IOP Conf. Series: Materials Science and Engineering **726** (2020) 012006 doi:10.1088/1757-899X/726/1/012006

Study of bending resistance of sandwich structures

O Šuba, M Kubišová, O Šuba Jr., D Měřínská and L Pitnerová

Tomas Bata University in Zlín, Faculty of Technology, Vavrečkova 275, 760 01 Zlín, Czech Republic

mkubisova@utb.cz

Abstract. Article deals with the study of the flexural limit state of sandwich structures based on fiberglass and polymeric foams. Whether geometrical and material parameters influence the resulting load-bearing capacity of these structures are studied experimentally using FEM models. This study shows it is necessary to particular emphasis attention to the issue of flexural strength, the load capacity when of the walls designing sandwich shell products to avoid possible failures in the practical use of these types of structures. Subsequently, Horn's evaluation method is used to compare the experimental testing and the FEM model.

1. Introduction

Production technologies, along with the study of the properties of sandwich structures on a polymeric basis, are steadily rising and are the subject of many researchers. Sandwich structures are generally characterised by excellent mechanical properties at the very low weight. On the other hand, the choice of the sandwich component concept also brings problems associated with its macrostructure [1-3]. As a result of the geometric and material parameters of the sandwich wall, it is layered, and therefore non-homogeneous, element whose some aspects of mechanical behaviour may differ significantly compared to a conventional homogeneous wall. The resulting level of structural strength is determined by factors that generally reduce the theoretical bending strength resulting from the bending theory [4-5]. In particular, a standard three-point test cannot be used to measure the exact bending properties. The reason is mainly the effect of the generally significant shear stiffness, the low values of the shear modulus of the elasticity of the expanded core the resulting useful mechanical behaviour of the sandwich element. In the three-point bending test, in addition to the flexural-normal deformation of the supporting layers, the shear stresses, which are known to be transmitted by virtually only the layer of the expanded core, are involved in the resulting deformations relatively extensively. Due to the low stiffness of the core, the shear deformations are significant, and the test is therefore unusable for determining the bending properties. Also, the results are often devalued by possible indentations at the support sites [6-7].

2. Materials and methods

2.1. Problems of bimodularity of supporting layers

For the pure bending stiffness of the layer-composite cross-section (without the influence of the shear deformations of the core), the modification of the technical bending theory can be laid.

$$K_O = E_+ \, J_R \tag{1}$$

where E_+ is the modulus of elasticity of the surface laminate tensile layer and J_R value represents the quadratic moment of the reduced cross-sectional area of the layer structure to the neutral axis - see Figure 1.

The so-called reduced cross-sectional area of the non-homogeneous-composite element is generally determined by reducing the widths of the individual layers relative to the selected reference (usually the largest) value of the modulus of elasticity of the structure.

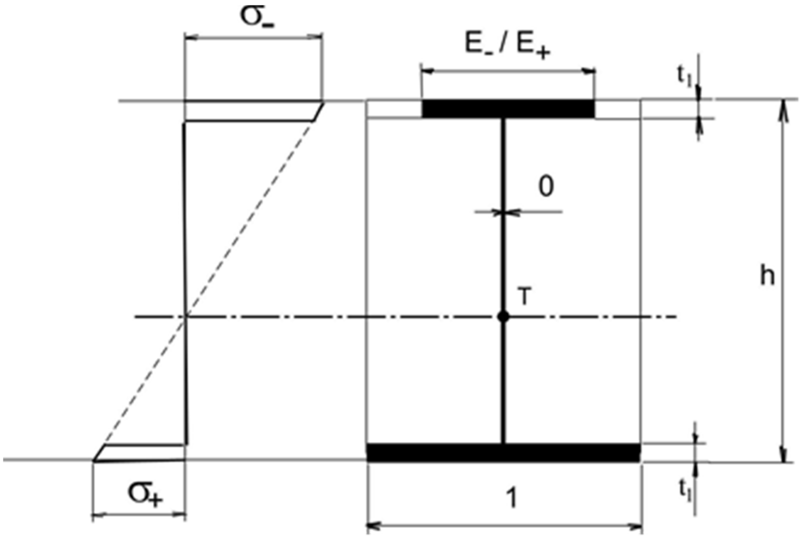

Figure 1. Reduced cross-sectional area and bending stress, considering the bimodularity of the supporting layers.

