WOOD RESEARCH
60 (4): 2015
633-644

PROPERTIES OF OSB BOARDS AFTER A FEW CYCLES OF AGING TESTS

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(Received August 2014)

ABSTRACT

The study determined the possibility of assessing the properties of OSBs after V313 test, based on the alterations found in the boards after V100 test. An advantage of V313 test is the possibility of assessing both the modulus of rigidity (MOR) and the internal bond (IB). However, its significant disadvantage is the time required for the determination of the board properties. The testing procedure takes 21 days vs. just 21 hours necessary for V100 test. The results of both tests were compared with the properties of the boards exposed to outdoor conditions. The study showed that the modulus of rigidity, modulus of elasticity (MOE) and internal bond were by 46, 26 and 14 % higher after V313 than V100 test. However, neither the test type, nor the number of cycles significantly affected OSB swelling. It was found that V100 aging test was much more compatible with the outdoor conditions than V313 test.

KEYWORDS: Ageing test, mechanical properties, oriented strand boards.

INTRODUCTION

Oriented strand boards are typical engineering material designed for replacing plywood or solid wood in structural elements. They are usually used for wall, floor and roof sheathing and as the webs of I-shaped beams. Beams of this type are used in the construction of ceilings, wall columns or roof structural elements, and their production enables significant cut down on the consumption of solid wood, particularly of high strength classes. Environmental conditions in which the OSBs are used require that they have not only excellent initial mechanical properties, but also very high durability.

The mechanical properties of OSB depend on such factors as strand geometry (Barnes 2001, Chen et al. 2008a, b), the share of small chips or subscreen fractions (Fakhri et al. 2006a, b, Han et al. 2006, 2007, Lee and Tahir 2003, Jastrząb 2008, Mirski and Dziurka 2011a, b, Mirski et al. 2012), and wood species (Hermawan et al. 2007, Sumardi et al. 2007, Cheng et al.

2012, Wang and Winistorfer 2000). The effect of strand size used during the production process on the physical and mechanical properties of OSBs has been widely discussed in the literature (Canadido et al. 1990, Suzuki and Takeda 2000, Nishimura et al. 2004, Chen et al. 2008a, b). Fakhir et al. (2006a, b) pointed out that the strand size affected also air permeability of the boards, which is important when using them as a sheathing material. Durability and usage of the boards largely depend on the adhesive. The most popular resin used in the OSB manufacture is phenol-formaldehyde (PF) resin (Andersen and Troughton 1996, Kim and Watt 1996, Sellers 2001, Han et al. 2005, Gündüz et al. 2011). It ensures high water resistance and good durability of the boards. However, the use of isocyanates (polymeric Methylene Diphenyl Diisocyanate - pMDI) and a four-component resin, melamine-urea-phenol-formaldehyde resin (MUPF) in the manufacture of OSB gain in popularity in Europe (Brochmann et al. 2004, Smith 2005).

Durability of wood-based boards is determined based on the accelerated aging tests. The basic tests include a cooking test (EN 1087, 1995) and V313 test that allows for defining a resistance to humidity in cyclic testing conditions (EN 321, 2002). An additional desirable feature of these boards is their high dimensional stability in the presence of high humidity or water. An assessment of this feature should be carried out for all freshly manufactured OSB using the basic test set. It is assessed by determining the swelling in thickness after soaking in water (EN 317, 1993). The literature data indicate that the swelling in thickness after 24 hours of soaking (EN 317, 1993) is 2 to 3 times greater, and after 2 hours of cooking (ASTM 1037, 1989) 4 to 6 times greater in OSB than plywood (Go et al. 2001). Thus, OSBs as a substitute for plywood still need improvement in their properties. The choice of aging factors, the period of their operation and a sequence of application do not need to reflect the actual conditions to which a specific material is exposed. However, the test should demonstrate the durability of the investigated material after a set number of cycles. On the one hand, the aging tests should be easy to carry out in a relatively short time, but on the other hand, they should also reflect the actual service life of the material.

