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Elastic Buckling Response of a Composite Panel Stiffened Around Cutouts

S. B. Rayhan*

School of Aeronautics, Northwestern Polytechnical University, Xi'an, China

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ABSTRACT

Perforated composite panels are widely used in many engineering applications as subcomponents of complex structures including aircraft, ships, and other transport vehicles. In many of these applications, the primary objective of using the panel is to resist buckling. In this present study, a finite element analysis is performed adopting popular commercial software code Ansys on the buckling behavior of a simply supported quasi-isotropic symmetric composite panel with central circular cutouts, reinforced with stiffeners on both sides of the cutouts under uniaxial, biaxial and combined loading conditions. The main objective is to achieve the elastic buckling response of the perforated composite panels considering some important aspects of the stiffener as follows: (1) effect of the presence of reinforcement, (2) effect of stiffener area, (3) effect of stiffener thickness, (4) effect of stiffener material and (5) effect of fiber orientation angle. It is observed that reinforcement can significantly improve the critical buckling load of a panel, which is already reduced due to cutouts. Then, increasing the area of the stiffener does not have a major impact on the buckling stability of the panels. However, increasing the thickness can play a crucial role to strengthen the buckling stability. Finally, it is found that in comparison to aluminum and titanium alloys, epoxy-carbon is more practical as a stiffener material with correct fiber orientation angle (90°), considering the low weight increment and higher buckling achievability.

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1. INTRODUCTION

Composite panels are often used as fundamental structural components in both the transportation and infrastructure industries. Cutouts are frequently found in these panels to meet the specific requirements based on applications like maintenance, pipe and cable access, hydraulic lines, weight reduction, etc. However, due to cutouts, in-plane compressive loading capability (also known as critical buckling) of thin-walled panels, reduces significantly with increasing cutout diameter [1-3]. Besides, various cutout shapes (circular, elliptical, square, triangular, etc.) present in the panel can significantly affect the critical buckling load [4], in some cases up to 50% [5]. In general, both circular and elliptical cutouts provide optimum buckling load [6] while their location in the panel is also crucial [7].

Among other important parameters, boundary and loading conditions have a great influence in the buckling load assessment of composite panels [8-11]. For instance, buckling load of a rectangular panel with clamped-clamped type boundary condition is twice that of clamped-simply supported condition, irrespective of various linearly varying in-plane compressive loads [12]. Furthermore, square panels with partial edge compression showed completely different behavior compared to those with full edge compression [13].

It is not always feasible to determine buckling strength of composite panels due to the complex setups (e.g., poor hand layup manufacturing process of composite panels [14], shear loading [15], etc.) and costs involved. On the other hand, readily available analytical formulas are not always applicable for panels, especially with cutouts [16]. Therefore, commercial finite element analysis (FEA) packages, namely, Abaqus, Ansys, MSC Nastran, etc., are widely adopted to conduct various parametric studies on the buckling strength of panels [17-22]. In most cases, the predicted buckling [23, 24] and

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*Corresponding Author Institutional Email: *rayhan,saiaf@mail.nwpu.edu.cn* (S. B. Rayhan)

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post-buckling [25] strength using FEM agrees quite well with the experiments. However , in some particular instances, the discrepancy may reach up to 30% due to imperfections found in the tested specimen, material and experimental boundary conditions [26].

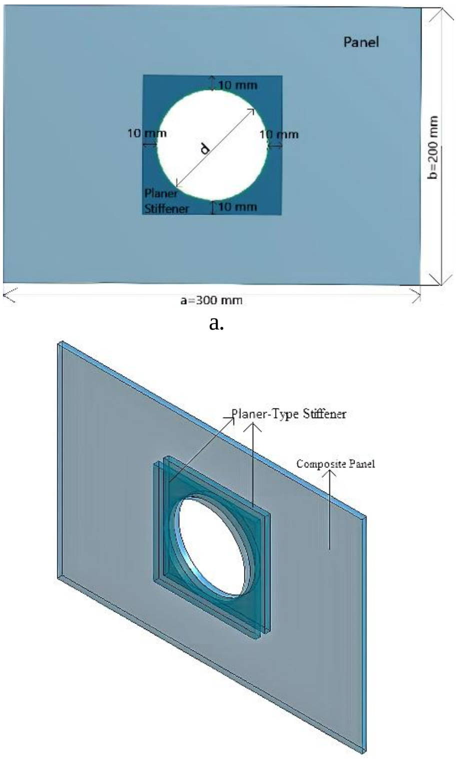
As described earlier, cutouts are inevitable in panels, which eventually decrease the in-plane compressive loading capability of structures. Therefore, it is common in offshore structures to adopt various reinforcement types to strengthen the buckling load capability of isotropic panels, which are mainly selected based on loading conditions [27]. Apart from that, perforated composite panels can also be strengthened with flange reinforcement, ring reinforcement, flange and ring reinforcement, and double ring reinforcement. It is reported that for composite panels under shear loading, double ring reinforcement is most effective; when considering both stress reduction and buckling stability [28]. Subsequent research reveals that the critical buckling load of a composite C-section flange can be increased by 20.9% with a reinforcing L-shape stiffener [29]. More recent investigation on the reinforcement of composite perforated panels suggests that longitudinal and planer type stiffener can improve the buckling load capacity of panels by 2.8 and 1.9 times in contrast to the panel without the stiffener, respectively [30].

While several contributions] are made to investigate the critical buckling load of the panels, only a few studies are reported to reinforce the cutouts and improve the buckling stability of the panels [1-13, 17-21, 23-30]. Moreover, no investigations are found to address the effect of reinforcement parameters like area and thickness of stiffener, stiffener material and fiber orientation angle of composite stiffener on the buckling stability of the panels. Therefore, the main objective of this current research is to study the critical buckling improvement of simply supported composite panels, while reinforcing planer type stiffeners on both sides of the panel around the cutout under three different loading conditions, namely uniaxial, biaxial, and combined loading, based on commercial finite element code Ansys.

