Effect of wetting/drying on the properties of OSB/3 and birch plywood

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Abstract. In this study the thickness swelling (TS), restore dimensions (RD), density (D) and modulus of rupture (MOR), after ten cycles of wetting over/drying, of commercial boards, i.e. 3-layered OSB/3 (“SWISS KRONO”, thickness 12mm) and 9-layered birch (betula sp) plywood with phenol-formaldehyde (UPM-Kymmene, Otepää, Estonia), were investigated according to EN standards. Test samples (dimensions of 290x50x12 mm³) for determination of a change in the investigated parameters, according to the standard EVS EN 326-1:2002, were cut from the boards in the parallel (ǁ-major axis) direction to the face (outer layer) strand. The cutting forehead and the facet edges of the test samples were coated with the water repellent mastic Kiilto Fibergum (“KIILTO OY”). The specimens were altered by soaking in a tank with water (22±1°C) for 24 hours and dried for 48 hours in a ventilated drying box at 65 ± 1°C. Before testing, the samples were conditioned in a climatic chamber at a relative humidity of 65% at 21°C. The surfaces and cross-sections of the initial dry samples after the first wetting/oven-drying cycles were studied using the X-ray technique. The analytical exponent- and linear-fractional equations were used to approximate the obtained experimental data depending on the number of cycles.

1. Introduction
Wood-based panel products such as plywood, fibreboard, particleboard and oriented strand board (OSB) provide a substitute for solid wood while retaining the requisite structural properties with favourable performance and low cost. Plywood is the dominant wood-based panel type, accounting for 42 % of all wood-based panel production in 2016. The production of OSB accounted for 7.2% in 2016 [1]. However, the global OSB market is expected to grow approximately 28% by 2022. OSB is taking an increasingly higher share in the structural panel products market in applications such as walls and roof sheathing, I-beam webs and single layer flooring [2]. Thus plywood and OSB are the largest growing wood-based panels in the global market.

Plywood is a material manufactured from thin layers or "plies" of wood veneer which are glued together with adjacent layers having their wood grain rotated up to 90 degrees to one another. This cross-graining has several important benefits: it reduces the tendency of wood to split when nailed in at the edges; reduces expansion and shrinkage, providing improved dimensional stability; and makes the strength of the panel consistent across all directions. There are usually an odd number of plies, so that the sheet is balanced, which reduces warping. The face veneers of a typical plywood panel have
higher grade than the veneers. The principal function of the core layers is to increase separation between the outer layers where bending stresses are the highest, thus increasing the modulus of rupture (MOR) of plywood.

Oriented strand board (OSB) is a material made from large, flat strands of wood, where the outer layers’ strands are oriented parallel to the long edge of the board or to the production line, and the core layer is often formed of smaller strands oriented at right angles to the outer layers [3]. The outer layers of OSB are compressed to attain higher density, ensuring the basic physical and mechanical properties of the boards. The moisture transfer properties of OSB differ from those of both plywood and construction lumber [4]. OSB is a hygroscopic material and its dimensional stability and physico-mechanical properties are dependent on many factors including adhesive content, water sorption, number of soaking-oven-drying periods and ambient temperature.

The objective of the current study was to find out and compare the effect of wetting and oven-drying on the physico-mechanical properties of OSB and plywood. For this, commercially available 3-layered OSB/3 and 9-layered birch (Betula sp) plywood were investigated. The investigated physical and mechanical properties of OSB/3 and plywood were thickness swelling (TS), restore dimensions (RD), density (D) and modulus of rupture (MOR), respectively.

2. Experimental methods

Twelve OSB/3 and plywood test samples (dimensions 290×50×12 mm³) per each wetting/oven-drying cycle were prepared for determination of a change in the investigated parameters according to standard EVS EN 326-1:2002 [5]. The test samples were cut in parallel (l-major axis) to the face (outer layer) strand from two plywood boards and from one OSB/3. The cutting forehead and the facet edges of the test samples were coated with the water repellent mastic Kiilto Fibergum (“KIILTO OY”). The samples were altered by soaking in a tank with water (22±1) °C for 24 hours and dried after that (for 48 hours) in a ventilated drying box at 65 ± 1°C. Before testing the samples were conditioned in a climatic chamber at 21°C and relative humidity 65%.

All investigated parameters of the test samples were determined immediately after they were taken out of the water tank or the drying box and were arranged in accordance with the standards: TS and RD (EN 317:1996) [6], MC (EN 322:2002) [7] and D (EN 323: 1993) [8]. Also, the modulus of rupture (MOR) of OSB/3 and that of plywood were compared. MOR was determined by the three-point bending test performed in accordance with EN 310:1993b [9], using the computer-controlled mechanically actuated universal testing machine Instron 3369. Deflection for calculating the modulus of elasticity was measured by an optical gauge (Advanced Video Extensometer 2663-821). Density was determined as the ratio of the mean mass of twelve test samples to their volume, in our case for dry samples [10, 11].

The surfaces and cross-sections of the dry samples at the initial time point and after the first wetting/oven-drying cycle were studied using the X-ray technique (Yxlon FF35 CT).

