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Research article

INFLUENCE OF LAYER ARRANGEMENT ON THE STABILITY AND FAILURE OF THIN-WALLED COMPOSITE STRUCTURES

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ABSTRACT

The purpose of this article is to study the effect of the layup n stability and load carrying capacity of a thin-walled composite structure with an open section - angle. The research part carried out by means of the finite element method, using the commercial software Abaqus®, presents the analysis of the limit states of compressed composite profiles, made of carbon-epoxy (CFRP) material, with a variable layer configuration.

KEYWORDS: Composite, thin-walled structures, FEM, finite element method, buckling, failure

1. Introduction

This paper deals with the compression of a thin-walled structure made of CFRP-polymer-carbon composite, where the matrix is polymer and the reinforcing material is carbon fiber, produced by the autoclave method, with an open structure-angle. Research was carried out on the issue of loss of stability and load-bearing capacity of composite materials. The research was carried out by computer simulation, using the finite element method with the use of damage criteria dedicated to composite materials. Numerical calculations were carried out using dedicated software - ABAQUS® [1,2].

Composite materials, do not have one cohesive, clear definition. The reason for this is that the terminology in the field covering composite materials, has sources in various fields of science and technology, including metallurgy, ceramics, polymers, materials engineering and many others [3].

The definition presented by Krock and Broutman in 1967 formulates that a composite material is a man-made material consisting of at least two chemically distinct materials, with clear separation boundaries between the components. The components that make up the composite form it through their overall contribution to its volume, and the composite produced has different properties from its components [4]. This definition excludes natural composites, such as wood or bone, but does not present a clear boundary between the components of the composite, formed by chemical reactions and diffusion processes occurring between the components [5,6].

Thin-walled structures, belong to the group of load-bearing elements, characterized by high rigidity and strength, while maintaining low dead weight. They are used in modern engineering, for example, as thin-walled structures. They are subject to the phenomenon of loss of stability, so-called buckling, resulting from the axial compression of the element, consisting of deformation due to a critical force (the force necessary for the formation of the buckling form), causing a rapid redistribution of internal stresses. which can lead to the destruction of the material [7,8] As the compressive force increases, other post-buckling states, such as failure initiation and delamination, are observed once the critical force is exceeded [9,10].

2. Research object

The object of analysis is an open profile - an angle bar. Made of four layers with a thickness of 0.1 mm, constructed of carbon-epoxy composite (CFRP), manufactured by autoclaving method whose material data are shown in Table 1. The values of the forces necessary to destroy the composite are shown in Table 2.

Table 1. Properties of carbon-epoxy composite CFRP

Module Younga [MPa]		**Poisson's ratio [-]**	**Kirchoff module [MPa]**	**Tensile strength [MPa]**		**Compressive strength [MPa]**		**Shear strength [MPa]**
E_1	E_2	ν	$G_{\pm 45°}$	F_{t1}	F_{t2}	F_{c1}	F_{c2}	$F_{S+45°}$
130000	6500	0,3	5000	2000	100	1500	50	100

Table 2. Properties of Fail Stress

Ten Stress Fiber Dir [MPa]	**Com Stress Fiber Dir [MPa]**	**Ten Stress Transv Dir [MPa]**	**Com Stress Transv Dir [MPa]**	**Shear Strength [MPa]**	**Stress Limit [MPa]**
1867.2	1531	29.97	214	100.5	0

The research carried out was done using the finite element method included in the commercial software Abaqus, which is included in the subgroup of specialized tools supporting engineering work.

The composite profile was discretized using SC8R type finite elements, an 8-node wide-use Continuum Shell type with three degrees of freedom. The global size of the generated mesh is 3 mm. Iterations between different layers of the composite were modelled using tie suboptions. The boundary conditions of the tested laminate were given in an indirect manner, using modelled plates to simulate the compression of the component. The bottom plate was restrained by taking away all degrees of freedom, while in the case of the top plate, to which the load realizing compression of the composite was applied, a free degree of freedom was left on the Z-direction, along the vertical axis of the composite, which makes it possible to realize compression. Plates which were developed, are composed of R3D4 type finite elements with a global mesh size of 1 mm, placed at the two ends of the angle with a surface to surface contact relation given to the corresponding surfaces of the composite layers. In the normal direction, the relationship was modelled as Hard Contact, and in the tangential direction, a friction coefficient of 1 was assumed, which prevents the composite from moving across the plane of the plate relative to the X and Y axes. The above analysis was carried out in two stages, the first stage was a linear analysis, in which the buckling form and the value of the critical force leading to loss of stability were determined. The next stage was a nonlinear stability analysis based on progressive failure analysis (PFA), based on Hashin's criteria [11].