The aim of this study was to determine the properties of OSB/3 after several cycles of V100 and V313 tests and to compare the results with the properties of boards exposed to the outdoor conditions.

MATERIAL AND METHODS

The tests were performed using an industrially manufactured 18 mm thick OSB/3, the inner layers of which were glued with isocyanate adhesive (pMDI), and the outer layers with melamine-urea-phenol-formaldehyde resin (MUPF). The basic properties of the boards used in the study are presented in Tab. 1. The data contained therein indicate that the boards meet the requirements of EN 300 standard, 2006.

Moisture resistance was assessed based on the assumptions of EN-1087, 1995 (V100) and EN-321, 2002 (V313) standards. EN-1087, 1995 standard recommends that the tested boards are subjected to one cycle of the following conditions: boil treatment, soaking in cold water and drying at an elevated temperature, and EN-321, 2002 standard requires three cycles of soaking, freezing and drying at a temperature about 10°C lower than in the case of V100 test. Both tests require also assessing other properties, based on which the board durability is determined. After the cooking test (V100), the board samples were evaluated for their internal bond (IB), as per EN 319, 1993 standard. Following the cyclic test (V313), the boards were assessed for their swelling in thickness according to EN 317, 1993 and internal bond as per EN 319, 1993, or modulus of rigidity (MOR), but only for the longer axis (EN 310, 1993). Considering the above, to facilitate

Tab. 1: Properties of OSB boards.

Property	Testing method	Unit	Numerical value		
			EN 300		
ρ	EN 323	kg.m^{-3}	-	604	15.15*
Gt	EN 317	%	15		
MOR II	EN 310	N.mm^{-2}	20	30.9	2.20
MOR ⊥	EN 310	N.mm^{-2}	10	18.9	1.03
MOE II	EN 310	N.mm^{-2}	3500	6150	410
MOE ⊥	EN 310	N.mm^{-2}	1400	3410	260
IB⊥	EN 319	N.mm^{-2}	0.32	0.44	
IB$_{V100}$	EN 1087-1	N.mm^{-2}	0.13	0.15	0.02

* – standard deviation.

the comparison of board properties after the aging tests, the cooking test (V100) was performed for the samples allowing also for the determination of their modulus of rigidity. Thus, the tested samples were 18 x 50 x 410 mm in size and were cut out along their longer axis. Prior to testing, the spots for thickness measurements were marked on the samples (Fig. 1). Furthermore, 6 testing cycles were carried out for each test, and the mechanical properties and changes in thickness (t) were evaluated after each cycle.

The properties of the boards after the aging tests were compared with those stored under roofing (V400). The boards stored outdoors were placed in racks in such a way so as to ensure free flow of air between them and to protect them from direct precipitation. The parameters of air during OSB storage and theoretical board moisture content are shown in Fig. 2.

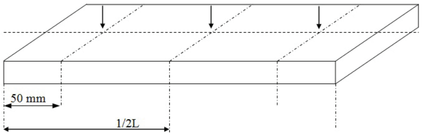

Fig. 1: Positions for thickness measurements.

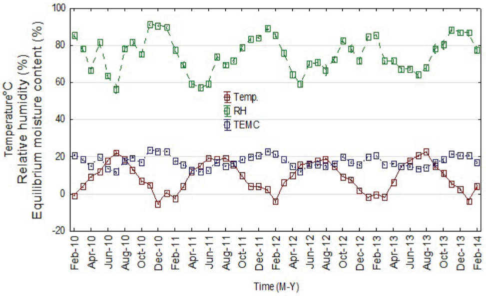

Fig. 2: Mean monthly air parameters and theoretical moisture content of OSBs (TMEC) stored under roofing.

