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MODELLING OF OSB SANDWICH PANELS WITH ORIGAMI-INSPIRED CORE

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ABSTRACT: This research is focused on the development, and experimental and numerical testing of wood-based sandwich panels with both covers and a core made of oriented strand boards (OSBs). The core shapes are inspired with an origami pattern. Wood-based sandwich panels are structural elements that maintain essential features of wood, such as lightness, while having an increased load-bearing capacity and stiffness. Thanks to these properties, they find application in high-rise and residential construction. Laboratory tests presented in this study are aimed at determining selected material properties of the boards, namely the Young's moduli in the longitudinal and transverse direction. The experimentally identified parameters are afterwards used as orthotropic coefficients in the numerical analysis of six sandwich panels, differing in the core type and the thickness of the core boards. The numerical models are prepared in the Abaqus environment and analysed using the finite element method (FEM). Two types of models are built for each panel: a 3D shell model of the whole panel and a 3D solid submodel of a section of the panel. The submodels are aimed at the detailed analysis of stress distributions in the areas of the connections between the covers and the core.

KEYWORDS: Sandwich panel, OSB, FEM, Submodelling

1 INTRODUCTION

Modern civil engineering faces many problems that force engineers to seek for new, creative solutions, both within materials and structures. Due to the rapidly progressing urbanisation and the increasingly frequent requirement to strive for sustainable solutions, scientists have started to pay more attention to wood, which has been used in the construction for centuries. One of the first steps toward the improvement of this natural material was the development of wood-based products such as oriented strand board (OSB), laminated veneer lumber (LVL), glued or cross-laminated timber (GLT or CLT). These materials can be used in multi-storey buildings thanks to their improved load-bearing capacity and good elastic properties while maintaining a low weight.

OSBs consist of slender strands of wood which are bonded together using water-resistant resins [1]. The boards have usually three layers of strands, which are oriented perpendicularly to one another, and the strands of outer layers are mostly oriented along the main axis of the board. OSBs are widely used as engineering products in the construction industry due to their favourable mechanical properties [2].

The research on OSB has focused mainly on the determination of its physical and mechanical properties, using both the numerical and experimental studies. Zhu et al. [3] investigated material properties of OSB by performing experimental tests covering in-plane behaviour of the boards as well as their properties in the perpendicular direction. They proved that OSB is an orthotropic material with better mechanical properties along the main strands orientation direction. Moreover, they proposed an elastic-plastic constitutive model of OSB, which they implemented in the finite element (FE) analysis. Islam et al. [2] conducted laboratory tests on OSB samples in order to determine various technical parameters of the boards, e.g. ultimate strengths, Young's modulus, shear modulus, and Poisson's ratio. They tested samples which were cut from the board along three directions: transverse, diagonal and longitudinal. Hrázský and Král [4] studied the effect of density and glue amount changes on the mechanical behaviour of OSB. They determined bending strength, modulus of elasticity and tensile strength of OSBs of different thicknesses, varying in density and the amount of glue. Plenzler et al. [1] performed experiments aimed at determining elastic and strength properties of the layers of commercial OSB panels. They confirmed that the physical and mechanical properties of the face and core layers of OSB differ significantly. Feraboli [5] studied the notched response of OSB wood composites. He collected a large experimental database proving that OSB may be considered a notch-insensitive material thanks to its heterogeneous inner structure.

Although the OSB is a well-known material that has been used since a very long time in various civil engineering applications, and many studies on its mechanical properties can be found in the literature, it is still problematic to find full information on the mechanical behaviour of specific types of OSBs. Therefore, the authors of this paper have decided to perform

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experimental tests aimed at identifying certain orthotropic coefficients of the boards used for the construction of the investigated OSB-based sandwich panels.

Wood-based sandwich panels are understood here as composite slabs consisting of two thin covers and a thick but lightweight core. Such structural elements maintain the essential features of wood, such as lightness, while having the increased load-bearing capacity and stiffness [6]. Thanks to these properties, sandwich structures would find application in high-rise and residential construction. Covers can be made of wood-based materials like OSB, CLT or composite elements. For the core, there is a wide range of structural systems used, including basic trapezoidal or trapezoidal-like shapes [7], or light openwork structures such as lattice-shaped cores [6], especially XX-type lattice [8] and 2D lattice truss [9]. Each shape responds differently under the load, allowing for the design of structures that meet even very high demands. Sandwich structures could be assembled using traditional wood and wood-based materials or, more surprising, bamboo [10] or jute fabrics/epoxy composite [11].

