

**Jānis IEJAVS, Uldis SPULLE**

## **COMPRESSION STRENGTH OF THREE-LAYER CELLULAR WOOD PANELS**

*The invention of a lightweight panel with the trade mark Dendrolight is one of the most distinguished wood industry innovations in the last decade. At present, three-layer cellular wood panels have wide non-structural application. The aim of the research was to evaluate the compression properties of three-layer cellular wood panels for structural application. 8 specimens were manufactured for both perpendicular and parallel compression tests for each of 6 structural panel models. Scots pine cellular wood and solid pine wood ribs were used as the core layer of the structural panels. The cellular wood core was placed in a horizontal or vertical direction. Solid Scots pine wood panels and birch plywood as top layer material were used. The common stress type in subfloor and wall panels is compression, therefore the influences of the cellular material orientation, ribs and top layer material on the sandwich-type structural panel compression strength were evaluated according to LVS EN 408. 15 [LVS EN 408]. Extra parameters, such as the moisture content and apparent density, were determined. Different structural models have a great effect on the compression strength of cellular wood material panels. The highest compression strength in a parallel direction, 17.5 MPa, was achieved with a structural model with cellular material placed vertically, with the ribs and top layers of solid timber, but in a perpendicular direction, 4.48 MPa was achieved with a structural model with cellular material placed vertically and the top layers of plywood. Solid wood ribs significantly influence the compression strength when the panels are loaded in a parallel direction.*

**Keywords:** lightweight panel, sandwich panel, compression strength.

### **Introduction**

A reduction in the manufacturing, transporting, assembling and exploitation costs of structural building elements is an important issue due to both eco-

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Jānis IEJAVS, Forest and Wood Products Research and Development Institute,  
Jelgava, Latvia

e-mail: janis.iejavs@e-koks.lv

Uldis SPULLE, Forest and Wood Products Research and Development Institute,  
Jelgava, Latvia

e-mail: uldis.spulle@e-koks.lv

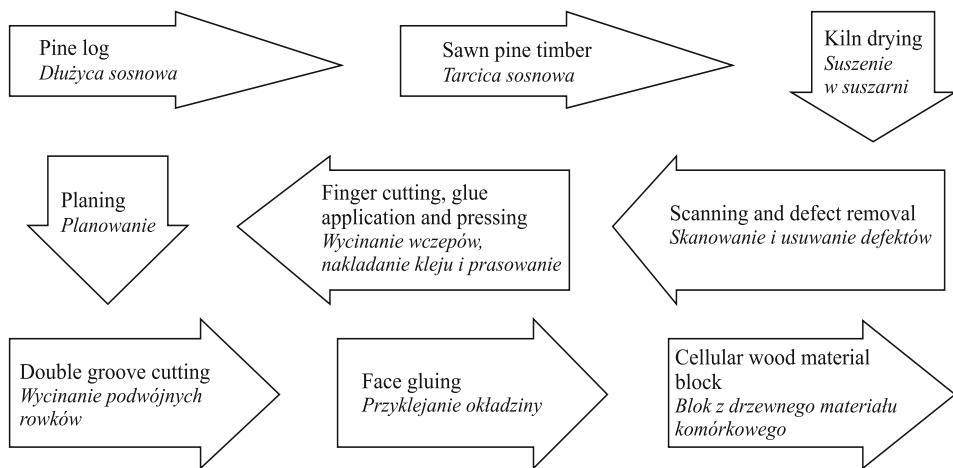
gical and economic aspects. Several researchers [Skuratov 2010; Voth 2009] have been looking for new lightweight constructions for the manufacture of wooden houses and for achieving the cost effectiveness of sandwich materials [Pflug et al. 2003]. One way to reduce the weight of the structural elements during the manufacturing process is to modify their structure by replacing the high density material of the members with a lower density material. The invention by Johann Berger in Austria of a light-weight panel with the trade mark Dendrolight is one of the most distinguished wood industry innovations in the last decade.

