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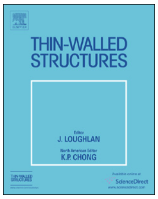

Experimental investigation of channel-section composite profiles' behavior with various sequences of plies subjected to static compression

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ABSTRACT

This paper deals with the buckling of thin-walled channel-section composite columns subjected to static compression. It was assumed that the columns were supported with articulated joints at both ends. For experimental testing, three series of specimens were manufactured with autoclaving technique. The specimens had identical dimensions but differed about ply sequence. The Hexcel′s HexPly M12 carbon-epoxy prepreg was used in order to fabricate the channel-section profiles. During the stand tests minimal critical forces of the real structure and the corresponding buckling modes were determined with an application of electrical strain gauges. In addition, post-critical equilibrium paths for small overloads—150% of the critical load for the ideal structure—were determined. The experimental results were compared to the ones obtained numerically with the finite element method (FEM).

1. Introduction

In the design process of complex composite materials a sequence of plies plays an important role , having a decisive influence on load carrying abilities of particular components of the stress state. This applies to thin-walled composite structures and stability as well, in which a specific ply sequence can have an essential influence on a value of critical load or a structure′s stiffness in post-critical state [1].

This paper presents the experimental results for thin-walled composite columns having channel-section subjected to compressive load. It was assumed that the profiles are supported with articulated joints at both ends. The purpose of the conducted research was the determination of the ply sequence influence on critical load value for the real structure and the mode of stability loss of the compressed columns. For small imperfections, it was accepted that the critical load value for real structure was a lower estimation of the critical load for the ideal structure. Moreover, an attempt to assess the influence of the ply sequence on the structure′s stiffness in post-critical state was made. The obtained experimental results allowed to verify numerical calculations performed with the finite element method (FEM).

2. Subject and scope of research

The experiments were performed on thin-walled composite columns with channel-section. The columns were made of the M12/35%/UD134/AS7/300 carbon-epoxy unidirectional prepreg tape (HexPly, Hexcel). The composite′s matrix was epoxy resin (mass density: $\rho=1.24\ \mathrm{g/cm^3}$; mechanical characteristics: $R_m=64$ MPa; $\nu=0.4$; $E=5.1$ GPa), whereas the reinforcements were the AS7J12K carbon fibers ($\rho=2.5\ \mathrm{g/cm^3}$, $R_m=4830$ MPa; $\nu=0.269$; $E=241$ GPa). Test specimens were manufactured with autoclaving technique, providing high strength of the fabricated structures, as well as repeatability of the production process [2]. The quality control of the samples revealed that they were almost perfect: walls of the samples were flat and there were no any defects in the laminate. Three types of 8-ply composite columns were tested. The layups were symmetrical, as follows: (a) $[0,-45,45,90]_s$, (b) $[0,90,0,90]_s$, (c) $[45,–45,90,0]_s$. Each ply had the same thickness of 0.131 mm. In Fig. 1 the dimensions of the profiles and plies sequences were given.

For the used composite prepregs the following mechanical characteristics were determined experimentally: Young moduli: $E_1=130.71$ GPa, $E_2=6.36$ GPa; Kirchhoff modulus: $G_{12}=4.18$ GPa; Poisson ratio: $\nu_{12}=0.32$. In destructive tests the following features were additionally estimated: tensile strength in the 0°-direction (longitudinal) $\sigma_{M1}=1867.2$ MPa and in perpendicular 90°-direction: $\sigma_{M2}=2597$ MPa; shearing strength for the $\pm 45°$-direction: $\tau_{12M}=$ 100.15 MPa and compressive strength in the two perpendicular