The subject of the research presented in this paper is the development and experimental and numerical testing of a wood-based sandwich structure with both covers and a core made of OSBs. The core shape is inspired with an origami pattern [12, 13]. An example of a physical model of a section of the analysed structure is presented in Figure 1. This is an illustrative example aimed at showing the authors' idea, not the model that has been tested in the laboratory.

Figure 1: *Physical model of the OSB sandwich plate section*

This study focuses on two aspects of the broader research, which is a part of the research project realized by the authors at the Warsaw University of Technology, funded by the National Science Centre in Poland. In Section 2, results of laboratory tests conducted on OSB samples of various thicknesses are presented. The tests were aimed at determining selected orthotropic coefficients of the boards, that is Young's moduli in two directions: longitudinal and transverse. Section 3 contains results of numerical analyses of sandwich panels carried out in Abaqus software using the finite element method (FEM) [14], with the material properties determined in the experimental study.

2 EXPERIMENTAL TESTS

In order to determine selected material parameters of OSB, experimental tests on OSB samples of three different thicknesses were conducted. Altogether, 60 OSB samples were tested: three different board thicknesses (10 mm, 15 mm, and 22 mm), and for each board ten samples cut in each of the two directions (along the longitudinal axis and transverse to it). The tested samples were rectangular with the following dimensions: 25 mm x 200 mm for the 10 mm thick OSB, 25 mm x 300 mm for the 15 mm thick OSB, and 25 mm x 400 mm for the 22 mm thick OSB. The specified lengths of the samples are not their actual lengths, but their spans (distances between the supports in the testing machine). Figure 2 shows 20 samples cut from the 22 mm thick OSB: ten in the longitudinal direction (T00) and ten in the transverse direction (T90).

The tests were aimed at determining the Young's moduli in two directions: longitudinal (E_1) and transverse (E_2).

Figure 2: *Samples of the 22 mm thick OSB in two directions: T00 – longitudinal, T90 – transverse*

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Three-point bending tests were performed using a universal testing machine Instron 3382, with one concentrated force applied in the middle of the span. The loading was applied using a displacement-controlled method with the speed of 10 mm/min, and the displacements of the samples were measured with a laser sensor, which observed the bottom surface of the sample. The test setup is showed in Figure 3, which depicts one of the 22 mm thick OSB samples under bending.

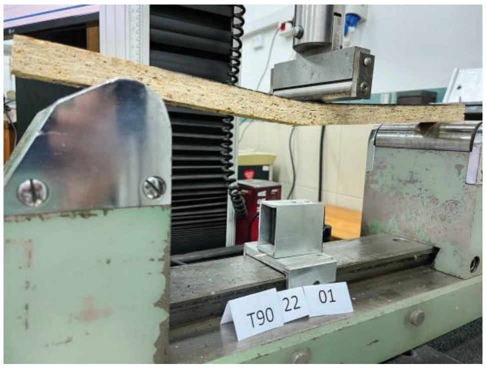


Figure 3: *Bending test on the 22 mm thick OSB sample in the transverse direction*

Figures 4 and 5 present results obtained from the bending tests (force-displacement curves) for the 22 mm thick OSB samples. Similar tests were performed on the 10 mm and 15 mm thick boards. However, as the main aim of this study was to determine the Young's moduli, the curves obtained for other samples are not presented here. Instead, all results (calculated values of the Young's moduli) are gathered in Table 1.

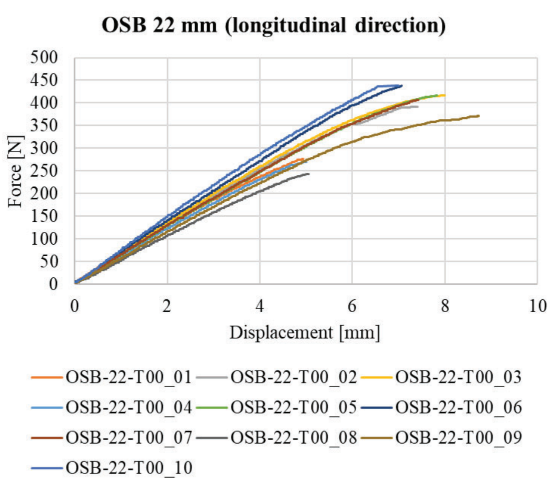


Figure 4: *Results of bending tests performed on the 22 mm thick OSB samples in the longitudinal direction*