The existence of carrier bimodularity shows some aspects that negatively affect or reduce the load-bearing capacity of the sandwich structure compared to the expected values according to the conventional technical bending theory. As the floor of Figure 1, due to the asymmetry of the reduced cross-sectional area to the neutral axis, the bending stress in the printed carrier layer is more significant, while the modulus of compression flexibility is less than in the tension. From a mechanical point of view, this is a negative tendency, since it is a mechanical problem of the stability of the printed layer on the elastic core.

2.2. Numerical analysis of the ultimate state of the flexural load-bearing sandwich structure in bending

To study the flexural stiffness of the sandwich, wall on the rigidity of the expanded nucleus, linear elastic FEM models of bending tests with a structure corresponding to samples prepared for bending test was used. Solidworks/Cosmos tools software was used to build the FEM model. The model represents a four-point bending test, with the supports and load shown in Figure 2. With this arrangement, the central part is loaded with a constant bending moment and thus with zero transverse forces (pure bend).

The calculation is performed as a modal analysis of a 2D solids. Mechanical data were entered based on experimentally obtained values. In our case, the laminate layer exhibited a tensile modulus of 22 000 MPa and compression modulus of 15 000 MPa.

The solution is performed as a modal analysis of the specially modified four-point bending test model (Figure 2). The detail of generated mesh is shown in Figure 3.The samples are adjusted using additional bars so that a clean bend condition is ensured during the test. There is no rigid bond between the strips and the support layers so that the rigidity of the edge portions is only slightly affected. The model naturally assumes the ideal rigid bond between the layers of the structure, so the result is a theoretical, practically unreachable limit state representing a loss of stability of the laminate layer.

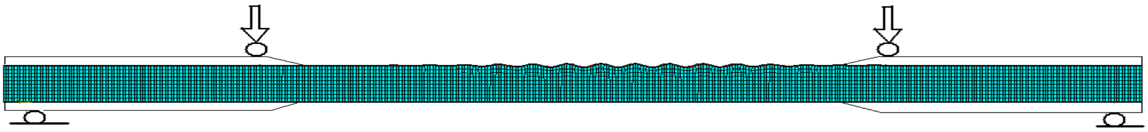

Figure 2. Special arrangement of the four-point bending test.

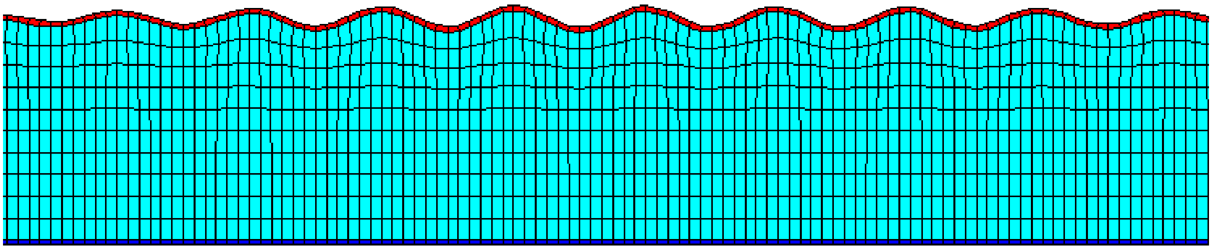

Figure 3. Detail of the model limit state of loss of stability of the printed carrier layer.

2.3. *Experimental testing of sandwich structures*

When the verification of the results of numerical modelling was prepared, sandwich structure coated glass pre-impregnated fabrics of the basis weight of 296 g.m^{-2}. The impregnating component in the case of this prepreg (PH840-300-42) was a phenolic resin in a total amount of 42 % by weight. Polyethene terephthalate (AIREX T90.100) - core PET foam - a density of 100 kg.m^{-3}, with a modulus of elasticity of 70 MPa, was used as the core of the prepared structures.

From the above materials, sandwich structures were formed, consisting of one, two and three layers of prepreg from the top and bottom and a core of PET with a thickness h = 20 mm. The resin curing technology in the prepreg under the flexible foil in the curing oven was used to produce it. Curing started at 130 °C for 30 minutes, followed by the residence time of 120 minutes at this temperature. After deformation, test bodies were cut from the sandwich panels for standard bending tests.

