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THE INFLUENCE OF MOISTURE CONTENT ON THICKNESS SWELLING AND MODULUS OF ELASTICITY IN ORIENTED STRAND BOARD BENDING

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ABSTRACT

The main theme of this study was an analysis of the moisture content (MC), thickness swelling (TS) and its relationship to modulus of elasticity in bending (MOE), For this case samples from OSB/3 Superfinish (Czech producer Kronospan) were used. All analyses were performed with EN 310 standard-sized specimens. The specimens were exposed to 15, 35, 50, 65, 85 and 100% relative humidity (RH) and 20°C for absorption and desorption. Analysis results clearly show that MOE decreases with an increase of board moisture content. For an MC change from 5 to 22 %, an average MOE loss of 44 % in the parallel direction and 39 % in the perpendicular direction was measured. This MOE loss corresponded to a 21% thickness swelling. Predictive equations expressing the MOE bending as a function of MC and TS were determined.

KEY WORDS: oriented strand boards (OSB), moisture content, thickness swelling, modulus of elasticity in bending

INTRODUCTION

Oriented Strand Board (OSB) is one of the wood particle composites that have been widely used in many applications, in particular structural – sheathing, flooring, and I-joist material and non-structural – furniture, packaging etc. usually a flexural load and fluctuating moisture contents appear in these types of applications.

Previous research reported that after exposure to an elevated relative humidity environment, wood composite panels and OSB also increase in thickness (Halligan 1970, Wu and Piao 1999, Gu et al. 2005) and have reduced strength characteristics (Suchsland 1973, Kelly 1977, Suchsland and Xu 1991). In contrast to solid wood, thickness swelling in composite materials has recoverable and non-recoverable components (Halligan 1970). The proportion of both components is determined by the panel manufacturing process and humidity level. Usually both types occur concurrently. Recoverable thickness swelling (RTS) is the natural swelling of the wood fibres due to hygroscopicity. Non-recoverable thickness swelling (NTS) in OSB is primarili attributed to the release of compressive stresses and differences between high and low density areas in the panel.

This causes differential swelling within a composite panel and often evokes stresses so great that the adhesive bonds rupture (Suchsland and Xu 1991; Wu and Piao 1999).

The modulus of elasticity in bending is a common strength predictor. Equations for MOE loss of OSB as a function of MC and NTS have been determined (Wu and Suchsland 1997). The correlation between MOE loss and MC is not as good as the correlation between MOE loss and NTS. MOE loss very reliably indicates the NTS component, but it is not very easy to investigate the proportion of NTS in construction panels. In this study predictive equations expressing MOE bending as a function of MC and total thickness swelling (TS) by simulation of real conditions in constructions were determined.

The exact knowledge of behavior of wood-based meterials under flexural load at different moisture contents improves the options to design modern materials optimized for diverse types of application and can help to expand their use in construction.

MATERIAL AND METHODS

Commercially manufactured OSB/3 – Superfinish (according to ČSN EN 300) were selected for the study. The material characteristics are presented in Tab. 1.

Tab. 1: Physical properties of OSB/3 – Superfinish

Panel characteristics	Binders
Thickness: 12 mm	Face:
Wood: Spruce (80 %). Pine (20 %)	MUF 8.5 %
Face to Core flake weight ratio: approx. 50/50	Hardening agent 2.4 %
Moisture content: Core 10.5 %. Face 5.5 %	Core:
Wax: 1.2 %	MDI 3.5 %

Tab. 2: OSB/3 – Superfinish, pressing conditions

Continual press Dieffenbacher CPS 280-38; Length: 38.5 m. Speed: 276 mm.s^{-1}		
Entry zone:	220-225 °C	3 N.mm^{-1}
	215-230 °C	1.6 N.mm^{-1}
Middle zone:	205-215 °C	1.7 N.mm^{-1}
	205-215 °C	0.8 N.mm^{-1}
Output zone:	180-200 °C	0.05 N.mm^{-1}

Rectangular specimens of the length of 20 times the nominal thickness plus 50 mm (that was 290 ± 1 mm) and a width of (50 ± 1) mm were used.

The cutting was carried out according to ČSN EN 326-1:1997, except for the number of test pieces (12 instead of 6), for both transverse and longitudinal directions from 10 panels. The samples were divided into two different groups: group 1 consisted of 120 specimens for longitudinal direction, group 2 consisted of 120 specimens for transverse direction. In each of six testing steps, one corresponding specimen from every ten panels was tested for the transverse and longitudinal directions. After twelve testing cycles the total number of specimens measured was 240.

