Possibility of Using Accelerated Aging Tests to Assess the Performance of OSBs Exposed to Environmental Conditions

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This study evaluates the impact of the number of cycles of the V313 test (EN 321 2002) on the mechanical properties of 15-mm-thick OSB/3 and OSB/4. The obtained results were compared with the properties of the boards exposed to external environmental conditions. The results of the study indicate that the tested boards were characterized with a 50% decrease in static bending strength and a 70% decrease in tensile strength perpendicular to the plane. However, both types of boards met the requirements of the standard (EN 300 2006) with respect to their modulus of rupture. The method of exposing boards to outdoor conditions has a substantial influence on the change of the physico-mechanical properties of OSBs. In the boards used in this study, however, those changes occurred slower than those evoked by the V313 test, especially after an upright exposure. For these reasons, for that type of board storage, an equation was determined that can bring the property changes following the V313 test into an acceptable range to allow for the evaluation of the board properties. In the case of vertical exposure, from the second year forward, changes in the properties of the OSB/3 were similar to those presented by the boards demonstrated from the second cycle of the V313 test.

Keywords: OSB; Humid conditions; Dimensional stability; EN 321; Flakes; Chips

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INTRODUCTION

Despite the fact that OSB has been produced for over 40 years, it is still technologically a rather new product that requires refinement of its production process. Such technological elements as chip geometry (Barnes 2001; Chen *et al.* 2008), application of small chips or fine fractions (Fakhri *et al.* 2006a, b; Han *et al.* 2006, 2007; Mirski and Dziurka 2011a,b), and application of chips other than pine chips (Cheng *et al.* 2012; Hermawan *et al.* 2007; Sumardi *et al.* 2007) have been quite thoroughly studied. Both chip geometry and the type of wood from which they originate have a significant impact on the board density. The increase in the density or dimensions of the chips results in an increase of the density of the boards produced from these chips (Kruse *et al.* 2000; Steiner and Xu 1995). Both of these factors considerably influence the formation of the board's mechanical properties (Hrázský and Král 2009; Wong *et al.* 1999). Fakhir *et al.* (2006a,b) demonstrated that the size of the chips used during production influences not only the physico-mechanical properties of the boards, but also the air permeability through those boards, which substantially affects their application as sheathing material. The basic binding agents used for OSB production are phenol-formaldehyde resins (PF) (Gündüz *et al.* 2011; Han *et al.* 2005; Sellers 2001), isocyanate resins (polymeric methylene diphenyl diisocyanate - pMDI) (Brochmann *et al.* 2004; Smith 2005), and 4-component resin melamine-urea-phenol-formaldehyde (MUPF) in Poland. These resins guarantee a high water resistance, which means a high durability of the board during exploitation. Because boards of this type are mainly used as sheathing and structural material for construction, they are on numerous occasions exposed to water for long periods of time. Producers of OSB for applications in humid conditions must prove the compliance of the properties of their boards with one of the two methods of assessing their water resistance. Usually, because of the celerity of the testing procedure, producers provide the information on internal bond strength after the cooking test (V100). The second of the two methods, also called the test of accelerated aging or the V313 test, is rarely used, as it lasts for about 35 days. It generally applies only to internal laboratory tests, and the results are usually not presented in the certificate of properties of a given lot.

Laboratory accelerated aging tests are commonly used for assessing the properties of materials or products during their utilization on the basis of a short-term impact of especially selected environmental factors. They should closely imitate the real application conditions or allow for a reliable correlation of the imposed conditions with time-determined influence of real conditions. Employing factors with parameters unusual for product application, such as water at boiling temperature, aims at shortening the time of testing procedures during accelerated aging tests. The majority of accelerated aging tests are designed so that there is a close relation between a cycle or a few cycles and the product’s lifespan in the given conditions, usually expressed in years. To determine the properties of a given material in an X number of years, one should carry out a specific number of cycles for a given test.

The aim of this study was to determine the properties of OSB/3 and OSB/4 exposed to a few cycles of the V313 test as well as to determine their relation to the properties of boards exposed to environmental conditions.

EXPERIMENTAL

Industrially produced 15-mm-thick OSB/3 and OSB/4 were used for the study. In the core, they were bonded with isocyanate bonding agent (pMDI), while the external layers were resinated using melamine-urea-phenol-formaldehyde resin (MUPF). Their properties are shown in Table 1.

Table 1. Properties of Resins Used for OSB Boards Manufacture

Property	MUPF	pMDI
Color	Yellow-brown	Brown
Density, g/cm^3	1.29 – 1.30	1.20
Viscosity, cP	280 – 350	250 – 400 (25°C)
pH	8.7 – 9.5	6 – 9
Solids content, %	64.5 – 65.0	100
Gel time, s	85 – 90	–
NCO content, %	–	29 – 32

Table 2 presents the original physico-mechanical properties of the boards used for testing. In order to evaluate the mean value of each OSBs property following quantity of samples were tested:

- 15 in case of the swelling in thickness (TS) and internal bond (IB) – 50 × 50 mm,
- 12 (for each direction) in case of modulus of rupture (MOR) and modulus of elasticity (MOE) – 350 × 50 mm.

The evaluation of their water resistance was carried out following EN 321 (2002), which recommends three cycles of soaking, freezing, and drying at a higher temperature. According to the standard, one cycle involves the following:

- soaking samples in water at 20 ± 1 °C for 70 ± 1 h,
- freezing at -12 °C to -25 °C (applied temperature -20 °C) for 24 ± 1 h,
- drying at 70 °C ± 2°C for 70 ± 1 h,
- cooling at 20 ± 1°C for 4 ± 0.5 h.

