ITM Web of Conferences **15**, 07013 (2017) DOI: 10.1051/itmconf/20171507013
CMES'17

Stability of rectangular plates with notch using FEM

Katarzyna Falkowicz[1,*]

[1]Faculty of Mechanical Engineering, Department of Machine Design and Mechatronics, Lublin University of Technology, Nadbystrzycka 36, 20-618 Lublin, Poland

Abstract. Buckling behaviour analysis of thin-walled composite plate under an axial compressive force is presented. The plate with central notch is made of a carbon-epoxy composite – a laminate consisting of eight symmetrically oriented plies. This paper addresses an influence of notch on buckling behaviour of laminated composite plates. In this analysis, FEM was applied to perform parametric studies on various plates based on stacking sequences, shape of notch, and its size. Buckling behaviour of laminated composite plates under an axial compression load is studied using ABAQUSS software.

1 Introduction

A composite material, given the high strength and rigidity as well as low weight, has been increasingly used not only in the aerospace and automotive sectors, but also in designs, where low structure weight is crucial. An in-depth understanding of their structural behaviour is essential, especially concerning buckling load, distributions of stresses and strain, deflection behaviour or influence on composite layers sequence.

Problems with plate are often a part of much larger overall stiffened or built-up structure, an aircraft wing or a ship. The mentioned elements happen to be weakened by any type of holes. The need of notching is typically actuated by weight optimisation and practical concern. There is a question about a carrying capacity of this type of structures in concrete work conditions, as well as the influence of the size and type of notch on the load capacity. In general, the analysis of composite laminated plates is more complex due to their heterogeneous and anisotropic nature. Studies on buckling analysis of plates and thin-walled structures under compressive loads are relatively pioneering as not many have been conducted, so far [1,2,3,4].

The buckling problem of a simply supported rectangular plate subjected to an axial load was studied in 1961 by Timoshenko [5]. Azizian and Roberts [6], Rockey et al. [7], Shanmugam and Narayanan [7], and Sabir and Chow [9] used the FEM to study the buckling of perforated square plates subjected to uniaxial and/or biaxial compression. Shanmugam et al. [10] used the FEM to develop a design formula to determine the ultimate load carrying capacity of axially compressed square plates with centrally located perforations. Ouinas and Achour [11] analysed the buckling of square plates with elliptical notch, investigated the impact of the size and location of the notch, as well as the influence of unsymmetrical layer of layout on critical force. Dinesh, Kumar and Singh [12] studied the influence of boundary conditions and post-buckling behaviour of quasi-isotropic laminate [45/-45/0/90]2s with different cut shapes. Based on the literature review, the conclusion that the buckling analysis of plates with notch is significant can be drawn.

In this paper, the influence of different shapes of the notch on the buckling load of thin composite laminate plates are taken into consideration. This study also contains the impact of size of the notch and of lay-orientation on buckling behaviour of the plate. The scope of research will include issues of linear stability composite plates structures subjected to uniform compression. The research will be lead on a few plate models using numerical calculations basing on the finite element method.

2 Material and Geometric Properties

In this study, a thin rectangular plate of length A=160mm and width B=80mm (Fig.1) with notch is used. To reduce the effect of stress concentration on shorter edges of the plate, above the central notch, technological cut-outs were used. The ratio between the length a=100 and the width b=30mm of the plate notch is R=5mm, and the thickness of each composite layer equals t=0,131mm.

The laminate consists of carbon fibres as reinforcement material and epoxy as matrix material, based on the previous study [13,14,15].

* Corresponding author: k.falkowicz@pollub.pl

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (http://creativecommons.org/licenses/by/4.0/).

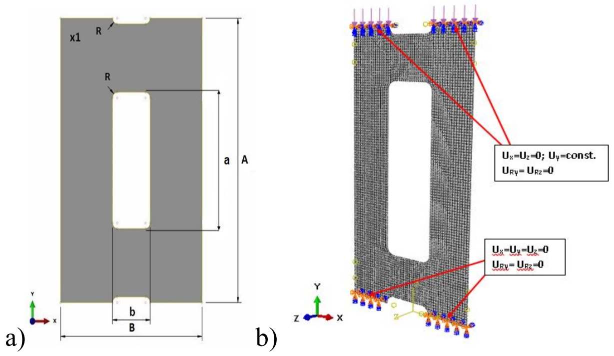

Fig. 1. Dimensions of plate containing notch (a) with FE-model of the plate (b)

The mechanical properties of used material were determined according to ISO standards and shown in the Tab.1.

Table 1. Mechanical properties of carbon-epoxy laminate.

