EVALUATION OF BENDING PROPERTIES OF THREE LAYER CELLULAR WOOD PANELS USING SIX DIFFERENT STRUCTURAL MODELS

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Abstract

Invention of light weight panel with a trade mark of Dendrolight is one of the most distinguished wood industry innovations of the last decade. At present three layers cellular wood panels have wide non structural application. The aim of the research is to evaluate the bending properties of three layer cellular wood panels for structural application. There were 8 specimens manufactured with thickness 136 or 152 mm, width 300 mm and length 2,500 mm of each of the six horizontal load bearing panel structural models. Scots pine (*Pinus sylvestris* L.) cellular wood and solid pine wood ribs were used as internal layer of the structural panels. Cellular wood core was placed in horizontal or vertical direction. Scots pine solid wood panels and birch plywood were used as top layer material. Applied glue was polivinilacetate Cascol 3353. The most common stress type in structural subflooring panels is bending; therefore, the influence of the cellular material orientation, ribs and top layer material on the sandwich type structural panel bending strength (MOR) and stiffness (MOE) were evaluated according to LVS EN 408:2011. Extra parameters like moisture content and apparent density were determined. Cellular wood in vertical direction can be used as raw material for structural panel production. Panels with solid timber external layers, with ribs and with vertical orientation of the cellular material showed the highest MOR (35.2 N mm^{-2}) and MOE (11,500 N mm^{-2}) values. The influence of the solid wood ribs on the bending properties is directly dependent on external layer material.
Key words: light weight panels; cellular wood; bending strength; bending modulus of elasticity.

Introduction

The reduction of manufacturing, transportation, assembling and exploitation costs of the structural building elements is important theme due to both ecological and economical aspects. Several researchers (Skuratov, 2010; Voth, 2009) are looking for new light weight constructions for wooden house manufacturing and cost effectiveness of sandwich materials (Pflug et al., 2003). One way how we can reduce the weight of the structural elements during manufacturing process is by modifying their structure by replacing high density material of the members with lower density material. Invention of light weight panel with trade mark of Dendrolight in Austria by inventor Johann Berger is one of the most distinguished wood industry innovations of the last decade. At present three layers cellular wood panels have wide non structural application in furniture, internal cladding, door production and 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 lower density. Non structural cellular wood material initial research (Iejavs et al., 2009) and start-up of the new industrial plant in Latvia with manufacturing capacity of 65 thousand m^3 cellular wood panel material per year lead down to the necessity to use cellular wood material in building as a structural element.

The aim of the research is to evaluate the bending properties of three layer cellular wood panels for structural application. Industrially produced Scots pine (*Pinus sylvestris* L.) cellular wood material was used to produce internal layer of the structural panels. There are several structural materials (fibreboard, chipboard, strand board, plywood and solid timber panels) that 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 were evaluated as external layer material. Wooden ribs were made of Scots pine solid timber and two different directions of the cellular wood material were used. In total six different structural models were designed to evaluate bending properties of panels. Bending is the most common stress type in subfloor panels (Heikila and Herajarvi, 2008); therefore, the essential importance of the research is to evaluate the influence of the cellular material orientation, solid timber ribs and top layer material on the sandwich type structural panel bending strength and stiffness properties. Stiffness and strength were tested in static bending test according to LVS EN 408:2010. Extra parameters like moisture content and apparent density were evaluated.

Materials and Methods

Manufacture of the Scots pine cellular material

As a raw material for cellular wood material production Scots pine (*Pinus sylvestris* L.) timber was used with nominal dimensions: thickness – 32 mm, width – 112 mm and length – 4,200 mm, and the total amount of 6.2 m^3. Cellular material was manufactured industrially on the automatic production line of the company Dendrolight Latvija Ltd. Schematic illustration of the cellular wood material production is given in Figure 1.