2. PROBLEM STATEMENT

A quasi-isotropic symmetric layup $[0°/45°/-45°/90°]_{2s}$ is considered as a composite panel with a dimension of 300 mm (length, a) × 200 mm (width, b) × 3 mm [total thickness of the panel, 0.1875 mm (= t_{ply}) × 16] along with central circular cutouts having a diameter (d) of 20 mm, 40 mm, 60 mm, 80 mm, 100 mm and 120 mm. The cutouts are reinforced from both sides of the panel with square planer type stiffeners. These stiffeners have the same circular cutouts as the panels to which they are affixed. The length of each side of the stiffener is defined as 10 mm + d + 10 mm (see Figure 1). The thickness of each stiffener attached on both sides of the panel is 0.1875 mm (the same as a single ply thickness of composite laminate).

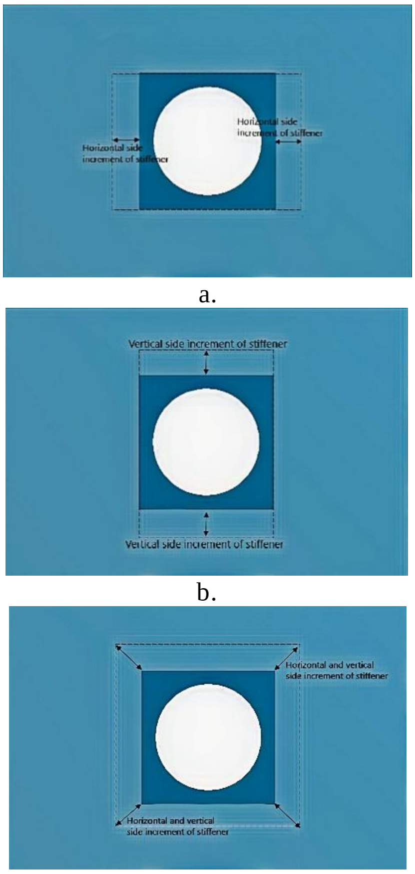
First, to study the effect of the area of the stiffeners, the horizontal sides are increased by 5 mm intervals up to 30 mm while the lengths of the vertical sides are kept fixed. Then, the vertical sides are lenghthened by similar 5 mm intervals while the lengths of the horizontal sides are kept constant. Next, both the horizontal and vertical sides are lengthened together in such a way that the area increase matches the area of the stiffeners in the previous steps of lengthening the horizontal or vertical sides. In summary, the buckling load due to cutout reinforcement is studied in the cases of incremental lengthening of the horizontal side of the planer stiffener, incremental lengthening of the vertical side of the planer stiffener, and incremental lengthing of both sides simultaneously (Figure 2). In addition, when investigation is conducted on the stiffener thickness, the initial area of the stiffener, that is, 10 mm + d + 10 mm, is kept constant while the thickness is increased as doubled, tripled and quadrupled for both the affixed stiffeners. Similarly, during the investigation of the area increment of stiffener, the initially assumed thickness of the stiffener is kept fixed, to be precise, 0.1875 mm. Finally, to study the effect of



a.

b.

Figure 1. Composite panel with circular cutouts and reinforced stiffeners; a: 2D view of the composite panel with stiffener and dimensions, b: 3D view of the stiffeners bonded with composite panels



a.

b.

c.

Figure 2. Area increment plan of stiffeners; a: Horizontal side increment plan, b: Vertical side increment plan, c: Simultaneous horizontal and vertical side increment plan

the material, both initial thickness and stiffener area are kept constant. The following assumptions are made to carry out the critical buckling investigations of the perforated panel:-

(1) The Planer stiffener is perfectly bonded with the panel around the cutouts. This assumption is valid since the study is limited to critical buckling which occurs in the elastic zone and does not have any effect on the connection until the sudden post-buckling collapse takes place in the plastic region [31].

(2) This investigation is limited to critical buckling only. Further first ply failure, damage, etc. are not sought since critical buckling itself is a type of failure which takes place far before the damage is initiated in the composite panels [32-34].

The material of the composite panel is assumed to be epoxy-carbon while for reinforced stiffener, aerospace type aluminum alloy T3-2024 is adopted. To compare the effect of the stiffener material on the buckling behavior of the perforated panel, apart from aluminum alloy, the same composite material of the panel with ply orietation of 0°,30°,45°,60°, 90°, and titanium alloy is chosen. The mechanical properties of all the materials used for this case study are given below in Table 1.

3. FINITE ELEMENT PROCEDURE

Commercial FE code Ansys is employed to investigate the eigenvalue buckling of the reinforced composite panel. Meshing the structure to prepare for finite element analysis is one of the most crucial steps since poor meshing adoption often leads to inappropriate results and special consideration should be taken for structures with discontinuity, for instance, the panel with holes. Therefore, for meshing the panel and the stiffener, mapped face meshing with quadrilateral shell elements is applied. Since the cutouts are sensitive, meshing is more refined towards the cutout (Figure 3). Besides, for each cutout ratio, the mesh element number is kept in such that increasing the element number would not lead to any further change in eigenvalue buckling.

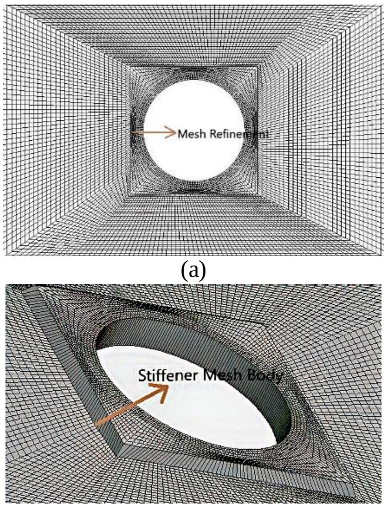
For the boundary conditions of the panel, all edges are considered as simply supported since most aerospace panels are simply supported [35]. Three loading cases are considered for the panel, namely, uniaxial, biaxial, and combined loading (shear and uniaxial together), (see Figure 4).

