ONLINE ISSN 2069-7430
ISSN-L 1841-4737

PRO LIGNO
www.proligno.ro

Vol. 9 N° 4 2013
pp. 491-497

STRUCTURAL PROPERTIES OF CELLULAR WOOD MATERIAL

Jānis IEJAVS
PhD student – Forest and Wood Product Research and Development Institute
Address: Dobeles str. 41, Jelgava, Latvia, LV-3001
E-mail: janis.iejavs@e-koks.lv

Uldis SPULLE
Asoc.prof.Dr.sc.ing. – Forest and Wood Product Research and Development Institute
Address: Dobeles str. 41, Jelgava, Latvia, LV-3001
E-mail: uldis.spulle@e-koks.lv

Abstract:

Invention of light weight panels with a trade mark of Dendrolight with the unique manufacturing technology opens up an opportunity for new light weight panel and construction development. The aim of the research is to evaluate mechanical properties of cellular wood material for structural application. Eight stiffness and strength properties were determined according to the standard EN 408+A1:2012 and corresponding characteristic values were calculated. Extra parameters like moisture content and apparent density were determined. Cellular wood material apparent density is 38% less in average compared with solid pine timber density. Due to the structure of the cellular wood material significant decrease of strength and stiffness properties were observed when cellular wood material compared with solid timber. Obtained properties can be compared with the traditional building material properties and the results will be applied for new building element light weight structural panel design.

Key words: dendrolight; *light weight panel; cellular wood, mechanical properties.*

INTRODUCTION

The reduction of manufacturing, transporting, assembling and maintenance costs of the structural building elements is important issue 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 layer cellular wood panels have found non structural application in furniture, internal cladding, door production and transport manufacturing industry. During the manufacturing process due to the longitudinal grooves solid timber becomes by 40% lighter, and it is possible to produce wooden material with lower density. Start-up of the first in the world industrial plant in Latvia in 2010 with manufacturing capacity of 65 thousands m^3 cellular wood material per year lead down to the necessity to use cellular wood material in buildings as a structural element. The initial study on three layer cellular wood material panels for structural application were carried out in 2010 and 2011 when bending (Iejavs *et al.* 2011) and compression properties were evaluated of six different panel models. Industrially produced pine (*Pinus sylvestris* L.) cellular wood material was used to determine main structural properties of cellular wood material. Bending, compression, tension and shear regarded as common stress type in structural panels therefore for structural cellular wood material panel design and new product development eight strength and stiffness properties and their characteristic values of cellular wood material were determined: modulus of rupture (MOR) in bending, tension, compression, shear and modulus of elasticity (MOE) in bending, tension and compression, according to the structural element test standard EN 408+A1:2012. Due to the structure and symmetry of the cellular wood material only two directions of the material are necessary to test. Extra parameters like moisture content and apparent density were evaluated. Since the cellular wood material with current structure was patented only in 2005 there is lack of information about cellular wood material properties for structural element design.

OBJECTIVES

The objective of the presented work was to evaluate main properties of pine cellular wood material for new light weight structural element and product design.

METHOD, MATERIALS AND EQUIPMENT

Manufacture of the pine cellular wood material

The structure and the manufacturing technology of the cellular wood material significantly influence both physical and mechanical properties of cellular wood material and product, therefore full process of cellular wood material production is described below. Pine (*Pinus sylvestris* L.) wood with nominal dimensions: thickness 32mm, width 112mm, length 4200mm and strength class C24. According to standard EN 338:2010 table 1 finger jointed timber with strength class C24 has following characteristic values: bending strength 24MPa; compression strength parallel 21MPa; compression strength perpendicular and shear strength 2.5MPa; mean modulus of elasticity parallel 11000MPa. Cellular material was manufactured industrially on the automatic production line especially designed and produced for cellular wood material production in the company Dendrolight Latvija Ltd. Principle of the complex cellular wood material manufacturing process is shown on Fig. 1.

a *b* *c*

***Fig.* 1**
Principle of the cellular wood material manufacturing process: a - boards with longitudinal grooves; b - face gluing of boards with 90° direction and c - cellular wood material block (www.dendrolight.lv).

