Thin-Walled Structures 85 (2014) 324–331

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

On buckling collapse and failure analysis of thin-walled composite lipped-channel columns subjected to uniaxial compression

Andrzej Teter [a,*], Hubert Debski [b], Sylwester Samborski [c]

[a] Department of Applied Mechanics, Lublin University of Technology, Nadbystrzycka 36, 20-618 Lublin, Poland
[b] Department of Machine Design, Lublin University of Technology, Nadbystrzycka 36, 20-618 Lublin, Poland
[c] Department of Applied Mechanics, Lublin University of Technology, Nadbystrzycka 36, 20-618 Lublin, Poland

ARTICLE INFO

Article history:
Received 29 July 2014
Received in revised form
8 September 2014
Accepted 13 September 2014
Available online 1 October 2014

Keywords:
Thin-walled column
Far post-buckling state
Collapse
Finite element analysis
Carbon-epoxy laminate
Acoustic emission

ABSTRACT

The paper deals with buckling of short thin-walled lipped-channel columns, simply supported on both ends and subjected to uniformly distributed compressive load. The main objective of the study was to investigate the structure's work in far post-buckling state and at collapse corresponding to the moment of the column's stiffness loss. The following measuring devices and methods were applied: electrical strain gauges for strain measurements, a laser sensor to measure the displacements, and the Acoustic Emission method. Along with running the experimental tests, the non-linear stability of compressed composite columns was analyzed with the Finite Element Method. The numerical and experimental results showed good agreement.

1. Introduction

The problem of stability of thin-walled structures has been intensively studied in numerous papers [1–3] and application tests, particularly in the aircraft and automotive industries [4]. The growing demand for hi-tech composite materials or – in the case of thin-walled structures – for fibrous composite laminates adds to the intensity of this research [5], with the studies investigating the strength and rigidity properties of these structures [2] being particularly important. This is especially true with regard to thin-walled load-carrying structures, also known as primary structures. They include, among others, thin-walled composite profiles with complex cross-section shapes that are used in load-carrying structures to stiffen the coating of these structures.

It is characteristic of thin-walled load-carrying structures that their individual members are prone to stability loss under allowable service loads. For this reason, thin-walled structures must meet not only strength requirements, but also relevant rigidity requirements to prevent premature collapse due to stability loss. Hence, the knowledge of a structure's behavior in post-buckling states and at the collapse should be thoroughly investigated in order to fully exploit the potential of composite structures subjected to compressive loads [6–8].

The current research results demonstrate that thin-walled structures can carry loads even after their stability loss when working in the so-called post-buckling elastic state [6]. Therefore, it is vital to know the characteristics of these structures in full load range until the collapse. The behavior of composite structures in far post-buckling state and at stability loss has not been fully examined. Failure criteria for laminates reported in the literature [9,10] are only preliminary attempts to describe failure of composite structures. What lacks is a reliable study that would verify the applied criteria of a composite material's failure in a real structure. A thorough analysis of post-buckling states of thin-walled structures requires performing experimental tests for the full load range until the structure's collapse. Such tests of thin-walled profiles with both open and closed sections were conducted on structures made of isotropic materials by [2,11–13]. The literature offers studies investigating thin-walled structures made of materials with orthotropic properties (composites) [14–18]; these studies, however, present only theoretical results. To the best knowledge of the authors of the present paper there is a limited number of works that report experimental results [19–24]. To put it differently, there is a marked lack of experimental data on thin-walled columns made of hi-tech composite materials.

* Corresponding author. Tel.: +48815384572; fax: +48815384205.
E-mail addresses: a.teter@pollub.pl (A. Teter), h.debski@pollub.pl (H. Debski), s.samborski@pollub.pl (S. Samborski).

http://dx.doi.org/10.1016/j.tws.2014.09.010
0263-8231/

This study presents the results of research undertaken to investigate the post-buckling states and the moment of collapse of thin-walled composite structures with a complex open-section subjected to a uniform compressive load. The main aim of the investigations was to examine the work of these structures for the full load range, specifically with regard to short simply-supported columns prone to local buckling. In the experiments, thin-walled columns simply-supported on their ends were tested. The structures were subjected to monotonically increased load at the column's both ends using an universal testing machine equipped with a special test fixture. The failure-initiation moment of the composite material was determined with the Acoustic Emission (AE) method. In addition, strain gauges were used to measure the strains, while the displacements were measured with laser sensors. The experimental results were then utilized to design FEM-based numerical models for analyzing the work of composite structures under fully compressive load.