3. VALIDATION OF THE PRESENT STUDY

The present finite element analysis results are validated with available experimental data for various composite panels with central circular cutouts found in literature [36], (see Table 2). It can be observed that most of the current finite element predictions are closer to the experimental results than the author’s finite element results.

TABLE 1. Mechanical properties of Epoxy-Carbon Unidirectional, Aluminum and Titanium Alloy

Material	**Density, P (Kg/m^3)**	**E_{11} (GPa)**	**E_{22}=E_{33} (GPa)**	**G_{12}=G_{13} (GPa)**	**G_{23} (GPA)**	**V_{12}=V_{13}**	**V_{23}**
Epoxy-Carbon	1490	121	86	4.7	3.1	0.27	0.4
Aluminum Alloy	2780	73.1		27.481		0.33	
Titanium Alloy	4620	96		35.3		0.36	



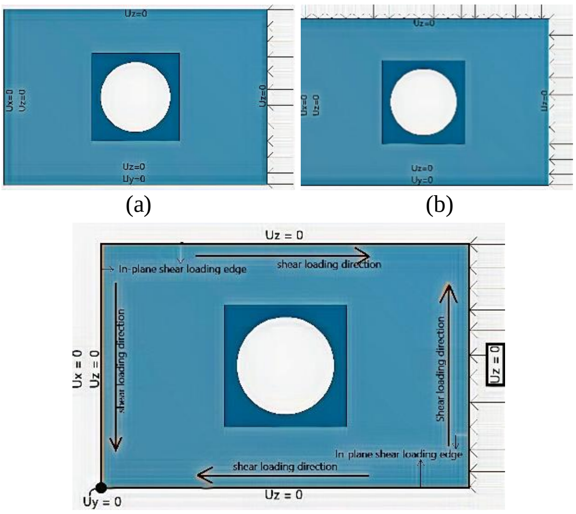
(a)

(b)

Figure 3. Composite panel meshing with stiffeners; a: Composite panel meshing with refinements, b: Closure view of stiffener meshed body

5. NUMERICAL RESULTS AND DISCUSSIONS

5. 1. Effect of Reinforcement Firstly, a comparative study of perforated composite panels with and without reinforcement is carried out to investigate the influence of stiffeners on the critical buckling load for cutout ratios (d/b) 0.1 to 0.6 as shown in Figure 5. It is observed that for all loading cases, stiffened panels show better critical buckling stability than panels without having stiffeners. The studies also revealed that, as the cutout ratio increases, due to the reinforcement, the percentage of buckling stability of a panel increases significantly compared to the same panel without having stiffeners (see Figure 6). The highest buckling achievement occurs for a combined loading case with the cutout ratio 0.6. In this case, reinforcing the panel improves buckling stability by 26%. However, for biaxial loading, the increment percentage is relatively low compared with other loading cases. Besides, for the cutout ratio of 0.1, reinforcement does not greatly affect the critical buckling load; it only changes by an increment of around 5% for all loading cases.



(a) (b)

(c)

Figure 4. Boundary conditions of the panel; a: Uniaxial loading, b: Biaxial loading, c: Combined loading

TABLE 2. Comparison of buckling loads with central circular cutouts

Plate length by plate thickness	Laminate Code	Boundary Condition	Author FE results, N	Experimental results, N	Present Study, N
75	$[90^\circ/45^\circ/-45^\circ/0^\circ]_s$	Clamped-Clamped	377.4	410	458.2
	$[90^\circ/45^\circ/-45^\circ/0^\circ]_{as}$		540.65	465	510.77
	$[90^\circ/45^\circ/-45^\circ/0^\circ]_s$	Clamped-Pinned	185.2	215	222.78
	$[90^\circ/45^\circ/-45^\circ/0^\circ]_{as}$		277.3	240.6	262.2
	$[90^\circ/45^\circ/-45^\circ/0^\circ]_s$	Pinned-Pinned	94.2	89.1	101.7
	$[90^\circ/45^\circ/-45^\circ/0^\circ]_{as}$		133.7	144.69	125.1
37.5	$[90^\circ/45^\circ/-45^\circ/0^\circ]_s$	Clamped-Clamped	1608.7	1326	1571
	$[90^\circ/45^\circ/-45^\circ/0^\circ]_{as}$		2120.3	2209	2000
	$[90^\circ/45^\circ/-45^\circ/0^\circ]_s$	Clamped-Pinned	792.7	759	755
	$[90^\circ/45^\circ/-45^\circ/0^\circ]_{as}$		1096.7	1244	1033.9
	$[90^\circ/45^\circ/-45^\circ/0^\circ]_s$	Pinned-Pinned	414.5	358	395.76
	$[90^\circ/45^\circ/-45^\circ/0^\circ]_{as}$		520.8	518	488