At present, three-layer cellular wood panels have a wide non-structural application in furniture, internal cladding, door production and the transport manufacturing industry. During the manufacturing process, due to the sawn longitudinal grooves, solid timber becomes by 40% lighter, and it is possible to produce cellular wood material with a lower density. Since cellular wood material with its current structure was patented only in 2005, there is a lack of information about cellular wood material properties for structural application. Initial research on non-structural cellular wood material [Iejavs et al. 2009] and the opening of the world's first industrial plant in Latvia in 2010, with an annual manufacturing capacity of 65,000 m<sup>3</sup> cellular wood panel material, has led to the necessity of using cellular wood material as a structural element in building. An initial study on three-layer cellular wood material panels for structural application was carried out in 2010 [Iejavs et al. 2011], when bending properties were evaluated. Industrially-produced Scots pine (*Pinus sylvestris* L.) cellular wood material was used to produce the core layer of the structural panels. There are several structural materials (fibreboard, particle board, oriented strand board, plywood and solid timber panels) which can be combined with cellular material to produce structural panels. In this research, only solid Scots pine timber panels and birch (*Betula pendula* L.) plywood as top layer material were evaluated. Wooden ribs were made of solid Scots pine timber and two different directions of the cellular wood material were used. In total, six different structural models were designed to evaluate the compression strength of the panels. Compression is regarded as a common stress type in structural subfloor and wall panels, therefore the influence of the cellular material orientation, ribs and top layer material on the compression strength of the sandwich-type structural panel in a perpendicular and parallel direction to the top layer of the panel was evaluated according to Standard LVS EN 408. 15 [2010]. Extra parameters, such as moisture content and apparent density, were evaluated. The aim of the research was to evaluate the influence of the cellular material orientation, solid timber ribs and top layer material on the compression strength of the sandwich-type structural panel because compression is a common stress type in structural panels.

## Materials and methods

### Manufacture of the Scots pine cellular material

As the raw material for the cellular wood material production, Scots pine timber was used with the following nominal dimensions: thickness – 32 mm, width – 112 mm and length – 4200 mm, and a total amount of 6.2 m<sup>3</sup>. The cellular material was manufactured industrially on a unique automatic production line especially designed and built for the production of cellular wood material by Dendrolight Latvija Ltd. A schematic illustration of the complex cellular wood material production process is given in fig. 1.



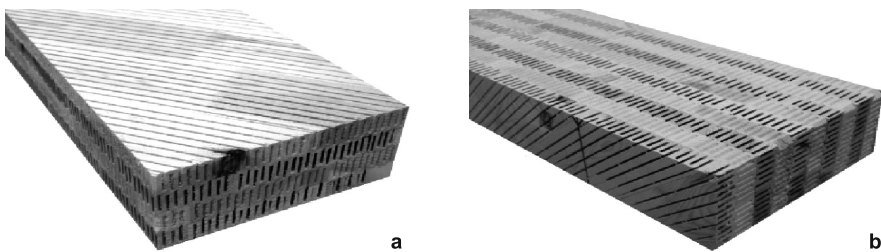
**Fig. 1. Schematic illustration of the cellular wood material manufacturing process**  
**Rys. 1. Schematyczna ilustracja procesu produkcji drzewnego materiału komórkowego**

All significant wood defects were removed before timber finger jointing. The technical data for the finger jointed pine wood was as follows: finger length – 10 mm, finger pitch – 4 mm, tip gap – 1 mm. A finger joint end pressure of 12 MPa was applied for at least five seconds. The average moisture content of the boards was 12%. One component, polyvinylacetate (PVA), was used for all the gluing operations in the cellular wood material and panel production. According to Standard LVS EN 204 [LVS EN 204], the moisture resistance class of the adhesive is D3. Technical information for the resin was as follows: specific gravity 1080 kg·m<sup>-3</sup>; viscosity 8000 m·Pa·s (Brookfield, 25°C); spreading amount 60–200 g·m<sup>-2</sup>; open and closed assembling time 5 and 8 min; press time 3–6 min at 60–75°C; end pressure 15 MPa; plane pressure 0.1–1.0 MPa; dry matter 52% and wood moisture content 5–15%. After finger jointing, the fingers were visible on the flat face of the timber. During the manufacturing process and before testing, all materials were kept in a constant atmosphere at a temperature of 20±2°C