The tests involved in this study include testing for thickness swelling (TS) and modulus of elasticity in bending (MOE).

The samples were direstly taken from the wod-processing factory (relative humidity) 65%, temperature 20^0C and were measured for initial weight, width and thickness after oven drying (103 ± 2 °C for 3 days). After conditioning wet weight, width, thickness and MOE were measured.

For absorption and desorption tests, specimens were conditioned to a constant mass in a conditioning chamber at a relative humidity (RH) of 15, 35, 50, 65, 85 and 100 % and a temperature of 20°C. Constant mass was reached when the results of two successive weighing operations, carried out at an interval of 24 h, did not differ more than 0.1 % of the mass of the test piece (except RH 100 %). Due to condensation of water the specimen's mass at RH 100 % was still increasing after two weeks conditioning (normal time for equilibrium). In the conditions of this humid environment all specimens were measured after two weeks and then again after one week. Values ovtained during second measurement were used like starting values for desorption measurement.

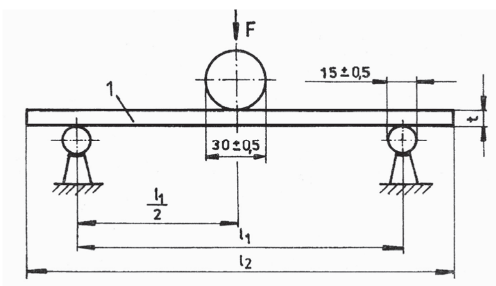
The specimens for desorption tests were saved and then tested under the same RH conditions as the absorption test.

Thickness swelling expressed in % was calculated from this equation:

$$TS = \frac{(T_C - T_0)}{T_0} * 100 \qquad (1)$$

where: T_c is the specimen thickness after conditioning (mm)
T_0 is the specimen thickness after oven drying (mm)

The MOE was evaluated at a test machine UTS 100K according to the ČSN EN 310 (1995). The bending MOE was determined by applying load to the centre of a specimen supported at two points (Fig. 1). The modulus of elasticity was calculated using the slope of the linear region of the load-deflection curve (Fig. 2). During the test the deflection of the test piece in the middle of the span (below the loading head) was measured by cross –head travel with an accuracy of 0.01 mm. The testing method used includes shear as well as bending, so the calculated value is the apparent modulus, not the true modulus.



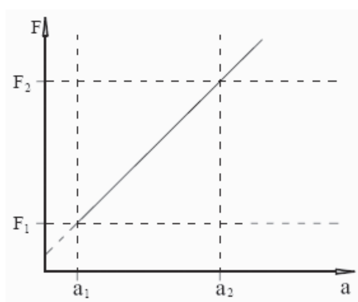


Fig.1: Arrangement of the bending apparatuses and Fig. 2: Load-deflection curve within the range of elastic deformation

The modulus of elasticity in bending was calculated using the following equation:

$$E_m = \frac{(F_2 - F_1) l_1^3}{4bt^3 (a_2 - a_1)} \tag{2}$$

where: l_1 is distance between the centers of supports (240 mm)
b is the width of the test piece (mm)
t is the thickness of the test piece (mm)
$F_2 - F_1$ is the increment of load on the straight line portion of the load-deflection curve (N); F_1 shall be approximately 10 % and F_2 shall be approximately 40 % of the maximal load
$a_2 - a_1$ is the increment of deflection at the mid-length of the test piece (mm), corresponding to load increment $F_2 - F_1$

RESULTS AND DISCUSSION

The basic descriptive statistics were computed: arithmetic mean m, standard deviation S, coefficient of variation V and the range of data expressed with the maximum and minimum value. The assumption of the measured data's normality by a Shapiro-Wilks W test was verified before computing the statistical analysis (using Statistica 8,0 CZ). The results of tests on the physical properties of the OSB/3 Superfinish are presented in Tabs. 3 to 5 and Figs. 3 and 4.