The presented data indicate that the investigated boards experienced four periods of gradual wetting and drying, corresponding to the following periods Feb 10–Dec 10–Feb 12–Feb 13–Jan 14. Mean air temperature during the exposure period was slightly higher than 9°C and a relative humidity was 75 %.

When assessing the impact of individual factors, we decided to use, in addition to the mean values for individual populations, a relative (Eq. 1) difference for a specific parameter, describing its decline from the initial value, i.e.:

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

where: X_0 – mean value of an individual parameter for the control sample,
X_c – mean value of an individual parameter after a specific cycle.

The resulting relative differences for specific parameters in the investigated periods (cycles/years) were estimated using a regression Eq. 2:

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

and the relationships between the results of V100 and V313 tests were determined using the Eqs. 3 and 4:

$$y = cx + d \tag{3}$$

$$y = ex. \tag{4}$$

The results were compiled using Excel spreadsheets. For most tests the series of 14 samples were used. The statistical analysis included 12 samples, as the minimum and maximum values from each series were rejected. The statistical analyses were performed using Statistica 10 software for the significance level α = 5. The error bars presented in the figures reflect the standard deviation for a specific sample.

RESULTS

Relative changes in the modulus of rigidity are shown in Fig. 3. As can be inferred from the presented data, a degree of board damage increased with each consecutive cycle, regardless of the test type. Except for rare cases, each cycle caused greater and significantly different changes in the modulus of rigidity. A detailed analysis employing "post hoc" testing revealed that this trend changed after the fourth cycle of V313 test. Since then, smaller changes were observed and the differences between the results, determined in this case as the standard deviation, increased. This means that the changes between the cycles 4 and 5, and 5 and 6 were no longer significant (Tukey's HSD Test: 4:5 - 0.0512, 5:6 - 0.4003). This may indicate that the change in strength in OSB samples exposed to V313 test may approach its maximum value. For all the cycles, much more intense changes in the modulus of rigidity were observed during V313 test than during V100 test. Directional coefficients of linear regression equations a) further indicated that consecutive cycles of V313 test caused greater changes in the modulus of rigidity than consecutive cycles of V100 test. These differences were even more pronounced when the modulus of elasticity (MOE) was analyzed (Fig. 4).

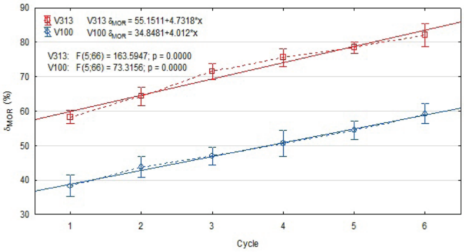

Fig. 3: Relative changes in the modulus of rigidity in OSBs exposed to 6 cycles of V100 and V313 test.

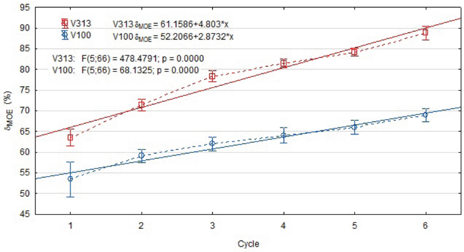

Fig. 4: Relative changes in the modulus of elasticity in OSBs exposed to 6 cycles of V100 and V313 test.

The intensity of changes in the modulus of elasticity during consecutive cycles was similar to the intensity observed in the case of modulus of rigidity (a_{MOR} = a_{MOE} ≈ 4.803). However, the changes in MOE caused by a greater number of cooking cycles seemed to be slower (a_{MOE}_100 < a_{MOE}_V313). Moreover, the modulus of elasticity was found to be more susceptible to changes triggered by aging factors than the modulus of rigidity. A relative change in MOE after the first cycle was about 55 (V100) or 65 % (V313), while the changes in MOR amounted to nearly 40 (V100) and 60 % (V313).