Cyclic tests involve three subsequent cycles, during which the changes affect a narrow rim on which the samples are placed during the subsequent cycle. EN 321 (2002) assumes that following the cyclic test, it will be possible to determine the thickness swelling for a given material in accordance with EN 317 (1993), as well as its internal bond strength, in accordance with EN 319 (1993) or modulus of rupture only for longer axis in accordance with EN 310 (1993). For the purpose of this study, the boards undergoing the test were exposed to 6 cycles, where an evaluation of their mechanical properties and changes in thickness took place following each cycle.

Table 2. Properties of OSBs

Property	Testing method	Unit	Numerical value				
			Type of board				
			OSB/4 - 2002		OSB/3	2002	2009
ρ	EN 323	kg/m^3	-*	670**	-*	635**	625**
TS	EN 317	%	*12*	8.7	*15*	8.8	9.7
MOR II	EN 310	N/mm^2	*28*	35.1	*20*	34.6	34.4
MOR ⊥	EN 310	N/mm^2	*15*	23.1	*10*	23.7	24.3
MOE II	EN 310	N/mm^2	*4800*	5950	*3500*	5840	5860
MOE ⊥	EN 310	N/mm^2	*1900*	3540	*1400*	3430	3510
IB	EN 319	N/mm^2	*0.45*	0.84	*0.32*	0.65	0.64
V100	EN 1087-1	N/mm^2	*0.15*	0.15	*0.13*	0.18	0.12

* - value indicated by the standard: EN 300 (2006), ** - mean value

In addition to the average value of each property, their relative change in relation to the property of the control board was also calculated,

$$\delta_x = \frac{|X_0 - X_c|}{X_0} \cdot 100\% \tag{1}$$

where X_0 is the average value of a specific parameter for a control sample (Table 2) and X_c the average value of a specific parameter for a given cycle.

The results obtained for the boards tested were compared with the results of field tests. Boards for those tests were prepared so that samples measuring ≈ 500 x 1250 mm with secured narrow rims were placed on the props under two situations (Fig. 1):

1. Under the shelter:
    - with one face exposed (marked as A); period of exposure 10 years (tests were completed)
    - with two faces exposed (marked as B); period of exposure 3 years (study in progress)
2. Without the shelter (marked as C); period of exposure 3 years (study in progress)

Samples in tests marked A and B were placed perpendicularly, while those in test C were placed at a 30° angle. Placing the boards at such a small angle aimed at reducing the speed at which water would flow down and to some extent keep the snow on the surface of the board in the winter.

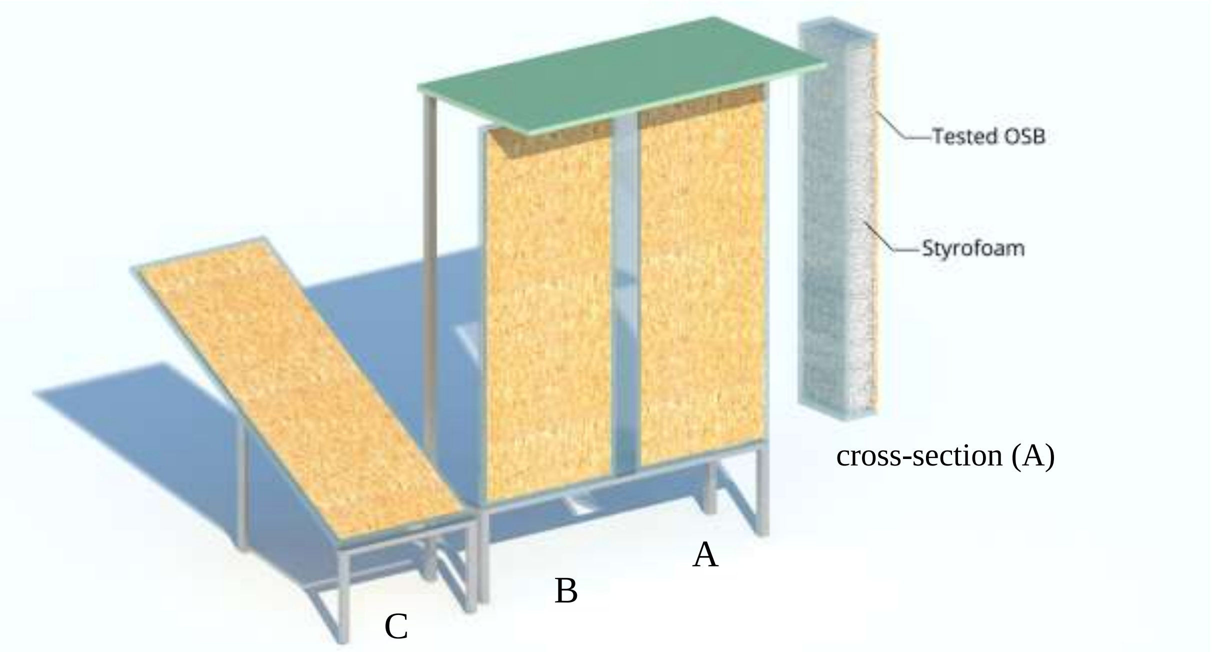

Fig. 1. The placement of tested boards (explanation in text)

To determine the correlation between the cycles of the test and the period of outdoor exposure for the test marked A, linear regression analysis was carried out between the accelerated aging agent and the outdoor exposure of the boards:

$$y = ax + b \tag{2}$$

However, because at most 7 points are considered when determining the correlation, the situation was considered satisfactory when $R^2 \geq 0.9$ and the value of coefficient b was between -5% and 5%. Additionally, it was assumed that for the modulus of rupture and elasticity modulus, it would be sufficient when established requirements were met by just one axis.