The results of the load-carrying capacity of the individual structures - with the composition of the bearing layers with the number of mono-layers - lamin 1, 2 and 3 showed a significant dependence on the local value of the adhesion of the layers. The torque values thus varied within a considerable range. Quality values of laminate-foam glued joints were evaluated after each test.

The test consisted of visual inspection of the individual layers, using a microscopic technique and the magnification was optimised 50x [7-8]. It has been found that the consistency of these primarily commercial types of sandwiches showed considerable scattering (from very weak to high-quality cohesion values) and the resulting flexural strength values also corresponded. The theoretically predicted phenomenon of loss of stability was not observed. The results of the measured values of the limit bending moments are plotted for the individual structures (layers with 1, 2 and 3 laminates) in the graph in Figure 4. The results were processed using the Horn method (Table 1).

Table 1. Experimentally determined values of boundary-bending moments of individual structures. The upper value in each column is the theoretical moment determined by FEM by modal analysis.

	Sandwich 1	Sandwich 2	Sandwich 3
	Slat 1	Slats 2	Slats 3
Lower limit (Horn minimum) confidential level 5%	24.5 kN	30.7 kN	36.9 kN
Medium (Horn centre)	37.5 kN	53.4 kN	69.2 kN
Upper limit (Horn maximum) confidential level 95%	66.1 kN	69.5 kN	72.9 kN
Theoretical maximum	37.9 kN	71.5 kN	106.5 kN

By mere visual observation, we did not observe the loss of stability due to the corrugation of the printed layer in any specimen, even in samples whose measured, M_{LIM} was relatively close to the theoretical value. We, therefore, used to monitor the moment of the high-speed camera violation, and the tracking results were shocking. The Olympus i-Speed - II high-speed camera was used. Its parameter setting was: frame rate of 10,000 fps (frames per second), resolution of the sensor 800x600 pixels. The image was analysed by internal software, which is part of the supplied high-speed camera system called i-Speed. With samples with excellent consistency, we managed to capture the moment of loss of stability of the printed layer. This effect took place only a very short moment, which the human eye cannot capture. Figure 5 shows behaviour of the sample 0.04 seconds ($t_{(s)}$ = loss of stability – 0.04 sec) before ripple, in Figure 6, then the very phenomenon of loss of stability. Then the destruction of the slate according to occurs (Figure 7).

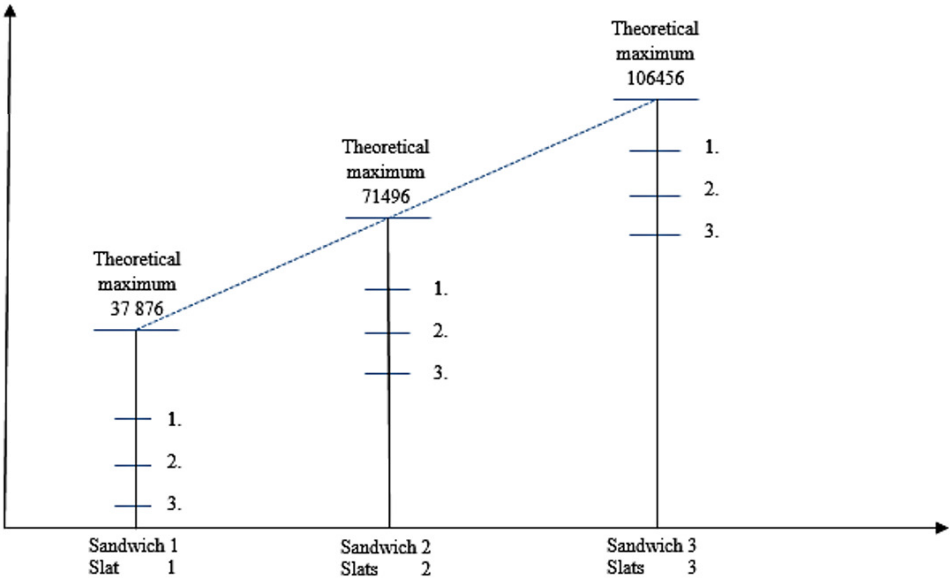

Figure 4. Analysis of small selections.