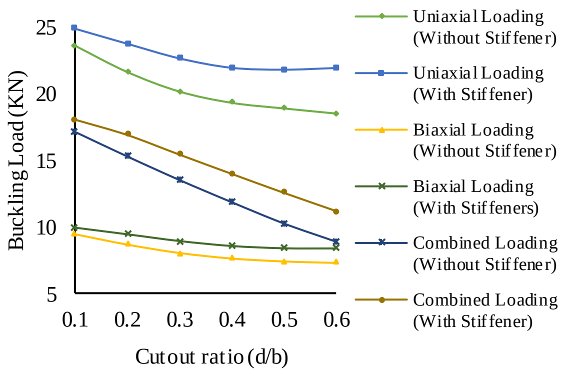


Figure 5. Buckling load of perforated panels with and without stiffeners

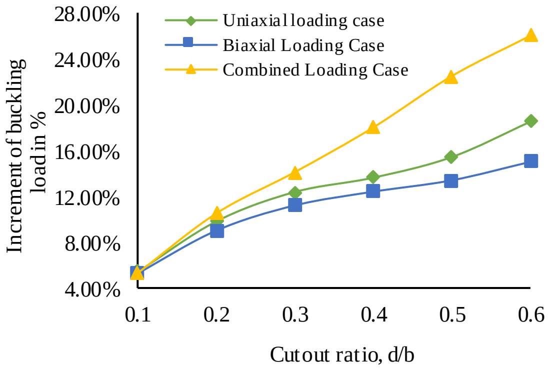
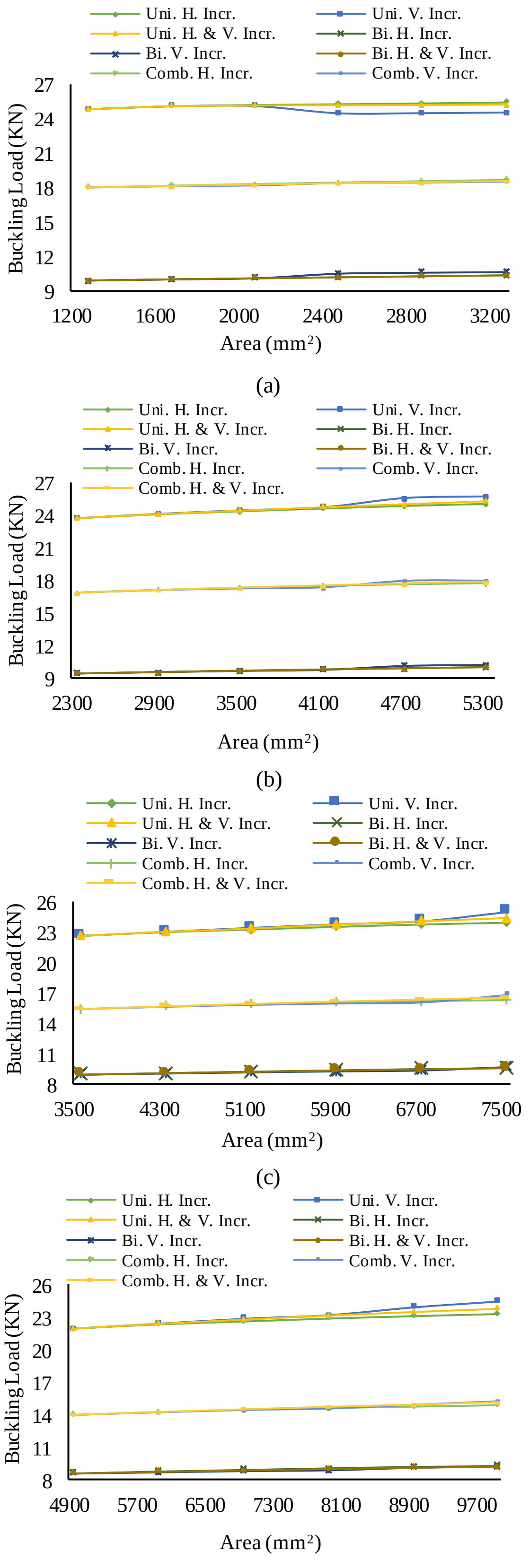


Figure 6. Cutout ratio vs. buckling load increment under various loading conditions

5. 2. Effect of Increasing the Area of Stiffeners

Since the reinforcement has a positive impact on the buckling load of perforated panels, a further investigation is performed by increasing the area of the stiffener to check whether additional area provides better stability to the panels. The results suggest that for any loading condition, increasing the area horizontally, vertically, or simultaneously does not have a major effect on the buckling behavior of reinforced panels with cutout ratio 0.1 and 0.2 as shown in Figures 7(a) and 7(b). Similar trends can be observed for cutout ratios 0.3 and 0.4 except for the uniaxial loading case, where the maximum increment of the vertical area provides an increment of 8% critical buckling value to the panel as illustrated in Figures 7(c) and 7(d). This trend continues for cutout ratios 0.5 and 0.6 too, where buckling strength can be further increased by 12 and 13.5%, respectively; for the highest increment of the area, as shown in Figures 7(e) and 7(f). For the other two loading conditions, the increment of the area of any form has minor effects on the overall critical buckling value of the panel observed in Figures 7(e) and 7(f).



(a)

(b)

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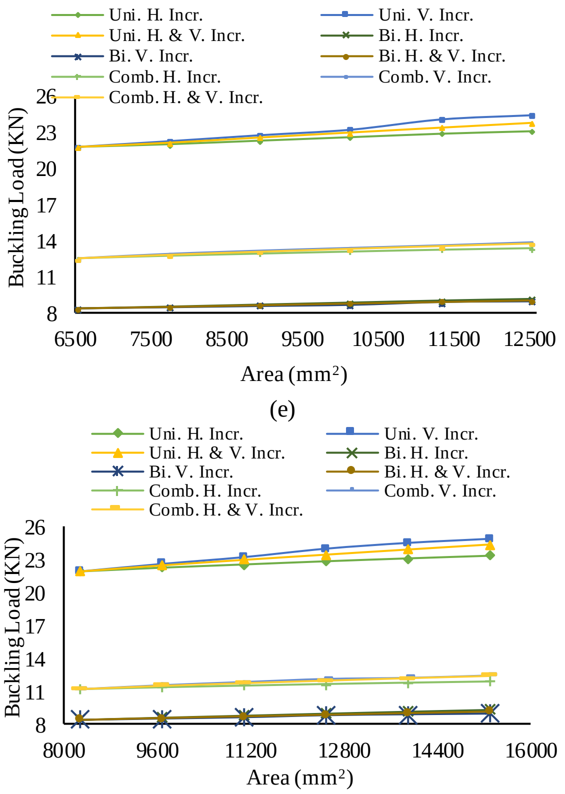
(d)



(f)