RESULTS AND DISCUSSION

Physico-mechanical properties of the tested OSB determined for 6 cycles of the V313 test are presented in Figs. 2 through 7. As can be concluded from the data presented in Fig. 2 that the modulus of rupture of the boards determined for their longer axis, following the first cycle of the V313 test, met the requirements of EN 300 (2006) in that respect, and the values obtained, especially in the case of OSB/3, significantly exceeded the expected value.

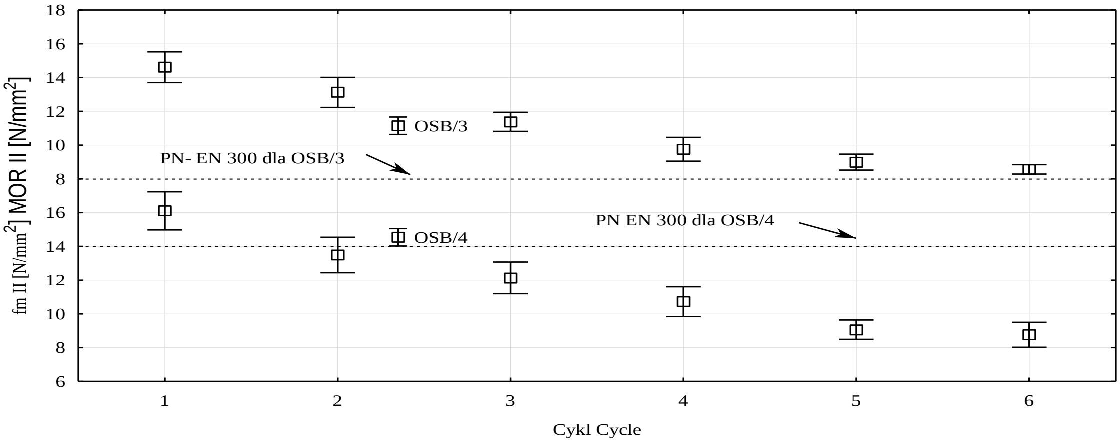

Fig. 2. Impact of the number of cycles on MOR determined for the longer axis of OSB/3 and OSB/4

For OSB/3, the determined modulus of rupture was over 6.5 N/mm^2 higher, and for OSB/4 it was 2.1 N/mm^2 higher, than the requirements of the above-quoted standard. Assuming, however, that the acceptable decrease in the static bending strength of the boards expressed in percentage terms would stay at 60% and 50% for OSB/3 and OSB/4, respectively, only OSB/3 would meet that criterion. In the case of OSB/3, the drop in modulus of rupture amounted to 57.8%, while for OSB/4 it is 54.6%. Therefore, a high static bending strength of the sample boards confirmed following the first cycle of the V 313 test was probably the result of the fact that the boards had a very high initial static bending strength, which for OSB/3 was approximately 170% higher than the level of strength recommended by EN 300 (2006).

Despite the fact that EN 300 (2006) does not require it, changes in the modulus of rupture for the shorter axis were also determined (Fig. 3). The absence of this determination might be the result of the fact that one of the features of the oriented boards is their orientation ratio (Eq. 3), assumed in the quoted standard at level 2. This means that the static bending strength for a shorter axis is 50% lower and the degradation proceeds evenly in both directions,

$$U = MOR_{\parallel} \cdot MOR_{\perp}^{-1} \tag{3}$$

where MOR$_{\parallel}$ is the modulus of rupture for the longer axis and MOR$_{\perp}$ the modulus of rupture for the shorter axis.

However, in the case of the boards under analysis, the orientation ratios were 1.42 and 1.53 for OSB/3 and OSB/4, respectively. Therefore, for the tested boards, the shorter axis had a higher strength than the longer axis when compared with standard requirements; moreover, for OSB/3, that correlation was even more favourable. The observed decrease in the strength of OSB/4's shorter axis amounted to approximately 49%, and for OSB/3, similar to the situation with the longer axis, it slightly exceeded 57%. Therefore, OSB/3, with a lower orientation ratio, was characterized by a similar decrease in the modulus of rupture for both axes.

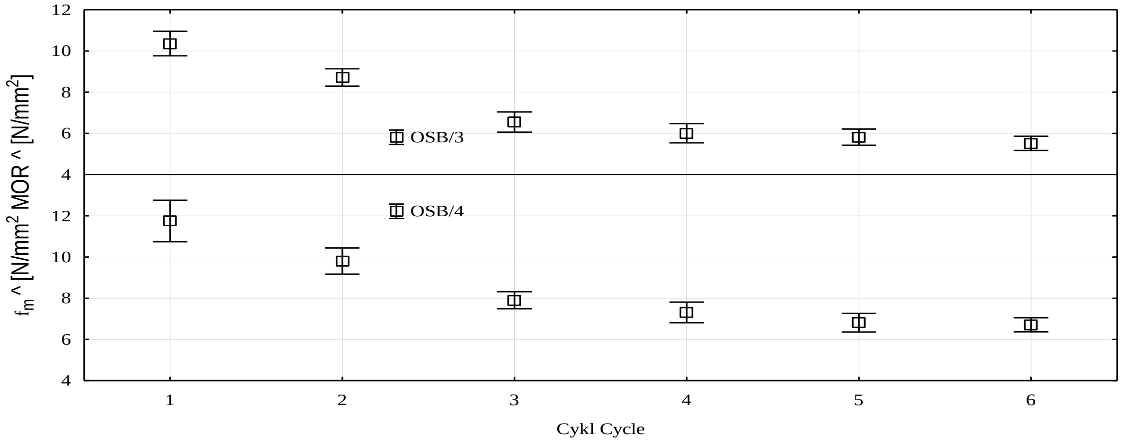

Fig. 3. Impact of the number of cycles on MOR determined for shorter axis of OSB/3 and OSB/4

