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Swelling Pressure and Form Stability of Cellular Wood Material

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Abstract. Cellular Wood Material (hereinafter CWM) middle layer of the Dendrolight® has been developed in the beginning of this century as a wood material for minimization of internal stresses, because of the material structure and reduced swelling and shrinking impact to products in end use application. Some research has been conducted on the physical – mechanical and physical – chemical properties of CWM, while dimensional stability has not been well researched. The goal of this research is to perform an assessment of the CWM shrinkage and swelling impact on dimensional characteristics of the CWM multilayer composite materials. CWM *swelling pressure* in length, width, and height of the material were determined and compared to the relevant indicators of pine solid wood. The *form stability* or the impact of combination of the CWM with some facing materials – wood particle board, medium density fibre board (hereinafter MDF), oriented strand board (hereinafter OSB), pine solid wood, gypsum plaster board used in wood products was investigated. The hypothesis that swelling pressure of CWM must be lower than that of pine solid wood was proved, it is 2.3 times lower in the radial direction and 3.9 times lower in tangential direction compared to pine solid wood. The CWM samples, manufactured for determining the form stability in wetting conditions deflected in the height direction by 4%, thus creating deflections also in the seams between separate lamellas of the CWM. Swelling pressure of the CWM is several times smaller than that of solid wood and can be further limited by creating complex wood and non-wood composite material panels using gluing technique.

Key words: dimensional stability, moisture uptake, wood, wood composites.

INTRODUCTION

Shrinkage and swelling create the biggest problems in manufacturing of wood construction and carpentry elements, since the wood materials used have a moisture content lower than 30% (Vitckopfs, 1944). Swelling pressure of wood has been studied (Tarkow & Turner, 1958; Perkitny & Helinska, 1963; Kollmann & Cote 1984; Mantanis et al., 1994).

Properties of earlywood and latewood have an impact on shrinkage and swelling. Latewood swells approximately twice as much as earlywood, because the density of earlywood is lower than that of latewood (Rowell, 1995; Rowell, 2012). According to a research made in Russia, swelling pressure of 20×20×30 mm pine wood samples with moisture content of 12–15% in radial direction was between 0.82 and 1.1 MPa, while in tangential direction it was higher, 1.44–2.14 MPa (Wood Moisture Content, 2013).

In longitudinal direction, the maximal swelling and shrinking are the smallest, from 0.1 to 0.3%; in radial direction, may reach 5 to 7%, while in tangential direction 10 to 12%, therefore it may be 1.5 to 2.0 times greater than in radial direction (Bowyer, 2003).

When moisture content of wood composite material, such as plywood, changes by 1%, the length and width of plywood changes by approximately 0.15 mm per 1 meter, the relevant thickness changes from 0.3 to 0.4% (Handbook of Finnish Plywood, 2002). Other wood based materials like wood particle board, MDF and OSB are shrinking and swelling even more.

CWM is characterized as a dimensionally stable material. It is produced from integrated groove-profiled pinewood sawn materials (Fig. 1, type 1), glued together in four layers by placing each subsequent board perpendicularly on top of the previous one (Fig. 1, type 2), thus creating a cellular material block (Fig. 1, type 3). Subsequently, the cellular material block is being sawed into lamellas of the required thickness, (Fig. 1, type 4). The obtained cellular material lamella can easily be combined with different materials and can be used as an end-product in both carpentry production and construction products sector (Dendrolight Latvija, 2013).

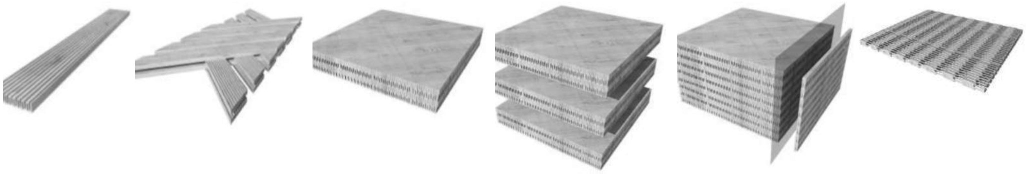

Figure 1. CWM production steps – starting from left to right hand (Dendrolight Latvija 2013).

The inventor of CWM, Johann Berger (Berger, 2008), mentioned that material has a lower density, from 100 to 300 kg m^{-3}, lower swelling in height direction, 2 to 4%, compared to other composite materials, and that changes are reversible. In a previously conducted research on CWM shrinkage and swelling indicators, it has been determined that swelling in width and length (hereinafter D g.p) directions of CWM (Fig. 2), is approximately 10 times lower than in height direction (hereinafter D) (New technological solutions…, 2012).

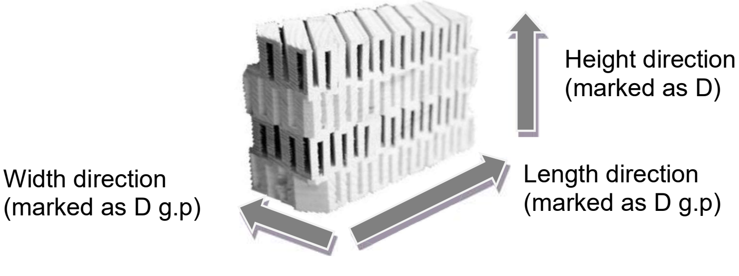

Figure 2. CWM directions.