Figure 1. shows the dimensions of the tested angle bracket, with a transverse profile edge length of 20 mm and a corner rounding of 0.1 mm, whose numerical model was made in Abaqus® software.

The layers were given the form of self-contained solid elements, the assembly of which forms the studied angle. Numerical calculations were performed for three profiles differing in the arrangement of layers, which are shown in Figure 2.

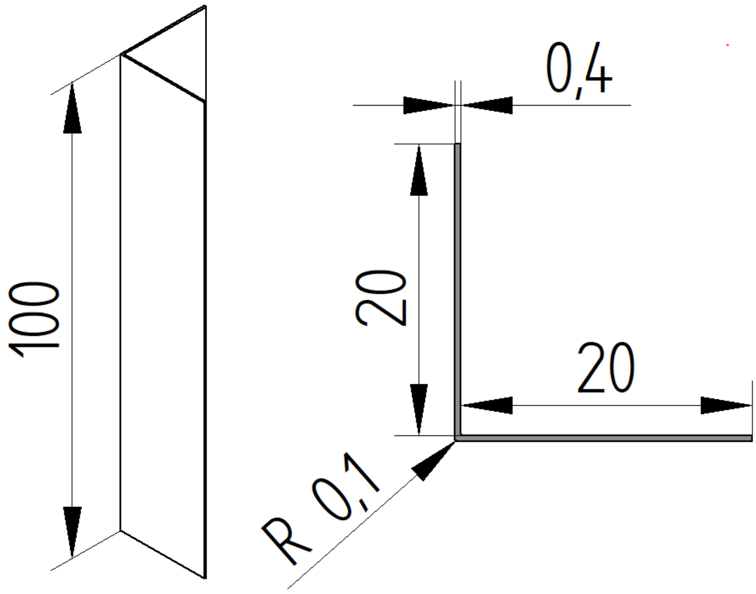

Figure 1. Dimensions of the tested angle profile

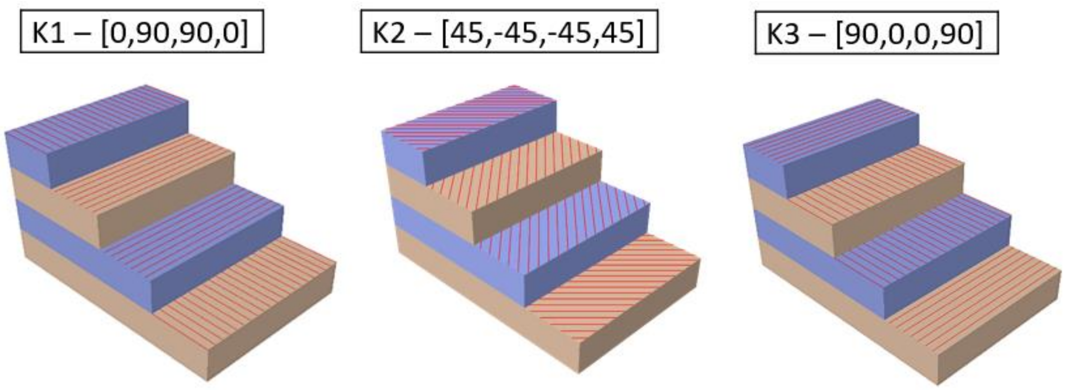

Figure 2. Analyzed layer layouts

3. Practical part

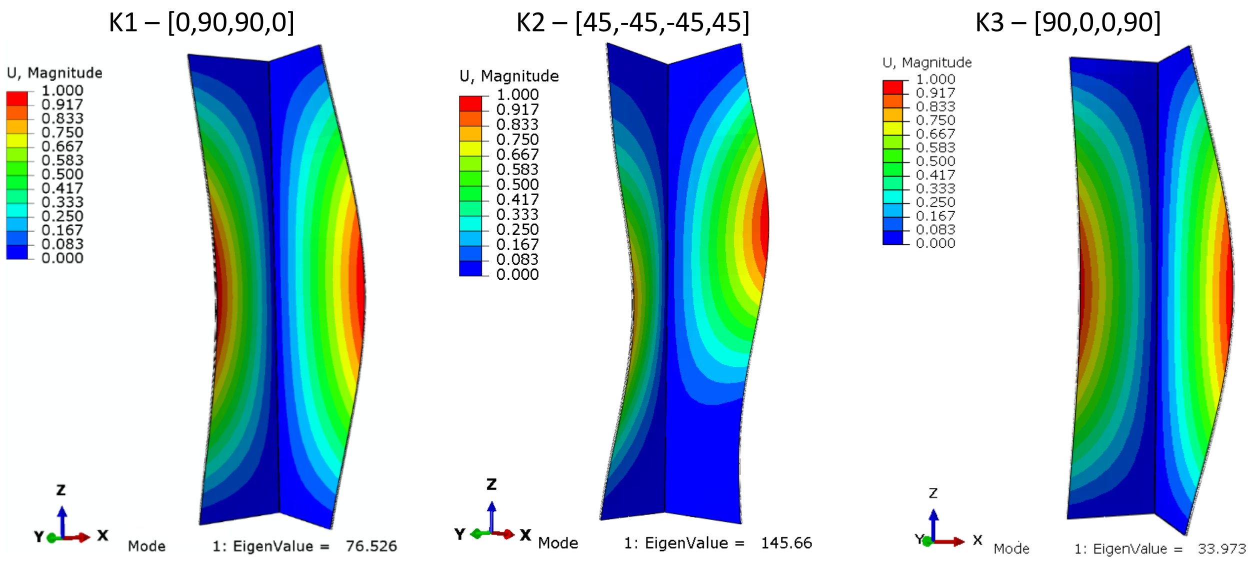

Figure 3. Visualization of buckling analysis results