The second important parameter for assessing board properties is the modulus of elasticity. As can be concluded from Figs. 4 and 5, regardless of the means of evaluating that property, OSB/4 showed a slightly smaller decrease. In the case of OSB/4, the decrease of the values of these properties, observed after the first cycle, were between 61.4% and 63.3%, respectively, for the longer and shorter axis. For OSB/3 the decrease was between 66% and 68.3%. Therefore, no impact of the direction of assessing the behaviour of the elasticity modulus was found for either type of board was found.

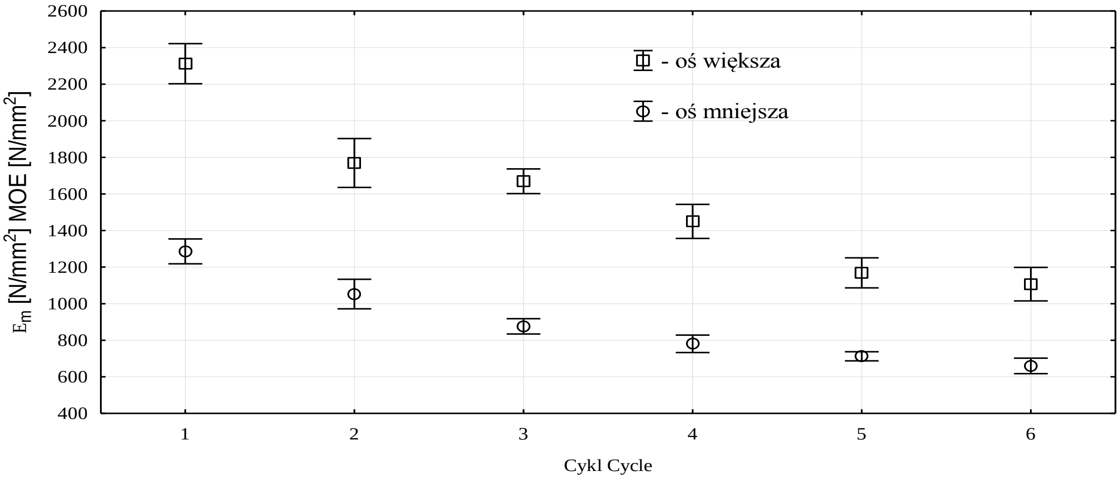

Fig. 4. Impact of the number of cycles of the V313 test on the elasticity modulus of OSB/4

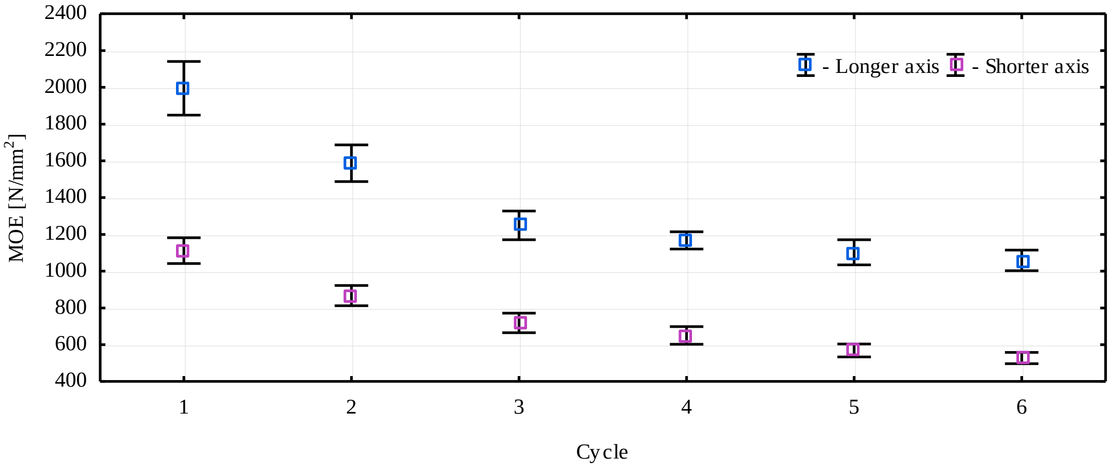

Fig. 5. Impact of the number of cycles of the V313 test on the elasticity modulus of OSB/3

The most profound decrease in the strength following the first cycle of accelerated aging test was revealed in the case of the tensile strength perpendicular to the planes (Fig. 6). Thus, a relative change in the tensile strength perpendicular to the OSB/3 plane exceeded 75%, and in the case of OSB/4, it reached almost 78%. Such a substantial decrease suggests intensive damage or degeneration of the bonds between the wood and the adhesive agent, degeneration of the wood itself, or degeneration of the resin. However, both boards met the requirements of EN 300 (2006) in that respect. The strength following the first cycle of the V313 test using OSB/3 was 0.16 N/mm^2, and that of OSB/4 was 0.19 N/mm^2 (Fig. 6). Therefore, in the first case it was 0.01 N/mm^2 higher, and in the second case 0.02 N/mm^2 higher, than recommended by the quoted standard.