All significant wood defects were removed before timber finger jointing. Technical data of the finger jointed pine wood: finger length 10mm, finger pitch 4mm, tip gap 1mm. Finger joint end pressure 12MPa was applied at least for five seconds. The average moisture content of the boards was 12%. One component polivinylacetate (PVA) adhesive Cascol 3353 was used for cellular wood material production. According to the standard EN 204:2001, the moisture resistance class of adhesive Cascol 3353 is D3. Technical information of the resin: specific gravity 1080kg·m^{-3}; viscosity 8000m·Pa·s (Brookfield, 25°C); spreading amount 60 - 200g·m^{-2}; open and close assembling time 5 and 8min; press time 3 - 6min at 60 - 75°C; end pressure 15MPa; plane pressure 0.1 - 1.0MPa; 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 all materials were kept in constant atmosphere at 20±2°C temperature and relative humidity of 65±5% to prevent wood material moisture changes. The thickness 28mm and width 106mm were obtained after four side planing operation of the fingerjointed boards. After the planing operation all boards were cut to 2010mm 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 24mm, pitch of 6.4mm and width of 3.2mm. Adhesive Casco 3353 was used for 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 continuously working warm press. Oscillation method was used to ensure glue spread from 200 to 300g·m^{-2} between block layers. Pressing was carried out with pressure 0.2MPa at 60 - 75°C temperature and pressing time was 6min. After pressing pine cellular wood material blocks with dimensions: thickness 224mm, width 1350mm and length 2500mm were obtained. In further structural panel development process non-structural adhesive Casco 3353 will be replaced by structural adhesive to provide necessary heat resistance and delamination properties. After cellular wood material blocks were produced individual test samples were cut to determine physical and mechanical properties of cellular wood material.

Specimens, test methods and data processing

Due to the structure and symmetry of the cellular wood material only two main directions of the cellular material were tested. With parallel direction as cellular wood material block produced Fig. 2a and in perpendicular direction when cellular wood material block were rotated 90° over longitudinal axis Fig. 2b.

a

b

Fig. 2
Direction of the cellular wood material: a – parallel (suffix 0); b – perpendicular (suffix 90).

All specimens before testing were conditioned in the standard atmosphere at 65±5% relative humidity and 20±2°C temperature to the constant mass. The apparent density ρ_{12} and moisture content W of the cellular wood material were determined from 60 square specimens with length, width and depth of 112mm. Apparent density was determined by measuring and dividing specimen mass by dimension. Moisture was determined by weighing and drying method according to the standard EN 13183-1:2002. Static bending tests were carried out on the Instron 600kN material testing device to determine four point bending strength fm and local modulus of elasticity Em (MOE) in bending according to the standard EN 408+A1:2012 point 9 and 19 (Fig. 3a).

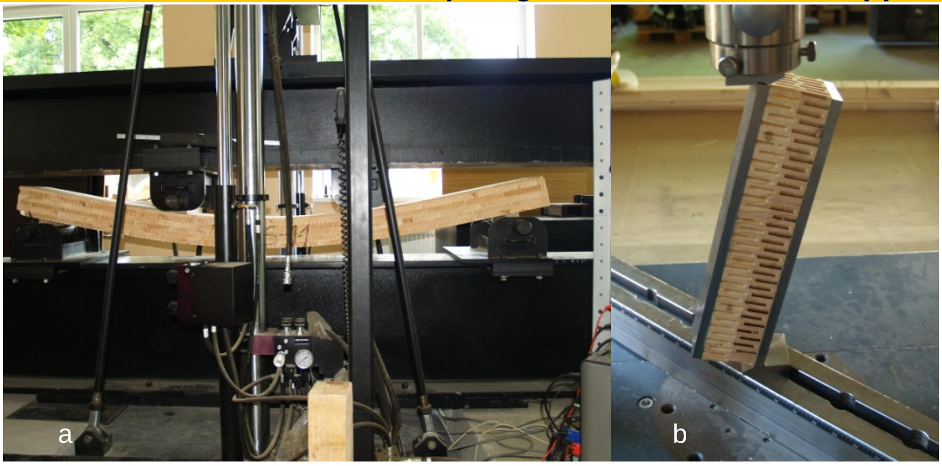

Fig. 3
Cellular wood material test setup with parallel direction of the cellular wood material: a - four point bending test; b - shear strength test.

Eight specimens with nominal length 2500mm, width 280mm and depth 136mm for each direction were tested. Due to the limited length of the cellular wood material support span was reduced down to 16 times the depth of the specimen and support span was 2176mm. Static compression and tension tests were carried out on the ZWICK Z100 material testing device to determine compressive strength fc, tension strength ft, MOE in compression Ec and tension Et according to the standard EN 408+A1:2012 points 16 and 17. Thirty specimens with length 112mm, width 112mm and depth 112mm of each direction were tested to determine compressive strength of cellular wood material. Eight specimens of each direction with the length 112mm, width 112mm and depth of 224mm were used to determine tension strength, MOE in tension and MOE in compression. Eight specimens were used to determine shear strength fv and shear modulus G in both directions of cellular wood material according to standard EN 408+A1:2012 point 18. Specimens with length 300mm, width and depth of 56mm were used to determine shear strength and calculate shear modulus. Shear modulus was calculated from shear strength tests where load and deformation measurements were taken. Calculation was based on the standard ASTM C 273-00 point 8.2 shear modulus calculation principles. For all tests the load was applied at constant loading-head movement so adjusted that maximum load was reached within 300±120s. All mechanically tested specimens were stressed until rupture. The mean values and standard deviations of the cellular wood material physical and mechanical properties were evaluated. To compare the mean values for both cellular wood material directions independent sample t-test with p-value method (α=0.05) was used. Characteristic values of all properties with exception of moisture content were calculated according to the standard EN 14358:2006. Characteristic values are defined as the population 5-percentile values obtained from the test results using test specimens at equilibrium moisture content.