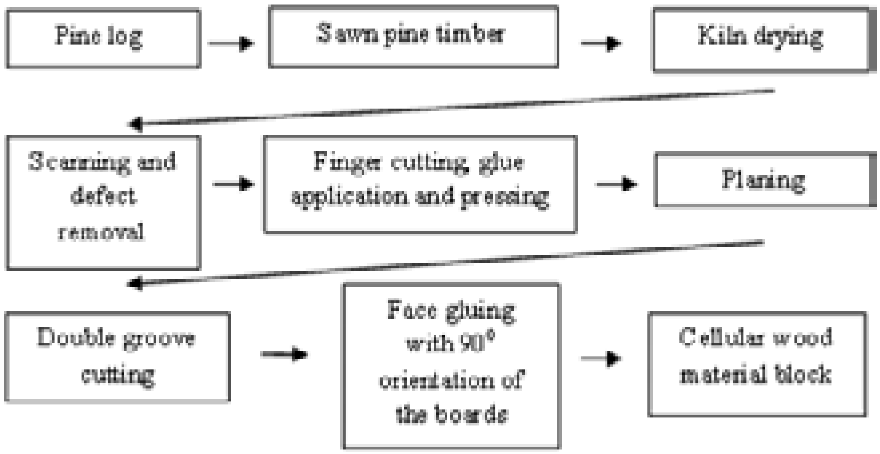

Figure 1. Schematic illustration of the cellular wood material manufacturing process.

All significant defects were removed before timber finger jointing. Technical data of the finger jointed pine wood: finger length - 10 mm, finger pitch - 4 mm, tip gap - 1 mm. Finger joint end pressure 12 N mm^{-2} was applied at least five seconds. The average moisture content of the boards was 12%. One component polivinylacetate (PVA) adhesive Cascol 3353 was used for all gluing operations in cellular wood material and panel production. According to the standard LVS EN 204:2002, the moisture resistance class of adhesive Cascol 3353 is D3. Technical information of the resin: specific gravity 1,080 kg m^{-3}; viscosity 8,000 m Pa s (Brookfield, 25 °C); spreading amount 60 - 200 g m^{-2}; open and close assembling time 5 and 8 min; press time 3 - 6 min at 60 - 75 °C; end pressure 15 N mm^{-2}; plane pressure 0.1 - 1.0 N mm^{-2}; dry matter 52% and wood moisture content 5 - 15%. After finger jointing fingers are visible on the flat face of the timber. During manufacturing process and before testing all materials were kept in constant atmosphere at 20±3 °C temperature and relative humidity of 65±5% to prevent wood material moisture changes. The thickness 28 mm and width 106 mm were obtained after four side planing operation. After the planing operation all boards were cut to 2,010 mm length. After that 8 double faced grooves were cut into longitudinal direction in the flat faces of boards with the following dimensions of the grooves: depth of 24 mm, pitch of 6.4 mm and width of 3.2 mm. Adhesive Casco 3353 were used in face gluing of grooved boards. Four layers of grooved boards were used to produce cellular wood material blocks. Each layer was aligned horizontally in 90 degree direction against the previous layer. Cellular material blocks were produced with steadily working heated press. Oscillation method was used to ensure glue spread from 200 to 300 g m^{-2} between block layers. Pressing was carried out with pressure 0.2 N mm^{-2} at 60 - 75 °C temperature and pressing time was 6 min. After pressing pine cellular wood material blocks with dimensions: thickness 112 mm, width 1,350 mm and length 2,500 mm, and total volume of 4.03 m^3 were obtained.

Manufacture of the structural panels

Twelve millimetres thick 9 layer birch plywood was used as two sided external layer material for structural models A, C and E (Figure 2). Solid pine flatwise glued planed boards with 20 mm thickness were used as two sided external layer material for structural models B, D and F. External layer material dimensions in all structural models were 300 by 2,500 mm. Two solid planed pine ribs with strength class C24 in edgewise direction were installed in structural models A and B. The dimensions of the ribs were: thickness - 20 mm, width - 112 mm and length - 2,500 mm, pith was 112 mm. After cellular wood material block cutting in certain dimensions the cellular wood material was glued in panels in two directions. Cellular wood material was installed in vertical direction in structural models E, B, E and F, and in horizontal direction (as produced) in structural model C and D. Illustration of the panels are given in Figure 2.