Young's Modulus [GPa]		**Poisson's Ratio [-]**	**Shear Modulus [GPa]**
E_1	E_2	v_{12}	G_{12}
0^0	90^0	0^0	$\pm45^0$
131.7	6.36	0.32	4.18

A discrete model of the plate was made of eight-node shell elements with reduced integration. Known as S8R, these elements have six degrees of freedom at each node. A reduced integration allows for removal of false forms of deformation of finite elements by using higher order polynomials in the description of the function of a given element [16]. A Layup-Ply technique was used to model the laminate structure, by which using the composite layer configuration of plate thickness was mapped. Properties of the composite material were described by defining a model of orthotropic material in a flat state of stress. Boundary conditions of the numerical model were defined by locking kinematic degrees of freedom of nodes on upper and lower edges of the plate. These conditions of the numerical model, which plotted the articulated support of the plate, were defined by blocking kinematic degrees of freedom of nodes located on upper (i.e. Ux = Uz = 0 and URy = URz = 0) and lower edges of the plate (Ux = Uy = Uz = 0 and URy = URz = 0, leaving only the possibility of free rotation relative to the edge of the plate). The compression load was applied uniformly along the upper edge. In the analysed case, based on the criterion of minimum potential energy, the eigenvalue issue was solved. As a result of the calculations, the lowest form of plate stability loss and corresponding critical load values were determined. Finite element software Abaqus was preferred as numerical tool for present study.

3 Results

Detailed calculations have been made for three variants. Variant 1 dealt with the influence of composite layers layout on the critical force value. Variant 2 included the influence of the notch shape on the buckling load. Variant 3 showed how the buckling load value can be affected by changing the notch geometry. Calculations were aimed at determining the influence of the presented construction solutions on the form of buckling and the lowest critical force value, relative to the form of buckling. In all variants, the dimensions of the plate, the boundary conditions and the compression load were the same.

3.1 Influence of Lay-Orientation

To observe the buckling behaviour of composite laminate plate, subjected to axial compressive loading, the calculations were performed for composite plates made of laminate layers in a symmetrical arrangement, according to the median plane of the plate in the following variants: [90/-45/45/0]s, [45/-45/90/0]s, [0/-45/45/90]s, [45/-45/45/-45]s, [0/90/0/90]s.
The critical load values presented in the Tab. 2 for all tested laminate layers corresponded to the lowest flexural buckling form of the plate. Results showed that changing the layout of the laminate layers, in the case of the discussed configurations, resulted in changing critical buckling load about 82%.

Table 2. Buckling load results with different ply orientation

Ply orientation	**Buckling load [N]**
[90/-45/45/0]s	36.74
[45/-45/90/0]s	43.01
[0/-45/45/90]s	156.82
[45/-45/45/-45]s	31.77
[0/90/0/90]s	171.91

The highest critical stiffness had the plate of configuration [0/90/0/90]s, whereas lowest buckling stiffness was characteristic for a plate with [45 / 45-45-45]s configuration. Consequently, the layers in the 0^0 direction, parallel to the direction of the compressive load, caused the increase of stiffness of the structure, increasing the critical force of the structure.

3.2 Influence of Notch Shape

In this section the influence of different shapes of the notch are considered. It is assumed that a notch is located at the centre line of the rectangular with ply orientation [0/90/0/90]s, and subjected to uniaxial loading. The overall plate dimensions and the boundary conditions are the same as previous sections. The different shapes and their dimensions are presented in the Fig.2.

DOI: 10.1051/itmconf/20171507013

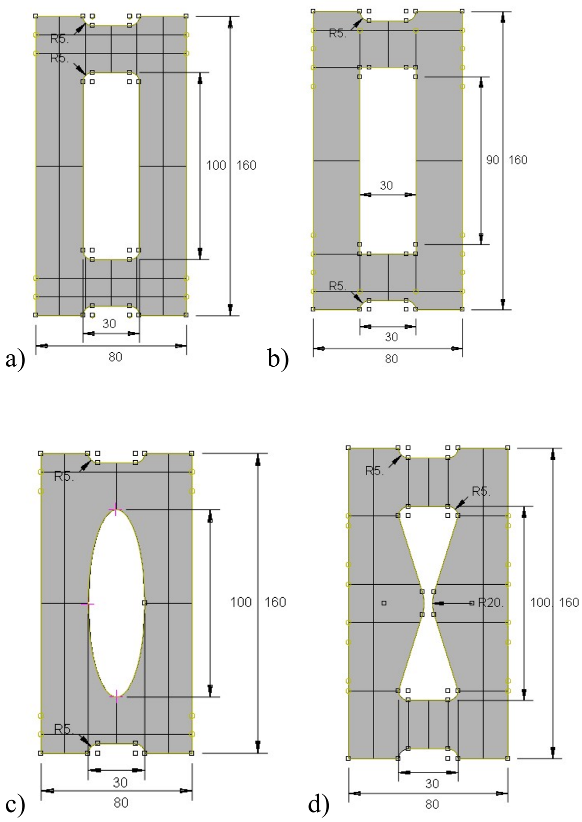

Fig. 2. Geometrical dimensions of the plate with notch: a) rectangular with sharp corners b) rectangular with rounded corners c) ellipse d) hourglass

Table 3 presents the impact of notch shapes on buckling behaviour of plates.