The objectives of present research is to investigate swelling pressure of CWM in height direction and compare results with pine solid wood characteristics in tangential direction, as much as find out impact of CWM material to some wood based materials – plywood, wood particleboard, OSB, MDF and gypsum plasterboard and compare results with CWM panel with no added materials.

MATERIALS AND METHODS

In order to determine the CWM swelling pressure in height direction, 80 groove-profiled pinewood CWM specimens were produced (width × length × height: 35×35×25 mm). Lamellas without visual wood defects (equal width of annual rings and percentage of latewood) were chosen for the samples. Two lamellas were glued together, each other perpendicularly, with total height of sample 50 mm (Fig. 3.). Totally 40 CWM pinewood samples were prepared.

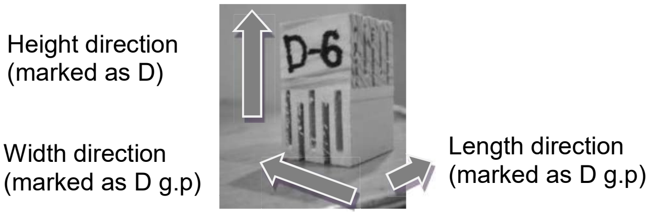

Figure 3. CWM swelling pressure determination sample.

After the samples had been produced, they were placed in a conditioning chamber with a constant temperature (shown in figures as t) 20 ± 2 °C and humidity (shown in figures as W_r) level 65 ± 5%, in order to reach the equilibrium wood moisture content. The average moisture content of wood was 11.55 after the equilibrium moisture content was reached. Determination of moisture content was done accordance with standard EN 13183-1 (EN 13183-1, 2002) and density with standard ISO 3131 (ISO 3131, 1975) requirements. In order to determine the pine CWM swelling pressure, measuring equipment was constructed and it is shown in Fig. 4. The samples were inserted between lower support 2 and upper support 3 (Fig. 4). The swelling force was measured with load cell *K25* (Fig. 4) and data logger *ALMEMO* and data colleting software *WINCONTROL*.

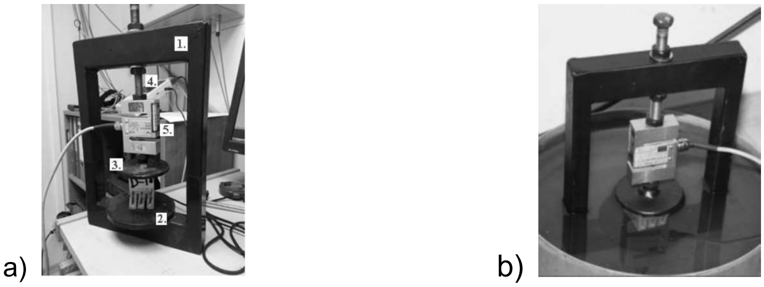

Figure 4. Swelling pressure measurement equipment with CWM sample in height direction (marked as D): a – sample before immersion in water; b – sample in a time of testing; 1 – frame; 2 – lower support; 3 – upper support; 4 –screw; 5 – load cell.

In order to compare the swelling pressure between CWM height and length-width direction, one CWM specimen with dimensions 50×50×50 mm was prepared.

For comparison of the same swelling indicators with pine solid wood, 20 grain oriented pine wood specimens with dimensions 35×35×35 mm were prepared. Ten specimens were tested in radial and ten in tangential grain orientation direction. The description, marking, number and sizes are given in (Table 1).

Table 1. Samples description

Name	Marking	Number of samples	Dimensions: height, length, width; mm
CWM in height direction	D	40	35×35×50
Solid wood in radial direction	R	10	35×35×35
Solid wood in tangential direction	T	10	35×35×35
CWM in length and width direction	D g.p	1	50×50×50

The same measuring technics were used for determination of swelling force of all specimen variations.

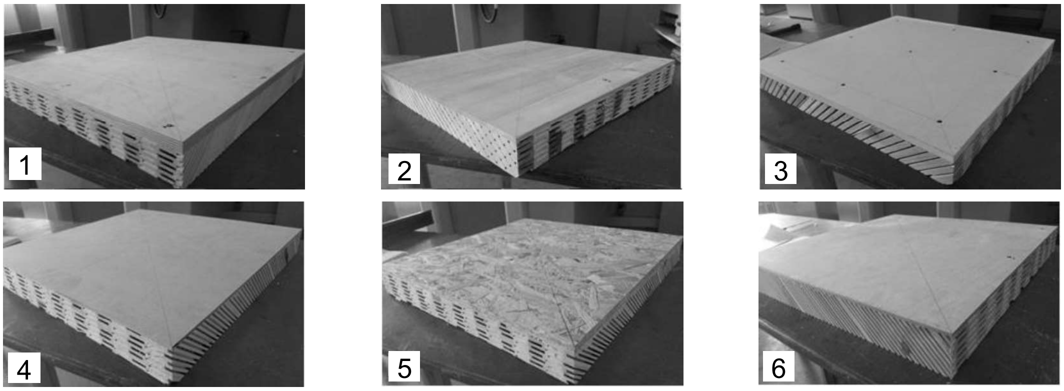

Figure 5. CWM combine samples of form stability: 1 – with plywood, 12 mm; 2 – with pine solid wood, 7 mm; 3 – with gypsum plasterboard, 12 mm; 4 – with MDF, 4 mm; 5 – with OSB, 12 mm; 6 – with plywood, 4.5 mm.