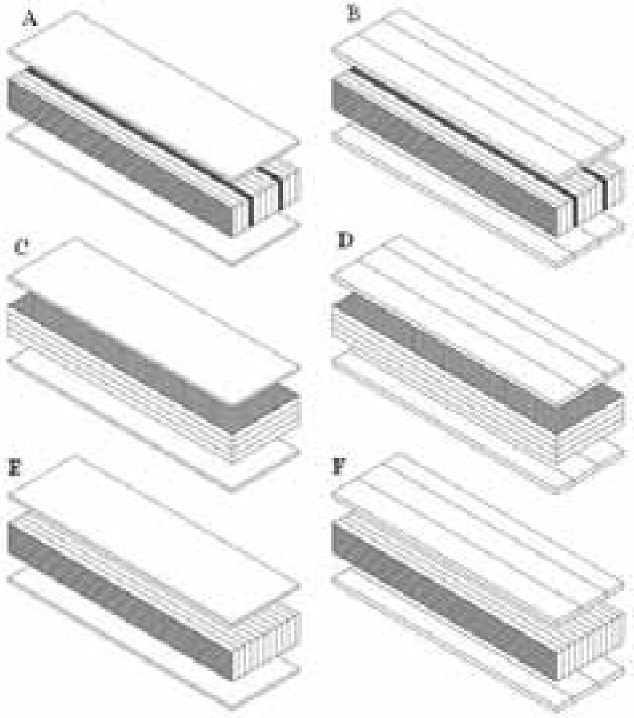

Figure 2. Illustration of the panel structural models A - F:
A - vertical direction of cellular material, with ribs and external layers of plywood;
B - vertical direction of cellular material, with ribs and external layers of solid timber;
C - horizontal direction of cellular material and external layers of plywood;
D - horizontal direction of cellular material and external layers of solid timber;
E - vertical direction of cellular material and external layers of plywood;
F - vertical direction of cellular material and external layers of solid timber.

In total six cellular wood material panels structural models (A - F) were manufactured. Eight samples for each model were used to determine and compare physical and mechanical properties. Characteristic of the panels are given in Table 1.

Table 1

Characteristic of panel structural models

Structural model	Panel dimensions			Internal layer			External layer	
	dept, mm	width, mm	length, mm	cellular material direction	thickness, mm	with wooden ribs	material	thickness, mm
A	136	300	2,500	vertical	112	yes	plywood	12
B	152	300	2,500	vertical	112	yes	pine	20
C	136	300	2,500	horizontal	112	no	plywood	12
D	152	300	2,500	horizontal	112	no	pine	20
E	136	300	2,500	vertical	112	no	plywood	12
F	152	300	2,500	vertical	112	no	pine	20

Rib gluing to cellular material and cellular material covering with external layers were carried out with adhesive Casco 3353. Adhesive in these operations were applied manually with a hand roller, and the average glue spread measured by weighing method was 200 g mm^{-2}. The cold setting hydraulic press was used in panel manufacturing with plane pressure 0.2 N mm^{-2} and pressing time of 20 min. In further panel development process non-structural adhesive Casco 3353 will be replaced by structural adhesive to provide necessary heat resistance and delamination properties.

