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The Effects of Various Cut-Out Areas, Stacking Sequences And Fillers on The Buckling Loads of Composite Plates

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Abstract

The aim of this study is to investigate the effects of cut-out shapes, cut-out areas, stacking sequences and fillers on the critical buckling load of laminated composite plates. The numerical analysis has been carried out on the composites with and without cut-out shapes under clamped-clamped boundary condition. For this purpose, two types of cut–out shapes are considered. The first type of cut-out shapes is chosen as circle, square, rhombus and hexagon and the second type of cut–out shapes is rectangle and ellipse. For both types, the effects of diameter or width of the cut-out shapes on the buckling loads are compared with both each other and uncut-out. Moreover, the cross-sectional areas of the cut-out shapes are kept constant to see the cross-sectional area effect. The effects of the stacking sequences the most preferred in the market on them are also investigated. In addition, the critical buckling loads of composites filled with various ceramic particles (SiC: Silicon Carbide, Al_2O_3: Aluminum Oxide, B_4C: Boron Carbide) are compared with those of the neat composite plates. The results are indicated that the shape and area of cut-out, stacking sequences, fillers affects quietly the critical buckling load.

Key words: Composite Plates, Buckling, FEA, Filler, Cut-out

1. Introduction

The purpose of making composite materials is to improve the weak way of the materials used and is to obtain a material that provides superior features in the desired direction. Therefore, composite materials, which have high strength, low weight, a good fatigue life and corrosion resistance, are widely used in many engineering applications of automotive, marine, aviation and defense industries. When a part of machine is produced from a composite material, rigidity and lightweight properties will come to the fore for this part. During the service life, this part must fulfill the all duties without damage and the system must remain in stable equilibrium. However, the part may be subjected to compressive loadings and this loading may be large enough to cause the part to deflect laterally or sideways. The ceramic particles (fillers), such as silicon carbide (SiC), aluminum oxide (Al_2O_3) and boron carbide (B_4C), are mostly utilized as reinforcement elements to enhance the load bearing capacity of the parts. These fillers, which are continuous or short fibers, whiskers or particles, are added into the metal–matrix composites to increase the properties of the single component alloys [1].

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The ceramic particles are also added into polymer matrix composites due to advantages in many aspects. Therefore, during the production of polymer matrix composites, the ceramic particles are added a certain amount into the resin and in this way the mechanical properties, such as stiffness and strength values of the composites, can be increased. Accordingly, load carrying capabilities of composites are increase according to amount of particles or type of ceramic particles [2, 3, 4]. For instance, Sayer [1] reported that the load carrying capabilities of composites filled with 10 wt% ceramic particles are found higher for small particle sizes and addition of 10 wt% boron carbide (B_4C) particles to composites increases the critical buckling load value of composite up to 42%.

As to aforementioned studies, addition of ceramic particles a certain amount into the resin is improve the mechanical properties of composites, but any a hole or cut-out in the composite will be decrease the strength and elastic stability of composite structures. Especially, buckling behavior of laminated composite plates subjected to in-plane loads is an important consideration in the preliminary design of aircraft components [5]. Sabik and Kreja [6] examined the stability performance of a panel can be influenced by a centrally located square cut-out and they reported that the presence of a hole remarkably changed the structural response. Tercan and Aktas [7] investigated the cut-out shape effects on the buckling behavior of 1×1 rib knitting glass/epoxy laminated plates in three different knitting tightness levels. Results showed that the buckling loads depend on the cut-out area and the level of tightness. Hakim et al. [8] studied on the behavior of woven glass fiber/epoxy laminated composite panels under compression load which laminated plates were with and without circular cut-outs. The results revealed that as the cut-out size increases, the maximum load of the composite plate decreases and cross-ply laminates possess the greatest ultimate load as compared to other types of ply stacking sequences and orientations.

Yazıcı [9] performed Finite Element Analysis (FEA) to predict the effects of cut-outs on the buckling behavior of plates rectangular plates made of polymer matrix composites. He found that the critical buckling loads were very few changed by increasing cut-out orientation angle and hole corner fillet radius. Brown and Yettram [10] investigated the effect of cut-out size, cut-out location and orientation of principal material directions on buckling loads for rectangular orthotropic plates with square or rectangular cut-outs. They found that the shear modulus has a major influence on critical load. Iyengar and Vyas [11] developed Finite Element Model (FEM) for optimal design of composite laminates with and without rectangular cut-out in order to maximizing the buckling load. They observed that for thick anti-symmetric laminates, the buckling load decreases with increase in both aspect ratio and fiber orientation angle.