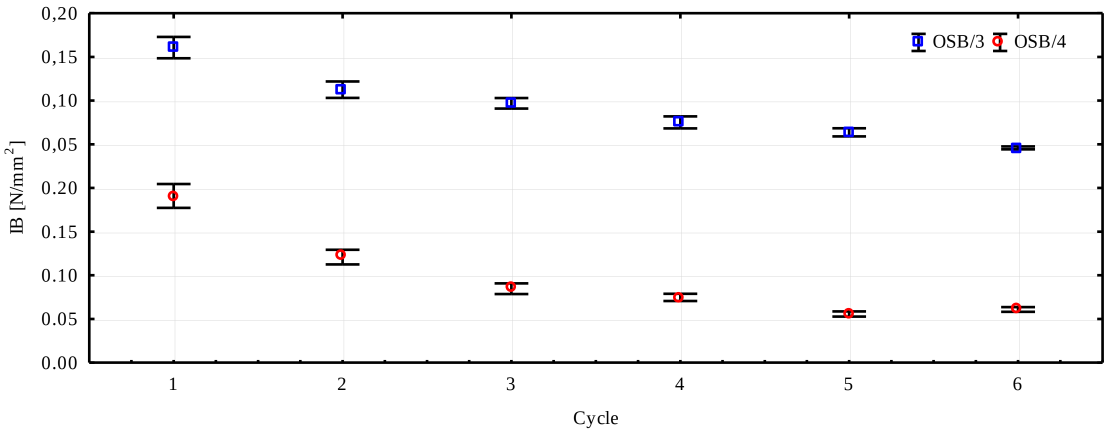

Fig. 6. Impact of the number of cycles of the V313 test on tensile strength perpendicular to the planes of OSB/3 and OSB/4

EN 321 (2002) recommends the assessment of board swelling following 24 h of soaking in water; however, there are no references used in relation to that property in EN 300 (2006). Therefore, it should be assumed that the swelling of the boards to be tested by V313 should not be higher than values recommended for boards assigned for general commercial sales. As is stipulated by the data presented in Fig. 7, the changes in board swelling following the first cycle of the study were rather insignificant, and the boards still met the requirements of the standard in that respect. For the subsequent cycles of the V313 test, no significant impact of the test factors on the value of board swelling, as the result of 24 h of soaking, can be stated.

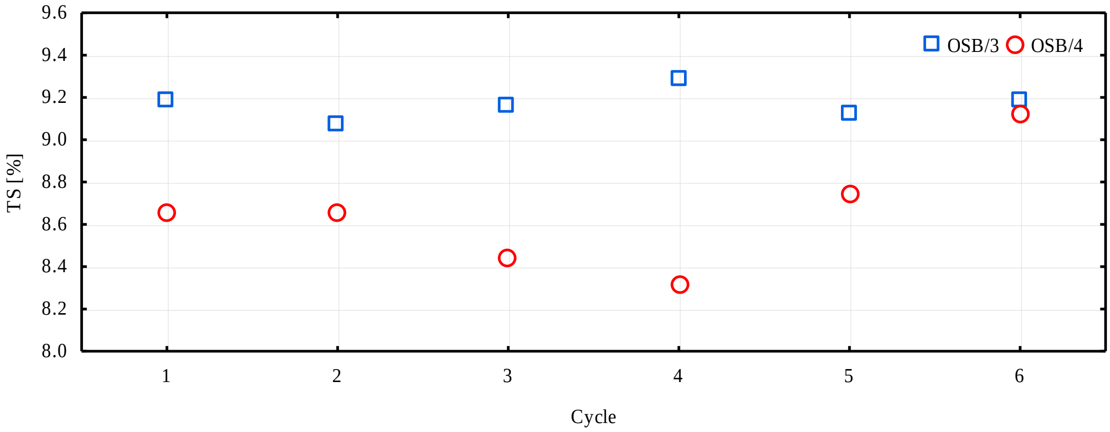

Fig. 7. Impact of the number of cycles of the V313 test on the swelling of OSB/3 and OSB/4 after 24 h of soaking in water

The results obtained for the subsequent cycles, regardless of the class of board, range within a level close to the initial values, and the change in the average values was statistically insignificant.

Changes in the swelling also did not correspond with the permanent changes in the boards' thickness (Fig. 8). In such a case for the subsequent cycles of the V313 test, a significant increase in the board's thickness was observed. After 6 cycles, a permanent increase in the thickness of OSB/4 reached over 28%, and that of OSB/3 reached almost 35%. However, following the first cycle, the increase in thickness for both types of boards was similar. Measurement of swelling following the accelerated aging test can be considered insignificant and provides little information on the real physical state of the tested board. Such behaviour of the boards was also observed in a previous study concerning the evaluation of static bending strength of OSBs exposed to the accelerated aging test in accordance with the recommendations of the standard for the cooking test (Mirski and Derkowski 2011). Despite the very significant changes in the mechanical properties of the boards, no profound changes in their swelling were noted.