The following assumptions were made for the mathematical expressions (values of the investigated properties vs number of wetting/oven-drying cycles): the approximation curve, first, cuts ordinate or starts from zero; and second, enables to determine limit values, in which the studied properties stabilize.

The following analytical linear-fractional and exponent equations were used to approximate the obtained experimental data depending on the number of cycles [12]:

\[ Y(x) = \frac{b(Y_f - Y_i)}{a(x + b)} + Y_i, \]  
\[ Y(x) = Y_f \left(1 - e^{-ax}\right), \]

where \( Y_i, Y_f \) are the calculated initial \((x = 0)\) and final \((x = \infty)\) values of the investigated properties, \( x \) is the number of wetting/oven-drying cycles and \( a \) and \( b \) are constants.

The equations allowed to predict the investigated parameters of the specimens to a certain extent when their values after applying a small number of soaking/oven-drying cycles were known.

The initial and final values of the properties and constants should be determined so that the measured experimental data are approximated in the best way by minimizing the square of error (least
squares regression). This problem was solved by using the program Mathcad 15 with the regression function \text{genfit}(vx,vy,vg,F). The TS and RD trend line of plywood were found by using the program MS Excel 2016 with the regression analysis function.

It is usually described by a parameter that defines the range within which the true values of the quantity to be measured is estimated to fall within the given confidence range 95%. Calculation of the expanded uncertainty of measured properties is carried out according to the standard EVS-EN 326-1: 2002 [5]. In our study the mean values of the experimental data were used for approximation.

3. Results and discussion
The average MC of the test samples after the first 24 hours of soaking (at 22 ± 1°C) were 25.3% and 43.5% (latter is Wet) for plywood and OSB/3, respectively. After 48 hours of drying in a ventilated box at 65 ± 1°C the average MC was 7.7% and 12.0% (latter is Dry) for plywood and OSB/3, respectively. The percentages of TS and RD of OSB/3 board and plywood, compared to their initial values, are presented in Figure 1 and Figure 2. It should be noted that the values of the calculated percentages are taken from the approximation curves.

![Figure 1. Dependence of Wet–thickness swelling and Dry – thickness swelling of OSB/3 on the number of soaking/oven-drying cycles: mean values of the experimental data and the curves of approximation with the determined quantity according to equation (2).](image)

The mean thickness of OSB/3 board after the first wetting/oven-drying cycle was 20.7% and after the first soaking cycle 22.1% of the initial values, which indicates that plastic deformations of the resin matrix are not restored.

The thickness 5.15% of plywood after the first wetting was markedly smaller than that of OSB/3 board and decreased even down to initial thickness after drying and its RD was - 1.35%. It is evident that for plywood, the values of TS remained constant within the experimental error irrespective of the number of wetting/oven-drying cycles (Figure 2).

The mean values of density depending on the number of wetting/oven-drying cycles in Figure 3 for OSB/3 were determined after drying. A notable reduction in the density values was found after the first soaking/oven-drying cycle and the obtained \(D_m(1)\) was 87.8% of \(D_m(0)\). Based on the limits of experimental error, the density values did not decrease significantly after three soaking/oven-drying cycles.
cycles and accounted for 74% of their initial values. Thus, the OSB/3 panel had lost one quarter of its initial density while its air permeability had consequently increased.

**Figure 2.** Dependence of Wet–TS and Dry–TS of plywood on the number of soaking/oven-drying cycles: mean values of the trend lines are 5.15% and -1.35%, respectively.

**Figure 3.** Dependence of the density of OSB on the number of soaking/oven-drying cycles: mean values of the experimental data and the formula and curve of approximation with the determined quantity according to equation (1).

The retention values vs initial values of MOR recorded after the first wetting/oven-drying cycle, were 79.8% of Dry-MOR, but only 44.2% of Wet-MOR for OSB/3. The following wetting/oven-drying cycles had less impact on Dry-MOR compared to Wet-MOR, see Figure 4.

The retention values vs initial values of MOR, recorded after the first wetting/oven-drying cycle, were: Dry-MOR 80.0%, but Wet-MOR 52.8% for plywood. The MOR values of the both wet and dry samples did not decrease considerably after the first cycle (Figure 5). On the other hand, the decrease of Wet-MOR values for both plywood (almost 53%) and OSB/3 (about 44%) was highly significant.
Figure 4. Dependence of Wet–MOR and Dry-MOR of OSB/3 on the number of soaking/oven-drying cycles: mean values of the experimental data and the curves of approximation with the determined quantity according to equation (1).

Figure 5. Dependence of Wet – MOR and Dry-MOR of plywood on the number of soaking/oven-drying cycles: mean values of the experimental data and the curves of approximation with the determined quantity according to equation (1).

This means, that both plywood and OSB/3 failed to meet the requirements for the ultimate limit state (e.g. as a sheathing board ensuring rigidity) in the case of 24 h of soaking in water.