As seen from the above literature survey, much of the investigations are related to the effect of the locate of cut-out, cut-out shape, cut-out size and cut-out orientation angle. However, there is not found a subject related to the load carrying capabilities of filled composite plates with cut-out in the open literature. So, the objective of this study is to investigate the effects of cut-out shapes, cut-out areas, stacking sequences and fillers on the critical buckling load of laminated composite plates.

2. Materials and Method

In this study, the effects of cut-out shapes, cut-out areas, stacking sequences and fillers on the critical buckling load of laminated composite plates have been investigated numerically.

2.1. Materials

The laminated composite plates with eight layers are composed of unidirectional E-glass/epoxy. The mechanical properties of the laminated composite plates are taken from Sayer [1] study. It was mentioned in that study that as compared to neat composites, the elasticity moduli and load carrying capability of the composites with 10 wt% filler increase more. The mechanical properties of the laminated composite plates with 0 (neat) and 10 wt% fillers are given in Table 1. Fillers used are silicon carbide (SiC), aluminum oxide (Al_2O_3) and boron carbide (B_4C).

Table 1: The mechanical properties of the laminated composite plates [1]

Quantity of Filler (wt%)	E_1 (MPa)	$E_2 = E_3$ (MPa)	$G_{12} = G_{13}$ (MPa)	ν_{12}	$\nu_{21} = \nu_{31}$
0%	30100	7405	2879	0.32	0.079
10% SiC	35700	9795	2255	0.32	0.087
10% Al_2O_3	37650	9936	2551	0.32	0.084
10% B_4C	41985	10043	2715	0.32	0.076

The dimensions of the composite plates are 40 mm in width (*W*) and 100 mm in length (*L*), and thickness (*t*) is 2.75 mm. In order to compare the effects of the cut-out shape and filler on buckling load, the neat composite plate without cut-out (NWC) is also considered. The diameter (*d*) or width (*e*) of the cut-out shapes is depicted in Figure 1.

To see the effect of the cut-out shapes on the buckling loads of the composite laminated plates, six kinds of cut-outs are perforated to the plates. The composite plates have central cut-outs and two types of cut–out shapes. As shown in Figure 1, the first type of cut-out shapes is chosen as circle (CI), square (SQ), rhombus (RH) and hexagon (HX), and the second type of cut–out shapes is rectangle (HR-Horizontal Rectangle, VR-Vertical Rectangle) and ellipse (HE-Horizontal Ellipse, VE-Vertical Ellipse).

To investigate the effects of the size of cut-out shapes on the buckling load of the composite plates, *d* and *e* are increased in the range from 4 mm to 32 mm with an increment of 4 mm for the first type. As for rectangular and elliptical cut-outs (second type), their widths are *e*, *f* (=*e/2*) and their heights are *f* (=*e/2*), *e* for horizontal and vertical cut-outs, respectively, as seen in Figure 1. These values are increased same manner with the first type.