and relative humidity of  $65\pm 5\%$  to prevent wood material moisture changes. A thickness of 28 mm and width of 106 mm were obtained after a four-side planing operation. After this, all the boards were cut to a length of 2010 mm. Following this, 8 double-faced grooves were cut in the longitudinal direction in the flat faces of the boards with the following groove dimensions: a depth of 24 mm, pitch of 6.4 mm and width of 3.2 mm. The same PVA adhesive was used in the face gluing of the grooved boards. Four layers of grooved boards were used to produce cellular wood material blocks. Each layer was aligned horizontally at a 90 degree angle to the previous layer. The cellular material blocks were produced with a steadily working heat press. The oscillation method was used to ensure the glue spread from 200 to 300 g·m<sup>-2</sup> between the block layers. Pressing was carried out at a pressure of 0.2 MPa, at a temperature of 60–75°C and the pressing time was 6 min. After pressing, pine cellular wood material blocks were obtained with the following dimensions: thickness 112 mm, width 1350 mm, length 2500 mm, and a total volume of 4.03 m<sup>3</sup>.

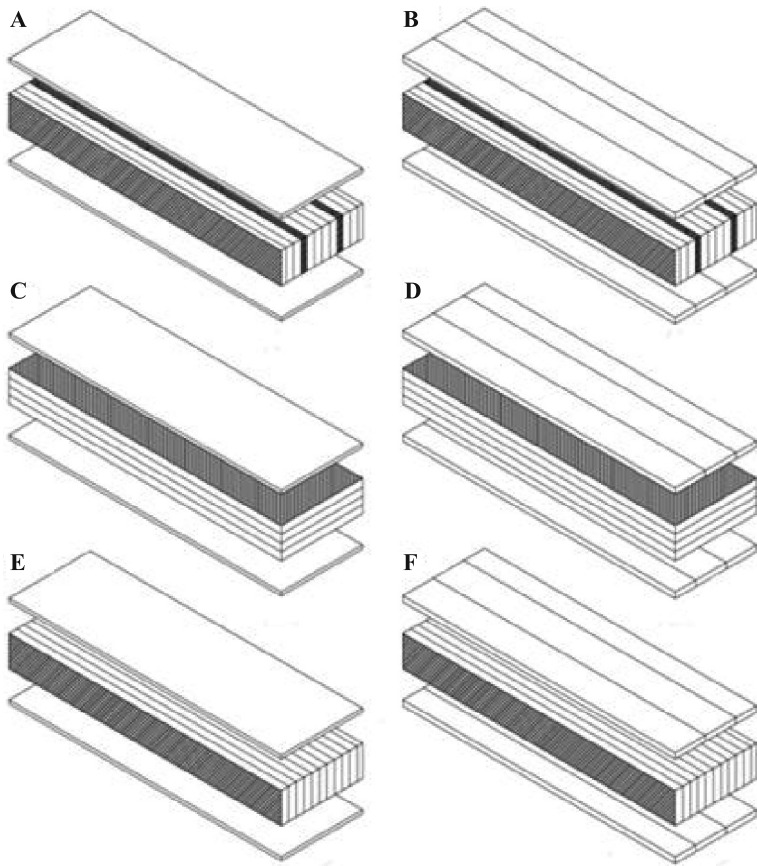
#### Manufacture of the structural panels

12 mm thick 9-layer birch plywood was used as a two-sided top layer material for the structural models A, C and E (fig. 2). Solid pine planed boards 20 mm thick and glued flatwise were used as a two-sided top layer material for structural models B, D and F. The top layer material dimensions in all the structural models were 300 by 2500 mm. Two solid planed pine ribs with strength class C24 in an edgewise direction were placed in structural models A and B. The dimensions of the ribs were: thickness – 20 mm, width – 112 mm, length – 2500 mm, and the pith was 112 mm. After the block cutting of the cellular wood material to certain dimensions, the cellular wood material was glued in the panels in two directions: horizontally and vertically (fig. 2).