Tab. 3: Moisture content of OSB for six different humidity degrees

Statistic value	Absorption						Desorption					
	15%	35%	50%	65%	85%	100%	100%	85%	65%	50%	35%	15%
m (%)	2.58	4.88	6.39	8.43	12.80	19.61	22.28	17.14	12.56	10.05	7.75	4.83
S	0.22	0.22	0.24	0.22	0.37	1.32	0.88	0.35	0.24	0.29	0.27	0.25
V (%)	8.34	4.52	3.70	2.62	2.91	6.75	3.95	2.06	1.95	2.91	3.50	5.27
Max	2.83	5.16	6.74	8.70	13.27	22.24	23.55	17.54	12.94	10.88	8.07	5.18
Min	2.20	4.55	6.02	8.06	11.88	17.74	20.73	16.52	12.19	9.53	6.99	4.35

n=20

Fig. 3 shows typical sorption isotherms for OSB/3 - Superfinish. Especially at lower RH levels, OSB showed lover equilibrium moisture content (EMC) values compared to wood, for both absorption and desorption. This is interpreted due to the higher press temperature which reduces the hygroscopicity of wood particles (Zylkowski, 2002; Paul et. al., 2005) and the wax content, used to protect the board against moisture absorption in OSB designed as exterior sheathing (Sun et al. 1994, Sedliačik 1998).

Tab. 4 shows the lower density of specimens after treatment. The OSB is a material composed of large flakes and in contrast to other particleboards contains macro-voids in a math structure (Kamke and Brooks 2004, Wu et al. 2004). After applying elevated moisture the presence of macro-voids further increases.

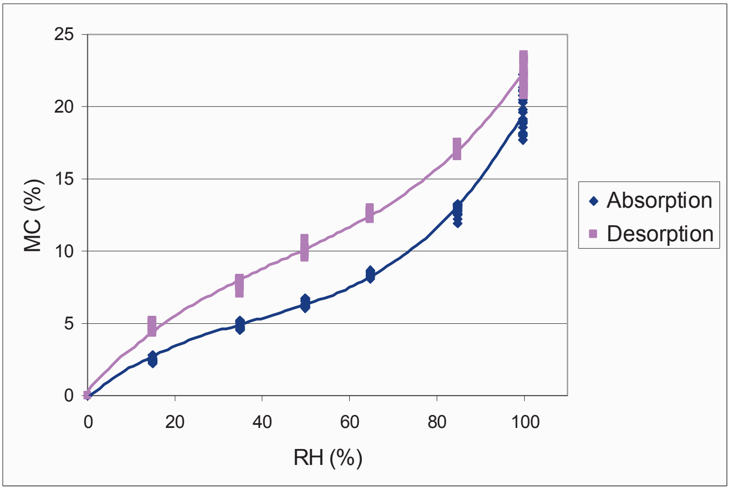


Fig. 3: Sorption and desorption curves of OSB for 20 °C

Tab. 4: Density of OSB for six different humidity degrees

Statistic value	Absorption					
	15%	35%	50%	65%	85%	100%
m ($kg.m^{-3}$)	576.79	592.13	593.07	593.05	592.99	582.12
S	13.53	17.28	18.44	20.17	22.09	16.64
V (%)	2.34	2.92	3.11	3.40	3.72	2.86
Max	610.90	622.64	624.12	627.72	640.61	622.55
Min	553.29	560.12	550.68	556.54	559.06	546.74
	Desorption					
	100%	85%	65%	50%	35%	15%
m ($kg.m^{-3}$)	576.66	565.91	563.16	557.28	552.09	550.27
S	26.80	17.85	24.18	23.63	19.28	19.99
V (%)	4.65	3.15	4.29	4.24	3.49	3.63
Max	632.79	597.78	604.83	604.22	582.70	590.75
Min	509.87	533.88	517.64	515.21	519.13	515.04

n=20

Tab. 5: Thickness swelling of OSB for six different humidity degrees

Statistic value	Absorption					
	15%	35%	50%	65%	85%	100%
m (%)	0.68	1.65	2.41	4.06	8.37	16.07
S	0.23	0.36	0.42	0.42	0.86	1.91
V (%)	33.16	21.75	17.44	10.36	10.23	11.91
Max	1.10	2.13	3.42	4.83	10.98	20.03
Min	0.26	0.59	1.88	3.14	6.83	13.12
	Desorption					
	100%	85%	65%	50%	35%	15%
m (%)	19.78	17.21	13.57	12.44	10.88	8.55
S	1.51	1.90	1.36	1.24	1.55	1.53
V (%)	7.64	11.06	10.01	10.00	14.26	17.95
Max	22.89	21.75	15.70	15.29	13.60	12.18
Min	17.15	13.64	10.78	10.41	7.67	6.77