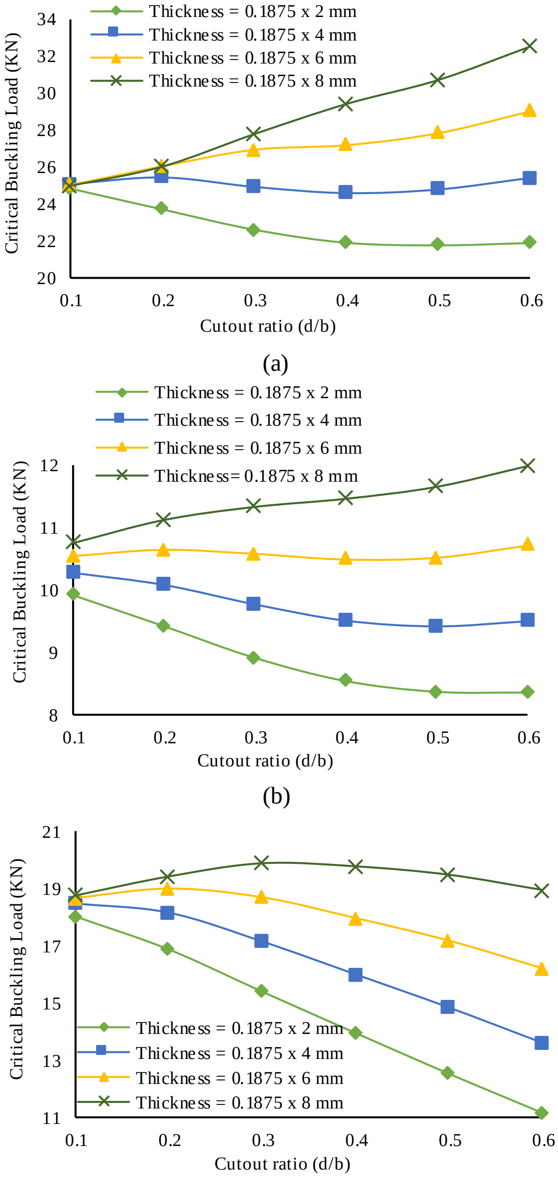
Figure 7. Effect of area increment of stiffener on the buckling load of panels; (a) Cutout ratio, d/b=0.1, (b) Cutout ratio, d/b=0.2, (c) Cutout ratio, d/b=0.3, (d) Cutout ratio, d/b=0.4, (e) Cutout ratio, d/b= 0.5, (f) Cutout ratio, d/b=0.6.

5. 3. Effect of Thickness of the Stiffener

Unlike the previously discussed case, increasing the thickness of the stiffeners has a major impact on the critical buckling load of the composite panels illustrated in Figures 8(a), 8(b), and 8(c). Even though, for cutout ratio 0.1, no significant load increase is observed. However, improvement of the buckling stability starts to take place from cutout ratio 0.2. For cutout ratio 0.3, for a thickness of 0.75 mm (×2) stiffener, the increment can be achieved up to 22.9, 27.1, and 29.87% for uniaxial, biaxial and combined loading, respectively. The highest impact on the critical buckling load due to increasing the thickness occured for cutout ratio 0.6 when doubling the thickness from 0.1875 to 0.375 mm for both the stiffeners will strengthen the buckling capacity of panels by 16.1, 13.67 and 22% for uniaxial, biaxial and combined loading cases, respectively. For a thickness of 0.75 mm (×2) stiffener, buckling strength can be increased further up to 49.5, 43.4 and 70% for uniaxial, biaxial and combined loading cases, respectively. Besides, for the uniaxial loading case, when the thickness of the stiffeners is 0.1875 mm × 6 and 0.1875 mm × 8, buckling load increases with the cutout ratios. A similar conclusion can be made for the biaxial loading caseas well, when 0.1875 mm × 8 reinforced stiffeners provide a rise in buckling load with the increase of cutout ratios. However, no such increase is observed for the combined loading case. Finally, it is important to note that increasing the thickness of stiffeners is most beneficial for strengthing stability of combined loaded panels.

5. 4. Effect of Stiffener Material and Fiber Orientation

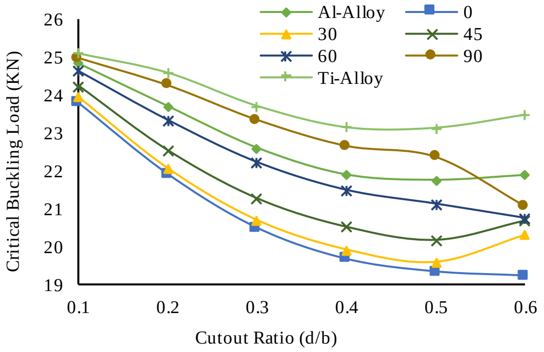
Reinforcement on a composite panel will definitely add up weights to the structure which should be minimized to achieve the desired strength of the panel. Material plays an important role to achieve the



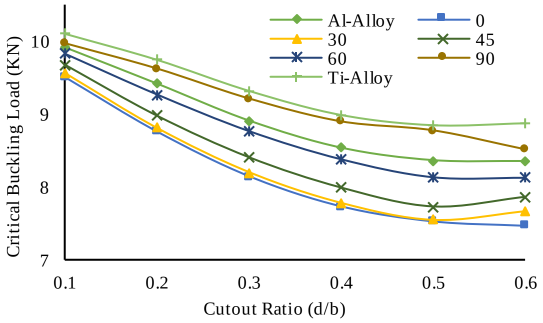
(c)

Figure 8. Buckling load at various thickness of stiffeners and cutout ratios at various loading conditions; (a) Uniaxial loading, (b)Biaxial loading; (c) Combined loading

convenient strength to weight ratio of a panel. Therefore, a detailed study is carried out on the stiffener material and it can be observed that, in case of composite stiffener, fiber orientation angle has a strong influence on the critical buckling load of composite panels. For all the loading cases and cutout ratios, changing the fiber orientation angle from 0° to 90°, leads to a sharp increase in the critical buckling load of the panels (see Figure 9). In comparison with the aluminum alloy, for all loading cases and cutout ratio, 90° fiber orientation performs slightly better than the alloy except for cutout ratio 0.6 when aluminum alloy provides a better stability to the uniaxial and combined loading cases up to 4.5 and 3.8%, respectively. Along with aluminum alloy and epoxy-carbon, titanium alloy is also investigated which outperforms both of them providing better stability to the panels. However, as described earlier, a strength to weight ratio must be maintained for lightweight structure; therefore, a comparison of weight increment and buckling load increment in percentage for all cutout ratios is shown in Figure 10. Interestingly, up until cutout ratio 0.3, for all loading cases, epoxy-carbon provides almost similar buckling strength to the panel compared with titanium alloy. However, for cutout ratio 0.4 and greater, titanium alloy provides increasingly more stability to the panels. This is most severe for uniaxial and combined loading cases and cutout ratio 0.6, when using titanium alloy provides almost 16.29 and 13% more stability to the panels. Nevertheless, looking at the weight increment, epoxy-carbon is more practical than titanium alloy because of its lower density.