**Fig. 2. Directions of the cellular wood material: a – horizontal; b – vertical**  
*Rys. 2 Kierunki drzewnego materiału komórkowego: a – poziomy; b – pionowy*

The cellular wood material was installed in a vertical direction in structural models E, B, E and F, and in a horizontal direction in structural models C and D. An illustration of the panels is given in fig. 3.



**Fig. 3. Illustration of the panel structural models A-F**

A – vertical direction of cellular material, with ribs and top layers of plywood; B – vertical direction of cellular material, with ribs and top layers of solid timber; C – horizontal direction of cellular material and top layers of plywood; D – horizontal direction of cellular material and top layers of solid timber; E – vertical direction of cellular material and top layers of plywood; F – vertical direction of cellular material and top layers of solid timber

**Rys. 3. Ilustracja modeli strukturalnych płyty A-F**

*A – materiał komórkowy ułożony w kierunku pionowym z żebrami i górnymi warstwami ze sklejki; B – materiał komórkowy ułożony w kierunku pionowym z żebrami i górnymi warstwami z litego drewna; C – materiał komórkowy ułożony w kierunku poziomym z górnymi warstwami ze sklejki; D – materiał komórkowy ułożony w kierunku poziomym z górnymi warstwami z litego drewna; E – materiał komórkowy ułożony w kierunku pionowym z górnymi warstwami ze sklejki; F – materiał komórkowy ułożony w kierunku pionowym z górnymi warstwami z litego drewna*

In total, the structural models (A–F) of six cellular wood material panels were manufactured. Eight samples for each model and each direction were used to determine the compression strength. The characteristics of the panel samples are given in table 1.

**Table 1. Characteristics of samples of panel structural models**  
**Tabela 1. Charakterystyka próbek modeli strukturalnych płyt**

Structural model <i>Model strukturalny</i>	Sample dimensions for each test direction <i>Wymiary próbek do badań w kierunku</i>				Core layer <i>warstwa wewnętrzna</i>			Top layer <i>górna warstwa</i>	
	Perpendicular <i>prostopadłym</i>		Parallel <i>równoległym</i>		cellular material direction <i>kierunek materiału komórkowego</i>	thickness <i>grubość</i> mm	with wooden ribs <i>z drewnianymi żebrami</i>	material <i>materiał</i>	thickness <i>grubość</i> mm
	depth <i>głębokość</i>	width and length <i>szerokość i długość</i>	depth <i>głębokość</i>	width and length <i>szerokość i długość</i>					
A	136	300	300	136	vertical <i> pionowy</i>	112	yes <i>tak</i>	plywood <i>sklejka</i>	12
B	152			152	vertical <i> pionowy</i>		yes <i>tak</i>	pine <i>sosna</i>	20
C	136			136	horizontal <i> poziomy</i>		no <i>nie</i>	plywood <i>sklejka</i>	12
D	152			152	horizontal <i> poziomy</i>		no <i>nie</i>	pine <i>sosna</i>	20
E	136			136	vertical <i> pionowy</i>		no <i>nie</i>	plywood <i>sklejka</i>	12
F	152			152	vertical <i> pionowy</i>		no <i>nie</i>	pine <i>sosna</i>	20

The rib gluing to the cellular material and the covering of the cellular material with the top layers was carried out with a PVA adhesive. The adhesive in these operations was applied manually with a hand roller, and the average glue spread was measured at  $200 \text{ g}\cdot\text{mm}^{-2}$ . An hydraulic cold press was used in the manufacturing of the panels with plane pressure at 0.2 MPa and a pressing time of 20 min. In the further panel development process, the non-structural PVA adhesive is replaced by a structural adhesive to provide the necessary heat resistance and delamination properties.