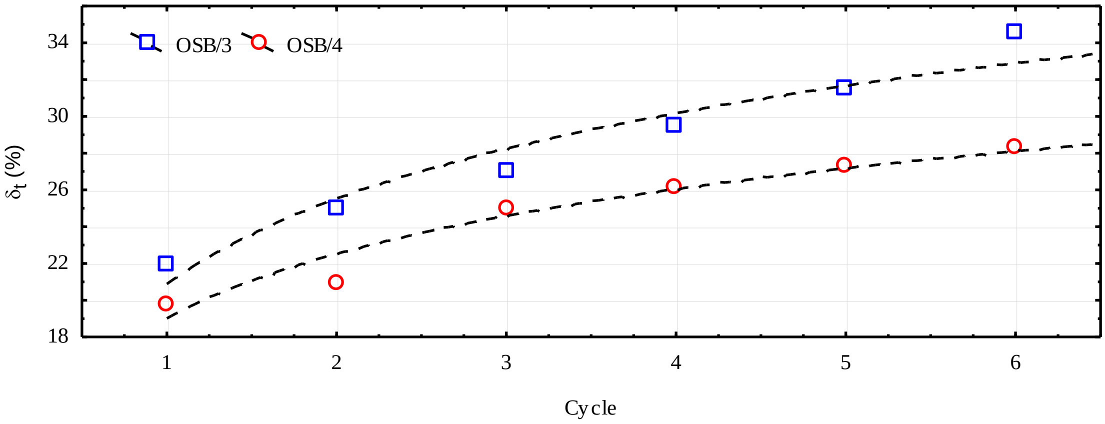

Fig. 8. Relative change in the thickness of OSB/3 and OSB/4 for subsequent cycles of the V313 test

Kojima and Suzuki (Kojima *et al*. 2009; Kojima and Suzuki 2011) presented properties of industrial OSB exposed to the accelerated aging test following a few cycles of that test. The studies were carried out using two types of OSB board, namely 11.8-mm-thick board produced from pine flakes and 12.4-mm-thick board produced from poplar flakes. Both boards were bonded using PF resin. The board produced from pine flakes can be characterized with initial physic-mechanical properties very similar to that of the OSB/3 used for this study. However, differences appeared following accelerated aging tests. The decreases in static bending strength determined for a longer axis following three cycles of the V313 was 42% for the pine board, whereas for the OSB/3 and OSB/4 tested in this study, it amounted to 67.1% and 65.8%, respectively. Hence, the board produced from pine flakes (Kojima *et al*. 2009; Kojima and Suzuki 2011) is characterized by a better bending strength than the OSB/3 and OSB/4 assessed in this study. The drop in elasticity modulus for the boards under analysis ranges from 55% to 72%, respectively, for boards produced from pine flakes and poplar flakes, in comparison with 78.7% and 72.2% for domestic OSB/3 and OSB/4. The similarities between the values obtained by the board produced from poplar wood and the boards tested in this study are most likely the result of the wood itself. The lower durability of poplar wood could not be improved, even with an excellent resin such as PF. PF is the only resin that provides a fully water-resistant binding. The advantages of using a phenol-based resin for the boards for applications in humid conditions are also confirmed by their high tensile strength perpendicular to the planes. Kojima and Suzuki (2011) concluded that the drop in the strength of pine board is 48%, 63%, and 67%, respectively, following one, two, and three cycles of the V313 test. The drop in the strength of OSB/3 amounts to 75.8%, 85%, and 93%, respectively, for the same cycles. Apart from that, no additional significant differences between the values concerning tensile strength perpendicular to the planes for OSB/3 and OSB/4 (Fig. 6) were found. Therefore, boards bonded with MUPF/pMDI were characterized to have over a 20% larger decrease in strength than the boards bonded using PF. Such results were the consequence of not only significantly lower water resistance of MUPF resin, but also the fact that boards bonded with pMDI show a more dramatic decrease in strength following accelerated aging tests, in relation to the their initial tensile strength, than boards bonded using a PF binding agent (Batubenga 1995; Milota and Wilson 1985).

On the basis of the previously presented data, the widest range of changes was noted for the first cycle of the V313 test. The decrease in mechanical properties of the boards amounts to approximately 65%. For the boards exposed to outdoor conditions in the first year of their exposure, no significant changes were found (Table 3, Fig. 9).

Table 3. The Influence of the Conditions and the Duration of Storage on the Mechanical Properties of OSB/3

Property	Conditions δ_x (%)								
	A			B			C		
	Time (year)								
	2	4	6	1	2	3	1	2	3
MOR ⊥	21.0* (11.4)**	32.3 (9.1)	57.6 (12.1)	21.2 (7.4)	29.2 (13)	41.6 (9.9)	32.7 (9.5)	62.3 (6.9)	73.8 (18.9)
MOE II	8.0 (8.9)	13.6 (6.4)	32.0 (9.3)	22.5 (6.8)	40.4 (12)	59.5 (7.2)	36.3 (5.6)	59.6 (8.3)	74.3 (19.1)
MOE ⊥	11.4 (5.9)	16.2 (9.6)	51.1 (8.8)	31.3 (7.5)	38.6 (9)	54.6 (7.3)	36.6 (5.9)	66.6 (8.2)	80.1 (11.2)
IB	16.6 (9.9)	26.1 (7.0)	46.7 (12.9)	28.9 (11.2)	36.5 (13.6)	48.2 (17.2)	34.2 (11.3)	61.1 (18.2)	82.3 (17.9)