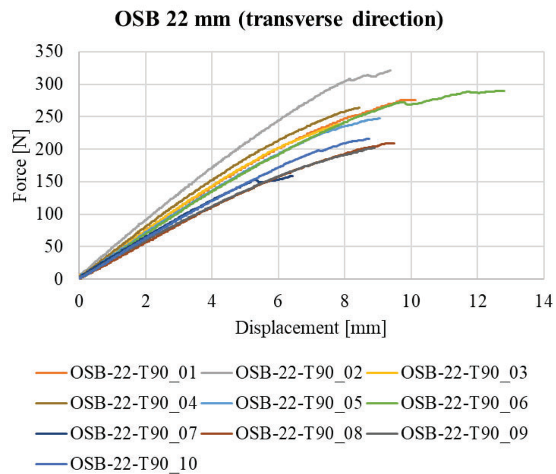


Figure 5: *Results of bending tests performed on the 22 mm thick OSB samples in the transverse direction*

Table 1: *Young's moduli of OSB determined in the experimental tests*

OSB thickness [mm]	Direction	Young's modulus [N/mm^2]: E_1 (T00) and E_2 (T90)		
		Average	Median	Standard deviation
10	T00	5191.22	5079.47	379.38
	T90	3471.12	3481.40	378.91
15	T00	4317.95	4202.95	615.03
	T90	2321.04	2316.10	270.40
22	T00	4072.05	4052.48	357.34
	T90	2271.99	2332.63	312.54

The Young's moduli were calculated using the formula

$$E = \frac{(F_{40} - F_{10})L^3}{48\, I(u_{40} - u_{10})}, \tag{1}$$

where:
E – Young's modulus,
F_{40} – force corresponding to 40% of the breaking load,
F_{10} – force corresponding to 10% of the breaking load,
u_{40} – vertical displacement at 40% of the breaking load,
u_{10} – vertical displacement at 10% of the breaking load,
L – span,
I – moment of inertia.

Calculated values of the Young's moduli were afterwards used in the numerical models of the considered sandwich panels.

3 NUMERICAL MODELLING

Finite element models of the OSB-based sandwich panels were developed in two stages using the Abaqus environment:

- stage 1 – 3D shell model of the panel;
- stage 2 – 3D solid submodel of a section of the panel.

The shell model was built using 4-node general-purpose shell elements with reduced integration (S4R) within the linear elasticity with an orthotropic material model, and the adopted finite element size was 0.01 m. The connection between the core and cover boards was modelled using the tie contact in Abaqus with automatic discretization. The uniformly distributed load of 2 kN/m^2 was applied to the upper cover of the panel in the vertical direction (direction 3 – perpendicular to the panel surface). The panel was supported at shorter edges of the lower cover: at one edge displacement constraints in two directions (U1 and U3) were applied, along the other edge the constraints were applied in the vertical direction (U3) and, additionally, constraints in the horizontal direction (U2) were applied in two corner nodes.

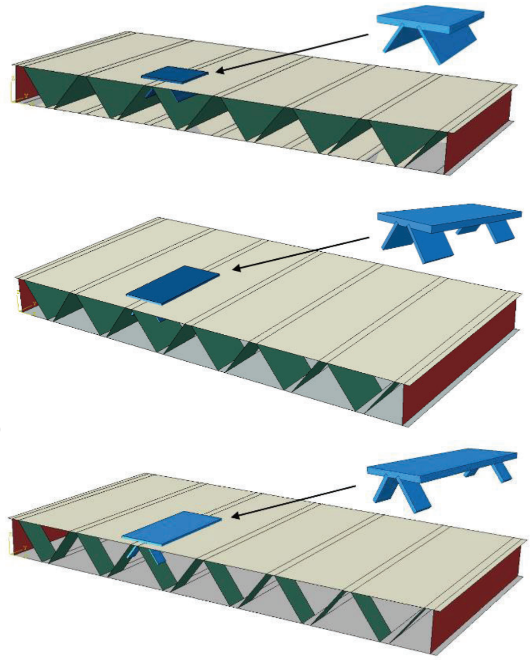
The submodel was generated using the Abaqus built-in procedure, which allows for the automatic reading of the boundary conditions and introducing them into the defined submodel. A shell-to-solid submodelling was used, where shell corresponds to the full model, and solid to the submodel. It is important to locate the submodel in the same coordinate system, so that it is consistent with the location of the corresponding elements of the shell model.