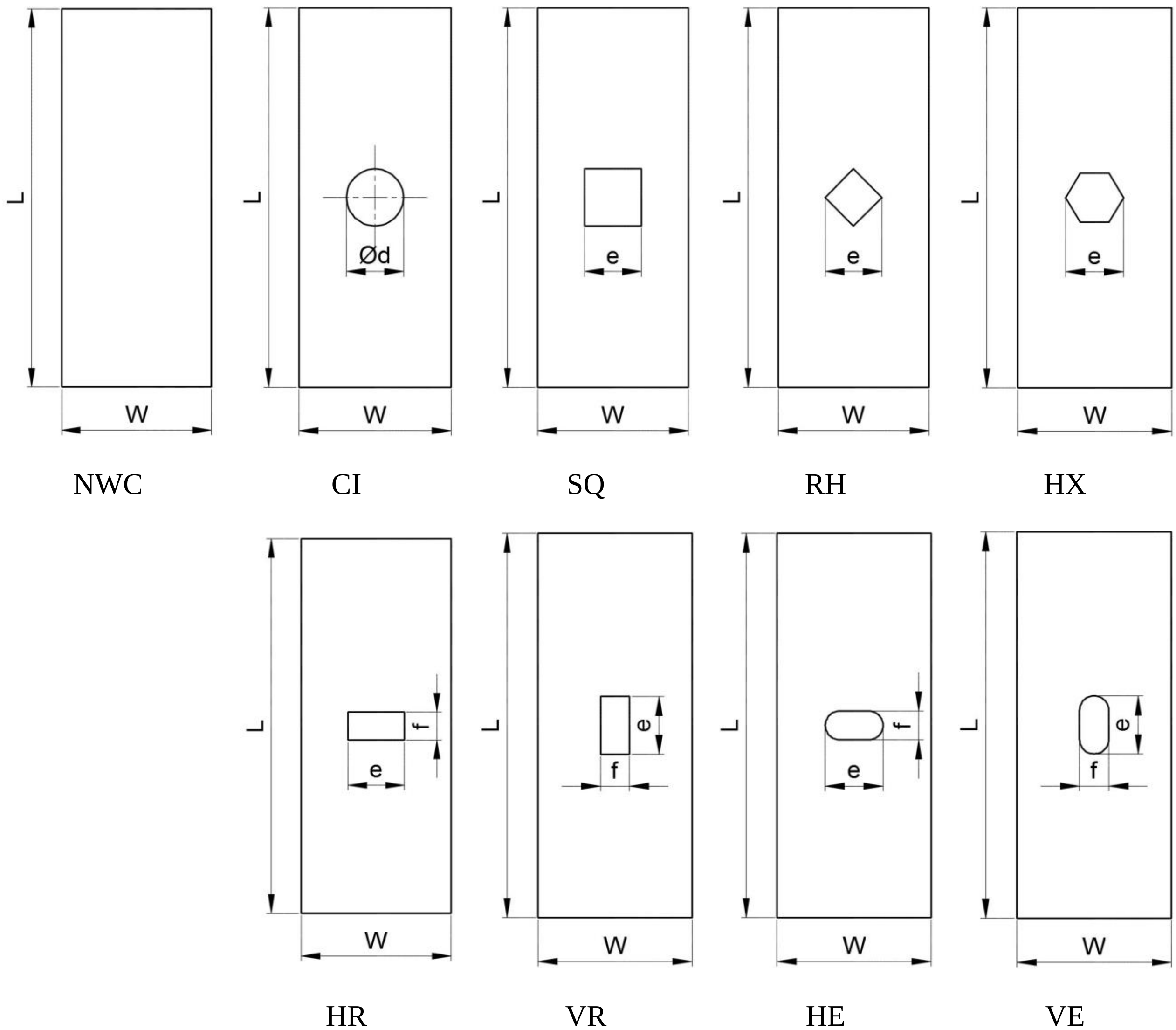


Figure 1: The schematic views of composite plates with and without cut-outs

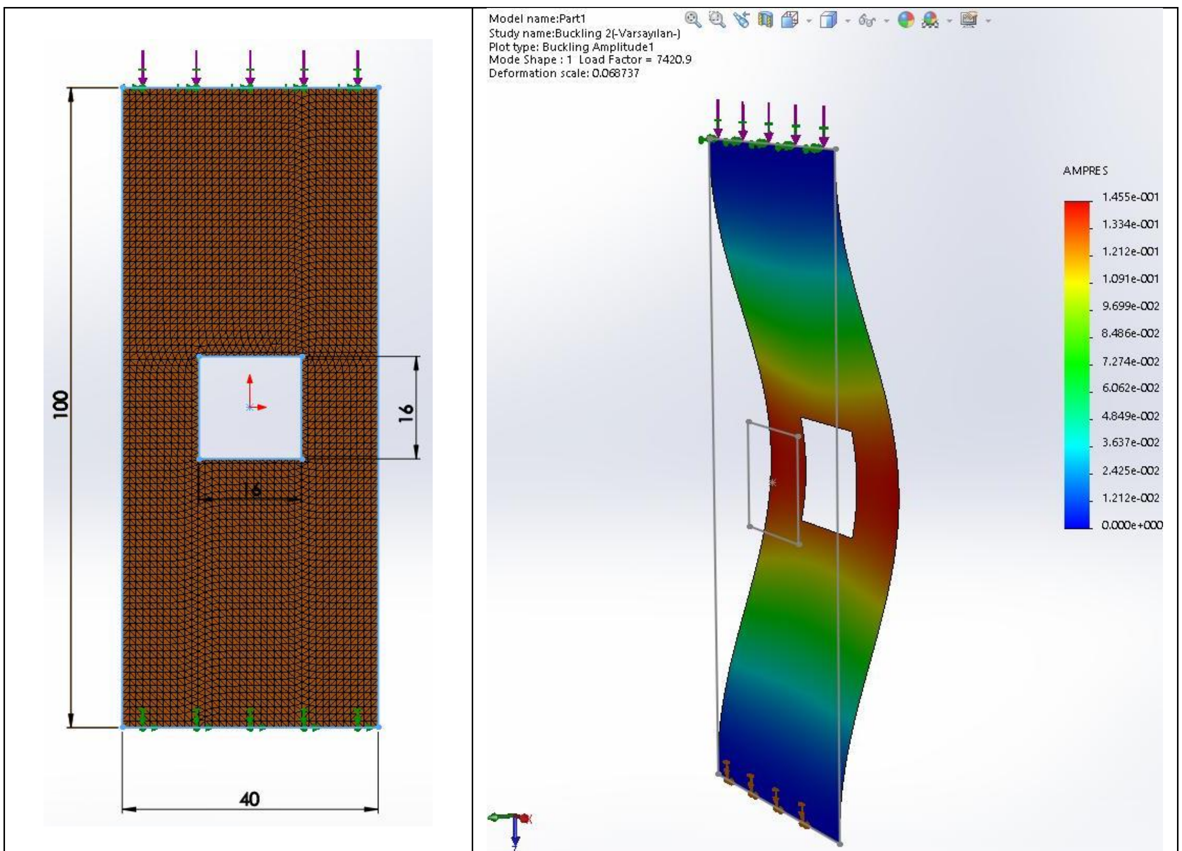
Moreover, the cross-sectional areas of the cut-out shapes are kept constant to see the cross-sectional area effect on the buckling load for the first type. The cross-sectional areas of the cut-out shapes are chosen as 50, 150 and 450 mm^2. That is, cross-sectional areas are increased three times in each step.

In order to see the effects of the various ceramic fillers on the buckling loads of the composite laminated plates, the buckling loads of composite plates with ceramic fillers are compared with those of neat composite plates. For this propose the composite plates with SQ cut-outs is taken into consideration.

The stacking sequences, which is the most preferred in the market on the composite plates, are $(0°)_8$, $(0°_2/90°_2)_s$, $((0°/90°)_2)_s$, $(0°/\pm45°/90°)_s$, $(0°/\pm45°/90°)_2$. The effects of stacking sequences on critical buckling loads of the composite plates are also investigated.

2.2. Numerical Buckling Analysis

The linear buckling analysis is performed for the composite plates, which are mentioned above, using finite element analysis. The numerical analysis is carried out by using Solidworks® (SolidWorks Corp., USA) commercial software. The composite plate is modelled as a surface in the Part Drawing Section of SolidWorks. The material properties of the each model are added to the material library of the SolidWorks according to Table 1. In total 77 numerical models are constituted, as a model for the