Design solutions for improving the lowest buckling loads of a thin-walled laminated plate with a notch

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Abstract

The study concerns thin-walled rectangular plates with a notch in their centre, subjected to uniform compression. The load was applied to the shorter edges of the plates. The plates were made of a carbon/epoxy laminate. The shorter edges of the plates were simply supported, while the longer ones were free. A numerical modal analysis was performed for two types of plate with a central notch: a plate with a symmetric lay-out of laminated layers and present initial curvature and a plate with isotropic stripes asymmetric relative to the middle surface of the plate. The main objective of the study is to determine the effect of the proposed design solutions on the lowest buckling loads of the tested plates. As a result, it will be possible to design plate elements with desired mechanical properties via changing the lowest buckling mode. Detailed analyses were performed by the finite element method.

Keywords: buckling, notch, composite, plates, FEM, FRP

1. Introduction

Thin-walled plates are structural elements which are easy to produce. They are characterized by low flexural rigidity. Under compressive loading, they may undergo buckling. The loss of stability occurs under a small load and is known as flexural buckling. The lowest buckling loads can be increased by the application of design solutions which force the plate to operate in a higher buckling mode. This can be done by making a notch in the centre of the plate and initiating the displacement, in an opposite direction, of the vertical stripes produced in the plate (Fig. 1) or by fixing stripes which are asymmetric relative to the middle surface of the plate. Both design solutions were investigated by the finite element method via solving an eigenvalue problem. The numerical simulations were performed using the ABAQUS software.

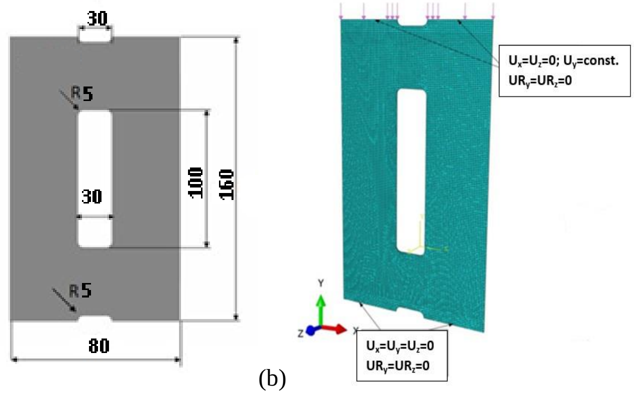
2. FE-model of a plate with a notch

The study was performed on a thin-walled rectangular plate, the dimensions of which are shown in Fig. 1a. The plate had a notch with rounded edges made in its centre. To reduce the effect of stress concentration, indentations were made on the loaded edges. The tested plate was made of a carbon/epoxy laminate used in previous studies by the authors [2-3]. The mechanical properties of the carbon/epoxy laminate are given in Table 1. Each laminate layer had the thickness of 0.13mm.

Table 1: Mechanical properties of carbon-epoxy laminate [1-2]

Young's Modulus [GPa]		Poisson's Ratio [-]	Shear Modulus [GPa]
E_1	E_2	v_{12}	G_{12}
0°	90°	0°	±45
131.7	6.36	0.32	4.18

The discrete model of the plate was made of four-node shell elements with reduced integration. Known as S8R, these elements have six degrees of freedom at each node. The boundary conditions of the numerical model reflected a simply-supported plate and were defined by blocking the kinematic degrees of freedom of the nodes located on the upper and lower edge of the plate. Other edges were free. The compressive load of the plate was modelled by the application of a uniform load to the shorter edge of the plate (Fig. 1b). Next, an eigenvalue problem was solved for the investigated cases. The lowest buckling loads and the corresponding modes of loss of stability were determined.



(a) (b)

Figure 1: Plate with a notch: (a) dimensions in mm,
(b) FE-model of the plate

3. Results

Detailed calculations were made for two cases. In the first case, the lowest buckling load was increased by selecting a symmetric lay-out of laminated layers with a forced buckling mode. This was done by providing the plate with a constant initial curvature. In the other case, a higher buckling mode was forced by the use of additional stripes made of isotropic material. In each case, the main geometry of the plate and the boundary conditions were the same.