Fig. 5 presents the internal bond in the samples after V100 and V313 tests. Similarly as in the case of MOR and MOE, much greater changes in this parameter were observed after V313 test. However, both tests resulted in much greater decline in IB than MOR or MOE. As soon as after the first cycle a relative change in IB amounted to about 75 and 85 % for V100 and V313, respectively. Furthermore, similar values were obtained for V313 test after the fourth, fifth and sixth cycle. This implies that greater number of cycles did not cause significant changes in IB any longer. This tendency regarding the IB values can be well described only by a logarithmic curve (r^2=0.978).

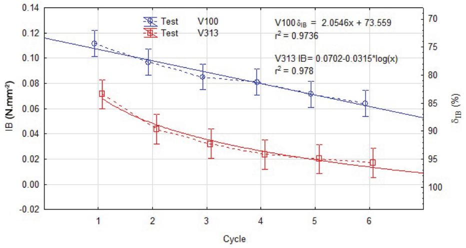

Fig. 5: Internal bond in OSBs exposed to 6 cycles of V100 and V313 test.

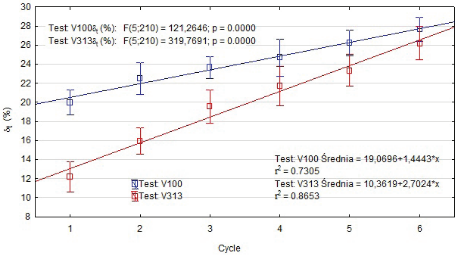

Fig. 6: Relative changes in thickness in OSBs exposed to 6 cycles of V100 and V313 test.

Fig. 6 illustrates the relative changes in OSB thickness after the two tests. The changes regarding OSB thickness across all cycles were greater in the case of V100 test than V313 test. The differences in the relative thickness change were greater in the first cycles and then they gradually decrease, showing high similarity after 6 cycles. Relatively large thickness changes, ranging from 12 to 28 %, made determining the changes in swelling difficult. As indicated by the data presented in Fig. 7, this parameter seemed to be similar and amounted to 8.5 %, regardless of the test type and the number of cycles. For this reason, the board swelling was not treated as a parameter for any of the employed tests, and thus it cannot serve as a descriptor of the changes perceived in OSBs exposed to the aging tests.

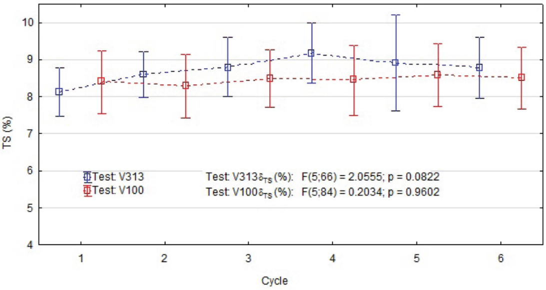

Fig. 7: Swelling in thickness of OSBs exposed to accelerated aging tests.

The data presented in the graphs suggest that the mechanical properties of the OSB panels assessed after 2, 4, and, in the case of MOR, 6 cycles of V100 test, were similar to the values obtained after the first cycle of V313 test. This finding was supported by an in-depth analysis using the Tukey's test. It revealed the following:

IB - 2_{V100} : 1_{V313} = 0.08730 (HSD test, Error: intergroup MS = 21.298, df = 150.00),
MOE - 4_{V100} : 1_{V313} = 1.00000 (HSD test, Error: intergroup MS = 48242, df = 132.00),
MOR - 6_{V100} : 1_{V313} = 0.99957 (HSD test, Error: intergroup MS = 7.8321, df = 132.00).

Tab. 2: Relative changes in the properties of OSBs stored under roofing.