(a)



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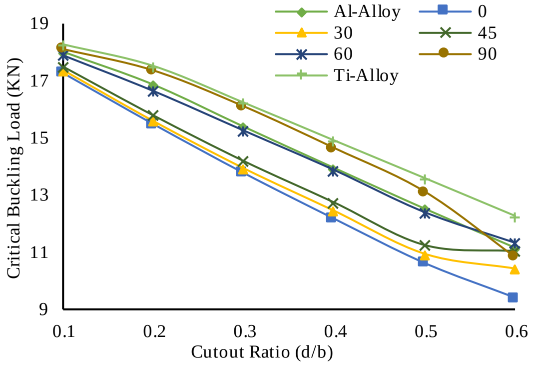
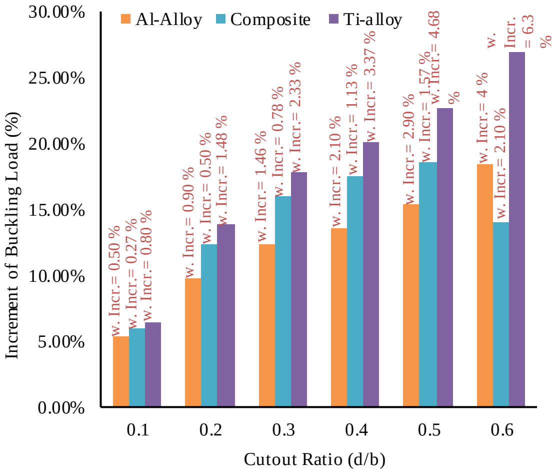


(c)

Figure 9. Stiffener material and fiber orientation angle on the buckling load at various loading condition; (a) Uniaxial loading, (b) Biaxial loading; (c) Combined loading



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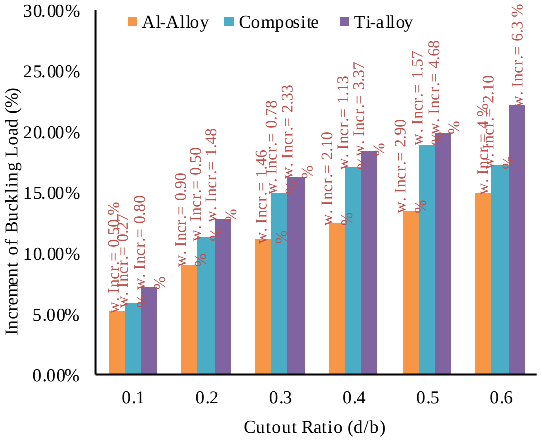

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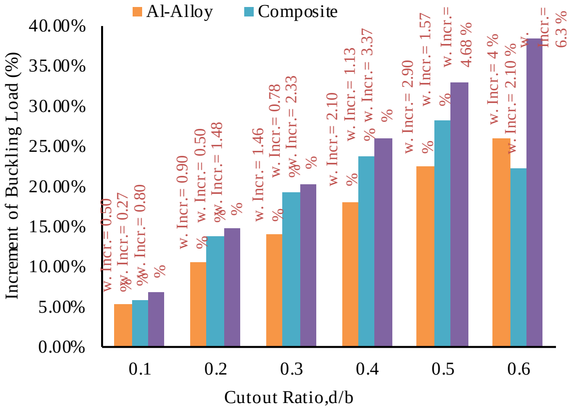

(c)

Figure 10. Effect of stiffener material weight and corresponding buckling increment; (a)Increment of Buckling load (in %) and weight increment (in %) at various cutout ratios under uniaxial loading case, (b) Increment of buckling load (in %) and weight increment (in %) at various cutout ratios under biaxial loading case, (c) Increment of buckling load (in %) and weight increment (in %) at various cutout ratios under combined loading case

6. CONCLUSION

A large number of simulations are carried out to investigate the effect of planer type stiffener as reinforcement to the quasi-isotropic perforated composite panels. Based on the investigations, key findings are outlined as follows.

1. Buckling stability of panels with smaller cutout ratios (0.1 and 0.2) does not improve greatlydue to reinforcement. Even increasing the stiffener thickness or choosing strong material like titanium alloy fails to increase the stability of the panels significantly. In summary, planar type stiffeners should not be chosen asreinforcement for smaller cutouts.

2. Planer reinforcement improves the buckling stability of the simply supported panels with central circular holes under any loading conditions.

3. The percentage of buckling stability that is due to reinforcement increases with increasing cutout area.

4. Increasing the area of the stiffener does not have a significant effect on the critical buckling load of the reinforced panels.

5. Increasing the thickness of the stiffener has a major impact on the critical buckling load of the panels.

For the uniaxial loading case, when the stiffener thickness is tripled and quadrupled, the critical buckling load of the panels increases with the cutout ratio.

6. In the case of choosing composite (epoxy-carbon) as stiffener material, fiber orientation has a great impact on the overall buckling stability of the panels.

7. For weight reduction and maximizing the critical buckling capability, composite (epoxy-carbon) material is preferable to metals (aluminum and titanium alloy)

8. Among all loading cases, the stability of stiffened panels under combined loading condition is mostly benefited from the reinforcement.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

1. Aydin Komur, M., Sonmez, M.,"Elastic buckling of rectangular plates under linearly varying in-plane normal load with a circular cutout." ***Mechanics Research Communications***, Vol. 35, No. 6, (2008), 361-371. DOI: 10.1016/j.mechrescom.2008.01.005.