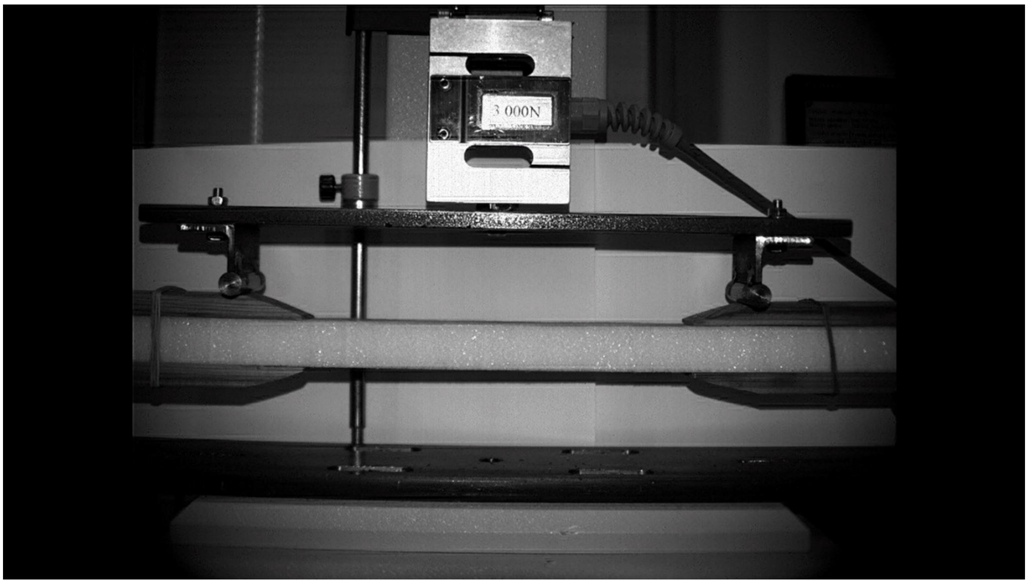

Figure 5. Behaviour of the sample 0.04 seconds before corrugation.

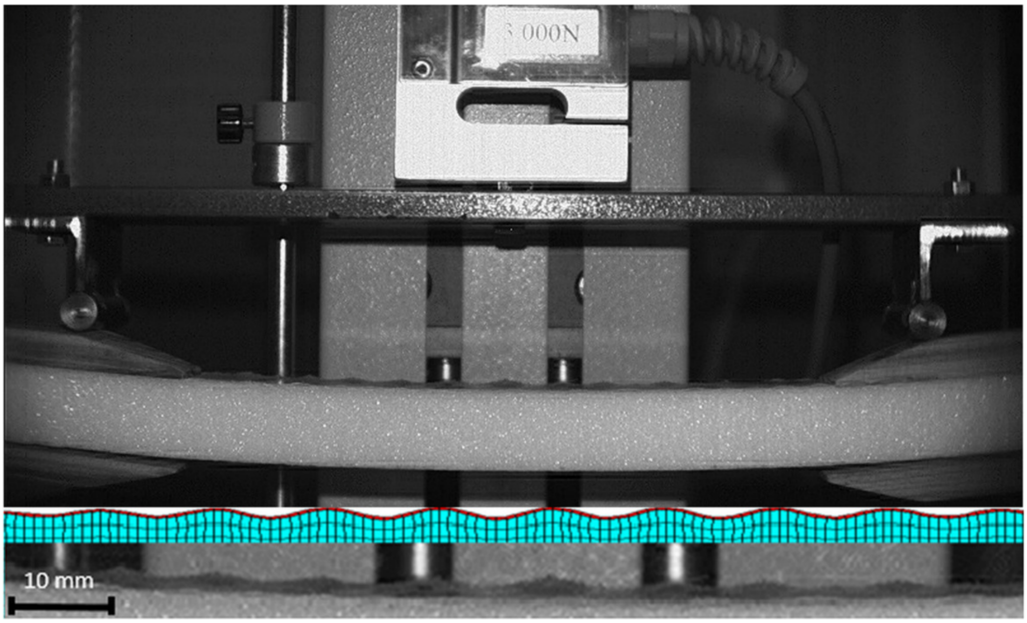

Figure 6. Maximum instability of the sample.