Property	**Conditioning period (Years)**				**Regression equation coefficient**		
	1	**2**	**3**	**4**	**a**	**b**	**r^2**
MC (%)	12.03* (6.59**)	11.39 (6.70)	10.97 (7.02)	11.84 (6.75)	-	-	-
-	**δx (%)**				**(%)**	**(%)**	**-**
MOR	18.1 (6.7)	22.8 (4.8)	25.6 (5.3)	28.1 (5.6)	3.3008	15.3837	0.3154
MOE	12.0 (6.8)	22.7 (4.2)	29.3 (5.1)	31.8 (3.9)	6.593	7.5047	0.6574
IB	13.8 (3.5)	20.5 (8.3)	27.0 (7.7)	30.5 (7.8)	5.664	8.7646	0.4569
t	0.9 (0.8)	1.9 (0.8)	4.3 (0.9)	5.8 (0.8)	1.7105	-1.0282	0.8242

* – moisture content after the sample collection/moisture content after conditioning (determination of properties)

** – standard deviation.

Tab. 2 shows the relative changes in the physical and mechanical properties of OSBs stored in the outdoor conditions, but not directly exposed to rain or snow. The greatest changes in the investigated properties, assessed in relation to the previous year, took place in the very first year of the study, except for the board thickness. The changes after the fourth year were similar to those observed after the third year. The initial substantial changes in the investigated properties were probably due to the fact that the initial period featured considerable increase in OSB moisture content (20 %), as compared to the boards stored in a manufacturer storehouse (ca. 6 %). Moreover, the properties of the boards were assessed after a conditioning period, when their moisture content was again about 7 % (Tab. 2), and this may have contributed to the occurrence of additional stresses. Such a course of changes in the analyzed mechanical properties of the boards and only 4 checkpoints made it difficult to correctly interpret the situation based on the linear regression equation (low r^2 parameters).

DISCUSSION

In a previous paper (Mirski and Derkowski 2010) we tried to find out whether the OSBs subjected to the cooking test meet the requirements concerning the modulus of rigidity for these boards after V313 test. The study showed that despite mean 50 % decline in the board strength after V100 test, the obtained values were still significantly higher than the requirements for the boards subjected to an accelerated aging test (8 $N.mm^{-2}$ as per EN 300, 2013). In the present study it was found that the investigated boards had higher modulus of rigidity even after 6 cycles of V100 test and 3 cycles of V313 test (δ_{MOR} <74 %).

Tab. 3: The coefficients of regression equations defining the relationship between V313 and V100 test.

Property	Equation 3			Equation 4	
	c	d	r^2	e	r^2
MOR	1.1595	15.3626	0.9667	1.4692	0.8962
MOE	1.6301	-23.1856	0.9940	1.2601	0.9424
IB	1.1176	1.8092	0.9174	1.1399	0.9171
t	0.5293	13.633	0.9856	1.1811	-0.591
TS					

Tab. 3 presents the coefficients of equations allowing for the determination of the board degradation degree after V313 test and the cooking test. In the case of internal bond and modulus of elasticity the equations involving an independent part had a very high coefficient of fit r^2 amounting to 0.9667 and 0.9940, for MOR and MOE, respectively. Therefore, they allowed for a very accurate estimation of the dependent variable based on a known value of the independent variable. In Eq. (4) the coefficients of fit were much lower, but they were enough for the technical estimation and they enabled easy determination of the sought value. In the presented network of relationships the relative changes in modulus of rigidity after V313 test were about 26 % higher than those obtained after V100 test, and for MOE this difference was about 47 %. Different course of δIB (IB) values after V100 and V313 tests meant that the coefficients of fit for both estimation (Eqs. 2 and 3) were almost identical and amounted to r^2= 0.917, and the directional coefficients of both lines were very similar $c \approx e \approx 1.13$. Thus, a decrease in IB after V313 test was about 13 % higher than after V100 test. In the case of changes in thickness, the estimation equation 3 allowed for a correct estimation of thickness increment after V313 test, but in a simplified equation r^2 value was too low and the equation had to be rejected. A similar situation was observed for the swelling parameter, when low r^2 coefficients prevented the use of the estimation equations in practice. However, this situation was an effect of very similar changes in the board swelling after both tests.

