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Influence of autoclaving process parameters on the buckling and postbuckling behaviour of thin-walled channel section beams

Jaroslaw Bienias [a], Adrian Gliszczynski [b], Patryk Jakubczak [a], Tomasz Kubiak [b,*], Krzysztof Majerski [a]

[a] Department of Material Science, Lublin University of Technology, Nadbystrzycka 36, 20-618 Lublin, Poland
[b] Department of Strength of Materials, Lodz University of Technology, Stefanowskiego 1/15, 90-924 Lodz, Poland

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ABSTRACT

The postbuckling behaviour and load carrying capacity of thin-walled composite channel sections subjected to uniform compression are presented. An analysis of the influence of parameters of the composite manufacturing process on strength properties and load carrying capacity of the thin-walled structure made of this composite has been conducted. The microstructure characteristics of composites is presented and discussed. The postbuckling behaviour and load carrying capacity of thin-walled channel section columns subjected to compression have been determined with the finite element method. The ANSYS software has been employed.

1. Introduction

Composite laminates are an important class of construction materials used in many different structures. Laminates are present in everyday life; this type of materials is used in both simple everyday household structures (housings of cellular phones) as well as in advanced structures (airplanes, yachts, cars). The most spectacular example of the use of laminate structures are passenger aircrafts that have appeared recently on the market. Composite structures are often used in responsible load-bearing elements and the economic efficiency of their use is steadily increasing [1–5]. Laminates have been used for many years, so many studies have been conducted on their use, e.g., in aircraft wing girders [6], blades of helicopters [7] or girders of wind turbine blades [8]. The authors of the above-mentioned papers indicate that the layer alignment affect the behaviour of the laminate structure. Some experimental results can also be found in the literature of recent years [9,10] showing an impact of ply arrangements in thin-walled composite columns on their stability. For practical reasons, it is very important to know the material properties of such structures and their use in the modelling process [11], which allows one to evaluate the existing composite construction work or to support the construction process for new applications.

Currently, one of the most advanced methods of producing composite laminates allowing for achieving the highest quality and repeatability of structures is an autoclaving method. The main disadvantages of the autoclaving method are relatively high costs and limited capacity [12,13]. Although their manufacturing costs compared to steel elements are still higher, laminates have a very good strength to density ratio, which, combined with the requirements for energy minimisation, contributes to their growing popularity.

At present, the activities on reducing manufacturing costs while maintaining high quality products are underway. Main directions of research on lowering manufacturing costs are focused on the optimisation of process parameters, the automation of lamination and the use of resins with short curing time. The modification of the process parameters such as temperature, pressure and cure time has a significant influence on physical–chemical properties, the risk of porosity, a distribution and a volume content of reinforcing fibres in the laminate and, consequently, may substantially affect mechanical properties [14–18].

The nonlinear stability problem of thin-walled structures is very well known and described in the world literature. The following monographs [19–23] and surveys [24–26] dealing with the nonlinear stability problem of thin-walled profiles and containing a detailed overview of the relevant literature could be mentioned. The buckling and postbuckling behaviour problem of

* Corresponding author.
E-mail addresses: j.bienias@pollub.pl (J. Bienias), 159141@edu.p.lodz.pl (A. Gliszczynski), p.jakubczak@pollub.pl (P. Jakubczak), tomasz.kubiak@p.lodz.pl (T. Kubiak), k.majerski@pollub.pl (K. Majerski).

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thin-walled structures made of isotropic as well as of orthotropic materials has been investigated theoretically [19,27–31] and experimentally [22,24]. There are also some papers showing the results of experimental investigations on thin-walled structures made of composite materials [32–36] in the world literature. However, in the authors' opinion, there is a lack of experimental investigations presenting an effect of manufacturing process parameters on material properties and numerical simulations showing an influence of production parameters and the lay-up arrangement in laminate structures on their buckling and post-buckling behaviour. In an attempt to fill in this gap, the authors of the present study have conducted experimental investigations allowing them to describe the microstructure and to find material properties for composite laminates made with an autoclaving technique and with different manufacture parameters, and then to perform numerical investigations of thin-walled laminate channel section beams with various different ply sequences subjected to pure bending.

2. Influence of autoclaving process parameters on the laminate microstructure

Different material properties can be obtained from one type of the prepreg laminate. It was decided to carry out an analysis on the basis on changes in temperature, curing time as well as heating and cooling rates, while pressure and underpressure were maintained at a constant level.

