Construction Board Resistance to Accelerated Aging

Radosław Mirski,* Adam Derkowski, and Dorota Dziurka

Physical and mechanical properties were evaluated for industrial and laboratory boards intended to be used in the construction industry. The boards were subjected to accelerated aging tests including resistance to humidity in the conditions of cyclic test in accordance with EN 321 (2002), and determination of dimensional changes resulting from changes in relative humidity according to EN 318 (2002). The greatest changes were observed after one test cycle. Moreover, the boards made of fine chips demonstrated slightly higher resistance to the tested factors. Although laboratory boards showed a much lower density, their behavior following the exposure to the assessed factors was similar to that of industrial plates.

Keywords: Chipboards; MFP boards; Humid conditions; Mechanical properties; Construction materials

*Contact information: Poznań University of Life Sciences, Department of Wood-based Materials, 28 Wojska Polskiego Str., 60-637 Poznań, Poland, Poland; *Corresponding author: r.mirski@up.poznan.pl*

INTRODUCTION

The market of wood-based boards for the construction industry is not as large as the market of boards for the furniture sector, yet it has a considerable share in a production portfolio of leading manufacturers of wood-based materials. When analyzing statistical records (*e.g.*, Eurostat), it is difficult to clearly define which manufactured wood-based materials are supplied to the strictly defined construction industry and which to the furniture sector. In the last 17 years, production of wood-based materials in Poland has increased by as much as 85%, and production of oriented strand board (OSB) nearly doubled between 2009 and 2016 (Concise Statistical Yearbook of Poland 2018). In the EU, production of OSB increased by *ca*. 50% from 2009 to 2016 (Eurostat). According to the forecasts, the production of OSB boards in the USA will increase by *ca*. 70% between 2014 and 2025 (Grand View Research). This increase in OSB production stems from problems with access to raw material faced by plywood plants, the output of which has decreased or remained at the same level for many years. A significant increase in plywood production is observed in Russia and China, which have sufficient material resources.

Although raw material used for production of OSB is of significantly lower quality, it is still small diameter roundwood. Quality, or more precisely, linear parameters of chips used for production of OSB boards, require raw material of high quality (Barnes 2000 and 2001; Mayers 2001; Moriarty 2002; Chen *et al.* 2008). Although numerous attempts have been made to expand the raw material base for OSB boards, *e.g.*, by implementing into production of previously unused species (Shupe *et al.* 2001; Sumardi *et al.* 2007; Cheng *et al*. 2012; Mirski and Dziurka 2015; Mirski *et al.* 2016), mixing chips of several species of wood (Wang and Winistorfer 2000), or using fine chips or subsieve fractions (Fakhri *et al.* 2006a,b; Han *et al.* 2006, 2007; Mirski and Dziurka 2011a,b; Mirski *et al.* 2016), no comprehensive solutions have been proposed for this problem until now. The standard chipboards for the construction industry based on the requirements of EN 312 (2010), type

5, and the OSB boards have been known in Europe for years and currently face competition from the board manufactured by the Pfleiderer Corporation. It differs from standard chipboards as it comprises uniform structure of chips on its entire cross-section. Linear dimensions of these chips resemble those of the chips designated for the core of three-ply furniture boards, and the adhesive used for board production is based on melamine resin (Pfleiderer).

However, in boards manufactured for the construction industry, polymeric diphenylmethane diisocyanate (pMDI) or phenol-based resins can be used, as well as hybrids of phenol-formaldehyde (pMDI/PF) or even urea-formaldehyde (pMDI/UF) type (Irle and Bolton 1988; Sellers 1992; Pizzi 1994; Miller *et al.* 2002; Mirski *et al.* 2011; Dziurka and Mirski 2014). The boards manufactured by Pfleiderer adhesive are labeled as multi-functional panel (MFP). While numerous studies are regularly conducted for the OSB boards, they are still very scarce for the MFP boards. It is still a relatively new product, although conforming to EN 309 (2005), and this may make distinguishing between MFP and classic P5 boards difficult. Another characteristic feature of the MFP boards is their high density, ca. 35% higher than of the OSB boards. This higher density is associated with much higher demand for raw material. Although raw material used in these boards is of much lower quality, and its use in the OSB boards is frequently virtually impossible, yet this leads to higher costs of such production. The study by Mirski *et al.* (2018) presents a board made of small chips of density similar to the OSB boards, and at the same time meeting the basic requirements for P5 boards.