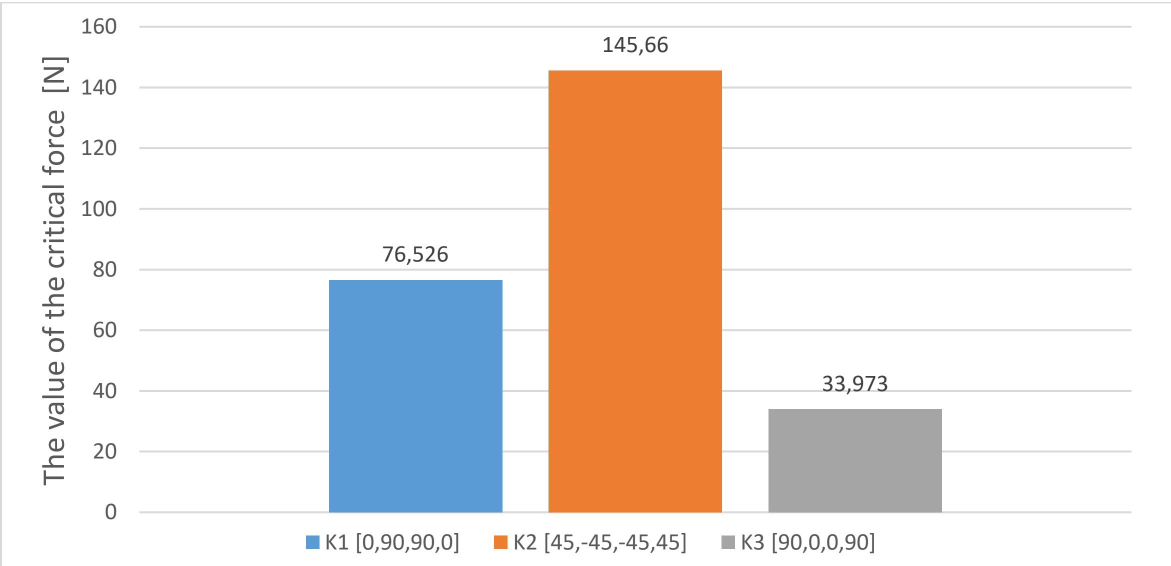

Figure 4. Comparison of the critical force of the studied layer systems

For all the studied K1, K2, K3 layer systems of the composite, the first buckling form takes the form of one half-wave. What is shown in the Figure 3. The results of the linear loss of stability analysis obtained, allow us to conclude that the layout of the layers affects the value of the critical force at which buckling occurs (Figure 4). The difference between the maximum buckling value K2 and the minimum value K3 is 111.687 N, which is 76.68% of the critical force K2. The difference between the layering of K2 and K1 is 69.134 N, which is 47.46% of the critical force of K2.