For determination of CWM composite panels form stability (deflection of flat surface) of the CWM in combination with other composite materials, CWM panel materials with length 600 mm, width 600 mm and thickness 52 mm were used. All the specimens were conditioned in constant climate to reach 10% moisture content before panels were glued together. Following composite materials were selected (Fig. 5): 12 mm thick birch plywood (Fig. 5, type 1), 7 mm thick pine solid wood (Fig. 5, type 2), 12 mm thick gypsum plasterboard (Fig. 5, type 3), 4 mm thick MDF (Fig. 5, type 4), 12 mm thick OSB (Fig. 5, type 5), 4.5 mm thick birch plywood (Fig. 5, type 6). Polyurethane glue *Kleiberit* 501, pressure 0.2 MPa and time under pressure 20 minutes were applied when gluing all the materials, except gypsum plasterboard. In order to stick together gypsum plasterboard with CWM panel (length 500 mm, width 500 mm and height 52 mm), the screws with diameter 3 mm and length 45 mm were used, placed within 5 cm from CWM panel edges, in the corners and lateral midpoints of the samples (Fig. 5). All the composite material panels were applied only from one side for better understanding of CWM shrinkage-swelling effect on multilayer composite materials with CWM core. After applying cover materials samples were cut in square dimension with side length of 500 mm.

One sample was produced with no added composite material for determination of CWM panel form stability. For each group one sample was prepared. After the samples had been produced, they were placed in a conditioning chamber with a constant temperature 20 ± 2 °C and humidity level 65 ± 5%, in order to reach the equilibrium wood moisture content. Average moisture content of samples were 11.5%.

After conditioning deflection of the samples were assessed in four surface directions, center lines of the sample (Fig. 6) (left hand), where a1 stands for CWM height direction, while a2 – length direction, and b1 and b2 – diagonal direction (Fig. 6) (right hand), and the deflections measuring performed at the center of sample.

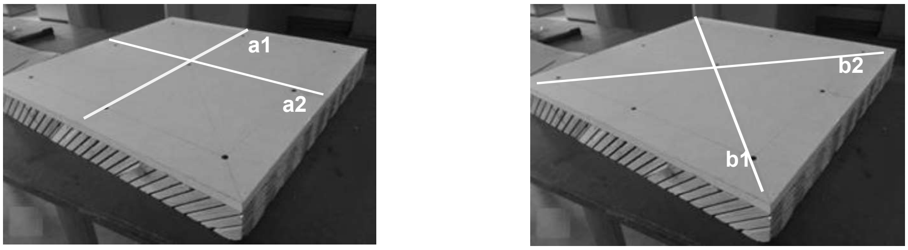

Figure 6. Measuring directions of deflection of samples: a1 – CWM height direction; a2 – CWM length direction; b1 and b2 – diagonal direction.

For assessment of sample deflection in the way of diagonal and center line, a calibrated metal band was used (Fig. 7,1.), placing it on the sample and determining the deflection incurred in the necessary direction (a1; a2; b1 and b2). A measuring probe with reading accuracy 0.5 mm were used for measuring the distance between metal band and sample in case it was there. (Fig. 7,1.).

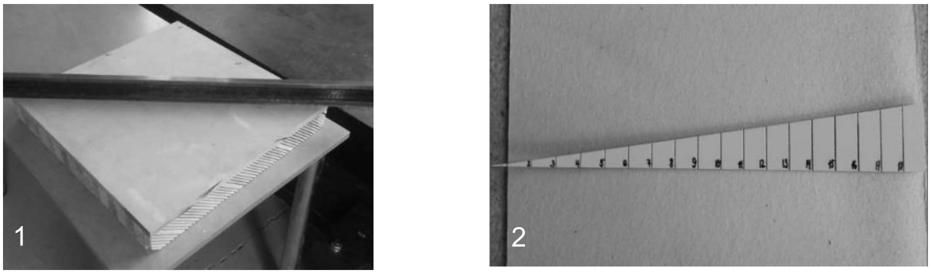

Figure 7. Equipment for measuring deflection of the samples: 1 – metal band; 2 – measuring probe.

Deflection was checked repeatedly after 24 hours and the measurement process was repeated every 48 hours. After 150 hours, sample deflection, the biggest one, were checked once again and samples were placed in a conditioning chamber with temperature 23 ± 2 °C and air humidity 25 ± 5% giving the target wood equilibrium moisture content 5.55. Sample deflection determination followed similar time interval pattern as described previously in this manuscript.