2. Object of experimental tests

In the tests, short thin-walled lipped-channel columns, simply supported on both ends and subjected to a uniform compressive load were examined. The columns were made of carbon-epoxy composite material. The technological process for preparing specimens ensured both high production repeatability and very high strength properties of the produced structures. All columns were inspected with regard to their quality. Only the columns that were free from defects and damage were used in further tests. Additionally, the tested columns were cut to the required dimensions to render ideal both the edges and the flatness of the column's end sections. The laminate structure consisted of 8 plies of unidirectional carbon-epoxy composite tape, each ply having a thickness of 0.131 mm. The plies were symmetrically oriented relative to the center plane of the package. The overall dimensions of the tested columns were as follows: the web width – 80 mm, the flange height – 40 mm, the width of the lips – 20 mm and the overall column's length – 300 mm (Fig. 1). The tests were performed for four configurations of the composite material's layups, respectively marked as: O1 for the ply configuration $[0/-45/45/90]_s$, O2 – $[90/-45/45/0]_s$, O3 – $[(0/90)_2]_s$ and O4 – $[45/-45/90/0]_s$.

The fundamental mechanical properties of the composite material were determined in accordance with the ISO standard [25]. In addition, the destructive tests involved measurements of the limit parameters of the composite material by static tensile, compressive and shear tests for the material's principal directions 1–2 regarding fiber orientation (see Table 1). The determined parameters of the composite were then applied in the numerical analysis in order to investigate the stress criteria at the composite's failure.

3. Experimental tests

The experiments consisted in subjecting lipped-channel columns to axial compression load until their collapse. The columns were simply supported owing to the use of the genuine fixture consisting of heads with a ball-and-socket joint (Fig. 2) specifically designed for this purpose; as a result, the specimens were accurately aligned with the rods of the testing machine [19–21]. In addition, the heads were equipped with thin inserts made of foamed PVC (soft plastic) to compensate any inaccuracies in the column's end sections, as well as to remove strong boundary effects that could affect experimental results. The experimental tests were performed under standard conditions using the ZWICK's Z100 testing machine.

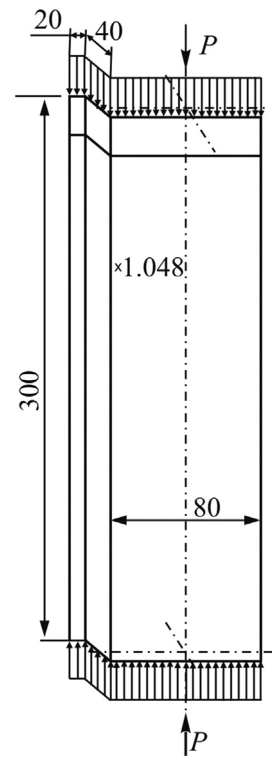

Fig. 1. Nominal dimensions of the tested lipped-channel column.

Table 1
Mechanical properties of the carbon-epoxy laminate [19–20].

Tensile strength F_{TU} [MPa]		Tensile modulus E_T [GPa]		Poisson's ratio ν_{12}	Shear strength F_{SU} [MPa]	Shear modulus G [GPa]	Compression strength F_{CU}[MPa]	
0°	90°	E_1 (0°)	E_2 (90°)	0°	±45°	±45°	0°	90°
1,867.2	25.97	130.71	6.36	0.32	100.15	4.18	1,531	214

The main objective of the experiments was to investigate the structure's work in far post-buckling state and at its collapse corresponding to the moment of the column's stiffness loss. This required that appropriate parameters had to be measured to determine characteristics of the structure for the full load range. To this end, the following measuring devices and methods were applied: electrical strain gauges for strain measurements, a laser sensor to measure the displacements, and the Acoustic Emission method. To measure the strains, two Vishay's resistance strain gauges were attached on both sides of the specimen, at the profile web's maximum deflection point, in the 0° direction parallel to the column's symmetry axis. Deflections were measured with the laser sensor at the point of maximum deflections of the profile's flanges or its web. The measurements were taken and recorded at the sampling frequency of 1 Hz using the MGC-plus measuring system manufactured by Hottinger. All the measurements were performed in a static loading regime. Thus, in the experiments, the cross-bar traveled at a constant velocity set to 1 mm/min.

Often, the collapse of a thin-walled composite structure is so sudden and momentary that there is a risk of loss of some process parameters. For this reason, it is important that the failure initiation moment of a composite material is identified. To this end, the tests involved not only measurement of the load and the strain of the tested composite structures, but also the application of the above-mentioned Acoustic Emission method. The method consists in recording elastic waves generated within the material