The submodel was built using 8-node linear brick elements with reduced integration (C3D8R) within the linear elasticity with an orthotropic material model, and the adopted finite element size was 0.0025 m. The connection between the core and cover boards was modelled using the tie contact in Abaqus with automatic discretization. The same uniformly distributed load of 2 kN/m^2 was applied to the upper cover of the panel, and the boundary conditions were applied automatically, based on the displacements of the shell model.

Using the procedure described above, six different sandwich panels were analysed. All panels had the same 22 mm thick OSB covers and different core structures:

- panel 1 – continuous core (full), 15 mm thick OSBs (Figure 6a);
- panel 2 – continuous core (full), 10 mm thick OSBs;
- panel 3 – discontinuous core (50% of the full core material), 15 mm thick OSBs (Figure 6b);
- panel 4 – discontinuous core (50% of the full core material), 10 mm thick OSBs;
- panel 5 – discontinuous core (25% of the full core material), 15 mm thick OSBs (Figure 6c);
- panel 6 – discontinuous core (25% of the full core material), 10 mm thick OSBs.

For each sandwich panel two FEM models were created: a shell model and a solid submodel (see Figure 6). Shell models had dimensions of 2.50 m x 1.25 m x 0.25 m, and the dimensions of the submodels differed depending on the panel: 0.25 m x 0.30 m x 0.12 m (panel 1 and 2), 0.25 m x 0.50 m x 0.20 m (panel 3 and 4), 0.25 m x 0.565 m x 0.20 m (panel 5 and 6). All submodels were cut from the same location of the shell models.



a)

b)

c)

Figure 6: *3D shell models with 3D solid submodels: a) panel 1; b) panel 3; c) panel 5*

The material properties used in the numerical analysis are presented in Table 2. Values of the Young's moduli in two horizontal directions (longitudinal and transverse) were taken from the experimental tests described in Section 2, and all other parameters were adopted based on the literature study – due to the fact that those parameters have much smaller effect on the mechanical behaviour of the structure that the tested Young's moduli, equal values in all directions and for all OSB thicknesses were applied. However, in the future study the authors plan to identify all orthotropic coefficients experimentally.

Table 2: *Material parameters used in the FE analysis*

OSB thickness [mm]	10	15	22
E_1* [N/mm^2]	5191.22	4317.95	4072.05
E_2* [N/mm^2]	3471.12	2321.04	2271.99
E_3** [N/mm^2]	1800	1800	1800
ν**	0.2	0.2	0.2
G** [N/mm^2]	1100	1100	1100

* values identified experimentally
** values based on the literature

Selected results of the numerical analysis are presented in Figures 7-10. Figure 7 depicts magnitudes of displacements obtained in three shell models of selected sandwich panels: 1, 3, and 5.

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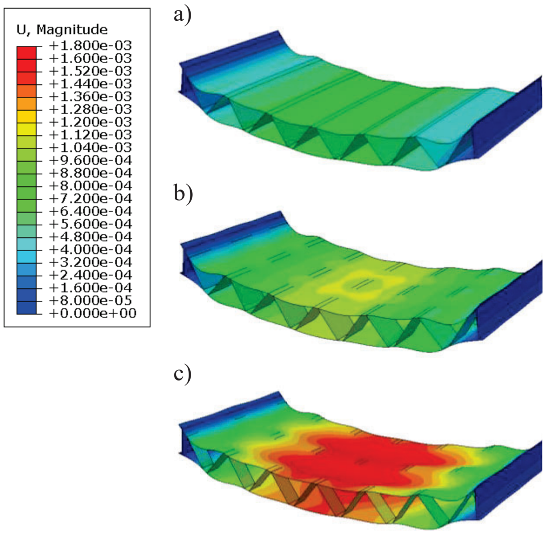

Figure 7: *Magnitude of displacements: a) panel 1; b) panel 3; c) panel 5*

It can be noticed that the reduction of the core material results in increased displacements of the panel. The following maximum displacements were obtained in sandwich panels with the 15 mm thick core boards: 0.79 mm for the full core, 1.14 mm for the 50% reduced core, and 1.72 mm for the 25% reduced core. Similarly, in sandwich panels with the 10 mm thick core boards, the maximum displacements were: 1.00 mm for the full core (26.6% increase in relation to the 15 mm thick core boards), 1.18 mm for the 50% reduced core (3.5% increase), and 1.80 mm for the 25% reduced core (4.7% increase).