RESULTS AND DISCUSSION

At first the swelling pressure of pine solid wood was determined. A similar results achieved compared to previous research done which stated pine solid wood swelling pressure in radial direction between 0.82 to 1.10 MPa. The swelling pressure obtained in this research was on average 0.77 MPa (*standard deviation* (hereinafter *s*) 0.14 MPa, *coefficient of variation* (hereinafter v) 17.9%). The discrepancy can be explained with structural characteristics of wood. The individual measurements showed that solid wood density has no significant impact on swelling pressure changes. The highest swelling pressure was in tangential direction. The swelling pressure indicators obtained as a result of the research, are 1.7 times higher in tangential than in the radial direction, demonstrating mean swelling pressure 1.3 MPa (s = 0.12 MPa, v = 9.6%). Compared to the results of previous research stating that swelling pressure is between 1.44 and 2.14 MPa, as well as to radial swelling pressure, minimal difference was observed and can be explained with wood structural characteristics.There were no linear connection observed between tangential direction swelling pressure and solid wood density.

CWM swelling pressure in height direction (Fig. 3.) was between 0.178 and 0.554 MPa and on average 0.33 MPa (s = 0.08 MPa, v = 23.7%). Relation between CWM density and swelling pressure shows weak correlation.

Fig. 8, depicts the pine solid wood in tangential direction (light grey curve) and radial direction (dark grey curve) demonstrating swelling force changes in time. When placing the sample in the measuring equipment, the force gradually increases until it reaches the peak and thereafter decreases very slowly. Average time required to reach peak swelling force for solid wood was about 10 hours in radial direction and 6 hours in tangential direction. CWM swelling force black curve (Fig. 8), shows that material reached peak swelling force considerably faster than solid wood thanks to its specific structure ensuring much faster water permeability inside the wood sample. Swelling force increases considerably at the beginning of the measuring, followed by a slower increase until it reaches the peak and a subsequent decrease. It occurs much faster than with pine solid wood (Fig. 8).

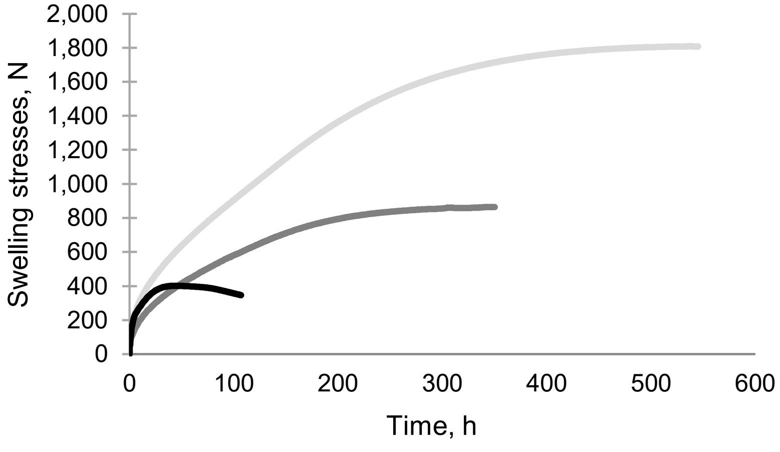

Figure 8. Solid wood in tangential direction (light grey curve), in radial direction (dark grey curve) and CWM in height (black curve) swelling force in a time scale.

When comparing the swelling pressure data obtained, it can be seen (Fig. 9), that CWM swelling pressure in the height direction is 11.5 times higher than in the length and width directions. The previous hypothesis that swelling pressure of CWM must be lower than that of solid wood was proved. It is 2.3 times lower in the radial direction and 3.9 times lower in tangential direction that in solid wood.

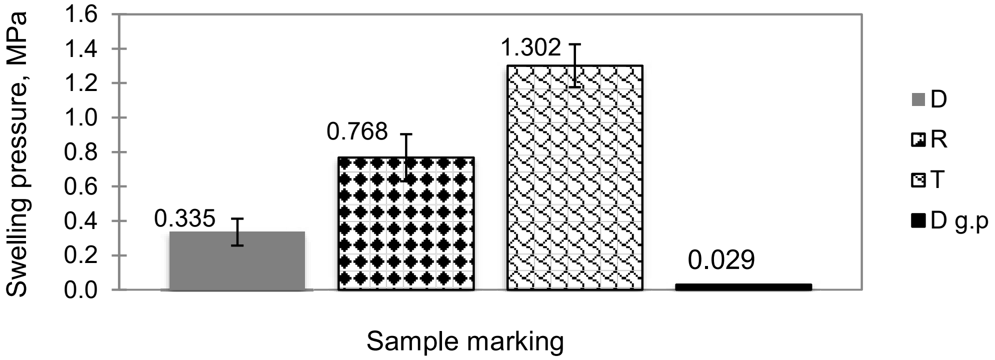

Figure 9. Swelling pressure of the CWM and pine solid wood: D – CWM in height direction; R – solid wood in radial direction; T – solid wood in tangential direction; D g.p – CWM in length and width direction.

Already after multilayer composite panels with CWM core sample preparation deformations occurred as a result of surrounding humidity and slightly glue induced humidity. Fig. 10, demonstrates that samples with solid wood and 12 mm plywood covered have identical indicators, CWM with 4.5 mm plywood covered shows a greater deflection, by 0.4% in height direction and 0.3% in direction of diagonals. Sample with gypsum plasterboard coating demonstrated good form stability after specimen preparation, while MDF gluing sample demonstrated a deflection in CWM longitudinal direction.