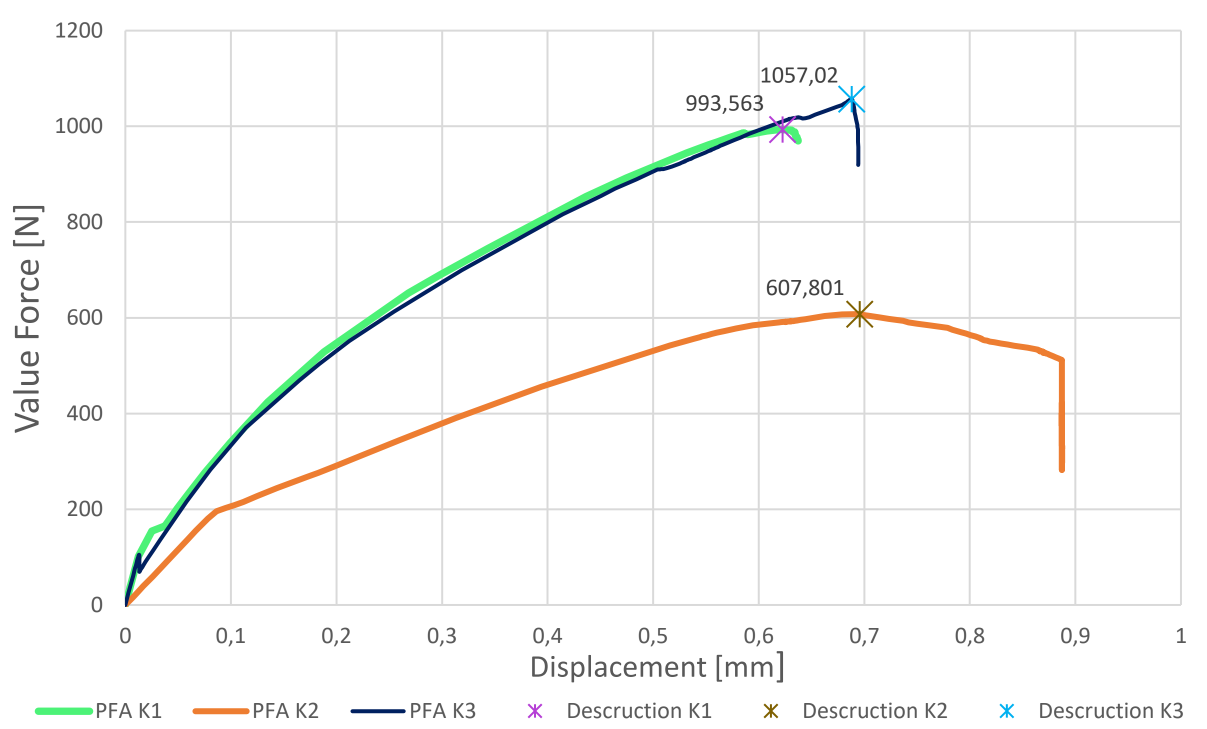

Figure 5. Comparison of limit states obtained by progressive destruction analysis

The graphical interpretation of the results presented in Figure 3 shows that, the highest force necessary for failure, in both analyses, is characterized by the K3 profile. In the progressive failure analysis, the force necessary for loss of load carrying capacity, for the K2 profile was lower by 449.219 N (42%), for the K1 profile lower by 63.457 N (6%) than the K3 profile.

4. Conclusions

The use of computational methods for determining strength, and in particular the finite element method, makes it possible to study, in a simulation manner, the performance characteristics of composite materials. It also makes it possible to reduce the time and cost associated with experimental testing methods, which require specialized testing equipment. However, in order to verify the results, it is necessary to carry out additional experimental tests that allow checking the compatibility of the above calculations with the real model.

The buckling analysis carried out showed that for all the configurations studied, the buckling of the angle bracket was stable. For all analysed cases, the occurrence of one half-wave was observed, at different locations, with divergent values of critical forces. The highest critical force was observed for ply configuration K2 [45,-45,-45,-45,45] amounting to, successively for laminate configuration K1 [0,90,90,0] amounting to. The smallest value of the force causing loss of stability, was registered for the K3 [90,0,0,90] configuration amounting to, which is more than four times smaller than the highest buckling force obtained.

The formation of buckling form of the composite, does not prevent the compressed profile from continuing to carry the load. For this reason, a progressive failure analysis was carried out, making it possible to describe the loss of load-bearing capacity. The results obtained through progressive failure analysis allow us to conclude that the angle bar with the K3 layer system is capable of carrying the highest load, a slightly lower load-bearing value is characterized by K1. A much smaller load-bearing force is characterized by the cross-ply system K2.

The analyses carried out make it clear that the layout of the layers has a significant impact on the stability and load transfer capability of the angle. At the same time, it was observed that as the stiffness of the constructure increases, the value of the maximum load-carrying force decreases, however, in order to confirm these observations, additional analyses should be carried out, for a larger number of layer configurations.

5. References

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