Figures 8-10 show distributions of normal stress in the longitudinal direction in the submodels of six panels.

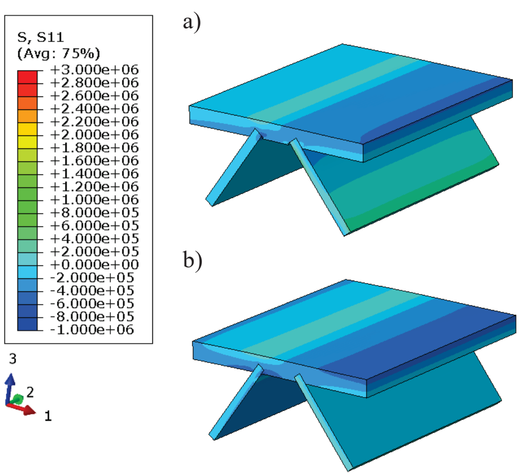

Figure 8: *Distribution of normal stress in the longitudinal direction: a) panel 1; b) panel 2*

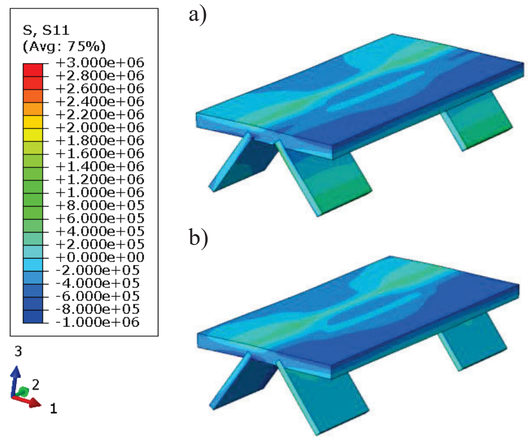

Figure 9: *Distribution of normal stress in the longitudinal direction: a) panel 3; b) panel 4*

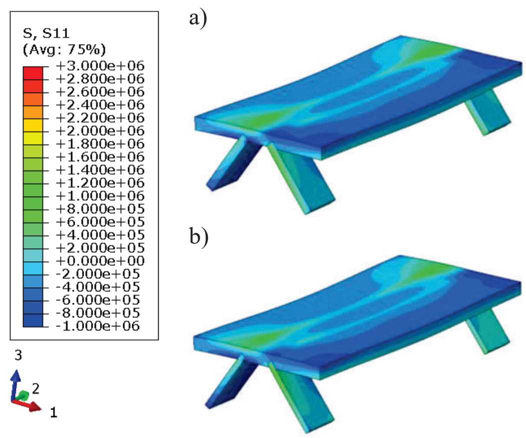

Figure 10: *Distribution of normal stress in the longitudinal direction: a) panel 5; b) panel 6*

The stress distribution is regular in the panels with full cores, and visible concentrations of stresses are observed in the panels with reduced cores, in OSB covers in the areas above the connections with the core boards. Changing the thickness of the core boards from 15 mm to 10 mm, does not affect much the distribution or values of normal stress in the longitudinal direction.

4 SUMMARY

This research focused on the development, and experimental and numerical testing of wood-based sandwich panels with two covers and an origami-inspired core made of OSB. First, laboratory tests on OSB samples of three various thicknesses (10 mm, 15 mm, and 22 mm) were conducted, in order to determine selected material properties of the boards – the Young's moduli in the longitudinal and transverse direction. The experimentally identified parameters were afterwards used in the finite element analysis of six sandwich panels, differing in the core type and the thickness of the core boards.

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Three types of cores were considered: full, reduced by 50%, and reduced by 25%. For each developed panel, two numerical models were built: a 3D shell model of the whole panel and a 3D solid submodel of a section of the panel. While the shell models showed the general behaviour of the panels under the assumed uniformly distributed load, the submodels allowed the authors to analyse stress distributions in the areas of the connections between the OSB covers and the core.

The future research will focus on the experimental identification of other orthotropic coefficients of OSB, and other core types will be studied, e.g. tensegrity-inspired cores.

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