element meshes of laminated plates

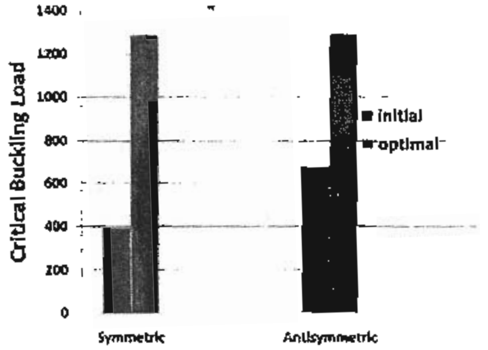


Fig. (4) Initial and optimal critical buckling load for symmetric and anti-symmetric laminated composite (Clamped - Clamped)

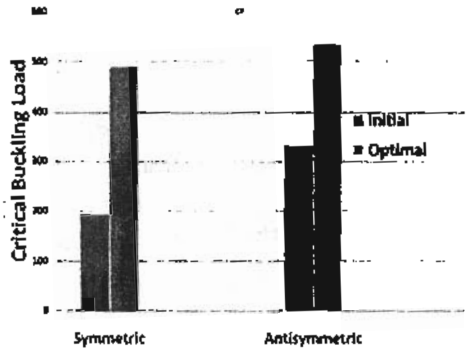


Fig. (5) Initial and optimal critical buckling load for symmetric and anti-symmetric laminated composite (Clamped - Pinned)

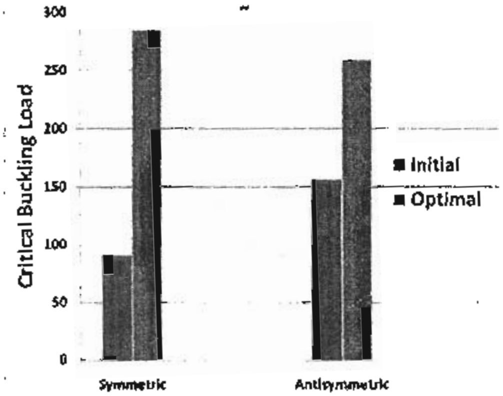


Fig. (6) Initial and optimal critical buckling load for symmetric and anti-symmetric laminated composite (Pinned - Pinned)

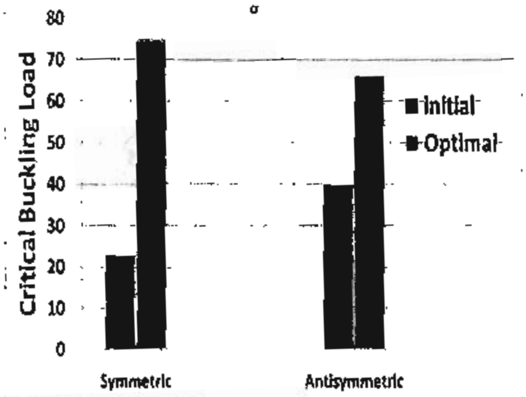


Fig. (7) Initial and optimal critical buckling load for symmetric and anti-symmetric laminated composite (Clamped - Free)

It was observed that for the initial design (the same ply angles) the buckling loads of anti-symmetrically laminated plates are higher than those of the symmetrically laminated plates for all boundary conditions; this is due to the effect of coupling stiffness which is associated with anti-symmetric laminate configuration. The increases percentage of critical buckling load between the initial anti-symmetric and initial symmetric design is about 72% for all boundary condition. As shown in Table (1). The increase percentage between initial buckling load and optimal buckling load varies with respect to the boundary condition and the plate type. It has the maximum value of 228% in clamped clamped symmetric plate, and the minimum value of 61% in clamped pinned anti-symmetric plate.

The ratio of the initial buckling load between symmetric and anti-symmetric sequence is similar and equal to 1.7 for all boundary conditions. Θ1 and Θ2 equal zero for all boundary conditions in initial and optimized plate.

5 Conclusions

An optimization of E-glass epoxy rectangular composite plates is investigated under uniaxial compressive load. It is found that the stacking sequence and the boundary conditions are the most significant parameters influencing the critical buckling load. It is concluded from the finite element analysis and the optimization procedure that; the buckling loads for clamped clamped boundary conditions are higher

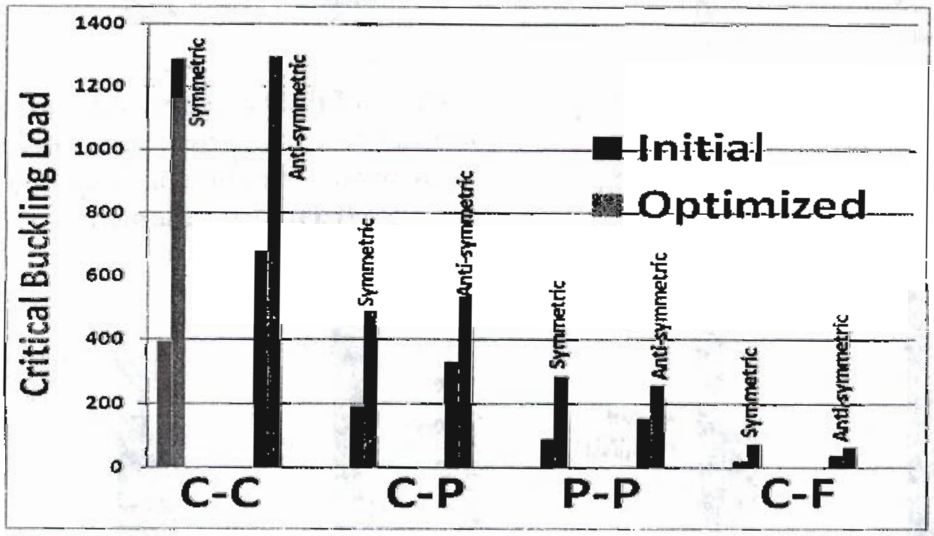


Fig. (8): Initial and optimal buckling load for all boundary conditions.