neat composite plate, 64 models for different cut-out shapes, 12 models for various cut-out areas. Then, the simulation module is run. The models are assumed as composite shell. And thickness, material properties and orientation angle are defined. The clamped-clamped boundary conditions are applied to the bottom and top edges of the model, and compression force as 1 N is applied to the top edge of the model. The models are meshed as fine mesh by using triangular element with three nodes. For example, the numbers of total nodes and elements are 13098 and 6390, respectively for SQ model with *e=16 mm*. Finally, the analysis program is run, and the critical buckling loads are obtained for the first mode. Figure 2 shows the boundary conditions and applied load on a modeled composite plate and the buckled model.



(a) (b)

Figure 2: A modeled composite plate by using Solidworks®, (a) boundary conditions and loaded state as uniformly and (b) buckled model.

3. Results And Discussion

The cut-outs are found in many composite structures in order to ventilation and sometimes to lighten the structure. Moreover, they are commonly used as access ports for mechanical and electrical systems, damage inspection, altering the resonant frequency of the structures, and to serve as doors and windows. The composite plates with cut-outs often lose stability at fairly low stress levels due to these usage areas [12]. So, the effects of the cut-out shapes, cut-out sizes, cut-out areas, fillers and stacking sequences on the buckling loads of the composite laminated plates are investigated by using Solidworks®.

