EXPERIMENTÁLNE SKÚMANIE NOSNOSTI KOMPOZITNÝCH PRAVOUHLÝCH SENDVIČOVÝCH DOSIEK ZAŤAŽENÝCH AXIÁLNYM TLAKOM

LOAD CAPACITY EXPERIMENTAL INVESTIGATION OF COMPOSITE RECTANGULAR SANDWICH PLATES UNDER AXIAL COMPRESSION

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Abstrakt

V článku sú prezentované určité výsledky experimentálneho skúmania nosnosti konštrukcie. Predmetom experimentu sú pravouhlé sendvičové dosky s laminovanými povrchovými doskami zaťažené axiálnym tlakom. Pozornosť bola venovaná rôznym fyzikálnym a geometrickým parametrom. V každej vzorke bolo vždy dosiahnuté kritické zaťaženie.

Článok popisuje prípravné skúšky, ktoré boli autormi vykonávané v značnom rozsahu.

Kľúčové slová: sendvičová konštrukcia, vláknom vystužený polymér, nosnosť,zbortenie.

Abstract

The paper presents certain results of structure load capacity experimental investigation. The subject of the experiment are rectangular sandwich plates with laminated faceplates loaded with axial compression. Various physical and geometrical parameters are concerned. The critical load for each specimen is always reached.

The paper describes introductory examinations conducted extensively by the authors.

Keywords: sandwich structure, fibre reinforced polymer (FRP), load capacity, buckling.

PREFACE

Determination of the airframe mass minimizing provokes constant quest for new solutions of load structure. The material composition as well as its distribution are the main trends in the structure design. One of these solutions, has been being developed since the half of the last century and meets the requirement of not only high strength, but also low mass simultaneously, is the sandwich structure. The concept of such construction has been traced back to the middle of the 19th century [1], although the principles of it may have been applied much earlier. Its wide introduction and later popularity sandwich structures have owed to the airplane industry. Nowadays they are very common in civil engineering, railways and shipbuilding as well [2]. Complete principles and advanced mechanics the Reader would find in many monographs, the fundamental are works of Teisseyre *et al* [3], Sullins *et al* [4], Romanow [5] or Zenkert [6] even. The researches are still on their way and for more literature we refer to reviews of Noor *et al* [7] or Librescu *et al* [8].

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Concerning the statics of sandwich shell, the model is very close to the monocoque. However, the combination of materials having completely different mechanical properties, makes the sandwich very distinctive. Therefore classical calculation procedures for isotropic objects cannot be applied directly. As the first concise description of the sandwich structure small deformation we can consider works of Libove and Batdorf [9] for plates. In the airplane design and further exploitation buckling of the structure is one of the most important factors. Regarding it, the topic of stability has taken over the leading position among the sandwich mechanics issues. The pioneering step has taken Mayers, led to unified theory of instability of sandwich plates with Benson [10]. The theory was developed by Mathews recently [11]. Since then, the results of new investigations, either analytical, or numerical, or experimental as well are published almost each year and there is no opportunity to quote them all. As the danger of failure in homogenous monocoque structures is strictly connected to overall buckling and post-buckling, as for the sandwiches failure due to local instability is more appropriate. Dependent on the form of sandwich one of the four buckling forms is possible (Fig.1). Except for general buckling (dependent on boundary conditions rather than on structure), the most common is faceplates wrinkling, most representative could be works [12-14]. Although, for honeycomb or corrugated cores face dimpling is also met.