As the materials designated for the construction industry are expected to feature high resistance to variable ambient conditions, and in particular, high dimensional stability, this study examined the response of light P5 boards, and OSB and MFP boards to aging tests.

EXPERIMENTAL

The study involved 15 mm thick OSB/3 and MFP boards from industrial production and two types of laboratory boards of the same thickness, labeled as RM/1 and RM/2. The laboratory boards were made of chips of parameters presented in the study of Mirski *et al.* (2018). The procedure used for production of these boards was also similar. However, the moisture content of external layers was 18% and 28.6% for RM/1 and RM/2 boards, respectively. The moisture content of chips in the core was 6.8%. The chips were glued with pMDI (ONGRONAT® 2100, BorsodChem group, Hungary), where adhesive dry weight was 4.5% of based on the dry weight of chips. The mat was pressed at 200 °C at a pressure of 2.2 MPa for 225 s.

After conditioning, basic physical and mechanical parameters of the boards used in the study were evaluated, including:

- Modulus of rupture (MOR) and modulus of elasticity (MOE) according to EN 310 (1993);
- Internal bonding strength (IB) according to EN 319 (1993);
- Thickness swelling (TS) after 24 h according to EN 317 (1993);
- Water absorption (WA) after 24 h based on EN 317 (1993);
- Internal bond after the boiling test (V-100) according to EN-1087-1 (1995).

Ten to fifteen samples were randomly selected for each test.

The relevant responses of the studied boards were evaluated under ambient conditions on a basis of two tests. The first one concerned the board resistance to humidity in conditions of a cyclic test, as described in EN 321 (2002), while the second analyzed the changes in board linear dimensions caused by changes in air relative humidity, according to EN 318 (2002).

As per EN 321 (2002) requirements, the conditioning consisted of three cycles, and in each cycle the samples were soaked, frozen, and then dried. The total time of passing through three cycles was 546 ± 10 h. The samples were then conditioned for three complete conditioning periods (9 cycles), *i.e.*, for ca. 1638 ± 30 h. Board parameters were evaluated after each cycle for OSB and MFP boards, and after only one cycle for the laboratory boards.

EN 318 (2002) specifies two directions for changes in the moisture content, *i.e.*, desorption and adsorption changes. However, the authors' previous studies indicated that adsorption changes were more important, and therefore, this study focused only on those alteration in moisture content. The samples were conditioned in the air at relative humidity of 30%, followed by 65%, and the process was terminated after conditioning in the air at relative humidity of 85%. As in previous research (Mirski *et al.* 2015), the relative changes in dimensions, MOR, and MOE were calculated according to Eq. 1,

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

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

For climatic tests, about 10 to 12 samples were selected from the OSB and MFP boards, and 9 samples were chosen from the laboratory boards. The results were analyzed using Statistica 13.0 package (StatSoft Inc., Tulsa, OK, USA).

RESULTS AND DISCUSSION

Basic characteristics of the boards used in the study are presented in Table 1 and in Figs. 1 and 2. All boards used in the tests, excluding the laboratory board of RM/1 type, met requirements of relevant standards concerning their possible use as load bearing boards intended for humid conditions (EN 312 and 300). A slightly lower value for MOR determined for the longer axis of the OBS board was deemed sufficient to meet the requirements of this standard. The density of boards used in the study varied significantly, and this was expected to affect water absorption during the test (Fig. 1a).