* - mean value, ** - coefficient of variation

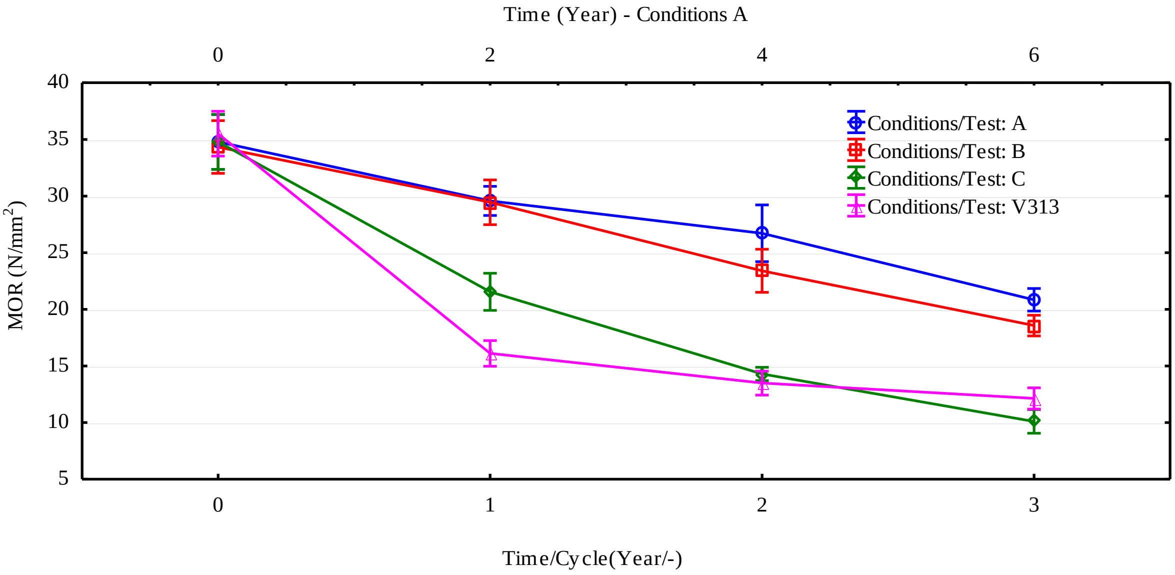

Fig. 9. MOR for boards exposed to outdoor conditions and the V313 test

In the case of the boards kept under the shelter even after the period of two to three years, the changes were dramatically lower compared to the first cycle of the V313 test. Furthermore, the boards with just one face exposed to the outdoor conditions lost their original mechanical properties twice as slowly. A steep decrease in the mechanical properties of OSB following the first cycle prevents an easy determination of correlations between the conditions of the V313 test and the field conditions. When the boards were placed under the shelter, high values of R^2 were obtained only following taking the logarithm of the relative change in physic-mechanical property of the board and multiplying it by the number of cycles (4) (Fig. 10),

$$\delta_x' = \log_{10}(\delta_x)\cdot C \tag{4}$$

where δ_x' is the relative change in mechanical properties of the boards for a given cycle of the V313 test. Excluding a V100 test, where the value of R^2 was high but lower than the assumed value, the remaining properties met the initial assumptions.