Test methods and data processing

The apparent densities of the panels were determined after the bending tests by measuring their masses and dimensions of the full cross section specimens with specimen length of 50 mm in the longitudinal direction of panels. Moisture content of wood and plywood has a considerable effect on its mechanical properties; therefore, the moisture content of the panels was controlled from the same density specimens and calculation was made according to standard LVS EN 13183-1:2003. Bending tests were carried out in Forest and Wood Product Research and Development Institute on the Instron 600 kN material testing device. The panels were tested in bending flatwise according to the standard LVS EN 408:2011. Bending modulus of elasticity (MOE) and bending strength (MOR) were determined in a static bending test. The distance between the span in bending test was reduced to 16 depths of the panel because of limited length of specimens. All panels were stressed until rupture. All specimens before testing were conditioned in the standard atmosphere to the constant mass according to the standard LVS EN 408:2011. Only the mean values of the panel's moisture content and apparent density were evaluated. According to initial compression and shear tests of the cellular material when significant amount of samples were tested distribution of mechanical properties comply with normal distribution function. Therefore, in order to compare the mean values of the different structural model MOE and MOR, independent sample t-tests were used with 95% confidence level.

Results and Discussion

The average apparent densities of panels varied from 363 kg m^{-3} to 404 kg m^{-3}, the highest values being in structural models A (404 kg m^{-3}) and B (400 kg m^{-3}). The lowest apparent densities were observed in model D (363 kg m^{-3}). For structural models E and F average apparent density was equal to 389 kg m^{-3}. Average apparent density 382 kg m^{-3} was achieved with structural mode C. The average panel moisture content varied from 12.2% to 12.5% after conditioning and the difference was not significant. The initial research shows that different structural models have a great effect on the cellular wood material panel MOR. The structural models influence on the cellular wood material panels MOR is given in Figure 3. Figure 3 presents mean values and 95% confidence interval of the MOR mean.

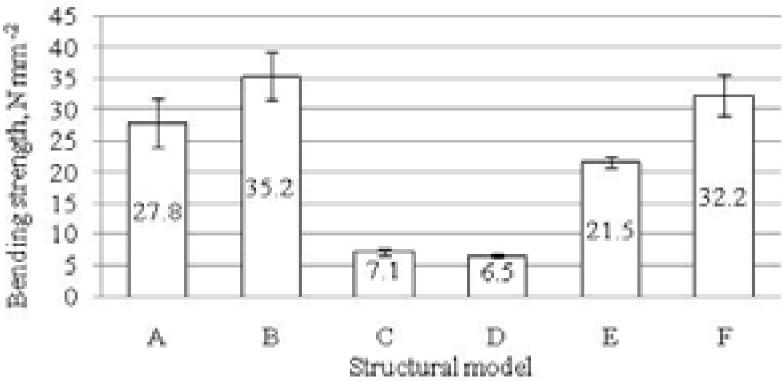

Figure 3. The influence of cellular wood material panel structural model on the panel bending strength – MOR (mean values and 95% confidence interval for mean):

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

The highest MOR was achieved with structural model B (vertical direction of cellular material, with ribs and external layers of 20 mm solid timber) with 35.2 N mm^{-2} bending strength. The influence of the external layer material on the panels MOR were observed when structural model B indicated significantly higher MOR values than the structural model A (vertical direction of cellular material, with ribs and external layers of 12 mm birch plywood). Structural models C (horizontal direction of cellular material and external layers of plywood) and D (horizontal direction of cellular material and external layers of 20 mm solid timber) with horizontally installed cellular wood material show several times lower MOR values compared with structural models A, B, E (external layers of 12 mm plywood) and F (external layers of 20 mm solid timber) with vertically installed cellular wood material. The wooden ribs did not influence MOR in case of structural models B and F with 20 mm solid pine external layer because mean bending strength did not differ significantly ($p=0.173$). In case of structural models A and E when as external material was used 12 mm plywood structural model A with ribs has significantly higher bending strength compared with structural model E without ribs.

The initial research shows that different structural models also have a significant effect on the cellular wood material panel MOE. The influence of the structural model on the cellular wood material panel's modulus of elasticity is given in figure 4. Figure 4 presents mean values and 95% confidence interval of the MOE mean.