Table 1. Basic Properties of the Investigated Boards

Board type	MOR II	MOR ⊥	MOE II	MOE ⊥	IB	V100
	5th percentile N/mm^2					
MFP	23.0 (1.36)*	19.7 (1.23)	3800^{a} (272)	3410^{b} (168)	0.79 (0.05)	0.23 (0.003)
OSB/3	19.5 (0.71)	10.7 (0.55)	3840^{a} (162)	2070^{d} (67)	0.36 (0.06)	0.07 (0.008)
RM/1	10.2 (1.33)		1940^{d} (208)		0.45 (0.01)	0.33 (0.02)
RM/2	16.7 (0.95)		2540^{c} (212)		0.67 (0.06)	0.39 (0.05)

*Standard deviation provided in brackets

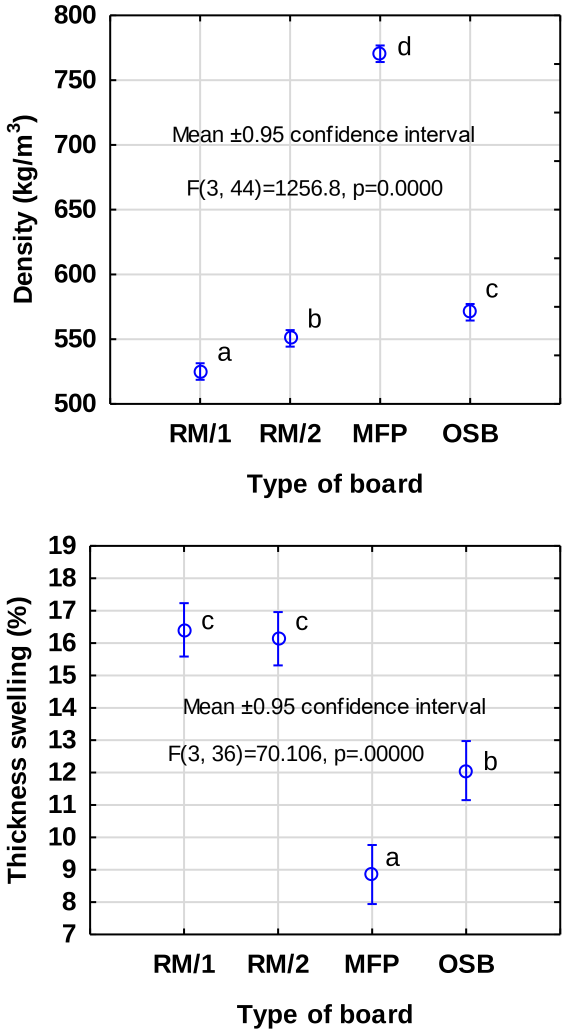

Fig. 1. The one-way ANOVA: a) Board density, and b) Thickness swelling of boards used in the study

Swellings of laboratory boards RM/1 and RM/2 were similar at 16%, while swelling of the MFP boards was nearly twice as low as for the laboratory boards, and over 25% lower than that of the OSB boards. The laboratory board swelling was slightly higher than the standard, as no reagents that would increase the board hydrophobic properties were used in their production. However, as indicated from previous studies, the swelling would possibly decrease to the acceptable level when paraffin emulsion was used in their production (Mirski and Dziurka 2011b). One of main factors disqualifying chipboards from the use for construction purposes is loss of their load bearing capacity. It is usually determined in the three-point bending test. Previous studies by the authors concerning OSB boards already implied that aging tests are very drastic (Mirski *et al.* 2015) and usually reflect even several years of board exploitation in unfavorable conditions.

The boards were characterized as four groups, uniform in terms of MOR and MOE (Table 1, Fig. 2). However, these groups did not overlap, as the average MOR obtained for P-axis of the OSB board was similar to that for R-axis of the MFP board, while for MOE, average values obtained for P-axis of the OSB board and for P-axis of the MFP board did not show statistically significant differences. As Fig. 2 indicates, the average MOR value for P-axis of the OSB board slightly exceeded 20 N/mm^2.