3.1. Effects of the cut-out shapes and sizes

The variation of buckling load versus to diameter or width of cut-out shape is presented for the first type in Figure 3. The value of the critical buckling load is 8100 N for the neat composite plate without cut-out shape (NWC). It can be seen in this figure that the buckling load decreases gradually with increasing the diameter or width of cut-out shape. The decrease in the SQ cut-out is more than the others. The minimum decrease is emerged in the RH cut-out. So, the maximum decrease is about 55 % for SQ and the minimum decrease is about 46 % for RH. As a result of this, it should be preferred to ones with RH for the composite plates with cut-out.

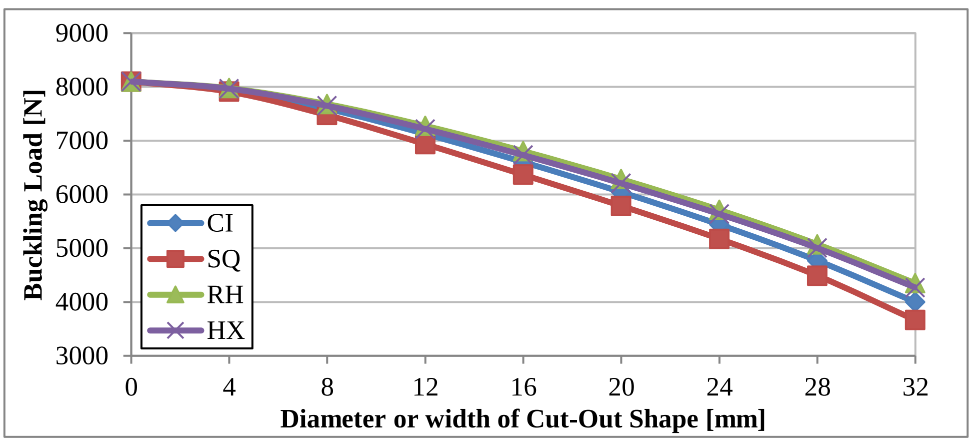


Figure 3: The variation of buckling load versus to diameter or width of cut-out shape for the first type

The variation of buckling load versus vertical or horizontal cut-out shape is presented in Figure 4 for rectangle and ellipse cut-outs (second type). The figure shows that the buckling load decreases gradually with increasing the width of the cut-out shape. Moreover, the decrease in the values of the buckling load of the composite plate with horizontal both rectangle (HR) and ellipse (HE) cut-out shapes is more than those of the composite plate with vertical both rectangle (VR) and ellipse (VE) cut-out shapes. The dimensions of cut-out shapes are *e* in width, *f* (=*e/2*) in height for horizontal rectangle and ellipse, and unlike are *e* in height, *f* (=*e/2*) in width for vertical rectangle and ellipse. Therefore, the maximum decrease is about 52 % for HR and the minimum decrease is about 20 % for VE. The variation of buckling load obtained for HR is almost the same with HE. The similar variation is also valid for VR and VE.

As a result, when compared with the first and second types, the load carrying capability of the composite plates with cut-out shapes is found to be maximum for VE. So, it should be preferred to VE, which is the most constituent, for the first and second types.

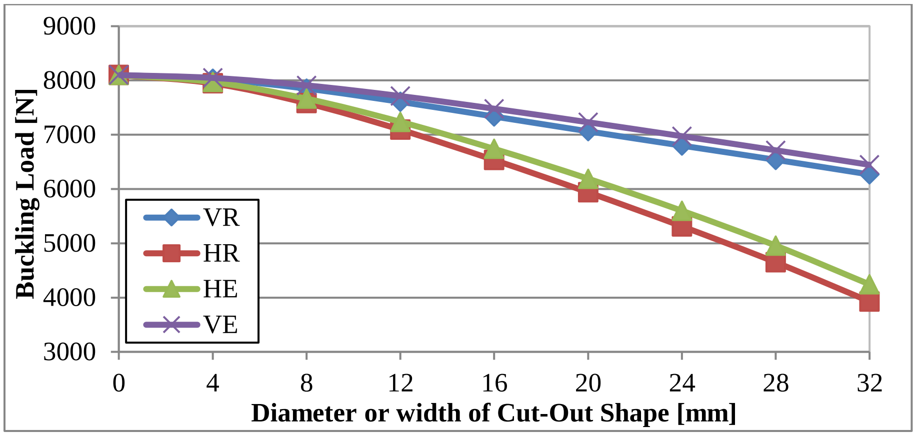


Figure 4: The variation of buckling load versus vertical or horizontal cut-out shape for second type