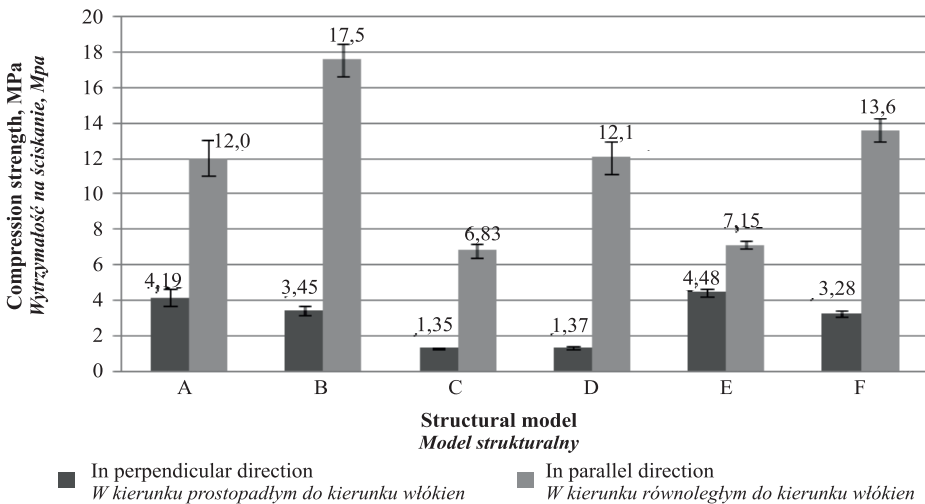
### Test methods and data processing

Before testing all the specimens were conditioned in a standard atmosphere of  $65\pm 5\%$  relative humidity and at a temperature of  $20\pm 2^\circ\text{C}$  to the constant mass. The apparent densities of the panels were determined before the compression tests by measuring and dividing the mass by the dimensions of the full cross-section specimens. The moisture content from 50 mm long specimens with a full panel cross-section was determined after the compression test by a weighing and drying method. Drying was carried out at  $103^\circ\text{C}$  until a constant mass was obtained according to Standard LVS EN 13183-1 [2003]. Static compression tests were carried out using an Instron 600 kN material testing device. The 8 specimens for each structural model were tested at compression in both a perpendicular and a parallel direction to the top layers of panels, according to Standard LVS EN 408. 15 [2010]. The load was applied at constant loading-head movement, adjusted so that the maximum load was reached within  $300\pm 120 \text{ s}$ . All the panels were stressed until their rupture. Only the mean values of each panel's moisture content and apparent density were evaluated. To compare the mean values of the different structural model compression strengths acquired from the 8 specimens, an independent sample t-test with a p-value method ( $\alpha = 0.05$ ) was used. The mean values and a 95% confidence interval for the mean are presented in fig. 3 and 4. To compare the compression strength values of the cellular wood material panels with solid wood and CLT (cross-laminated timber), the characteristic values of the compression strengths of all the structural models were evaluated according to Standard LVS EN 14358 [2007].

### Results and discussion

The average apparent densities of the panels varied from  $363 \text{ kg m}^{-3}$  to  $404 \text{ kg m}^{-3}$ , the highest values being in structural models A ( $404 \text{ kg m}^{-3}$ ) and B ( $400 \text{ kg m}^{-3}$ ). The lowest apparent densities were observed in model D ( $363 \text{ kg m}^{-3}$ ). For structural models E and F, the average apparent density was equal to  $389 \text{ kg m}^{-3}$ . An average apparent density of  $382 \text{ kg m}^{-3}$  was achieved with structural model C. The three-layer cellular wood material panels compared with the solid pine timber

at 12% moisture content [Wagenführ 1996] provided 22% less apparent density on average. The average panel moisture content varied from 12.2% to 12.5% after conditioning. Initial research showed that different structural models have a great effect on the compression strength of the cellular wood material panel perpendicular to the top layer of the panel. The influence of the structural models on the cellular wood material compression strength in the parallel and perpendicular direction is given in fig. 4., which presents the mean values and a 95% confidence interval for the compression strength mean.