X-ray investigations conclude with a manipulation of OSB/3 board of large increase in TS and decrease in density and MOR even after the first wetting/oven-drying cycle (Figure 6). The X-ray investigations allowed to make the following conclusion. A small amount of phenol formaldehyde
resin (matrix) tended to segregate along the wood strands boundaries forming an amorphous matrix in which the individual strands are embedded. Wood strands swelled during wetting and their increasing volume created stresses in the embedded boundaries of the resin matrix, resulting in plastic deformations. Next, as the volume of wetted strands decreased in oven-drying, the strands consequently (partially or fully) ripped off from the embedded boundaries of the matrix or fractured parallel or perpendicular to the grain. Because of the voids generated between the fracture surfaces of the strands and the embedded boundaries of their plastically deformed resin matrix, the dimensions of the samples did not restore after drying. Also, comparison of the TS of the wetted and dry samples indicated that the plastic deformations of the matrix did not recover, being 20.7% of Dry-TS and 22.1% of Wet-TS after the first wetting/oven-drying cycle and after the first wetting, respectively. Also, many surface strands fractured in volume and the MOR of OSB/3 decreased considerably after the first cycle (Figure 4).

![X-ray image of the texture of the 3-layered OSB/3 board from the: a) face (outer) layer, b) middle cross-section, in parallel with H axis, c) in parallel with T axis; purveyance dry (0 cycle), and after the first wetting/oven-drying cycle.](image)

4. Conclusions
After the first wetting the mean values of the wetted thickness swelling of OSB/3 board and plywood were 22.1% and 5.15%; the wetted modulus of rupture was 44.2% and 52.8% of the initial value,
respectively. Thus, 24 h of wetting resulted in a significant decline in the modulus of rupture of both OSB/3 and plywood boards, which failed to meet the requirements for the ultimate limit state as a part of the load bearing structure (e.g. as a sheathing board ensuring rigidity) of a building.

After the first wetting/oven-drying cycle the mean values of dry thickness swelling (restore dimension) of OSB/3 and plywood were 20.7% and -1.4%; the dry modulus of rupture accounted for 79.8% and 80.0% of its initial value, respectively. The density of dry OSB/3 board was 87.8% of its initial value.

The X-ray investigations of the OSB/3 samples revealed a significant change in the studied parameters after the first wetting and drying cycles as a result of non-restored plastic deformations of the resin matrix, in which embedded strands were jammed after wetting. For the same reason, the strands ripped off during oven-drying, resulting in the generation of air voids.

The proposed analytical functions approximated satisfactorily to the experimental data of thickness swelling, density and modulus of rupture depending on the number of soaking/oven-drying cycles.

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References
[1] Food and agriculture organization of United Nations 2016 Global Forest Products: Facts and Figures. Available from: http://www.fao.org/3/i7034en/i7034en.pdf
[2] Grand View Research 2018 Wood Based Panel Market Size, Share & Trends Analysis Report by Product (Plywood MDF Particleboard Softboard Hardboard) by Application (Furniture Construction Packaging) and Segment Forecasts 2018 – 2025 p 141
[3] Irle M A et al 2012 Handbook of Wood Chemistry and Wood Composites 2nd, ed R M Rowell (Boca Raton: CRC Press, Taylor & Francis Group) pp 321-412
[4] Carll C and Wiedenhoeft A 2009 Moisture Control in Buildings: the Key Factor in Mold Preventions 2nd ed ASTM International, MNL 18
[5] Estonian Centre for Standardization, 2002. EVS-EN 326-1: 2002 Wood-based panels. Sampling, cutting and inspection Part 1: Sampling and cutting of test pieces and expression of results (in Estonian)
[6] Estonian Centre for Standardization 2000 EVS-EN 317: 2000 Particleboards and fibreboards – Determination of swelling in thickness after immersion in water. (in Estonian). Available from: https://www.evs.ee/tooted/evs-en-317-2000
[7] European Standard 1993 EN 322: 1993 Wood-based panels – Determination of moisture content
[8] European Standard 1993 EN 323: 1993 Wood-based panels – Determination of Density
[9] European Standard 1993 EN 310: 1993b. Wood-based panels - Determination of modulus of elasticity in bending and of bending strength
[10] Tamm R 2018 Physical and Mechanical Characteristics of OSB/3-Boards after Repetitive Soaking and Oven-Drying Unpublished thesis (MScs) Estonian University of Life Sciences Tartu: Estonia (in Estonian)
https://dspace.emu.ee/xmlui/browse?type=author&value=Tamm%2C+Renee
[11] Kruus S 2016 Changes in Physical and Mechanical Properties of Moisture Resistant Birch Plywood after Soaking and Oven-Drying Cycles Unpublished thesis (MScs) Estonian University of Life Sciences Tartu: Estonia (in Estonian)
https://dspace.emu.ee/xmlui/browse?type=author&value=Kruus%2C+Silver
[12] Sooru M, Kasepuu K, Kask R and Lille H 2015 Proc. 2nd International Conference on Innovative Materials, Structures and Technologies vol 96 (Riga: Latvia IOP Publishing Ltd) 10.1088/1757-899X/96/1/012075.
[13] Hodoušek M, Böhm M, Součková, A and Hýsek Š 2018 BioResources 3 4856