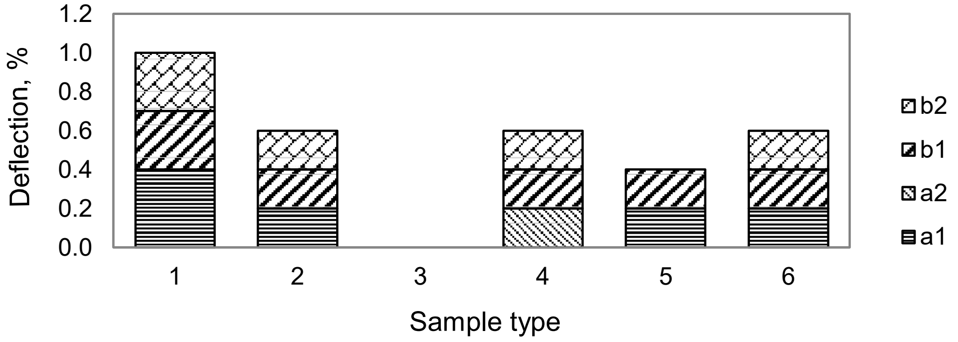

Figure 10. Form stability after preparing of samples: 1 – plywood (4.5 mm); 2 – solid wood (7 mm); 3 – gypsum plasterboard (12 mm); 4 – MDF (4 mm); 5 – OSB (12 mm); 6 – plywood (12 mm); a1 – height direction; a2 – length direction; b1, b2 – diagonal direction.

When environmental parameters change after spending 24 h in conditioning chamber (Fig. 11), in samples with solid wood, 12 mm and 4.5 mm plywood covered no deformation was observed, while the remaining samples showed a deflection in CWM height nd length direction. After conditioning, the moisture content of samples had increased up to 0.6% for 12 mm plywood covered samples and up to 1.9% for solid wood gluing CWM sample.

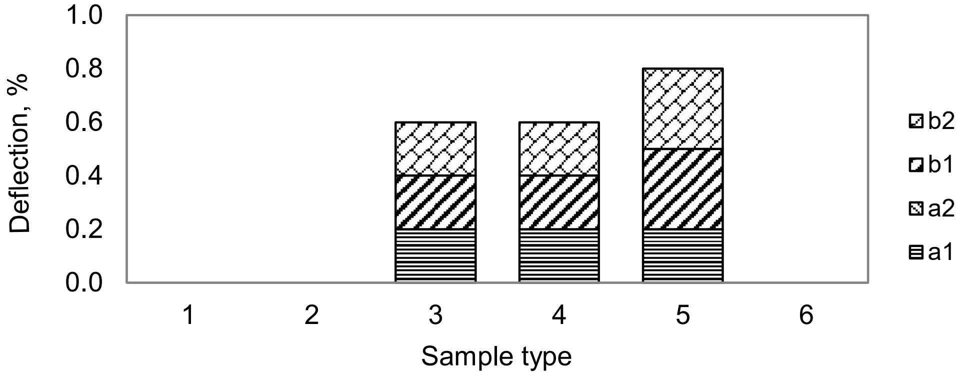

Figure 11. Form stability after 24 hours, $W_r = 65\%$, $t = 20$ °C: 1 – plywood (4.5 mm); 2 – solid wood (7 mm); 3 – gypsum plasterboard (12 mm); 4 – MDF (4 mm); 5 – OSB (12 mm); 6 – plywood (12 mm); a1 – height direction, a2 – length direction, b1, b2 – diagonal direction.

After repeated measuring 48 h, all samples showed increased deflection (Fig. 12), and all the deflections were directed in composite material direction. When sample moisture content was increased by 0.9% to 2.2%, more distinct deflection was seen in OSB gluing sample with deflections in directions of both center lines and diagonals. In remaining samples, a distinct deflection was seen in height direction, between 0.2 and 0.3%.

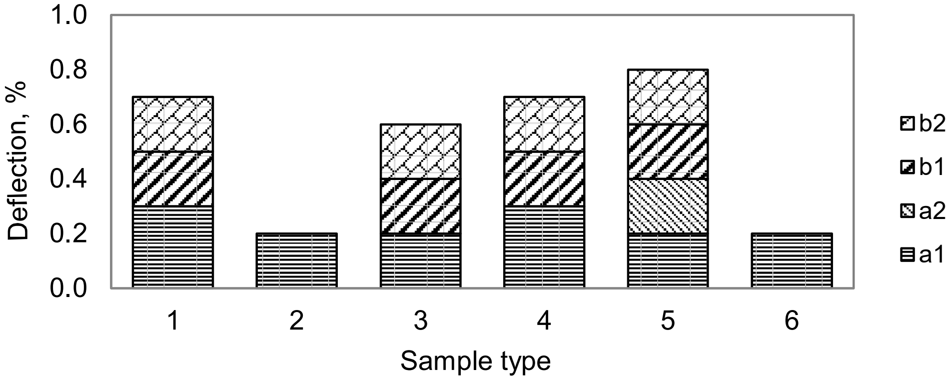

Figure 12. Form stability after 48 hours, $W_r = 65\%$, $t = 0$ °C: 1 – plywood (4.5 mm); 2 – solid wood (7 mm); 3 – gypsum plasterboard (12 mm); 4 – MDF (4 mm); 5 – OSB (12 mm); 6 – plywood (12 mm); a1 – height direction; a2 – length direction; b1, b2 – diagonal direction.