2. Aydin Komur, M., Sen, F., Ataş, A., Arslan, N., "Buckling analysis of laminated composite plates with an elliptical/circular cutout using FEM. " ***Advances in Engineering Software***, Vol. 41, No. 2, (2010), 161-164. DOI: 10.1016/j.advengsoft.2009.09.005.

3. Onkar, A., Upadhyay, C., Yadav, D., "Stochastic Finite Element Buckling Analysis of Laminated Plates with Circular Cutout under Uniaxial Compression." ***Journal of Applied Mechanics***, Vol. 74, No. 4, (2006), 798-809. DOI: 10.1115/1.2711230.

4. Erkliğ, A., Yeter, E., "The effects of cutouts on buckling behavior of composite plates." ***Science and Engineering of Composite Materials***, Vol. 19, No. 3, (2012), 323-330. DOI: 10.1515/secm-2012-0011.

5. Rayhan, S., "A comprehensive study on the buckling behaviour of woven composite plates with major aerospace cutouts under uniaxial loading." ***Journal of Mechanical Engineering and Sciences***, Vol. 13, No. 2, (2019), 4756-4776. DOI: 10.15282/jmes.13.2.2019.01.0398.

6. Tercan, M., Aktaş, M., "Buckling behavior of 1×1 rib knitting laminated plates with cutouts." ***Composite Structures***, Vol. 89, No. 2, (2009), 245-252. DOI: 10.1016/j.compstruct.2008.07.030.

7. Jana, P., "Optimal design of uniaxially compressed perforated rectangular plate for maximum buckling load." ***Thin-Walled Structures***, Vol. 103, (2016), 225-230. DOI: 10.1016/j.tws.2015.12.027.

8. Ghannadpour, S., Najafi, A., Mohammadi, B., "On the buckling behavior of cross-ply laminated composite plates due to circular/elliptical cutouts." ***Composite Structures***, Vol. 75, (2006), 3-6. DOI: 10.1016/j.compstruct.2006.04.071.

9. Topal, U., Uzman, Ü., "Effects of nonuniform boundary conditions on the buckling load optimization of laminated composite plates." ***Materials & Design***, Vol. 30, No. 3 (2009), 710-717. DOI: 10.1016/j.matdes.2008.05.012.

10. Rajanna, T., Banerjee, S., Desai, Y., Prabhakara, D., "Effect of boundary conditions and non-uniform edge loads on buckling characteristics of laminated composite panels with and without cutout." ***International Journal for Computational Methods in Engineering Science and Mechanics***, Vol. 18, No. 1, (2017), 64-76. DOI: 10.1080/15502287.2016.1276350.

11. Maarefdoust, M., Kadkhodayan, M., "Elastoplastic Buckling Analysis of Plates Involving Free Edges by Deformation Theory

of Plasticity." ***International Journal of Engineering, Transections A: Basics***, Vol. 26, No. 4, (2013), 421-432. DOI: 10.5829/idosi.ije.2013.26.04a.11