RESULTS

The apparent density of pine cellular wood material varied from 277kg·m^{-3} to 332kg·m^{-3}, the average value was 307kg·m^{-3} and characteristic value calculated from sixty test specimens was 285kg·m^{-3}. The moisture content of apparent density specimens after conditioning in the standard atmosphere varied from 11.9% to 13.6% and the average value was 12.5%. Cellular wood material apparent density compared with solid pine timber density at 12% moisture content (Wagenführ 1996) was 38% less in average. Mean value of apparent density can be used for calculation of the weight of cellular wood material and cellular wood material based products. Characteristic density can be used to calculate the strength of mechanically fastened connections. The most important mechanical properties and their characteristic values of cellular wood material for structural design are presented in Fig. 4 and 5.

The results show that cellular wood material directions have significant effect on the strength and stiffness properties of cellular wood material. Higher strength properties were observed when the cellular wood material was loaded in perpendicular direction (suffix 90) but higher stiffness properties with exception of shear modulus were observed when the cellular wood material was loaded in parallel direction (suffix 0). The average strength properties of cellular wood material range from 0.217MPa for shear strength in parallel direction to 2.15MPa for bending strength in perpendicular direction Fig. 4.

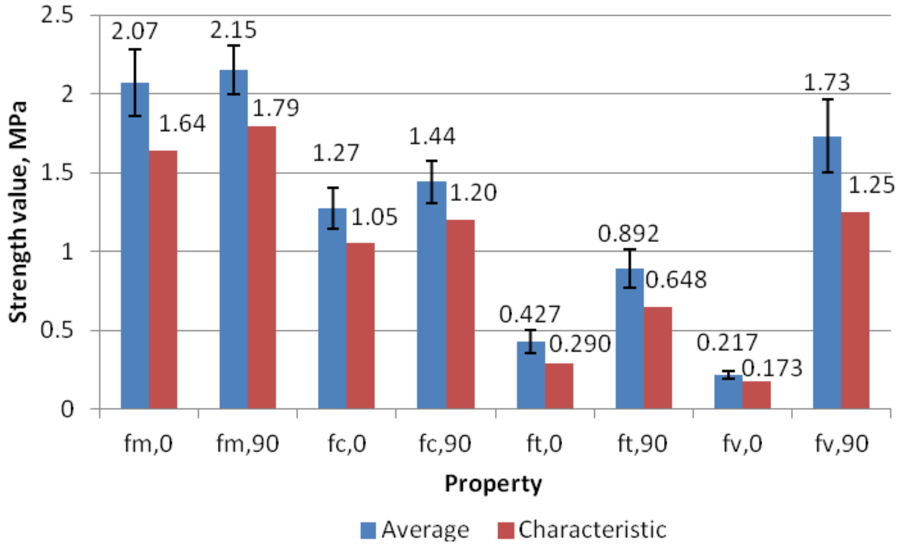

Fig. 4
Strength properties of cellular wood material: fm - bending strength; fc – compressive strength; ft – tension strength and fv – shear strength (suffix 0 in parallel and 90 in perpendicular direction).

After independent sample t-test the significant difference between average bending strength values was not observed ($p=0.381$) in both cellular wood material directions. Cellular wood material shows significantly lower ($p<0.05$) average compression strength, tension and shear strength values in parallel direction compared with perpendicular direction of the material. Characteristic bending strength value 1.64MPa can be used for structural design of cellular wood material in both directions. Compression, tension and shear strength characteristic values of the cellular wood material shall be taken separate for each material direction according to Fig. 4.

The average stiffness properties of cellular wood material range from 5.87MPa for shear modulus in parallel direction to 179MPa for local MOE in bending in parallel direction.