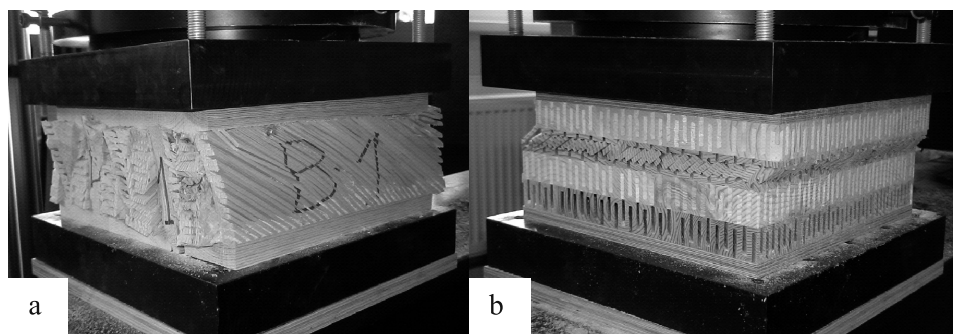
**Fig. 4. The influence of the structural model panel of cellular wood material (fig. 2) on panel compression strength properties**

*Rys. 4. Wpływ modelu strukturalnego płyty z drzewnego materiału komórkowego (rys. 2) na właściwości płyty w zakresie wytrzymałości na ściskanie*

The highest compression strength in the perpendicular direction was achieved with structural model E (mean value 4.48 MPa) with cellular material placed vertically and top layers of plywood, and the difference between models A and E with and without ribs was not as significant as for models B and F. Due to the density difference of the top layer materials for structural models B and F with solid wood top layers, they indicated significantly lower compression strength values when loaded perpendicularly compared to structural models A and E with external layers of plywood. The inserted wooden ribs in models A and B did not significantly increase the compression strength of the panels compared with models E and F without ribs, when the panels were loaded perpendicular to the top layer of the panel, due to the similar compression strength properties of the cellular wood material placed vertically and the solid timber perpendicular to the grain. The lowest compression strength, 1.35 N·mm<sup>-2</sup>, was observed in the case of structural model C. Due to the cellular wood material structure and various grain



orientations against the top layers, models C and D, with horizontally-inserted cellular wood material, showed significantly lower compression strength values compared with models E and F, where vertically-oriented cellular wood material was used. The typical type of fracture in the panels when loaded perpendicularly is given in fig. 5.



**Fig. 5. Type of fracture in panels when loaded in a perpendicular direction: a – model B; b – model C**

*Rys. 5. Rodzaj pęknięcia w płytach pod wpływem obciążenia w kierunku prostopadłym: a – model B; b – model C*

The characteristic values of the compression strength of the structural models of each panel are given in table 2.

**Table 2. Compression strength characteristic values for six panel models**  
*Tabela 2. Charakterystyczne wartości wytrzymałości na ściskanie dla sześciu modeli płyt*

Structural model <i>Model strukturalny</i>	Compression strength characteristic values <i>Charakterystyczne wartości wytrzymałości na ściskanie</i> MPa	
	perpendicular <i>w kierunku prostopadłym</i>	parallel <i>w kierunku równoległym</i>
A	3.10	9.61
B	2.88	15.20
C	1.22	5.90
D	1.14	9.73
E	3.86	6.59
F	2.81	11.90

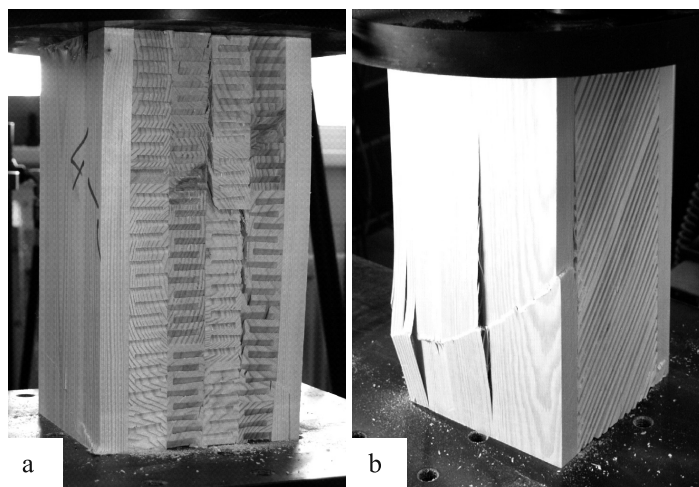
The characteristic compression strength values obtained for all the structural models varied from 1.14 MPa (model D) to 3.86 MPa (model E) when the panels were loaded in a perpendicular direction. The characteristic values of the compression strength of the panels in a perpendicular direction are comparable with the softwood structural timber compression strength values perpendicular