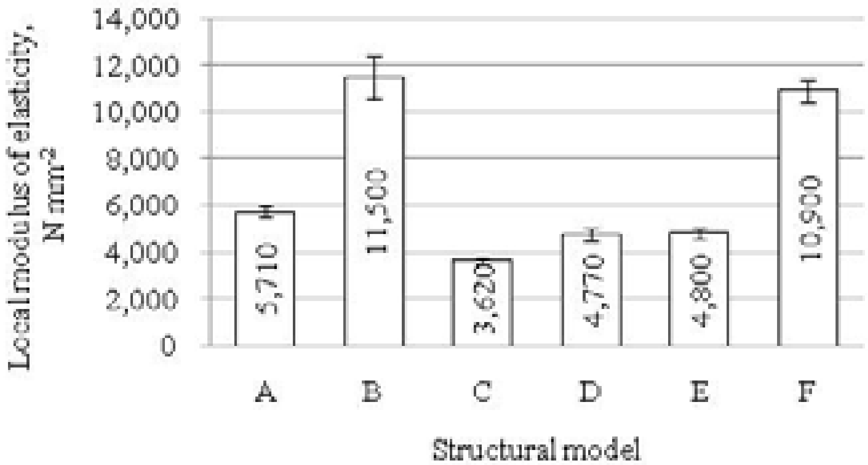

Figure 4. The influence of cellular wood material panel structural model on the panel bending modulus of elasticity - MOE (mean values and 95% confidence interval for mean):
A - vertical direction of cellular material, with ribs and external layers of plywood;
B - vertical direction of cellular material, with ribs and external layers of solid timber;
C - horizontal direction of cellular material and external layers of plywood;
D - horizontal direction of cellular material and external layers of solid timber;
E - vertical direction of cellular material and external layers of plywood;
F - vertical direction of cellular material and external layers of solid timber.

The MOE values significantly vary between the models. The highest average MOE value 11,500 N mm^{-2}, but also the highest standard deviations were observed in panel with solid pine external layer and solid wood ribs look at structural model B (Figure 4). Like with MOR the wooden ribs did not influence MOE in case of structural models B and F with 20 mm solid pine external layer because mean modulus of elasticity did not differ significantly ($p=0.201$). Mean MOE of structural models B and F are comparable with structural timber bending modulus of elasticity. Structural models B and F with vertically installed cellular wood material and external layer of solid timber show two times higher MOE values compared with structural models A, C, D and E. Structural models C and D with horizontally installed cellular material show the lowest MOE values. In case of structural models A and E when as external material was used 12 mm plywood structural model A with ribs have significantly higher MOE compared with structural model E without ribs. Generally, we can say that cellular wood material in vertical direction can be used as raw material for structural panel production from point of bending strength and bending modulus of elasticity. The influence of the solid wood ribs on the bending strength and bending modulus of elasticity of panels are dependent directly of external layer material properties. Solid 20 mm thick pine wood as panel external layer material provided significantly higher MOR and MOE if compared with 12 mm thick birch plywood external layer when cellular wood material was installed in vertical direction. The cellular material installation directions significantly influence the character of the panel failure. For structural models A, B, E and F failure mostly occurred in the middle of the panel under top supports, but in structural models C and F failure occurred in the ends of the panels in core cellular material layer. The panel failure mostly occurred in cellular material or external layer; therefore, the influence of non-structural adhesive on the panel MOR and MOE were not observed.

Conclusions

The results of this preliminary study showed that the structural model has a significant effect on the bending properties of panels with cellular wood material core. Panels with 20 mm thick solid timber external layers with vertical orientation of the cellular material showed the highest MOR (35.2 N mm^{-2}) and MOE (11,500 N mm^{-2}) values. The significant influences of the solid ribs on MOE and MOR in structural models with solid timber external layers were not observed because mean modulus of elasticity and mean bending strength did not differ significantly. The model F with solid timber external layer, without ribs and vertical direction of the cellular material will be used for further development of structural panels. 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 the promising cellular wood material.

Acknowledgements

This initial study carried out within project "Elaboration of innovative self supporting panels and building elements made of cellular wood material" no. 2010/0248/2DP/2.1.1.1.0/10/APIA/VIAA/019 co-financed by the European Union within the project framework of the European regional development fund.

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