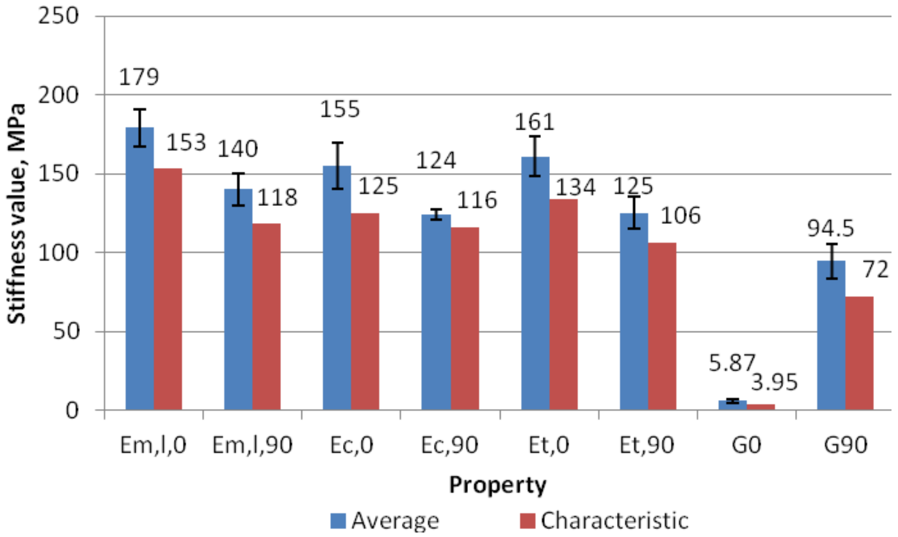

Fig. 5
Stiffness properties of cellular wood material: Em,l – local MOE in bending; Ec – MOE in compression; Et – MOE in tension and G – shear modulus (suffix 0 in parallel and 90 in perpendicular direction).

Significant difference between cellular wood material average stiffness properties was observed ($p<0.05$) in both cellular wood material directions. Significantly higher MOE values in parallel direction were observed when tested in bending, compression and tension but in shear test modulus was significantly higher in perpendicular direction of the cellular wood material. Individual stiffness characteristic values according to Fig. 5 for each property and each direction shall be taken into account for structural design of cellular wood material products. In general cellular wood material in perpendicular direction shows higher strength properties but lower stiffness properties compared with cellular wood material in parallel direction excepted for shear modulus where inverse coherency was observed.

Due both the loss of the material and change of the structure of the material significant decrease of strength and stiffness properties were observed if cellular wood material compare to solid timber with strength class C24 according to the standard EN 338:2010, from which pine cellular wood material was produced. Approximate 14 times decrease from 24MPa to 2.11MPa of characteristic bending strength and 54 times decrease from 7400MPa to 136MPa of characteristic local MOE in bending in average was observed. According to initial study on three layer cellular wood material panels for structural application cellular wood material covering with 20mm solid timber can increase the average bending strength property up to 32.2MPa and average local MOE in bending to 10900MPa. Solid wooden ribs glued between cellular wood material slices can significantly increase the strength and stiffness properties of the end product where it is appropriate (Iejavs *et al*. 2011). The characteristic compressive strength values 1.05MPa and 1.20MPa were obtained when material was loaded in perpendicular and parallel direction accordingly. Obtained compressive strength properties can be compared with solid timber when loaded in compression in perpendicular direction to the grain (2.5MPa). For comparison, characteristic compressive strength perpendicular to grain of cross laminated timber panels range from 2.85MPa (Bogensperger *et al.* 2011) to 3.3MPa (Serrano and Enquist 2010). The characteristic tension strength values 0.290MPa and 0.648MPa were obtained when material was loaded in perpendicular and parallel direction. Obtained characteristic tension strength properties can be compared with solid timber when loaded in tension in perpendicular direction to the grain (0.5MPa). Characteristic shear strength of the solid timber with strength class C24 is 2.5MPa in comparison obtained shear strength values for cellular wood material were 0.173MPa in parallel direction and 1.25MPa in perpendicular direction. Approximate 2-3 times decrease of average MOE in bending, tension and compression where achieved compared to solid timber mean MOE in perpendicular direction (370MPa). For perpendicular and parallel direction of cellular wood material approximate 7 and 118 times decrease of average shear modulus where achieved compared to solid timber mean shear modulus (690MPa).

CONCLUSIONS

Cellular wood material apparent density is 38% less in average compared with solid pine timber density. Due to the structure of the cellular wood material significant decrease of strength and stiffness properties were observed when cellular wood material compared with solid timber. Obtained pine cellular wood material properties will be used for new light weight structural element and product design. In future complex research on cellular wood material will be carried out where cellular wood material will be used as core material for light weight structural panel design. As top materials wide range of wood based panels will be used. Research on the size effect on cellular wood material properties shall be carried out to provide appropriate characteristic properties of cellular wood material.

ACKNOWLEDGEMENT:

This 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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