The composite structures in the form of plates made of a pre-impregnated tape consisting of E-type unidirectional oriented glass fibres and a thermosetting epoxy resin (SE 70 Gurit) were subjected to testing. The thickness of a single layer after curing was equal to about 0.26 mm.

The tested laminates were produced in an autoclave process maintaining three different sets of parameters (i.e., time and temperature). By varying the time and temperature of the autoclave process, the following three different parameter sets were considered for forming a laminate:

- optimal (denoted as OPTI), where the process parameters were in the middle range allowed by the prepreg manufacturer;
- long cure time (SLOW), i.e., the process was carried out at relatively low temperature and long curing time;
- short curing time at high temperature (QUICK).

The values adopted for the analysis of the cured profiles of glass fibres are shown in Table 1.

The panels were arranged in the following layouts: 4 layers of the pre-impregnate in 0° direction and 16 layers in $\pm 45°$ direction in order to prepare a set of samples for strength tests and structural analysis. The samples for microstructural tests were taken from representative areas of the composite plates. They were prepared for all the considered systems and processes. After the production process, a macroscopic visual inspection, non-destructive ultrasonic tests using a phased array technique were conducted with an OmniScan MXU-M device equipped with an Olympus 5L64 A12 head. The tests were carried out at the frequency of 5 MHz and the amplification of 8–14 dB. Microstructural observations of cross-sections were performed with a NIKON MA200 optical microscope.

Table 1
Assumed autoclaving parameters for composite laminate structures manufactured.

Process ID	Curing temperature [°C]	Heating/cooling rate [°C/min]	Curing time [min]	Pressure [MPa]	Vacuum [MPa]
QUICK	120	2	25	0.4	0.085
OPTI	100	1	60	0.4	0.085
SLOW	70	1	960	0.4	0.085

The results of structural observations of composite panels are presented in Figs. 1 and 2.

No visible defects in macroscopic scale were revealed in visual observations. A lack of defects in the form of foreign body inclusions was confirmed by means of completed non-destructive tests. On the basis of the obtained ultrasonic images (Fig. 1) and the macroscopic observations, it was found that the quality of laminates was very good: no delamination; uniform thickness; no porosity.

Fig. 2 illustrates microstructures of the composite laminates produced at different production process parameters.

The microscopic observations show that the composite laminate structure is made uniform. There was no discontinuity in the form of voids or delamination. In all the cases under consideration, a distribution of reinforcing fibres is correct, but parallel to an increase in temperature and process dynamics – more resin-rich areas were observed in zones between individual laminate layers. The microscopic observations demonstrated that the laminate marked as SLOW was characterised by significant density of reinforcing fibres. As a result of a lower heating rate in combination with low curing temperature, the dynamics of rheological processes is relatively low. Although the achieved level of minimal viscosity is usually higher than the one achieved in processes with a higher temperature gradient, the length of minimal viscosity platform increases, positively contributing to reducing the risk of thermally induced stresses and ensuring proper conditions for favourable resin flow. However, there is a danger of excessive resin discharge in the drainage textile direction, which may cause a contact between surfaces of individual fibres and, consequentially, an incorrect stress distribution and a reduction of load carrying capacity. Furthermore, too low the process temperature may lead to an insufficient polymerisation degree (Degree of Cure; DOC) and be followed by changes in mechanical properties [18]. More detailed observations reveal a correct type of boundary between fibres and the matrix.

3. Influence of autoclaving process parameters on material properties

To check an influence of autoclaving process parameters on material properties, tensile and compression tests were conducted. All tests were performed using an Instron universal testing machine modernised by Zwick-Roell with a range of the load cell from 2 to 200 kN.

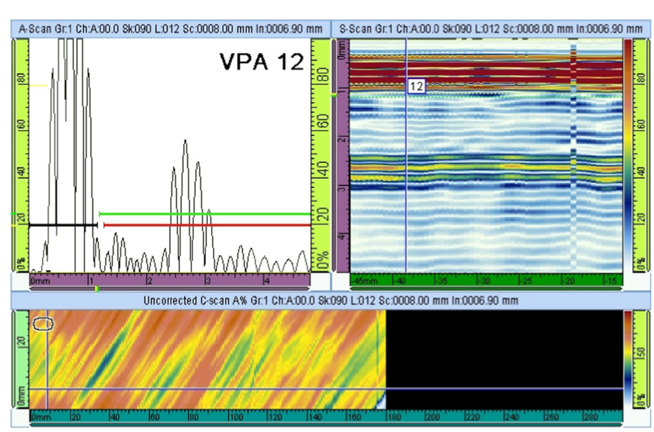

Fig. 1. Exemplary ultrasonic images.