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Thermal buckling analysis of compressed composite panel

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ABSTRACT: The study addresses the thermal buckling behavior of laminated composite beams, which is a significant area of research due to the increasing use of composite materials in engineering applications. The focus is on understanding how these beams respond to temperature changes, which can lead to structural failures if not properly analyzed. The experimental tests on MTS 809 testing machine equiped with thermal chamber and numerical analysis to predict the critical buckling value in different temperatures of work these beams were performed. This is crucial for ensuring the safety and reliability of structures made from composite materials, especially in environments where temperature fluctuations are common. The paper employs an optical non-destructive system Aramis to strain measure and approximation methods to determine experimental values of critical loads. Representative equilibrium paths were obtained, which made it possible to compare load ranges reflecting buckling at different temperatures.

KEY WORDS: thermal buckling, composite, thin-walled structures

1. Wytyczne ogólne

Laminated composites are widely used in the construction of various structures due to their tailorability properties [1]. The demand for high-strength, high-modulus, and low-density industrial materials has led to an increasing number of applications for fiber-laminated composite structures in various fields, such as submarines, sports equipment, medical instruments, civil engineering, enabling technologies, primary and secondary marine and aerospace structures, astronavigation, and many other industries [2]. However, all these structures are expected to operate under changing environmental conditions such as varying temperatures or moisture. The stresses arising due to temperature changes are known as thermal stresses. If these stresses are not considered during the analysis/design phase, they may result in the failure of the structure.

Aircraft and spacecraft experience temperature changes due to environmental factors, such as aerodynamic heating during high-speed travel [3]. This heating can lead to compressive stresses in geometrically perfect plates, which may buckle at a critical temperature [4]. The critical thermal buckling temperature is a crucial design consideration for engineers, especially for aircraft operating at high Mach numbers. Understanding this temperature helps in ensuring the structural integrity of components subjected to thermal loads

Moreover, composite materials are widely used in various applications, but their performance can be affected by the orientation of fibers. It has been noted that while mechanical properties are strong in the primary direction of classical fibers, they are relatively weak in the lateral direction. This orientation issue has led researchers to explore solutions, one of which is the use of unsymmetrical composites with HTCS properties [5,6].

This innovative approach aims to enhance the mechanical properties and resistance to thermal buckling.

The study aims to analyze the thermal buckling response of laminated panels with unsymmetrical fiber orientation. It seeks to model the behavior of these panels under thermal loads and validate the findings through numerical methods.

2. Research subject

This study investigated a thin-walled column provided with additional reinforcing surfaces (Fig. 1). These types of structures are the most basic elements of load-bearing structures used in aerospace and other technical sectors.

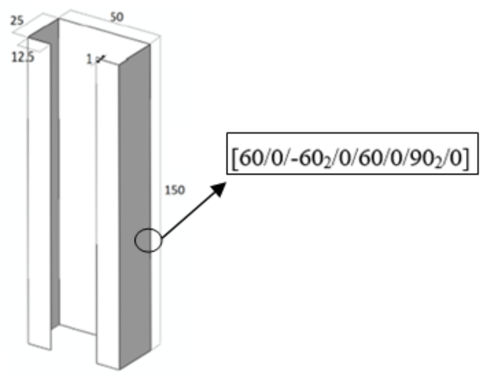

Fig. 1. Geometry and dimensions of tested samples

Experimental models were fabricated from carbon/epoxy composite using autoclaving method. The material mechanical properties were determined according to ISO standards and presented in Table 1.

Table 1. Mechanical properties of the tested composite material

E_1 [MPa]	E_2 [MPa]	ν [–]	G_{12} [MPa]
118 317	7 048	0.32	3 250

Choosen stacking sequence configuration is characterized by HygroThermally Curvature Stable properties (HTCS).

3. Research subject and methodology

Axial compression tests conducted on a MTS testing machine equiped with thermal chamber and liquid nitrogen to low temperature system (Fig.2). The tests were performed in wide temperature range, from -20°C to 80°C in average of 20-degree intervals and with continuous displacement rate of 1 mm/min. During the test recorded the load-displacement curves from machine and load-deflection curves from GOM ARAMIS system based on 3D Digital Image Correlation (DIC) method at each temperature and observed buckling behaviour.

a) b)

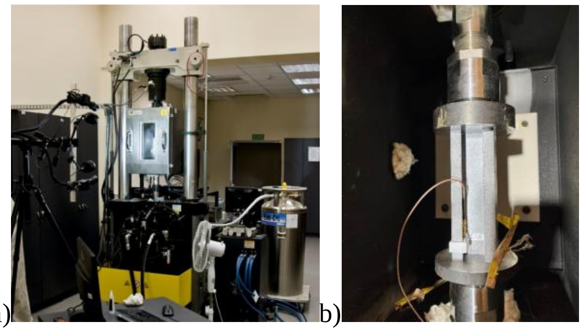

Fig. 2. a) Experimental test stand with high temperature stand,liquid nitrogen to low temperature system, digital measurements of deflection with the ARAMIS system, b) mounted sample

4. Results

Each test run provided information about buckling mode as a function of load, which made it possible to determine representative equilibrium paths and compare buckling modes at different temperature (Fig.3). The experimental results also made it possible to determine critical loads reflecting the first, local and elastic buckling modes by the profile walls and to determine the critical load value with approximation methods (P-w^2 and Koiter). The results presented in Table 2.

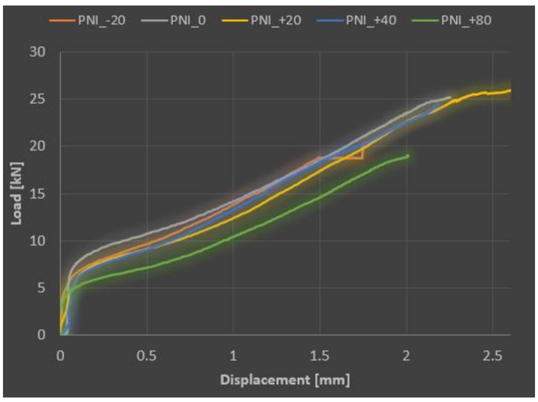

Fig.3. Exemplary load-deflection curves of tested omega profiles from DIC system for room temperature (20°C)

Table 2. Buckling load results

Temperature [C°]	-20	0	+20	+40	+80
*Buckling load (P-w^2) [N]	8059.2	9133.7	8456.8	7568.2	6588.7
Buckling load (Koiter) [N]	7901.8	8944.1	7877.7	7308.4	6410.3
FEM [N]		10208			
Different between two methods [%]	1.9	2.0	6.8	3.4	2.7
*Different according to the reference temp. (20°C) [%]	-5	+8	0	-11	-22

5. Conclusions

Summarize:

1) Temperature significantly affects the buckling resistance of composite profiles under axial compression.
2) Buckling mode changes with temperature: at -20°C, more half-waves are observed (changing from 3 to 4 with increasing temperature).
3) The highest load-bearing capacity observed at 0°C, the lowest at 80°C.
4) The results allow us to conclude that the compressed composite elements operating at higher temperatures are much more susceptible to buckling than when operating at low temperatures, with the differences being quite significant.
5) Assumptions made in the experiments were verified by performing numerical calculations by the finite element method, revealing a good agreement between the experimental results and those obtained for the reference model at a room temperature of +200C.
6) The findings are crucial for the design of structures in various industrial sectors exposed to variable temperature conditions.
7) Need to extend research to a larger number of samples and different configurations.
8) Need to extend research about testing of material properties at other temperatures.

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