n=20

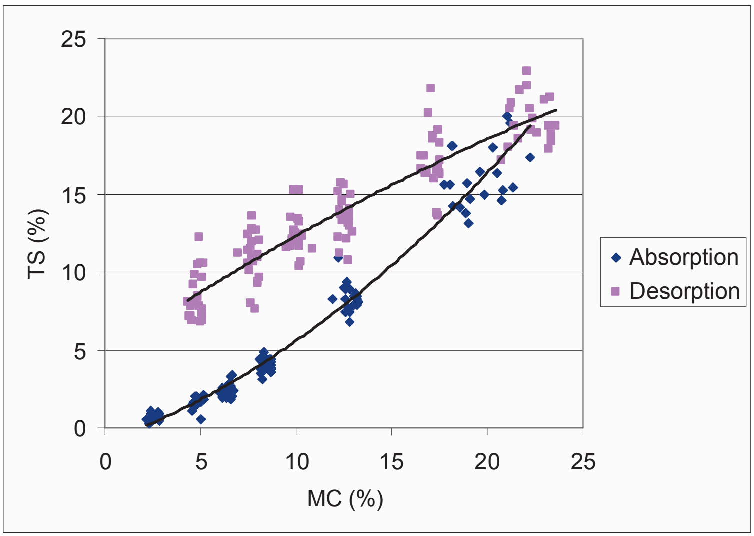


Fig. 4: Thickness swelling as a function of moisture content

As it can be seen from Tab. 5 and Fig. 4, TS does not increase linearly in accordance with increasing MC. In an elevated moisture environment TS increased quickly. This behavior corresponds with earlier results on OSB (Wu and Piao 1999), but specimens from OSB/3 Superfinish made with highly water resistant MUF and MDI adhesives have lower values of total thickness swelling than the panels made with phenol-formaldehyde adhesives (Paul et al.

2005) In the highest humidity the specimens were practically saturated and reached roughly 22 % EMC. The corresponding mean of TS was 20 %. The portion of NTS was about 8 % after treatment.

The polynomial function was determined to estimate the TS of OSB/3 Superfinish:

$$TS = 0.0214MC^2 + 0.4355MC - 0.9047 \quad (3)$$

This equation fitted the data well with a coefficient of determination $R^2 = 0.97$.

In constructions OSBs are mainly exposed by flexural stresses in the parallel direction. For this purpose, MOE values in the parallel direction were analyzed in detail. The basic MOE values in the parallel direction are given in Tab. 6.

Tab. 6: Basic values of MOE in the parallel direction

Statistic value	Absorption					
	15%	35%	50%	65%	85%	100%
m (MPa)	5550	5880	5710	5500	4910	3510
S	416	497	417	721	864	539
V (%)	7,50	8,45	7,31	13,12	17,58	15,37
Max	6090	6820	6500	6520	6120	4480
Min	5040	5290	5100	4200	3590	2890
	Desorption					
	100%	85%	65%	50%	35%	15%
m (MPa)	3270	3710	3910	4180	4370	4350
S	401	302	274	672	710	606
V (%)	12,27	8,14	7,01	16,09	16,25	13,91
Max	3880	4080	4330	5510	5940	5380
Min	2550	3210	3430	3310	3590	3450

n=10

A decreasing trend for MOE was evident with an increase in moisture content. The highest mean MOE (5 880 MPa) was shown by the group of samples at 35% RH. The minimum mean MOE was 3 270 MPa for 100% RH. This minimum represents 56 % of the maximum mean MOE. Desorption values are naturally lower and do not reach the previous strength values. The mean MOE of 35% RH for desorption was 4 370 MPa which is 74 % of the maximum mean MOE.

To determine significant differences between means in different groups of conditioned samples the analysis of variance (ANOVA-$F(5,54) = 21.650$, $p = 0.00000$) and multiple comparison test (Tukey HSD test) were used. The Tukey HSD test results for parallel MOE values in different groups are given in Tabs. 7 and 8.