After 150 hours of conditioning (Fig. 13), samples with MDF, OSB and 4.5 mm plywood covered demonstrated a distinct deflection, with moisture content increasing by 1.7 to 2.2%, peak form stability deflection in 0.6%. Sample with solid wood gluing demonstrated a deflection in all directions after conditioning, while sample gypsum plasterboard coating retained the form stability deflection it had acquired at the beginning of conditioning.

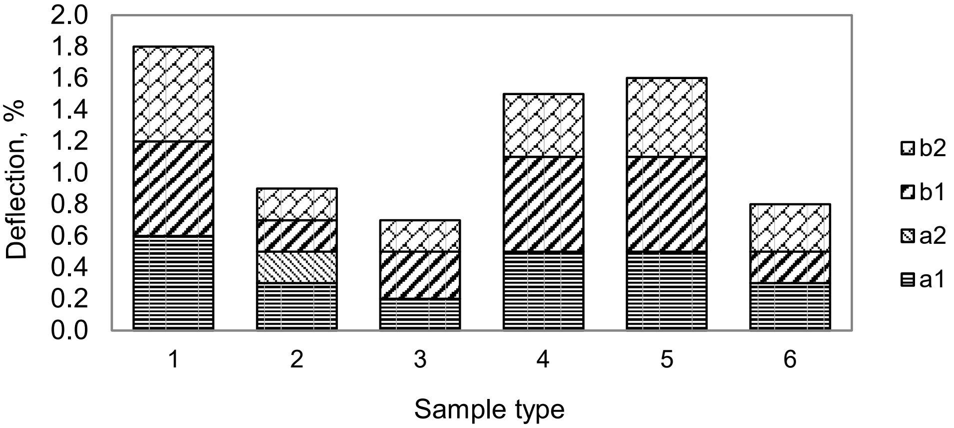

Figure 13. Form stability after 150 hours, W_r = 65%, t = 0 °C: 1 – plywood (4.5 mm); 2 – solid wood (7 mm); 3 – gypsum plasterboard (12 mm); 4 – MDF (4 mm); 5 – OSB (12 mm); 6 – plywood (12 mm); a1 – height direction; a2 – length direction; b1, b2 – diagonal direction.

When changing the environmental conditions to drier one – W_r 25% and t 23 °C, a significant deflection was observed. When environmental humidity was reduced, the samples starts deflect in the opposite direction. Fig. 14, demonstrates that all samples, except MDF+CWM, change the direction of deflection. Solid wood gluing sample demonstrates the peak deflection 0.4% in height and directions of diagonals at level when moisture content reduced by 0.2%.

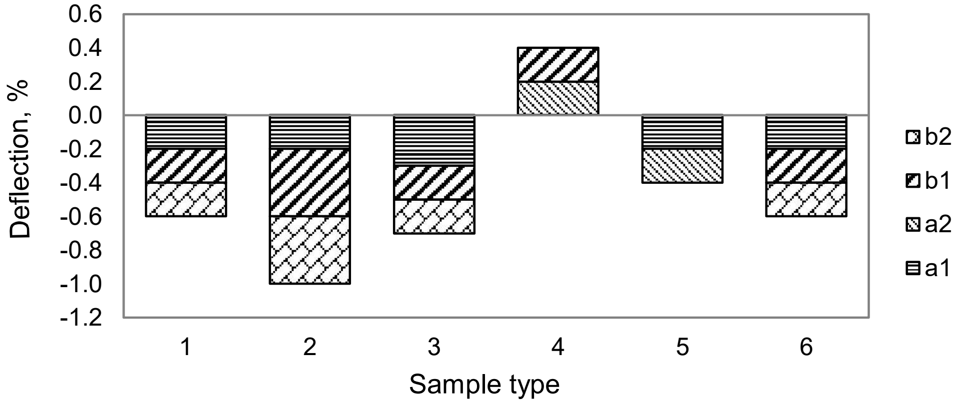

Figure 14. Form stability after 24 hours, W_r = 25%, t = 23 °C: 1 – plywood (4.5 mm); 2 – solid wood (7 mm); 3 – gypsum plasterboard (12 mm); 4 – MDF (4 mm); 5 – OSB (12 mm); 6 – plywood (12 mm); a1 – height direction; a2 – length direction; b1, b2 – diagonal direction.

Keeping samples for 48 hours in the aforementioned conditions, their deflection on average increased twice (Fig. 15). Reducing moisture content in samples by 0.2 to 0.8%, the greatest deflection was observed in solid wood gluing sample with deflection of 0.7% in height direction and b1 diagonal 0.7%, b2 diagonal 0.8% in transversal direction.

MDF gluing sample was the only one demonstrating a deflection in CWM length direction, in opposite direction compared to deflection of other samples.