Table 3. Impact of notch shape on the critical value

Shape od notch	Buckling load [N]
Rectangle with sharp corners	171.51
Rectangle with rounded corners	171.91
ellipse	183.62
hourglass	204.85

Buckling load shows the highest value for hourglass notch and the lowest value for rectangular shape notch, which is a difference of 16%. The buckling load for rectangular shape notch with sharp corners and rectangular shape notch with rounded corners having nearly closer value.

3.3 Influence of Notch Size

This section deals with the buckling behaviour of perforated [0/-45/45/90]s laminated composite plate with plate's aspect ratio i.e. A/B =2, where 'A' is length and 'B' is width of plate. The notch is positioned in the centre of plate. Plates are provided with vertical rectangular shape notch, having different aspect ratio of rectangle notch a/b = 10; 5; 2.5, where a is length and b is width of rectangular notch. Buckling analysis is carried out by increasing the area of notch. Results of buckling load are depicted in the Tab.4.

Table 4. Buckling load for [0/-45/45/90] s plate with different aspect ratios of notch

a/b (a=100)	Buckling load [N]
2.5	125.53
3.3	156.82
5	224.15
a/b (a=80)	**Buckling load [N]**
2.5	160.67
3.3	188.40
5	188.40

This shows that aspect ratio of notch has some impact on buckling load. For plate with notch aspect ratio 5 provide greater value of buckling load than that of same plate but with notch aspect ratio 2.5. Results show that the buckling load increases with decreasing the notch size.

4 Conclusions

Based on present study, which dealt with the buckling behaviour of rectangular laminated composite plate under compression axial load, the following conclusion are made:

- Buckling behaviour of laminated composite plate varies for different ply orientation (stacking sequence). Changing the layout of the laminate layers in the case of considered configurations results in a change of the critical load value by 82%.
- Layers in direction 0^0, parallel to the direction of the compressive load acting, cause increasing stiffness of the structure, increasing the critical force value.
- Laminated composite plate with simply supported boundary condition, with ply orientation [0/90/0/90] s subjected to axial compression shows the highest value of buckling load for hourglass notch and the lowest value for rectangular shape notch.
- The performed analysis has shown the significant influence of the geometric parameters of the plate central notch on the buckling load value. The significant impact on the changing of the critical load value has a notch aspect ratio.

Obtained results confirm the possibility of shaping the rigidity of the thin-walled structure by changing the laminate layer configuration, geometrical parameters and shape of the central notch [8,9,10].

References

1. M. Darvizeh et.al., Compos. Struct. **63**, 69–74 (2004).
2. M. Komur Aydin et.al., Adv. Eng. Softw. **41**, 161–164 (2010).
3. S. Wadhonkar, K. Kadam, IJIRSET **6**, 423-427 (2017).
4. D. Banat, Z. Kolakowski, R.J. Mania, Thin Wall. Struct. **107**, 335-344 (2016).
5. S.P. Timoshenko, J.M.Gere, *Theory of Elastic Stability*. 2nd ed. (New York (NY): McGraw-Hill Book Company 1961).
6. Z.G. Azizian, T.M., Proc. of the Int. Conf. on Instability and Plastic Collapse of Steel Struct., London: Granada Publishing, 392–8 (1983).
7. K.C. Rockey, R.G. Anderson, Y.K. Cheung, In: Proc. of the Int.l Conf. on Thin Wall Struct., Swansea (London), Crosby Lockwood, 148–69 (1967).
8. N.E. Shanmugam, R. Narayanan, In: Proc. of the Int. Conf. on FEM, Shanghai, August, (1982).
9. A.B. Sabir, F.Y. Chow, In: Morris LJ, editor. Proc. of the Int.Conf. on Instability and Plastic Collapse of Steel Struct., London: Granada Publishing, 311–21 (1983).
10. N.E. Shanmugam, V. Thevendran, Y.H. Tan, THIN WALL. STRUCT. **34**, 1–20 (1999).
11. D. Ouinas, B. Achour, Comp. Part B **55**, 575-579 (2013).
12. K. Dinesh, S.B. Singh, Compos. Struct. **92**, 769-779 (2010).
13. K. Falkowicz, H. Debski H., Adv. Sci. Technol. Res. J. **11**, 186-193 (2017).
14. K. Falkowicz., P. Mazurek P. Rozylo, P.Wysmulski, W. Smagowski, Adv. Sci. Technol. Res. J. **10**, 177-184 (2016).
15. P. Rozylo, A. Teter, H. Debski, P. Wysmulski, K. Falkowicz, Appl Compos Mater, **24**, 1251-1264 (2017).
16. O.C. Zienkiewicz, R.L. Taylor., *Finite Element Method* (5^{th} Edition), (Vol.**2** - Solid Mechanics, Elsevier, 2000).