Tab. 7: Tukey HSD test parallel direction, absorption

Cell No.	Tukey HSD test; variable Modulus of elasticity; Approximate Probabilities for Post Hoc Tests Error: Between MS = 3585E2. df = 54.000						
	Relative Humidity	1 5551.4	2 5883.6	3 5708.2	4 5496.1	5 4914.7	6 3507.0
1	15%		0.815114	0.991661	0.999950	0.182510	**0.000138**
2	35%	0.815114		0.986060	0.698549	**0.008279**	**0.000138**
3	50%	0.991661	0.986060		0.967768	**0.049012**	**0.000138**
4	65%	0.999950	0.698549	0.967768		0.268163	**0.000138**
5	85%	0.182510	**0.008279**	**0.049012**	0.268163		**0.000168**
6	100%	**0.000138**	**0.000138**	**0.000138**	**0.000138**	**0.000168**	

The significant differences (at p=0.05) are bold typed

Tab. 8: ANOVA – MOE parallel direction, desorption

Cell No.	Tukey HSD test; variable Modulus of elasticity; Approximate Probabilities for Post Hoc Tests Error: Between MS = 2749E2. df = 54.000						
	Relative Humidity	1 4354.8	2 4366.6	3 4178.2	4 3908.8	5 3707.5	6 3271.3
1	15%		1.000000	0.974078	0.412438	0.080056	**0.000463**
2	35%	1.000000		0.965736	0.383043	0.071128	**0.000405**
3	50%	0.974078	0.965736		0.858678	0.352063	**0.003946**
4	65%	0.412438	0.383043	0.858678		0.954670	0.088069
5	85%	0.080056	0.071128	0.352063	0.954670		0.437252
6	100%	**0.000463**	**0.000405**	**0.003946**	0.088069	0.437252	

The significant differences (at p=0.05) between groups are bold typed

The tendency for MOE is to decrease as MC increases. Nevertheless,there were no detectid statistically significant differences between groups from 15% to 65% RH. The significant decrease of MOE can be seen from 85% RH. The comparison test demonstrates a significant difference between MOE values for groups of specimens in 100% RH and all other groups for absorption. Thus, the high RH environment has a marked effect on the MOE.

The trend detected is similar in the perpendicular direction. The parallel strength values of OSB are higher than the perpendicular values due to the orientation of strands in face layers. For illustration, Fig. 5 shows the differences for both directions of boards.

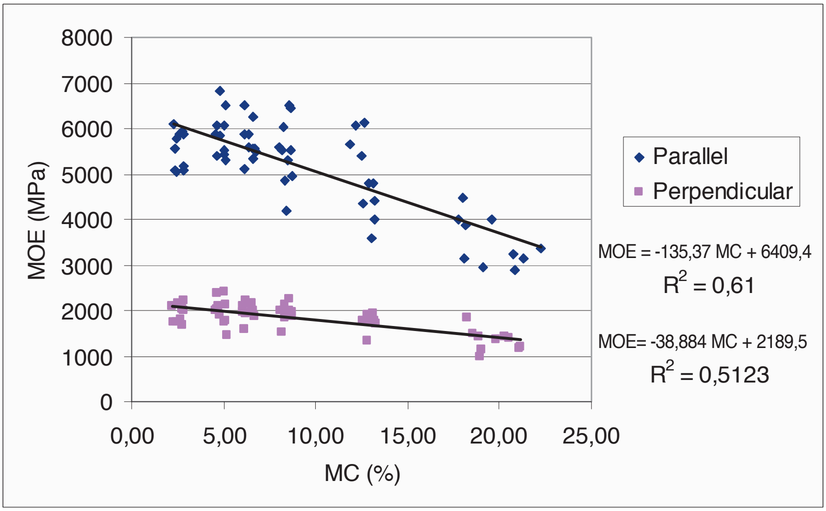


Fig. 5: MOE as a function of moisture content – absorption

This calculated regression is only valid for absorption. The regression for both values of absorption and desorption is given in Fig. 6.

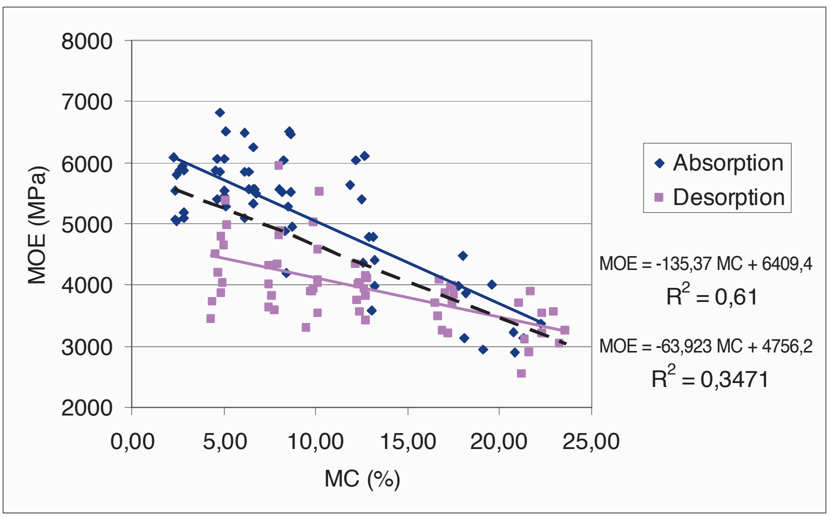


Fig. 6: MOE in the parallel direction as a function of moisture content

From this figure the differences between the linear regression trend for sorption and desorption are evident. The dashed line shows the linear regression fit of all data. The regression equation for absorption and desorption is the following:

