Buckling and limit states of composite profiles with top-hat channel section subjected to axial compression

Patryk Różyło[1], **Hubert Dębski**[1] **and Jan Kral**[2]

[1] *Faculty of Mechanical Engineering, Lublin University of Technology*
Nadbystrzycka 36, 20-618 Lublin, Poland
e-mail: p.rozylo@pollub.pl, h.debski@pollub.pl

[2] *Faculty of Mechanical Engineering, Technical University of Kosice,*
Letna 9, 042 00 Kosice, Slovak Republic
e-mail: kral.jan@tuke.sk

Abstract

The subject of the research was a short thin-walled top-hat channel section composite profile. The tested structure was subjected to axial compression. As part of the critical state research, critical load and the corresponding buckling mode was determined. Later in the study laminate damage areas were determined throughout numerical analysis. It was assumed that the profile is simply supported on the top-hat channel sections ends. Experimental tests were carried out on a universal testing machine Zwick Z100 and the results were compared with the results of numerical calculations. The eigenvalue problem and a non-linear problem of stability of thin-walled structures were carried out by the use of commercial software ABAQUS®. In the presented cases, it was assumed that the material is linear-elastic and non-linearity of the model results from the large displacements. Solution to the geometrically nonlinear problem was conducted by the use of the incremental-iterative Newton-Raphson method.

Keywords: finite element method, critical state, thin-walled plate structures, composites, damage initiation

1. Introduction

The thin-walled composite panel structures constitutes the elements with high load capacity, which allows their use in the aerospace industry. Despite the phenomenon of buckling widely recognized as a drawback of these structures, it is possible to continue operations of the structure in post critical state in the range of operationally acceptable loads. In terms of stability of the structure, the load causing buckling is defined as the critical load, beyond which the structure reaches a non-linear operations characteristics as a result of an axial compression. The work of thin-walled structures made of i.e. thin walled laminates can be divided into three main ranges. The first range is a pre-critical state, that is one in which the structure is axially loaded and its walls are only pressed. The second stage of the work is to achieve a critical state associated with reaching the point of bifurcation. The last post-critical stage of the structure's work is associated with the occurrence of deflection from the bending process, which strongly increases with further burdening of the system until failure. Figure 1 shows the general operating characteristics of thin-walled structures [5].

a) b)

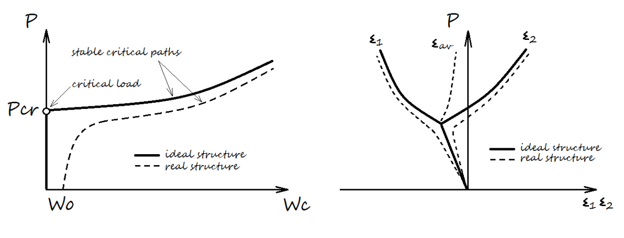

Figure 1: Characteristics of physical and the ideal objects: a) the comparison of the course of post-critical equilibrium paths, b) the comparison of the relative deformation and load.

The common problem of the research is caused by the lack of a universal approach to experimentally determine the value of the critical load, due to the diversity of approximation, allowing a more or less convergent results. The approximation of the post-critical equilibrium paths determined by the experimental tests allows to appoint the critical load value. Among available approximation techniques, the *P*-w_c^2 [2,3] and the *Koiter's* [2,3] methods are the most commonly used. The structure's operations in the strongly post-critical lead range leads to dangerous consequences for the structure. This manifests itself in the form of growing signs of damage of the structure until the complete destruction. In the literature to assess the degree of damage of the laminate, the theory of *First Ply Failure* is mostly used. The theory is based on the criteria of destruction initiation, which the most frequently used criteria are *Tsai-Wu* [4] and *Hashin's* [1].

The study dealt with the issues of determining the value of critical load of composite thin-walled structures and numerical evaluation of the initiation of laminate destruction.

2. The object of research

The subject of the research was a thin-walled profile with top-hat channel section made of carbon-epoxy laminate. The mechanical properties of the material were determined in experimental studies [3]: Young's modulus in the fiber direction E_1 = 130710 MPa and perpendicular to the fibers E_2 = 6360 MPa, Poisson's ratio ν_{12} = 0,32, the Kirchhoff modulus G_{12} = 4180 MPa. Additionally, strength properties were obtained via the destructive tests: tensile strength in the fiber direction F_{T1} = 1867.2 MPa and transverse to the fibers F_{T2} = 25.97 MPa, a compressive strength in the fiber direction F_{C1} = 1531 MPa and transverse to the fibers F_{C2} = 214 and a shear strength F_{S12} = 100.15 MPa. Figure 2 shows the geometric parameters of the sample.

* **Acknowledgment:** The research has been conducted under the project No. UMO-2015/19/B/ST8/02800 financed by the National Science Center Poland.

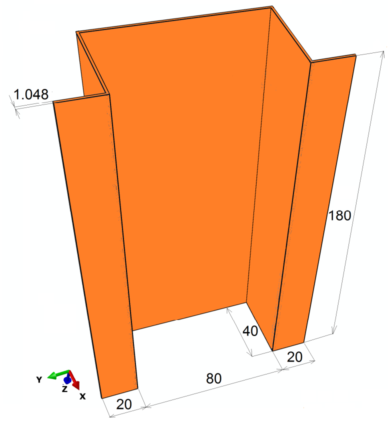

Figure 2: Test sample's geometry in [mm].