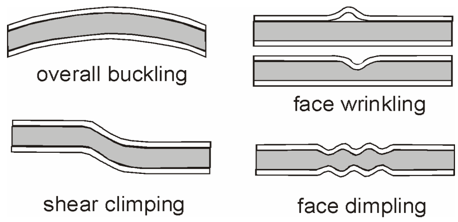

Fig.1 Instability modes for sandwich panels

Nowadays the plastics are essential materials for sandwich structures, but metals or natural wood are met although. The typical, modern sandwich in aviation application is consisted of thin glass fibre reinforced polymer (GFRP) or carbon (CFRP) faceplates connected to the foam core of low density. But polymers changed the relation between instability and load capacity. Brittle-vitreous state of resins applied to faceplates caused the buckling is tantamount to failure. Introduction of FRP allowed to obtain practically unlimited shape of the airframe parallel to the structure integrity of high extent. The load-bearing elements made this way, that is shells of large dimensions like wings or fuselages due to strong shear and compression are particularly exposed to danger mentioned above. The idea is illustrated in the Fig.2.

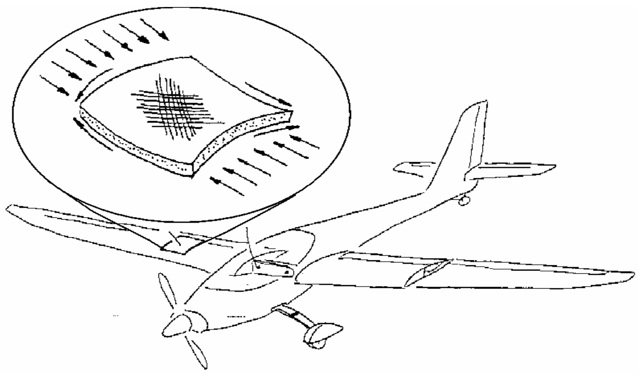

Fig.2 Main, potentially critical, loads in the airframe sandwich structure

In the present paper results of preliminary investigations of sandwich structures consisted of CFRP faceplates and PUR foam core are presented. Not only buckling analysis is carried on, but also is load capacity determined. The researches are the part of the gliders design programme started in early 1980s [15].

RESEARCHES

Sandwich composite and its components

The sandwich structure examined in this experiment was a representative for the modern aviation. It consisted of two thin external faceplates made of CFRP and a foam core.

The faceplates of the sandwich were made of CFRP based on epoxy resin Epidian®53 with Z1 curing agent and Porcher® 4531 carbon fabric (2 per 2 twill weave). Reinforcement ratio was 50% and the composite was cured in room temperature through 24 hours and through the next 8 hours in 60 degrees centigrade. Mechanical properties in tension of the CFRP composite were tested according to the ASTM D638-03 standard [16]. Shear modulus was obtained in the method proposed by Jones [17], and Poisson's ratio was measured using strain gages in CFRP beam bending. Result are presented below in the table 1.

Mechanical properties of CFRP composite **Table 1**

Property	Unit	Value	Property	Unit	Value
Tensile strength	MPa	560	Kirchhoff Modulus 12	GPa	35
Young Modulus 11=22	GPa	150	Poisson's ratio 12	1	0.34
Tensile strain	%	0.6	Stress resultant per one layer	N/mm	185

As a core standard for aviation applications PUR foam was used. It is produced by DIAB [18] and called Divinycell® H80 with mechanical characteristics provided by producer as follows in the table 2.

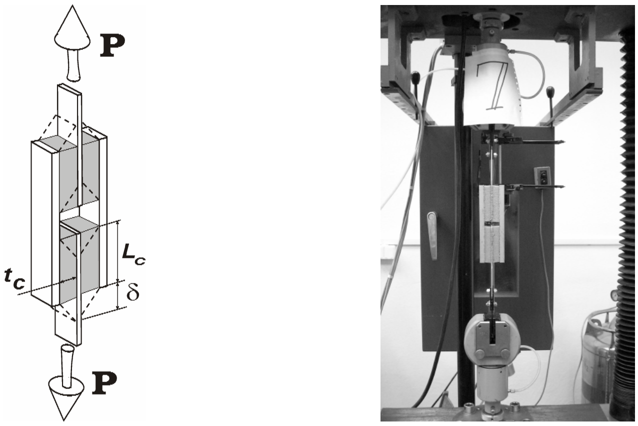

Fig.3 The specimen for Kirchhoff Modulus measurement; left – scheme, right – test-bed