$$MOE = -119.13\ MC + 5850.8 \quad (4)$$

$R^2 = 0.4828$

If calculated values include both values of absorption and desorption, then the described dependence of the MC is lower. The only significant difference is whether samples reached high humidity conditions or not.

The regression for both values of absorption and desorption MOE as a function of TS is given in Fig. 7.

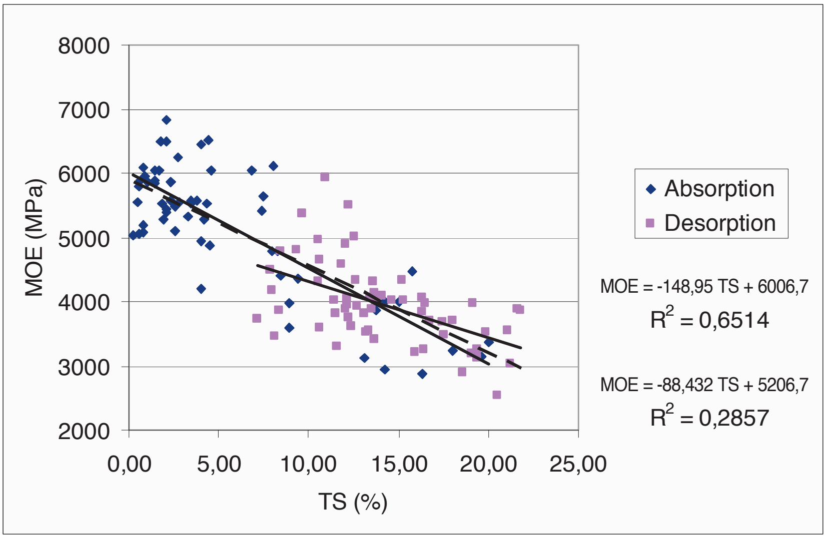


Fig. 7: MOE in the parallel direction as a function of thickness swelling

The dashed line shows the linear regression fit of all data. The regression equation for absorption and desorption is more uniform. The regression equation including all data is the following:

$$MOE = -135.09\ TS + 5895.8 \quad (5)$$

$R^2 = 0.6851$

TS has a higher influence to its values of strength than humidity has and this equation fitted the data with a higher coefficient of determination.

A multiple linear regression equation was performed to predict MOE bending using MC and TS as independent variables. Beta coefficients were used to evaluate the relative contribution of each predictor to the overall prediction of the dependent variable (Beta standardizes variables to a mean of 0 and a standard deviation of 1).

$$MOE = 5865.721 - 144.136\ TS + 11.056\ MC \quad (6)$$

$R^2 = 0.6861$

$Beta_{TS} = 0.883126$

$Beta_{MC} = 0.064480$

The Beta coefficient showed the very small contribution of MC to the predicted model.

CONCLUSION

Loss of strength characteristics and dimensional stability caused by thickness swelling affect the use of OSB for exacting exterior applications. As expected MOE values are permanently lowered due to the rupturing of the adhesive bonds between wood strands after treatment at a high RH. The high humidity environment has a consequential effect on the MOE bending of OSB and because of this it is very important to use OSB/3 board in strict accordance with the service classes (ČSN EN 1995-1-1) and to avoid creating a high relative humidity (> 85% RH) in constructions.

This study has shown the possibility of evaluating the MOE of OSB in dependence on TS and MC. Increases in the treatment MC led to increased TS and MOE losses. The elaborated model confirms more emphatic MOE losses in dependence on TS rather than on MC. However, the samples' variability has an effect on the accuracy of this model fit. Because the MOE of OSB is mainly influenced by strand alignment in the face layer exposed to tension, analysis of other factors (strand geometry and alignment in face layers and the adhesive used for the panel) need to be done to obtain a more accurate equation.

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