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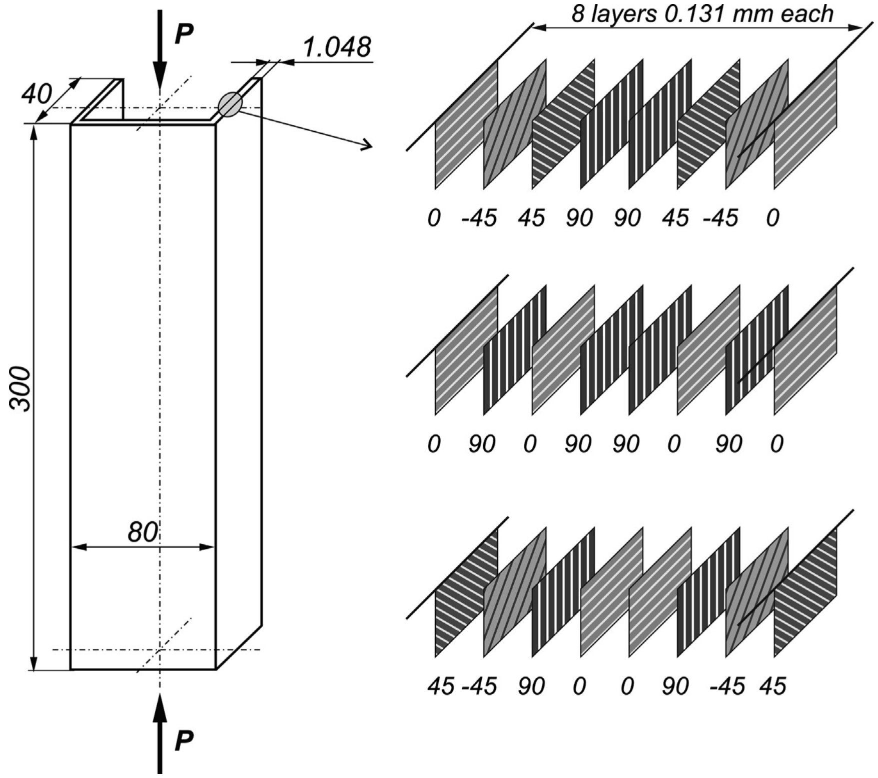

Fig. 1. Dimensions and exemplary ply sequence. Channel-section composite profile.

0°- and 90°-directions: $\sigma_{cM1}=1531$ MPa and $\sigma_{cM2}=214$ MPa, respectively. The experimentally determined strength characteristics of the carbon-epoxy composite were exploited in the definition of material model in the FEM calculations.

The manufactured composite columns underwent texture quality control of the laminate with non-destructive testing (NDT) methods and microstructural inspection considering a localization of possible flaw. The flaw can have a form of delamination or porosity cluster. They are the most frequently occurring laminate defects and can seriously deteriorate the material strength. Moreover, they can be the sources of failure of the composite structure. The NDT tests were done with OmniScan MXU-M ultrasonic defectoscope, equipped with an Olympus 5L64 A12 measurement head. The walls of all the produced profiles were inspected considering flaw identification. The A-scan and the B-scan techniques were used, as they allowed to localize and to dimension the possible flaw within the material. Additionally, microstructural research was led with X-ray micro-tomography (SkyScan 1174 microtomograph) and with optical microscopy (Nikon MA200). Both the techniques employed computer-assisted image analysis (Image Pro Plus, NIS-Elements). These methods enabled the additional analysis of the composite profiles round the corners' radii, where a possibility of discontinuity in the form of interlayer delamination was particularly high. The performed measurement confirmed very good quality of the manufactured composite profiles, as no internal flaws were detected.

3. Numerical calculations

The numerical calculations were performed with the FEM using the Abaqus software. The scope of the calculations covered critical state analysis—linear calculations with the *buckling analysis* option, enabling the determination of critical loads and the profiles' buckling modes for the ideal structures. The next stage of computations was a non-linear analysis of a structure. In the numerical analysis of post-buckling behavior it is necessary to assume the initial geometrical imperfection or add small perpendicular load initiate buckling [3–6]. The authors decide to introduce "small" geometrical imperfections related to the first buckling mode. The assumed amplitude of initial imperfections was equal to 0.1 of the thickness of the column wall. This enabled the observation of post-critical deformation. In non-linear calculations the Newton–Raphson incremental–iterative method was employed [3,4]. In the process of the structure discretization the S4R, i.e. 4-node shell elements with linear shape function and reduced integration having six degrees of freedom in each node, was used. A numerical model of the channel-section composite columns is presented in Fig. 2.

The scope of the numerical simulations covered also an attempt to assess the possibility of damage occurrence in the composite in post-critical range. An assessment of material effort, as well as an estimation of the failure load level was done with the Tsai–Wu criterion [7], using the experimentally determined limit parameters of the composite. In addition, a verification of the obtained FEM outcomes was done with the analytical–numerical (A–N) method [8–10], based on the Koiter theory [11].

4. Experiments

The experimental tests consisted of axial compression of the composite columns within a range from 0 up to ca. 150% of the critical load for the ideal structure. In order to provide fine axial loading conditions, special self-aligning grips with spherical bearings and special inserts for each column were designed and fabricated. Checks were performed, whether the shortening of a sample was equal for all walls. The grips transfered the load exerted with the Zwick Z100/SN3A universal testing machine to a specimen—Fig. 3. More details are shown in Fig. 4. The machine′s accuracy class was 1. Any imperfections of the columns' ends, able