One of them, the most important in sandwich point of view, Kirchhoff Modulus was checked by the means of original method published by Wada *et al* [19]. The certain number of H80 foam specimens, like this shown in the Fig.3, was tested. Results calculated with formula (1) were similar to the data from catalogue. The values were a little higher, but it can be explained by the producer's precautions.

$$G_c = \frac{Pt_c}{2L_c b_c \delta} \qquad (1)$$

Mechanical characteristics of Divinycell® H80 PUR foam **Table 2**

Property	Unit	Value	Property	Unit	Value
Nominal density ISO 845	kg/m^3	80	Shear strength ASTM C723	MPa	1.15
Tensile strength ASTM D1623	MPa	2.5	Kirchhoff Modulus ASTM C723	MPa	27
Young Modulus ASTM D1623	MPa	95	Shear strain ASTM C723	%	30

The semi-finished product for the sandwich plates as a composite of the materials described above was made. The CFRP faceplates were laminated onto the core directly and cemented while epoxy resin curing. The scheme of the sandwich technology preparation is shown in the Fig.4.

Fig.4 Sandwich semi-finished product final preparation in the workshop

TEST – BED

For experimental researches of sandwich plates the special station, shown in the Fig.5, was constructed. The specimen is placed in special grooves filled with silicon rubber or epoxy resin to simulate simply support or fixing respectively. Only one width of the plate is possible but the choice of the height is rather arbitrary and assures specimen aspect ratio from theoretically zero to 2.5. Such prepared specimen is clamped between thick facings at the edges and screwed to the very stiff frame. In front of the specimen the grid for shadow moiré is placed. The whole test-bed is attached to the testing machine and universal set for compression is used. During the trial all parameters were recorded and the moiré fringe patterns photographed.

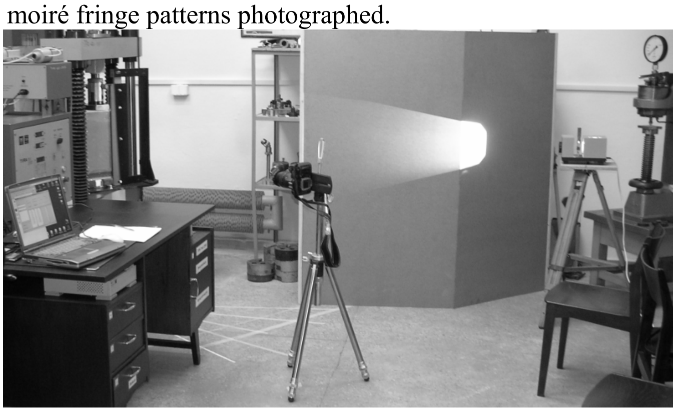

Fig.5 Test-bed for buckling of sandwich plates; left - specimen fixing, right – general view of the test in progress

RESULTS AND DISCUSSION

- ***A way to the failure***

The behaviour of sandwich plates before the loss of stability was typical for this kind of structures. Load capacity, very high on account of CFRP applied, depended both on the geometry and boundary conditions, and was close to the critical load. The loss of stability has always the same course. When the force reached the level of critical one, overall buckling appeared. Next, due to deflections and eccentric bending being apparent local loss of faceplate stability in a certain location took place. Typical plot is shown in the Fig.6.