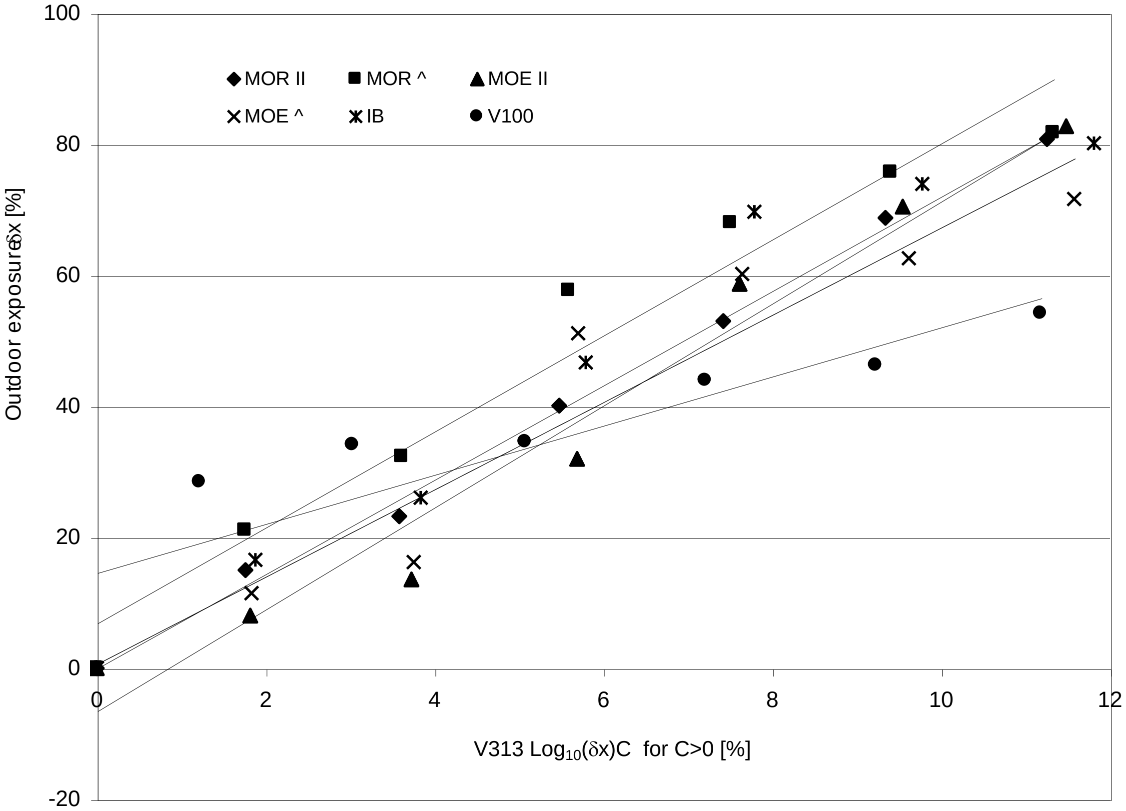

Fig. 10. Correlation between the cycle of the V313 test and an outdoor exposure (condition A) - The regression equations: MOR II y = 7,1957x + 0,1735, R^2 = 0,9972; MOR ⊥ y = 7,3262x + 7,0044, R^2 = 0,956; MOE II y = 7,8043x - 6,481, R^2 = 0,952; MOE ⊥ y = 6,662x + 0,837, R^2 = 0,9273; IB y = 6,662x + 0,837, R^2 = 0,927; V100 y = 3,7459x + 14,704, R^2 = 0,7906

Recalculating IB data for OSB (pine) included in the study by Kojima and Suzuki (2011) according to equations 2 and 4, an equally high level of adjustment (R^2 = 0.9531) between the results of the V313 test and the outdoor conditions was obtained, and the value of parameter b only slightly deviated from the assumed range (y = 8,1898x + 7,9765). Therefore, it may be assumed that the applied method allows for a prediction of the behaviour of the boards used outdoors based on the V313 test only in the situation of moderate conditions of use; for example, unprotected by the elevation elements of building, sheathing, or covering the holes in joinery (type A) or fencing (Kojima and Suzuki 2011). OSBs behave differently when the tested samples are placed in such a way that the snow covers them (type – C; for example unprotected roofing). In such a situation, the drop in the value of the board strength was significantly faster. Even though after the first year the samples under the test had a higher strength than the samples exposed to the V313 test, in the second and third year they showed a similar decrease in mechanical properties to that following the V313 test.

In Table 4, the results of the Tukey test are presented. These results conclude that the boards in type C conditions obtain statistically similar values in the second and especially the third year of their exposure, analogous to the number of cycles of the V313 test. Detailed analysis of the variance for physic-mechanical properties of OSB/3 subjected to the V313 test proved that the observed changes following the third and especially the fourth cycle are statistically negligible (Table 5). It may therefore be assumed that three cycles of the V313 test sufficiently describe the behaviour of boards as well as the conditions of outdoor exposure.

Table 4. The Value of Tukey Test for the Mechanical Properties of Boards Exposed to the V313 Test and the Outdoor Exposure Without a Shelter (Condition C)

HSD Tukey test	Property				
	MOR II	MOR ⊥	MOE II	MOE ⊥	IB
df	88.000	88.000	88.000	88.000	88.00
MS	5.3204	2.0156	86862	24654	0.00462
THT2**	0.989401	0.805708	0.000183	0.820952	0.000526
THT3***	0.385337	0.078596	0.887883	0.061195	0.999022

* - test results for the second cycle of the V313 test and the second year of exposure, ** - test results for the third cycle of the V313 test and the third year of exposure

Table 5. Value of Tukey Test for Mechanical Properties of the Boards Exposed to the V313 Test

HSD Tukey test (df = 77.000)	Property						
	MOR II	MOR ⊥	MOE II	MOE ⊥	IB	V100	TS
	THT						
MS	1.7681	1.7956	47477	29176	0.00058	0.00016	0.65593
Cycle	3						
4	0.0551	0.9531	0.9684	0.9582	0.2967	0.0002	0.9997
5	0.0008	0.8299	0.6518	0.3356	0.0191	0.0001	1.0000
6	0.0002	0.4919	0.3370	0.1022	0.0002	0.0222	1.0000
Cycle	4						
5	0.7953	0.9999	0.9904	0.9015	0.9084	0.9914	0.9985
6	0.3090	0.9725	0.8816	0.5745	0.0593	0.7170	0.9999

CONCLUSIONS

1. Despite the fact that the EN 300 (2006) standard indicates minimum values of MOR and IB that should be characteristic for OSB following the V313 test, it may be assumed that an acceptable decrease in the static bending strength is 50% and 60% for OSB/4 and OSB/3, respectively, and 53% for both types of boards in determining the tensile strength perpendicular to the planes. From the conducted tests, it may be concluded that both tested boards meet standard requirements in terms of static bending strength, but do not meet the requirements concerning tensile strength perpendicular to the planes. Accounting for the acceptable decrease in strength, only OSB/3 meets that provision for MOR.
2. The evaluation of boards in relation to thickness swelling required by the EN-321 seems to be a meaningless designator, as any changes are masked by permanent changes in thickness emerging during the V313 test. With the exception of the swelling in the subsequent cycles of the test, a further decrease in the mechanical properties of the boards was observed, regardless of their type. Those changes are considerably lower and have a tendency to die down and from the fourth cycle on the differences for the subsequent cycles cease to be statistically significant.
3. Relative changes of mechanical properties for both types of boards are very similar. The higher quality of OSB/4 may be observed only in their smaller thickness swelling.
4. The method of exposing boards to outdoor conditions has a substantial influence on the change of physico-mechanical properties of OSBs. However, for the boards used in this study, those changes occurred slower than those evoked by the V313 test, especially when an upright exposure is applied. For these reasons, for that type of board storage, an equation was determined that can bring the changes of properties following the V313 test into an acceptable range, allowing for the evaluation of the properties of the boards. In the case of vertical exposure, practically from the second year on, changes in the properties of the OSB/3 were similar to those presented by the boards demonstrated from the second cycle of the V313 test.

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