The composite consisted of 8 layers of the laminate formed in a symmetrical arrangement relative to the median plane configuration [0/90/0/90]s.

3. Experimental research and FEM

The conducted experimental studies allowed for determination of the structure's operations characteristics in the form of post-critical equilibrium paths. Axial compression test was conducted on a universal testing machine *Zwick Z100* at a room temperature. On the basis of experimentally determined post-critical equilibrium path, an attempt to determine the critical forces based on the approximation *Koiter's* and *P-*w_c^2 methods. The value of the critical load was set using *FEM* numerical methods by the solution of linear eigenvalue problem. Figure 3 shows the boundary conditions in experimental studies and *FEM* calculations.

a) b)

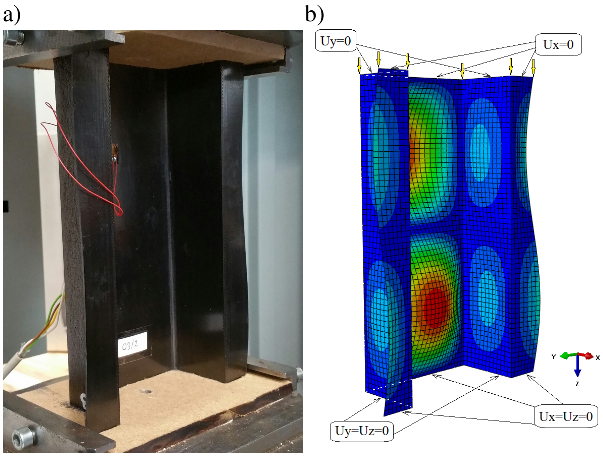

Figure 3: Boundary conditions: a) experimental b) *FEM*.

Discretization of the numerical model using a coating type element *Shell* with six degrees of freedom at each node was carried out. Numerical calculations conducted in the *ABAQUS®* allowed for accurate determination of the critical load parameter and an additional analysis of the origin of breakdown of the structure, on the basis of two independent criteria for the damage initiation, the *Tsai-Wu* and *Hashin's*.

As part of the experimental and *FEM* research, the values of critical forces and post-critical equilibrium path were determined (Fig. 4).

a) b)

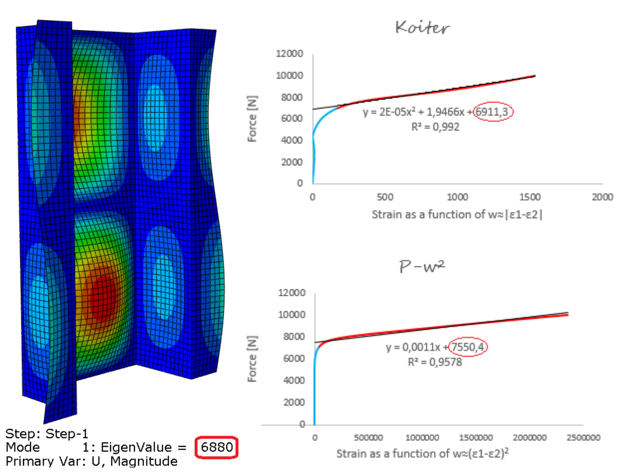

Figure 4: The values of the critical forces: a) *FEM*, b) experimental, including the two methods of approximation.

Figure 5 shows a map of a critical parameter obtained on the basis of destruction initiation criteria for the *First Ply Failure* of the composite.

a) b)

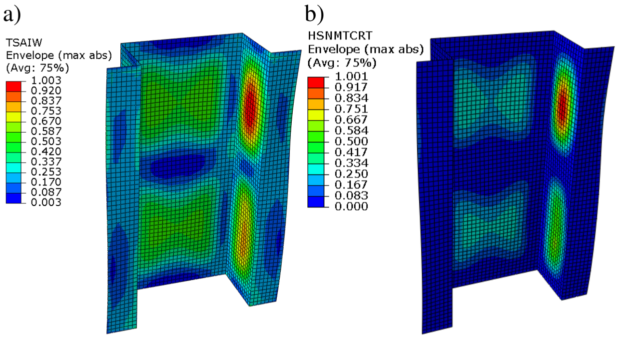

Figure 5: Laminate's destruction initiation: a) the criterion of *Tsai-Wu* (P=18 700 N), b) the *Hashin's* criterion-destruction of the extended matrix (P=18 730 N).

References

[1] Hashin Z., Rotem A.: A fatigue failure criterion for fibre reinforced materials. *Journal of Composites Materials*, t. 7, pp. 448-464, 1973.

[2] Paszkiewicz M., Kubiak T.: Selected problems concerning determination of the buckling load of channel section beams and columns. *Thin-Walled Structures*, vol. 93, pp. 112-121, 2015.

[3] Rozylo P., et al.: Experimental and numerical study of the buckling of composite profiles with open cross section under axial compression. *Appl Compos Mater*, pp. 1-14, 2017.

[4] Tsai SW., Wu EM.: A general theory of strength for anisotropic materials. *Journal of Composite Materials*, vol. 5, no 1, pp. 58–80, 1971.

[5] Zaraś J., Królak M., Kotełko M.: Metody doświadczalne wyznaczania obciążeń krytycznych i analizy zachowania się elementów konstrukcji w stanie zakrytycznym. *X Krajowa Konferencja Wytrzymałości Materiałów i Badania Materiałów*, Kudowa-Zdrój 20-22 wrzesień, 2006.