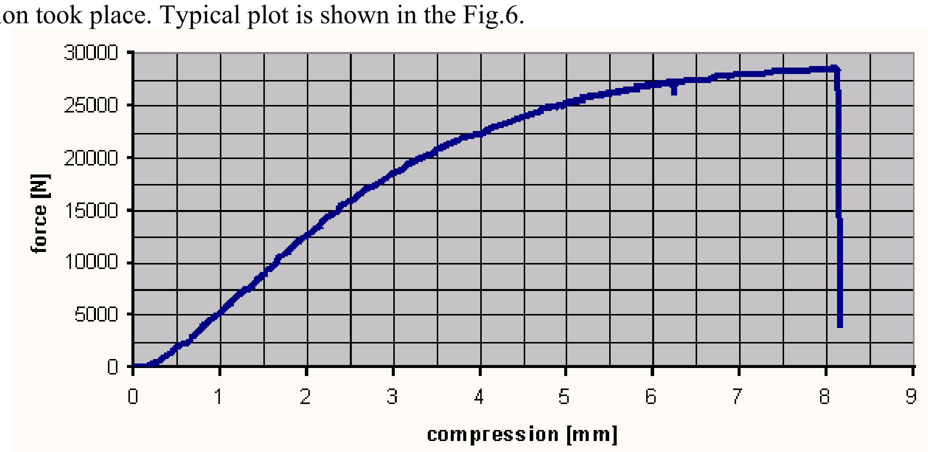

Fig.6 Plot for the specimen with vertical edges articulated, horizontal fixed and aspect ratio λ=1.65

- ***Modes of instability***

Two of four mentioned above instability modes of sandwich plates were observed during investigations. On the grounds of obtained results it was found, the buckling mode as well as its location depends on the boundary conditions precisely. Two sets of clamping were realised.

In the first case all the edges had elastic simply support. Before the damage, as the moiré fringe patterns showed, the plate deflection had long wave appearance with one half-wave in a comparable manner to the compressed strut with fulcrums on the both ends. Possibility of rotation on the axis along the horizontal edges initiated eccentric bending and the compressive stress in one of the faceplates increase. As a result, the damage always appeared in the vicinity of one of the horizontal edges and assumed the form of wrinkling with faceplate sank in.

When the horizontal edges are stiffly clamped the buckling mode is similar to the buckling of the strut with both ends fixed (displacement tangent to the strut's axis is free at one end). General buckling has also one half-wave, but with node in the middle of the plate's height, seen at moiré pattern evidently. Core shear is the reason of faceplate crimping, taking place in the wave node.

Another form of wrinkling was met, when the vertical edges were free or there was cut-out in the plate – faceplate delamination.

Every deformation, on account of materials mechanical properties, happened in the elastic range. Stable deflection remained only in the damage area.

Fig.7,8,9 present every buckling state mentioned. Moiré fringe patterns depict faceplate deformation right before and just after the destruction. Fig.9 in each row shows the post-buckling state.

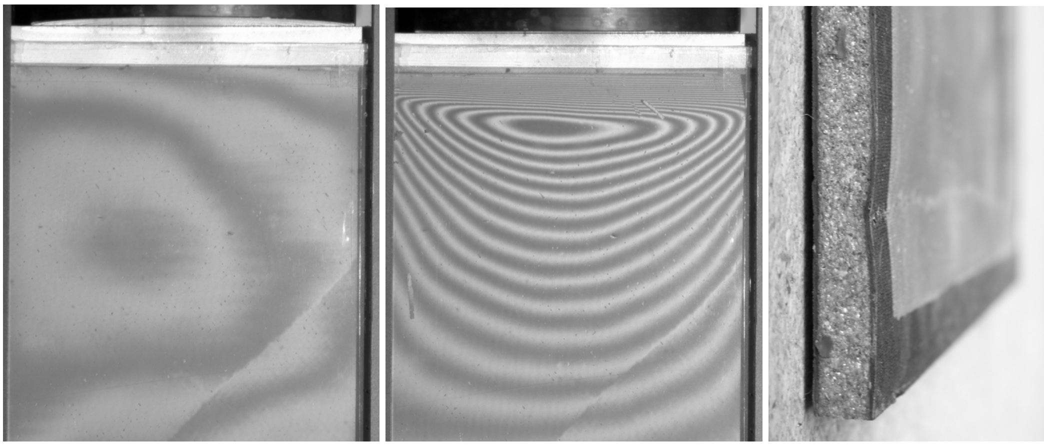

Fig.7 Example of faceplate wrinkling in the vicinity of the edge. Every edge simply supported. Critical load P_{CR}=25[kN], aspect ratio λ=1