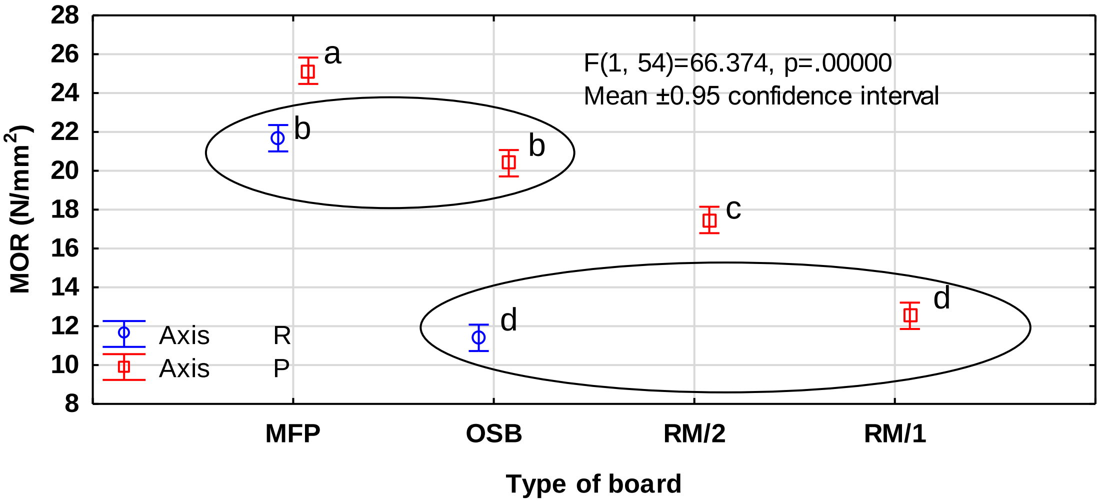

Fig. 2. Initial values for static bending strength – uniform groups according to the Tukey's HSD test

A significant drop in strength and MOR in MFP and OSB/3 boards was observed after the first cycle of the aging test (V313), as indicated by Fig. 3. The reason for this phenomenon may be that in the first cycle the weakest adhesive joints break, as a result of which the structure of the board becomes more porous and the board swells more in thickness. This causes a weakening of the board in terms of strength. In the OSB boards, the relative changes determined using Eq. 1 were slightly higher than those described in the study by Derkowski *et al.* (2014). Currently, the relative changes in MOR reached *ca*. 68% for P-axis and ca. 71% for R-axis, while changes in strengths of the MFP boards were much lower, amounting to *ca*. 52% for P- and 34% for R-axes. For successive cycles, these changes were only slightly higher and was roughly linear in their character.