3.1. Case 1. Plate with a symmetric layout of laminated layers

This case involved the investigation of an 8-layer plate with a symmetric layout of laminated layers. The examined layout was as follows: [0/-45/45/90]s. The lowest buckling mode for this laminate layout was flexural buckling (Fig. 3a). After replacing the vertical plate elements by shell elements with a present constant curvature and initial configuration identical to a higher buckling mode (Fig. 3b), the lowest buckling load significantly increases to the corresponding flexural-torsional buckling mode. Details are given in Table 2.

The shell system is characterized by a strong tendency to change from a higher, flexural-torsional buckling mode to the basic, flexural buckling mode. To prevent this, the vertical elements had to be strongly elevated.

3.2. Case 2 . Plate with stripes made of isotropic material

Case 2 involved an analysis of identical 8-layer laminated plates provided with aluminium stripes which were located asymmetrically relative to the middle surface of the plate. Each stripe had the thickness of 2mm. The FE-model is shown in Fig. 2. To determine the impact of the stripes on the plate's behaviour, plates with stripes located symmetrically on both sides of the plate (Fig. 2c) were examined. The thickness of the stripes was set to 1mm on each side of the plate. The numerical model was then put to experimental verification. The buckling loads of the structure with initial deflection were determined using experimental methods [1,4]. In this case, no bifurcation is observed.

The application of aluminium stripes, located symmetrically on both sides of the plate, leads to a considerable increase in both the rigidity of the plates and the lowest buckling loads corresponding to the flexural buckling mode. The use of asymmetric aluminium stripes (Fig. 2b) leads to an increase in the lowest buckling loads, forcing a flexural-torsional buckling mode (Fig. 3 and Table 2). In Case 2, we do not observe the phenomenon of transition of the buckling mode from flexural-torsional to flexural.

Table 2 gives the results of buckling loads obtained for the selected laminate layouts and buckling loads.

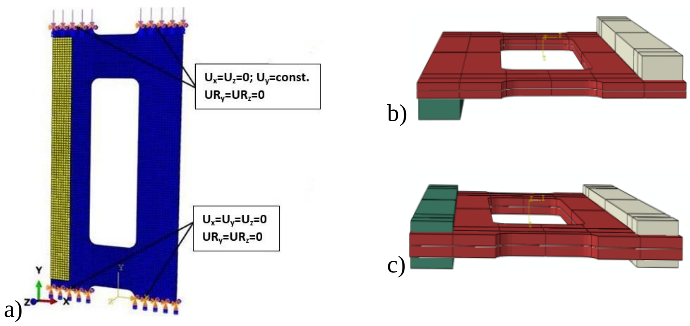


Figure 2: FE-model of the tested plate with fixed stripes

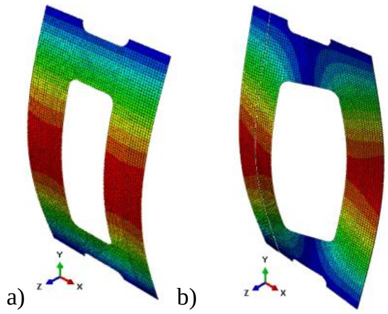


Figure 3: The buckling modes obtained using FEM
(a) flexural buckling mode, (b) flexural-torsional buckling mode

Table 2: Buckling loads (in Newton) for selected buckling modes

Case	Layout of laminated layers	Flexural buckling mode (Fig. 4a)	Flexural-torsional buckling mode (Fig. 4b)
1	$[0/-45/45/90]_s$	156.8	409.2
2	$[0/-45/45/90]_s$	1114.5	2432.2

4. Conclusions

This paper presented a numerical modal analysis of laminated plates under compressive load. The investigation of the buckling behaviour of the plates was conducted by the finite element method for two variants of plates: either by changing the layout of layers in the laminate and the application of curvature or by providing them with asymmetric stripes, without introducing any changes to the overall dimensions of the plate. The results demonstrate that the proposed design solutions have a significant effect on the behaviour of the plate under compression. As a result, it is possible to force the lowest buckling mode to correspond to the flexural-torsional buckling mode, thereby significantly increasing the lowest buckling modes. The shortcoming of the first solution is that there is a tendency for the buckling mode to change from flexural-torsional to flexural. The other solution is free from this defect yet requires the development of a method for making a permanent joint between a plate and a stiffening strip.

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