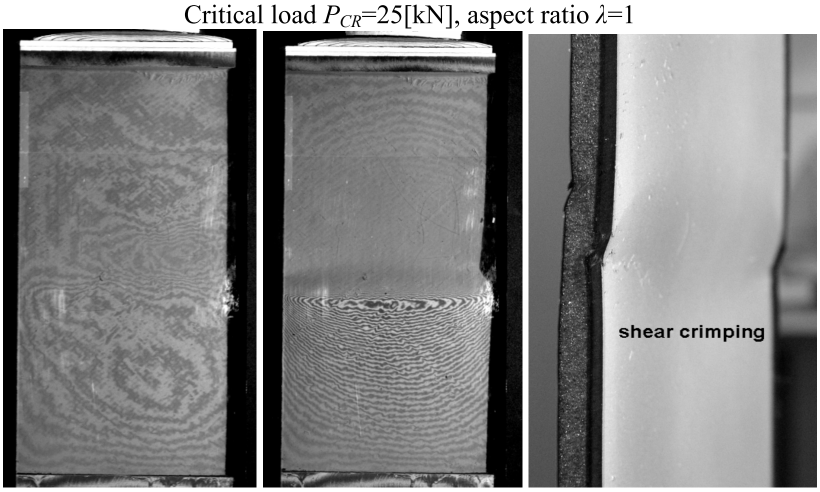

Fig.8 Example of shear crimping. Vertical edges simply supported, horizontal fixed. Critical load P_{CR}=28[kN], aspect ratio λ=1.65

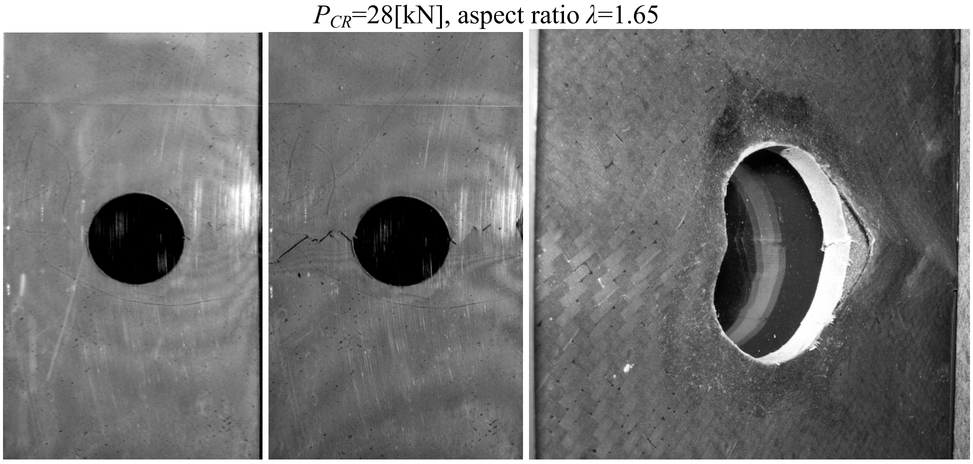

Fig.9 Example of different faceplate wrinkling. Vertical edges simply supported, horizontal fixed, centred hole diameter 60[mm]. Critical load P_{CR}=22.3[kN], aspect ratio λ=1.65

CONCLUSIONS

Introductory investigations of CFRP – foam core sandwich plates exposed to axial compression are presented in this paper.

Very high load capacity of CFRP was proved. The influence of boundary conditions on overall and local buckling mode was shown. Concerning it, possibility of the damage form as well as its location prediction takes shape. Not only gaining well repeatability, but also comparison with analytical and numerical solution is essential.

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