12. Narayana, A., Rao, K., Kumar, R., "Buckling analysis of rectangular composite plates with rectangular cutout subjected to linearly varying in-plane loading using fem.", ***Sadhana***, Vol. 39, No. 3, (2014), 583-596. DOI: 10.1007/s12046-014-0250-9.
13. Singh, S., Kulkarni, K., Pandey, R., Singh, H., "Buckling analysis of thin rectangular plates with cutouts subjected to partial edge compression using FEM." ***Journal of Engineering, Design and Technology***, Vol. 10, No. 1, (2012), 128-142. DOI: 10.1108/17260531211211935.
14. Elkington, M., Bloom, D., Ward, C., Chatzimichali, A., Potter, K., "Hand layup: understanding the manual process." ***Advanced Manufacturing: Polymer & Composites Science***, Vol. 1, No. 3, (2015), 38-151. DOI: 10.1080/20550340.2015.1114801.
15. Islam, M., khan, A., Walter, S., Jian, L., "A Study of Shear Stress Intensity Factor of PP and HDPE by a Modified Experimental Method together with FEM", ***International Journal of Mechanical, Aerospace, Industrial and Mechatronics Engineering***, Vol. 7, No. 11 (2013), 1177-1178. DOI: 10.5281/zenodo.1088948.
16. Kassapoglou, C., Design and Analysis of Composite Structures, John Wiley and Sons Ltd, West Sussex, 2010. DOI: 10.1002/9781118536933.
17. Özben, T., "Analysis of critical buckling load of laminated composites plate with different boundary conditions using FEM and analytical methods." ***Computational Materials Science***, Vol. 45, No. 4, (2009), 1006-1015. DOI: doi.org/10.1016/j.commatsci.2009.01.003.
18. Mohtaram, Y., Kahnamouei, J., Shariati, M., Behjat, B., "Experimental and numerical investigation of buckling in rectangular steel plates with groove-shaped cutouts." ***Journal of Zhejiang University Science A***, Vol. 13, No. 6 (2012), 469-480. DOI: 10.1631/jzus.A1100226.
19. Okutan Baba, B., Baltaci, A., "Buckling Characteristics of Symmetrically and Antisymmetrically Laminated Composite Plates with Central Cutout." ***Applied Composite Materials***, Vol. 14, No. 4, (2007), 265-276. DOI: 10.1007/s10443-007-9045-z.
20. Baba, B., "Buckling Behavior of Laminated Composite Plates." ***Journal of Reinforced Plastics and Composites***, Vol. 26, No. 16, (2007), 1637-1655. DOI: 10.1177/0731684407079515.
21. Geng, X., Zhao, L., Zhou, W., "Finite-element buckling analysis of functionally graded GPL-reinforced composite plates with a circular hole." ***Mechanics Based Design of Structures and Machines***, Vol. 48, No. 1, (2020), 1-17. DOI: 10.1080/15397734.2019.1707688.
22. Yousefi Khatuni, S., Showkati, H., "Buckling Behavior of Semi-scale Steel Tank with Carbon Fiber Reinforced Polymer Ring Subjected to Lateral Uniform Pressure Loading." ***International Journal of Engineering, Transections A: Basics***, Vol. 32, No. 10, (2019), 1407-1415. DOI: 10.5829/ije.2019.32.10a.10.
23. Yazici, M., "Influence of Cut-Out Variables on Buckling Behavior of Composite Plates." ***Journal of Reinforced Plastics and Composites***, Vol. 28, No. 19, (2008), 2325-2339. DOI: 10.1177/0731684408092058.
24. Turan, K., "Buckling behavior of adhesively patch-repaired composite plates." ***Journal of Composite Materials***, Vol. 48, No. 26, (2013), 3253-3261. DOI: 10.1177/0021998313508801.
25. Erdem, S., Kaman, M. and Gur, M., "Post-buckling behavior of carbon fiber epoxy composite plates." ***Journal of Mechanical Science and Technology***, Vol. 33, No. 4, (2019), 1723-1730. DOI: 10.1007/s12206-019-0324-z.
26. Baba, B., "Buckling Response of Rectangular Laminated Composite Plates with Cutouts". ***Science and Engineering of Composite Materials***, Vol. 14, No. 1, (2007), 17-24. DOI: 10.1515/SECM.2007.14.1.17.
27. Kim, J., Jeon, J., Park, J., Seo, H., Ahn, H., Lee, J., "Effect of reinforcement on buckling and ultimate strength of perforated plates." ***International Journal of Mechanical Sciences***, Vol. 92, (2015), 194-205. DOI: 10.1016/j.ijmecsci.2014.12.016.
28. Guo, S., "Stress concentration and buckling behaviour of shear loaded composite panels with reinforced cutouts." ***Composite Structures***, Vol. 80, No. 1, (2007), 1-9. DOI: 10.1016/j.compstruct.2006.02.034.
29. Guo, S., Li, D., Zhang, X., Xiang, J., "Buckling and post-buckling of a composite C-section with cutout and flange reinforcement." ***Composites Part B: Engineering***, Vol. 60, (2014), 119-124. DOI: 10.1016/j.compositesb.2013.12.055.
30. Shojaee, T., Mohammadi, B., Madoliat, R., "Experimental and numerical investigation of stiffener effects on buckling strength of composite laminates with circular cutout". ***Journal of Composite Materials***, Vol. 54, No. 9, (2019), 1141-1160. DOI: 10.1177/0021998319874101.
31. Zhu, S., Yan, J., Chen, Z., Tong, M., Wang, Y., "Effect of the stiffener stiffness on the buckling and post-buckling behavior of stiffened composite panels – Experimental investigation." ***Composite Structures***, Vol. 120, (2015), 334-345. DOI: 10.1016/j.compstruct.2014.10.021.
32. Kong, C., Hong, C., Kim, C., "Postbuckling Strength of Composite Plate with a Hole." ***Journal of Reinforced Plastics and Composites***, Vol. 20, No. 6, (2001), 466-481. DOI: 10.1177/073168401772678652.
33. Kumar, D. and Singh, S., "Postbuckling strengths of composite laminate with various shaped cutouts under in-plane shear." ***Composite Structures***, Vol. 92, No. 12, (2010), 2966-2978. DOI: 10.1016/j.compstruct.2010.05.008.
34. Vummadisetti, S. and Singh, S., "Buckling and postbuckling response of hybrid composite plates under uniaxial compressive loading." ***Journal of Building Engineering***, Vol. 27, (2020). DOI: 10.1016/j.jobe.2019.101002.
35. Ion, D., "Buckling of Flat Thin Plates under Combined Loading." ***Incas Bulletin***, Vol. 7, No. 1, (2015), 83-96. DOI: 10.13111/2066-8201.2015.7.1.8.
36. Okutan Baba, B., Baltaci, A., "Buckling characteristics of symmetrically and antisymmetrically laminated composite plates with central cutout." ***Applied Composite Materials***, Vol. 14, No. 4, (2007), 265-276. DOI: 10.1007/s10443-007-9045-z.

Persian Abstract

چکیده

پانل های کامپوزیت سوراخ دار به طور گسترده ای در بسیاری از برنامه های مهندسی به عنوان زیرمجموعه های سازه های پیچیده از جمله هواپیما ، کشتی و سایر وسایل نقلیه حمل و نقل مورد استفاده قرار می گیرند. در بسیاری از این برنامه ها ، هدف اصلی استفاده از پانل مقاومت در برابر کمانش است. در این مطالعه حاضر ، تجزیه و تحلیل عناصر محدود با استفاده از کد نرم افزار محبوب تجاری Ansys در مورد رفتار کمانش یک صفحه مرکب متقارن شبه ایزوتروپیک متقارن با برش های دایره ای مرکزی ، تقویت شده با سخت کننده های دو طرف بریدگی تحت تک محوری ، دو محوری و شرایط بارگیری ترکیبی هدف اصلی دستیابی به پاسخ کمانش الاستیک صفحات کامپوزیت سوراخ دار با در نظر گرفتن برخی از جنبه های مهم ماده سخت کننده به شرح زیر است: ، (٤) اثر ماده سخت کننده و (٥) اثر زاویه جهت الیاف. مشاهده شده است که آرماتورها می توانند بار بحرانی کمانش یک صفحه را بهبود بخشند ، که در حال حاضر به دلیل بریدگی کاهش یافته است. سپس ، افزایش سطح ماده سخت کننده تأثیر زیادی در پایداری کمانش صفحات ندارد. با این حال ، افزایش ضخامت می تواند نقشی اساسی در تقویت ثبات کمانش داشته باشد. سرانجام ، مشخص شد که در مقایسه با آلیاژهای آلومینیوم و تیتانیوم ، با توجه به افزایش وزن کم و قابلیت کمانش بالاتر ، اپوکسی کربن به عنوان یک ماده سفت کننده با زاویه جهت الیاف صحیح (٩٠ درجه) عملی تر است..