Difficulties in identifying the effect of the aging tests on OSB swelling were due to the fact that mean increase in the board thickness during the testing procedures may be as high as 30 %. Such considerable changes in thickness significantly affect MOR and MOE measurement, as the spacing of supports is determined based on the nominal thickness. Wu (1998) suggested that when the changes in board thickness were so substantial, a breaking resistance, defined as a product of modulus of rupture and section modulus S, should be taken into account MOR·S (Eq. 5):

$$MOR \cdot S = \left[\frac{3F_{\max} l}{2bt^2}\right] \cdot \left[\frac{bt^2}{6}\right] \tag{5}$$

where: F_{max} – the load (force) at the fracture point,
l – the length of the support span,
b – specimen width,
t – specimen thickness.

As indicated by the data presented in Fig. 8, when the analysis of modulus of rigidity after V313 and V100 tests accounted for the changes in board thickness, a decrease in board strength after V313 test was much greater than indicated by MOR. Moreover, it was found that the directional coefficients of the equations describing the course of the breaking resistance changes were very similar $\alpha_{V100} \approx \alpha_{V313} \approx -3.78 \pm 0.03$, and thus, irrespective of the number of the aging test cycles, MOR·S after V313 test was about 35 KNmm greater than the value recorded after V100 test. On the other hand, the value of c coefficient close to 1 for V100: V313 relationship indicated that to estimate the degree of change after V313 test, the relative change in the breaking resistance after V100 test should be increased by about 46 %.

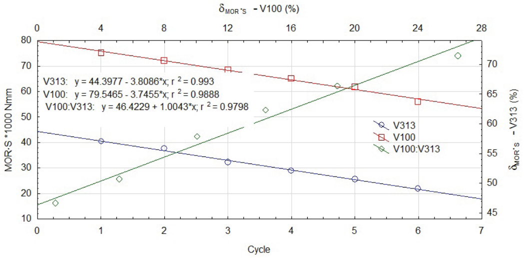

Fig. 8: Breaking resistance after the aging tests.

Investigating the relationships between accelerated aging and the conditions of use of glued elements (beams, panels) is not a novel idea. This research field has been explored for many years, and the earlier works concerned particle boards (Caster 1980), LVL (Hayashi et. al. 2005) and now the interest has shifted to OSB.

Tab. 4: Correlation coefficients for physical and mechanical properties for the accelerated aging treatments and the outdoor exposure.

Property	V100:V400			V313:V400		
	c	d	r^2	c	d	r^2
MOR	0.8141	12.642	0.9953	0.5528	13.624	0.9784
MOE	1.9195	90.53	0.9948	1.1322	59.941	0.9906
IB	2.3869	- 165.11	0.9905	1.5361	- 115.8	0.9640
t	0.8786	- 16.982	0.8944	0.4392	- 4.6414	0.9639

Tab. 4 shows the coefficients of correlation equations for physical and mechanical properties of the boards after accelerated aging tests and the properties of the boards exposed to the outdoor conditions. As indicated by the data it contains, the changes in mechanical properties of OSB panels, except for the changes in thickness, can be fairly accurately estimated based on the aging tests and taking into account the cycle and the year of the test. Slightly higher values of the coefficient of fit r^2 were found for the relationship V100: Testing conditions (V400). However, it should be taken into account that this analysis concerns a correlation of mean values for a specific parameter, and not the raw data discussed above. In a series of papers Kojima (Kojima et al. 2009, Kojima and Suzuki 2011) showed a good correlation between the properties of boards exposed to outdoor conditions and the aging tests. Although he described the relationships for many materials, these works only explore the correlations between a specific exposure time and an individual test. Determining long-term relationships seems to be a better approach, as they may serve as a basis for future estimation of OSB behaviour based on laboratory tests. One of the advantages of V100 test is its short duration, about 24 h, which is similar to JIB-B or APA D-1 tests.

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