to the grain. According to LVS EN 338 [2010], softwood structural timber compression strength values in a perpendicular direction for strength classes C14 to C50 should vary from 2.0 to 3.2 MPa. Only structural models C and D, with the cellular material placed horizontally showed lower compression strength characteristic values compared to the characteristic value of the compression strength of structural timber strength class C14. The characteristic compression strength perpendicular to the grain of the cross-laminated timber panels varies from 2.85 MPa [Bogensperger et al. 2011] to 3.3 MPa [Serrano, Enquist 2010]. When loaded in a perpendicular direction, structural panel models A and E with the cellular material placed vertically, with or without ribs, and with top layers of plywood, provide higher compression strength values compared with the cross-laminated timber panels. The influence of the structural model on the compression strength of the cellular wood material panel in a parallel direction is given in fig. 3.

The research shows that different structural models also have a significant effect on the cellular wood material panel compression strength in a parallel direction. Due to the parallel orientation between the grain direction of the solid timber top layers, the solid ribs grain direction and the load direction, the highest compression strength in a parallel direction was achieved with structural model B (17.5 N/mm<sup>2</sup>) with the cellular material placed vertically, while the lowest was achieved with model C with the cellular material placed horizontally, the top layers of plywood and without ribs. Structural models B, D and F, with 20 mm solid wood top layers, indicated significantly higher compression strength values when loaded in a parallel direction compared to structural models A, C and E, with external layers of 12 mm birch plywood, due both to the significant top layer crosscut area difference and the compression strength difference between the solid timber in the direction of the grain and the plywood compression on edge. The solid wood ribs in models A and B significantly increased the compression strength of the panels compared with model E and F without ribs, when loaded in a parallel direction to the top layer. Models C and D, with horizontally-inserted cellular wood material, showed various results compared with model E (difference was not significant) and F (difference was significant), where vertically-installed cellular wood material was applied. The typical type of fracture of the panels when loaded in a parallel direction is given in fig. 6.

The characteristic compression strength values obtained for all the structural models varies from 5.90 MPa (model C) to 15.2 MPa (model B) when the panels were loaded in a perpendicular direction. The compression strength characteristic values of panels in a parallel direction were significantly lower than the softwood structural timber compression strength values parallel direction to the grain. According to LVS EN 338 [2010], softwood structural timber compression strength values in a parallel direction for strength classes C14 to C50 vary from 16 to 29 MPa. Only structural model B with the cellular material placed vertically,

with ribs and top layers of solid timber, showed a compression strength characteristic value close to the compression strength characteristic value of structural timber strength class C14 of 16 MPa. The cellular wood panels in a parallel direction showed a significantly higher compression strength compared with panels in a perpendicular direction. The influence of the solid wood ribs on the panel's compression strength was directly dependent on the direction of the load. When the panels were loaded in a parallel direction, the solid wood ribs increased the compression strength significantly, but when loaded perpendicularly, no influence was observed. The direction of the cellular core material influenced the compression strength when the panels were loaded in a perpendicular direction. The results indicate that further development is required related to other structural properties of panels. In future, innovative products and production strategies might be developed based on promising cellular wood material.