Table (1): Comparison between initial and optimal buckling load.

B.C.	Plate Sequence Type	Initial design	Optimum design	Optimal ply angles sequence				Percentage increased of the buckling load for optimal design	Ratio between initial buckling load of Symmetric and Anti-symmetric design	Percentage increased of initial buckling load between Symmetric and Anti-symmetric design
				Θ_1	Θ_2	Θ_3	Θ_4			
(C-C)	Symmetric	392	1287	2	0	0	24	228%	1.7	73%
	Anti-symmetric	677	1295	2	0	0	1	91%		
(C-P)	Symmetric	192	490	21	0	0	11	155%	1.7	73%
	Anti-symmetric	332	536	75	0	0	4	61%		
(P-P)	Symmetric	91	285	2	0	0	25	211%	1.7	71%
	Anti-symmetric	156	259	20	0	0	2	66%		
(C-F)	Symmetric	23	75	2	0	0	25	226%	1.7	74%
	Anti-symmetric	40	66	87	0	0	8	65%		

than those for simply supported conditions for initial and optimal design. The greatest buckling loads were recorded in anti-symmetric plates under CC boundary condition, and the lowest buckling loads were recorded in symmetric plates under PP boundary condition.The maximum increase Percentage between initial buckling load and optimal buckling load is for clamped clamped boundary condition and the minimum increase is for clamped pinned boundary condition. Ratio of initial buckling load between symmetric and anti-symmetric design is similar for all plates and all boundary condition and equal to 1.7.

6 References

[1]- Makarand G. Joshi and Sherrill B. Biggers, Jr ,"Thickness optimization for maximum buckling loads in composite laminated plates", Composites Composites: Part B 27B (1996), pp. 105–114.

[2]- Buket Okutan Baba, Aysun Baltaci ,"Buckling Characteristics of Symmetrically and Antisymmetrically Laminated Composite Plates with Central Cutout", J. Appl Compos Mater, Vol. 14, (2007), pp. 265–276.

[3]- Cezar G. Diaconu, Masaki Sato, Hideki Sekine ," Buckling characteristics and layup optimization of long laminated composite cylindrical shells subjected to combined loads using lamination parameters", J. Composite Structures, Vol. 58, (2002), pp. 423–433 .

[4]- Umut Topal, Ümit Uzman ,"Optimum design of laminated composite plates to maximize buckling load using MFD method", J. Thin-Walled Structures, Vol 45, (2007), pp. 660–669.

[5]- Umut Topal, Ümit Uzman ,"Maximization of buckling load of laminated composite plates with central circular holes using MFD method", J. Struct Multidisc Optim, Vol. 35, (2008), pp. 131–139.

[6]- Hsuan-Teh Hu, Bor-Horng Lin ,"BUCKLING OPTIMIZATION OF SYMMETRICALLY LAMINATED PLATES WITH VARIOUS GEOMETRIES AND END CONDITIONS", J. Composites Science and Technology, Vol. 55, (1995), pp. 277–285 .

[7]- Makarand G. Joshi and Sherrill B. Biggers, Jr,"Thickness optimization for maximum buckling loads in composite laminated plates", Composites Composites: Part B 27B (1996), pp. 105–114.

[8]- Umut Topal, Ümit Uzman ,"Multiobjective optimization of angle-ply laminated plates for maximum buckling load", J. Finite Elements in Analysis and Design, Vol. 46, (2010), pp. 273–279.

[9]- M. Walker, S. Adali and V. Verijenko ,"OPTIMIZATION OF SYMMETRIC LAMINATES FOR MAXIMUM BUCKLING LOAD INCLUDING THE EFFECTS OF BENDING-TWISTING COUPLING", J. Computers & structures, Vol. 58, (1996), pp. 313–319.

[10]- M. Walker ,"Optimal design of symmetric laminates with cut-outs for maximum buckling load", J. Computers

and Structures, Vol. 70, (1999), pp.337–343.

[11]- A.A. Smerdov ,"A computational study in optimum formulations of optimization problems on laminated cylindrical shells for buckling I. Shells under axial compression", J. Composites Science and Technology, Vol. 60, (2000), pp. 2057–2066

[12]- B. Liu, R.T. Haftka, P. Trompette ,"Maximization of buckling loads of composite panels using flexural lamination parameters", J. Struct Multidisc Optim, Vol. 26, (2004), pp. 28–36.

[13]- Ozgur Erdal, Fazil O. Sonmez ,"Optimum design of composite laminates for maximum buckling load capacity using simulated annealing", J. Composite Structures, Vol 71, (2005), pp. 45–52.