3.2. Effect of the cut-out areas

To see the cross-sectional area effect on the buckling load for the first type, the cross-sectional areas of the cut-out shapes are chosen as 50, 150 and 450 mm^2. Figure 5 shows the variation of the buckling loads versus cross-sectional area of the cut-out shape. When the cross-sectional area increases, the critical buckling load gradually decreases as concave. While the decrease in the buckling load is minimum for SQ, the decrease is the maximum for RH.

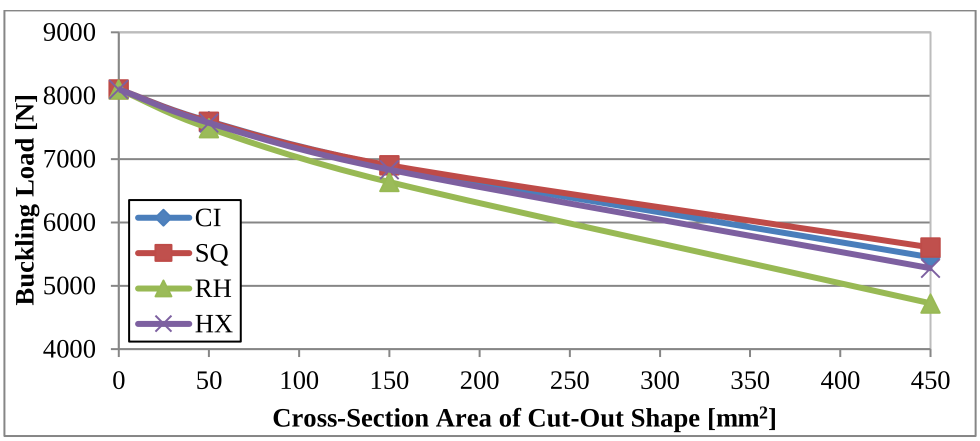


Figure 5: The variation of the buckling loads versus cross-sectional area of the cut-out shape

3.3. Effect of the fillers

The effects of the various ceramic fillers on the buckling loads of the composite laminated plates with SQ are depicted in Figure 6. The buckling loads of composite plates with ceramic fillers are compared with those of neat composite plates. As can be seen from the figure, the addition of the fillers to the composite plates causes the increase in the critical buckling loads. The critical buckling loads are found to be maximum values for B_4C composite plates as compared with neat, SiC and Al_2O_3 composite plates. The critical buckling loads of the neat composite plates decrease gradually with the increase in width of cut-out shapes. Similarly, the buckling loads of the filled composite plates having SiC, Al_2O_3 and B_4C decrease also gradually.

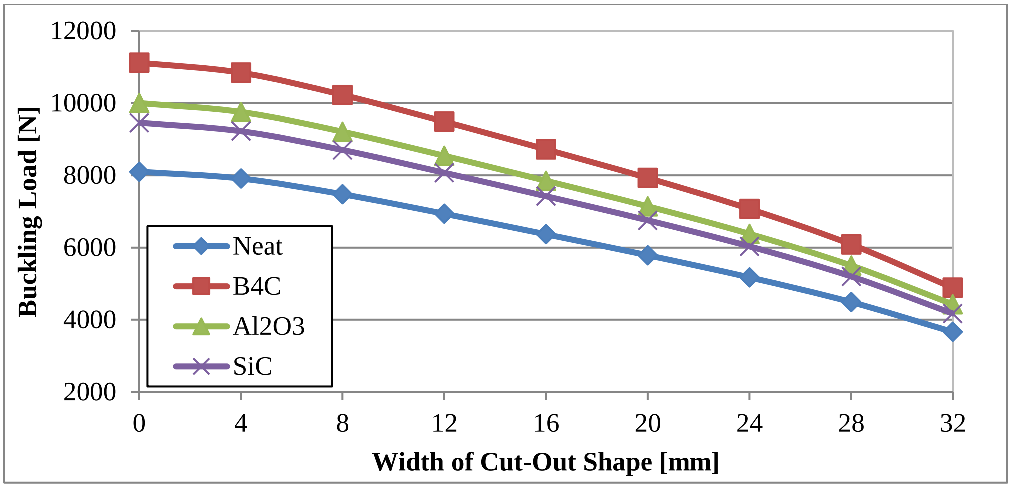


Figure 6: The variation of the buckling loads of filler composite plates versus width of the cut-out shape