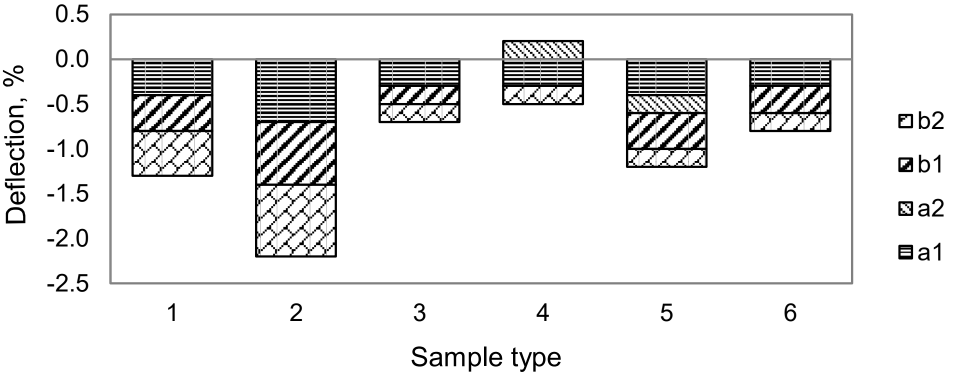

Figure 15. Form stability after 48 hours, $W_r = 25\%$, t = 23 °C: 1 – plywood (4.5 mm); 2 – solid wood (7 mm); 3 – gypsum plasterboard (12 mm); 4 – MDF (4 mm); 5 – OSB (12 mm); 6 – plywood (12 mm); a1 – height direction; a2 – length direction; b1, b2 – diagonal direction.

When looking at (Fig. 16), we can see that deflections have on average increased twice. The greatest deflection for all samples occurred in CWM height direction and in directions of diagonals. Reducing the moisture content in samples from 2.1 to 3.3%, the deflection is between 0.2 to 1.3%.

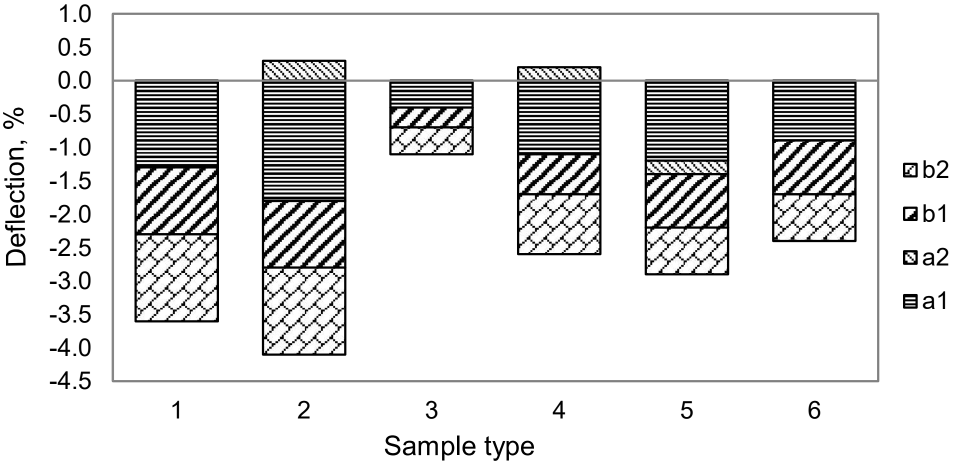

Figure 16. Form stability after 150 hours, $W_r = 25\%$, t = 23 °C: 1 – plywood (4.5 mm); 2 – solid wood (7 mm); 3 – gypsum plasterboard (12 mm); 4 – MDF (4 mm); 5 – OSB (12 mm); 6 – plywood (12 mm); a1 – height direction; a2 – length direction; b1, b2 – diagonal direction.

In all CWM combinations with other materials influence on dimensional stability can be observed. The greatest deformation can be observed in CWM a1 or CWM height direction (Fig. 17), which can be explained with the largest differences between in swelling-shrinking properties between CWM and facing material.

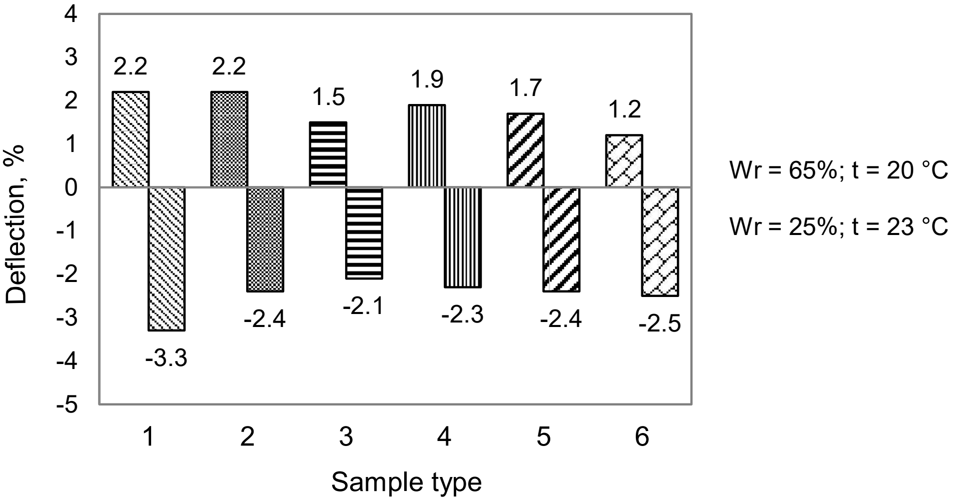

Figure 17. Influence of air condition to the samples moisture content: W_r – air relative humidity; t – air temperature.