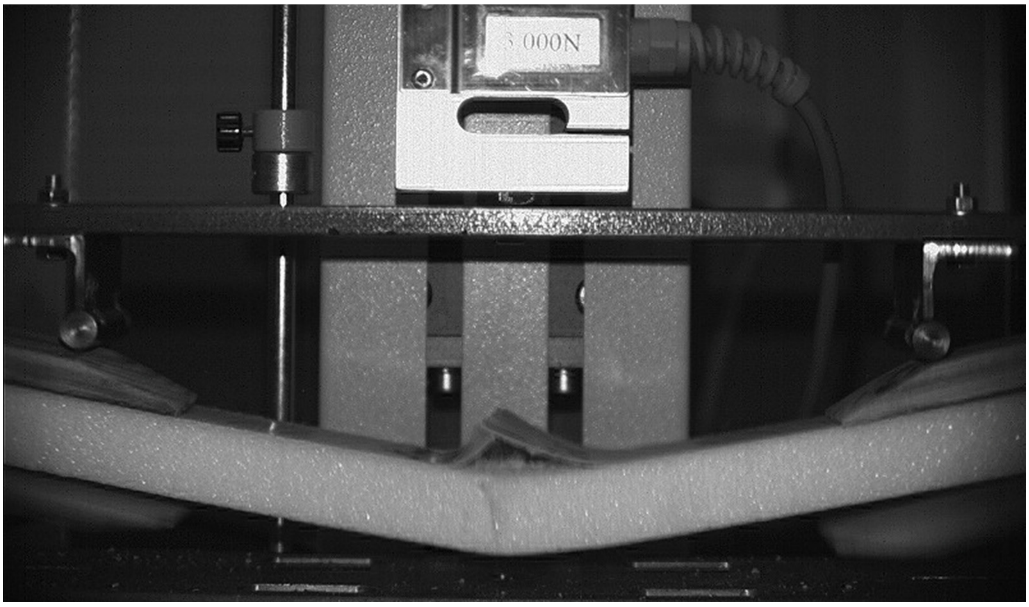

Figure 7. Destruction of the structure.

3. Conclusion

This study showed that particular attention should be paid to the flexural strength issue when designing sandwich products in order to avoid possible failures in practical applications of these types of structures. The limit state mechanism in the bending of sandwich structures based on laminate carrier layers and foam core has been found. It has been shown that the failure state of these sandwich structures represents a short time, in the order of hundredths of a second, in which the first compressed support layer loses its stability and then breaks down. Due to the bimodularity of laminate layers, the load-bearing capacity of sandwiches is always lower due to the lower modulus of the laminate in compression than in tension. Higher modulus values of the tensile layer are never used.

This was followed by verification of the model's self-results, which were achieved using the 4-point bend technique, the respective and described sandwich structures.

The results obtained by the four-point bend were then evaluated by the Horn method, which is recommended for the purpose and frequency of the samples examined [8].

The graphical comparison of the model results and the results obtained with the 4-point bend test was captured using the high-speed OLYMPUS I speed 2 camera system, with a recording speed of 10,000 fps (frames per second). At the point in time $t = 0.00$ s, the most significant match between the model and the real record occurred as the optically based image.

Acknowledgement

This work was supported by an internal grant of UTB in Zlín RVO/FT/2019/003 financed from Funds of specific academic research.

References

[1] Zenkert D 1997 *The Handbook of Sandwich Construction* (Worcestershire: EMAS Publishing) ISBN 978-094-7817-961

[2] ASTM C393/C393M-11 2012 *Standard Test Method for Core Shear Properties of Sandwich Constructions by Beam Flexure*, ASTM International.

[3] PH840-300-42 2014 *Material datasheet* Gurit. [online]. © 2014 [cit. 2018-10-18]. *Available from:* http://gurit.fangle.co.uk/files/documents/PH840-300-42.pdf

[4] Vinson J R and Sierakowski R L 2004 *The Behavior of Sandwich Structures of Isotropic and Composite Materials* (New York: Kluwer Academic Publishers) ISBN 1-4020-0904-6

[5] Gibson L J and Ashby M F 1999 *Cellular solids: structure and properties* (Cambridge: Cambridge University Press) ISBN 0521499119

[6] Valasek P and Muller M 2012 Polymeric particle composites with filler saturated matrix. *Manuf. Technolog.* **12** (13) 272-6

[7] Banghai J, Zhibin L and Fangyun L 2015 Failure mechanism of sandwich beams subjected to three-point bending *Compos. Struct.* **133** 739-45

[8] Meloun M, MILITKÝ M A and Forina M 1992 *Chemometrics for analytical chemistry* (New York: Ellis Horwood) ISBN 01-312-6376-5.