**Fig. 6. Type of fracture in panels when loaded in a parallel direction: a – model D; b – model F**

*Rys. 6. Rodzaj pęknięcia w płytach pod wpływem obciążenia w kierunku równoległym: a – model D; b – model F*

## Conclusions

1. The research shows that different structural models have a great effect on the cellular wood material panel compression strength when loaded perpendicularly and in a parallel direction to the top layer of the panel.
2. Structural models with 20 mm solid wood top layers indicated significantly higher compression strengths in the parallel direction, but significantly lower values when loaded perpendicular to the top layer, compared to the structural model with external layers of 12 mm birch plywood.

3. Solid wood ribs significantly increase the compression strength when the panels are loaded in a parallel direction to the top layer, but no significant increase was observed in a perpendicular direction.
4. Horizontally-inserted cellular wood material most often shows significantly lower compression strength values compared to panels with vertically-inserted cellular wood material.

## Acknowledgements

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## List of standards

- LVS EN 13183-1** [2003]: Moisture content of a piece of sawn timber – Part 1: Determination by oven dry method. Riga, Latvia
- LVS EN 14358** [2007]: Timber structures – Calculation of characteristic 5-percentile values and acceptance criteria for a sample. Riga, Latvia
- LVS EN 338** [2010]: Structural timber – Strength classes. Riga, Latvia
- LVS EN 408** [2010]: Timber structures – Structural timber and glued laminated timber – Determination of some physical and mechanical properties. Riga, Latvia

## WYTRZYMAŁOŚĆ NA ŚCISKANIE TRÓJWARSTWOWYCH PŁYT KOMÓRKOWYCH

### Streszczenie

Wynalezienie płyty lekkiej oznaczonej znakiem towarowym Dendrolight stanowi jedną z najznakomitszych innowacji w przemyśle drzewnym w ostatniej dekadzie. Obecnie trójwarstwowe płyty komórkowe są szeroko rozpowszechnione w zastosowaniach niekonstrukcyjnych, tj. meblach, okładzinach wewnętrznych, produkcji drzwi oraz w przemyśle transportowym.

Celem badań była ocena właściwości trójwarstwowych płyt komórkowych w zakresie ich wytrzymałości na ściskanie pod kątem zastosowań konstrukcyjnych. Dla każdego z sześciu modeli płyty konstrukcyjnej wytworzono osiem próbek do wykorzystania w badaniach wytrzymałości na ściskanie prostopadłe do kierunku włókien i ściskanie wzdłuż włókien. Jako rdzenia w płytach konstrukcyjnych użyto drewna komórkowego z sosny zwyczajnej oraz żeber z litego drewna sosnowego. Rdzeń z drewna komórkowego umieszczono w kierunku poziomym lub pionowym. Płyty z litego drewna sosny zwyczajnej oraz sklejka brzoza zostały wykorzystane jako materiał na górną warstwę. Głównym rodzajem naprężenia występującym w warstwie podpodłogowej oraz w płytach ściennych jest ściskanie, zatem wpływ ukierunkowania materiału komórkowego, żeber i materiału z górnej warstwy na wytrzymałość na ściskanie płyt konstrukcyjnych różnowarstwowych został oceniony zgodnie z normą LVS EN 408 [2010]. Określono dodatkowe parametry, takie jak wilgotność i gęstość pozorną.

Różne modele konstrukcyjne wywierają znaczny wpływ na wytrzymałość na ściskanie płyty z komórkowego materiału drzewnego. Najwyższą wytrzymałość na ściskanie w kierunku wzdłuż włókien, tj. 17,5 MPa, otrzymano w przypadku modelu konstrukcyjnego z umieszczonym pionowo materiałem komórkowym oraz z żebrami i górnymi warstwami wykonanymi z litego drewna, jednakże, w przypadku wytrzymałości na ściskanie w kierunku prostopadłym do włókien, najlepszy wynik, tj. 4,48 MPa, uzyskano dla modelu strukturalnego, w którym materiał komórkowy umieszczono pionowo, a górne warstwy wykonano ze sklejki. Żebra z litego drewna wywierają znaczący wpływ na wytrzymałość na ściskanie, kiedy płyty są obciążane w kierunku wzdłuż włókien.

**Słowa kluczowe:** płyta lekka, płyta różnowarstwowa, wytrzymałość na ściskanie