Summarizing the results on changes in CWM moisture content (Fig. 17), the moisture content has increased by 1.2 to 2.2%. When samples were exposed 150 h in environment with relative humidity 65% and temperature 20 °C. When the samples were moved to an environment with relative humidity 25% and temperature 23 °C, the moisture content of samples sample decreased several times. The aforementioned changes in humidity are the reason for dimensional changes of samples. Fig. 18 demonstrates the peak deflection of a sample after keeping it in both environments.

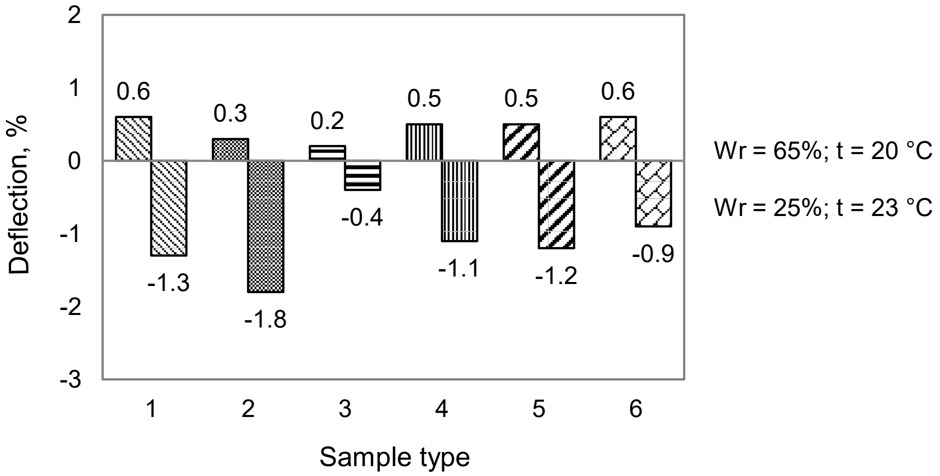

Figure 18. CWM maximal deflection at different environment conditions: W_r – air relative humidity; t – air temperature.

It was observed that the greatest deflection after keeping specimens in conditioning chamber can be observed in 4.5 mm plywood covered samples, which demonstrated a deflection in CWM height direction. When moved to a drier environment, the sample deflections change the direction radically to the opposite side demonstrating indicators almost twice as in height. In a drier environment, solid wood gluing samples show the greatest deflection – by 1.8% in CWM height direction.

When CWM sample without any facing materials was kept in a humid environment for 1h, it showed a deflection in material height direction by 2 cm or 4% (Fig. 19, 1). Upon changed humidity, sample demonstrated also deflection in lamella gluing seams (Fig. 19, 2.).

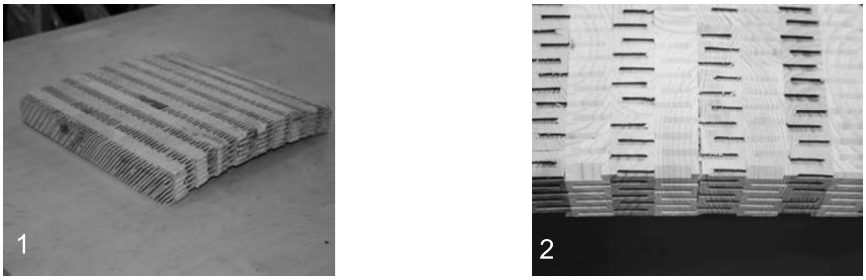

Figure 19. CWM deflection if asymmetric humidity applied to sample: 1 – global deflection; 2 – local deflection.

CONCLUSIONS

1. CWM swelling pressure in the length and width directions was 0.029 MPa, while in the height direction it was 0.335 MPa. CWM swelling pressure in the height direction is 11.5 times higher than in the length and width directions. Compared to pine solid wood, CWM swelling pressure in the height direction was more than 2.3 times lower in radial direction and more than 3.9 times in tangential direction.
2. Even small number of tested samples showed tendencies that CWM combination with different composite materials, such as plywood, MDF, OSB, gypsum plasterboard, solid wood, keeping them in an environment with different air relative humidity and temperature was observed that at heightened humidity, samples demonstrated a deflection in direction of the composite material gluing surface, while it turned in the opposite direction when moisture was reduced.
3. Dimensional changes were caused by different swelling-shrinking performance of CWM and facing materials. Symmetrical construction of multilayer wood based panel with CWM core layer should be produced to ensure panel flatness in products end use application.
4. When samples were kept in an environment with relative humidity 65% and temperature 20 °C, after 150 h the initial moisture content 11.5% has increased by 1.2 to 2.2%, and peak surface deflections is reached, 0.6%. When samples were kept in an environment with relative humidity 25% and temperature 23 °C, compared to initial moisture content decreased by 2.1 to 3.3% creating a peak surface deflections of 1.3%.

5. The existing relationship between CWM density and swelling was found as insignificant, since CWM consists of many lamellas of different density values.

6. The CWM without applying any composites form stability in the event of wetting had within 1h deformed in the height direction of lamella by 4%, damaging also the seams between lamella.

7. Since CWM swelling pressure is several times smaller than that of solid wood, it is much easier to create high dimensional stability multilayer composite materials using CWM core material than solid wood multilayer products.

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