3.4. Effect of the stacking sequences

The composite plates with the stacking sequences of $(0°)_8$, $(0°_2/90°_2)_s$, $((0°/90°)_2)_s$, $(0°/\pm45°/90°)_s$, $(0°/\pm45°/90°)_2$ are the most preferred in the market. Figure 7 shows the effects of stacking sequences on critical buckling loads of the composite plates. The neat composite plate is compared with SQ composite plate which has cross-sectional area of the cut-out of 150 mm^2 due to the high load carrying capacity according to the others in the first type. As expected, the highest buckling load is obtained for the unidirectional composite plates, $(0°)_8$. The buckling loads vary by the variation in the stacking sequences. The buckling load carrying capability for $((0°/90°)_2)_s$ and $(0°/\pm45°/90°)_s$ stacking sequences is approximately the same, as can be seen in the figure. The buckling load is found to be lowest for the composite plate with $(0°/\pm45°/90°)_2$ stacking sequence. As a result of this, stacking sequence in the composite plates is very important. Although the same orientation angles are used in the composite plates, the load carrying capacities vary due to the variation of the stacking sequences. For example, it can be seen from the figure that the buckling loads are quite different for the composite plates with $(0°_2/90°_2)_s$ and $((0°/90°)_2)_s$ or $(0°/\pm45°/90°)_s$ and $(0°/\pm45°/90°)_2$ stacking sequences.

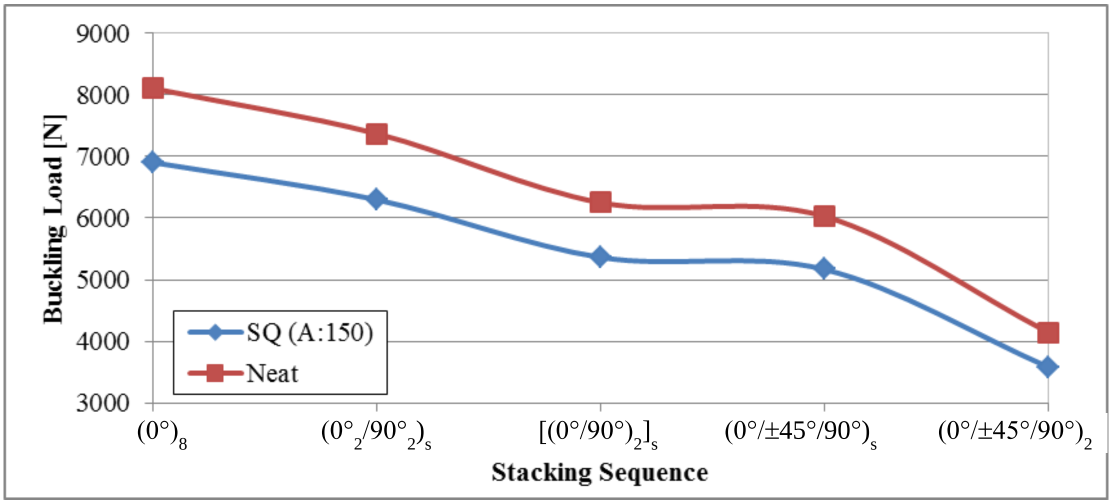


Figure 7: The variation of the buckling loads versus stacking sequences

Conclusion

- As consider the effects of shape and size of the cut-out shapes on the critical buckling loads, the plate with vertical-ellipse cut-out shape has more load carrying capability than those with other cut-out shapes.
- The maximum load carrying capability is obtained for the plate with square cut-out shapes in terms of the effects of cross-sectional areas for first type of cut out shapes.
- The addition of the fillers to the composite plates causes the increase in the critical buckling loads.
- The critical buckling loads are found to be maximum values for B_4C composite plates as compared with neat, SiC and Al_2O_3 composite plates.
- According to the effects of the stacking sequences, the highest buckling load is obtained for the unidirectional composite plates, $(0°)_8$.

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