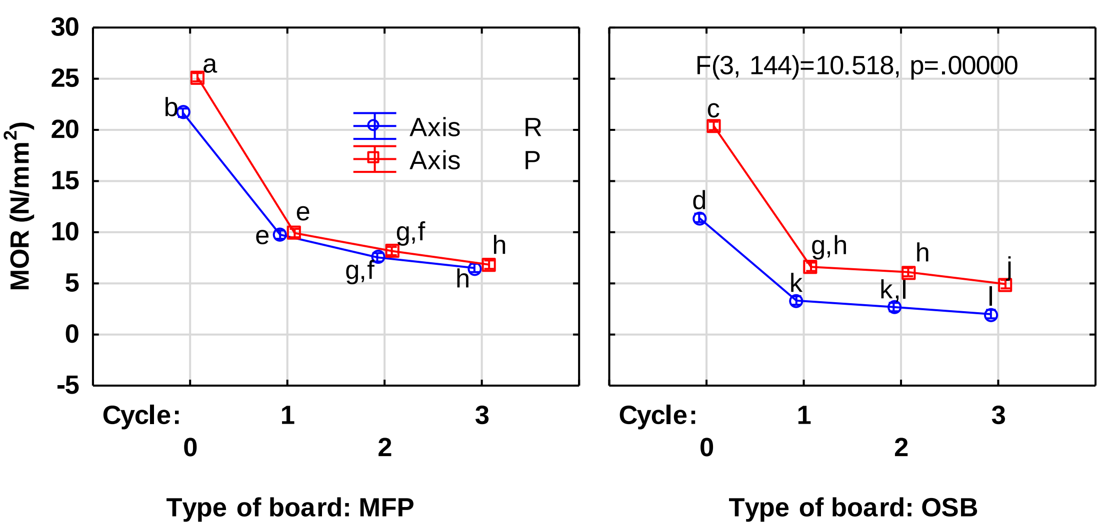

Fig. 3. Effect of number of cycles and board axes on static bending strength of MFP and OSB boards undergoing V313 test

Similar relations were also observed when effects of the V313 test on MOE characteristics are analyzed (Fig. 4). The analysis of group homogeneity indicated that MOR and MOE values determined for OSB in successive cycles were much lower than those determined for MFP. The MFP boards reached similar values of bending strength only after one more cycle, and of the MOE after at least two more cycles. Furthermore, MFP board characteristics determined for successive cycles became increasingly similar for both axes.

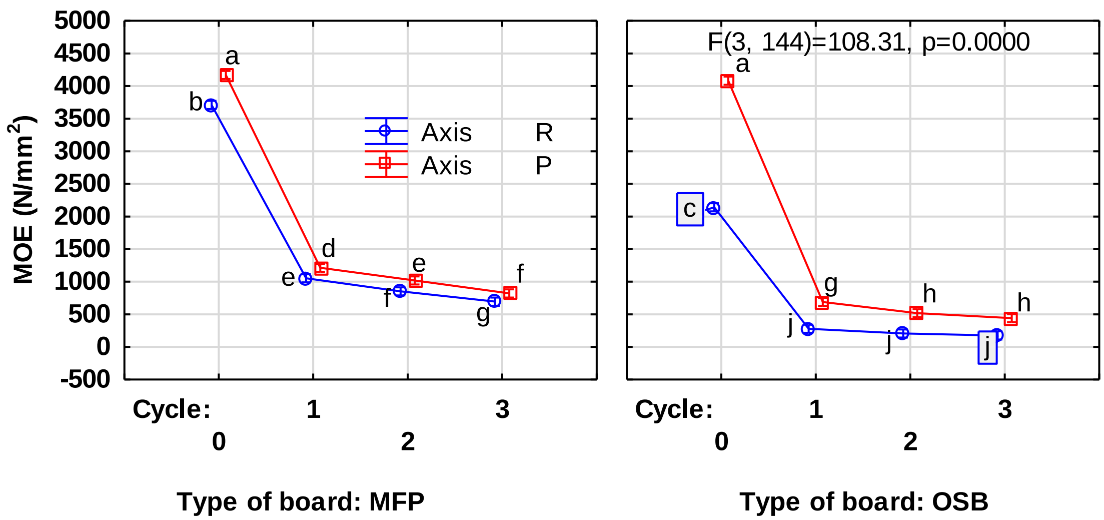

Fig. 4. Effect of number of cycles and board axes on the MOE of MFP and OSB boards undergoing V313 test

The laboratory boards endured conditions of the V313 test relatively well. Changes in their static bending strength and MOE were significantly lower than that for the remaining boards (Fig. 5). This was possibly the effect of quality of chips and a type of the binding agent used. After three cycles of the V313 test, they were characterized by a similar MOE as the MFP board, and strength similar to the MFP or OSB boards, depending on the board type/density. The use of chips even smaller than those used for the production of the MFP board, together with low density, possibly supported compensation for sorption tensions associated with processes of cyclic soaking and drying. The OSB boards are particularly susceptible to these changes, and significant changes were observed not only in their mechanical properties, but also in quality of their surface.

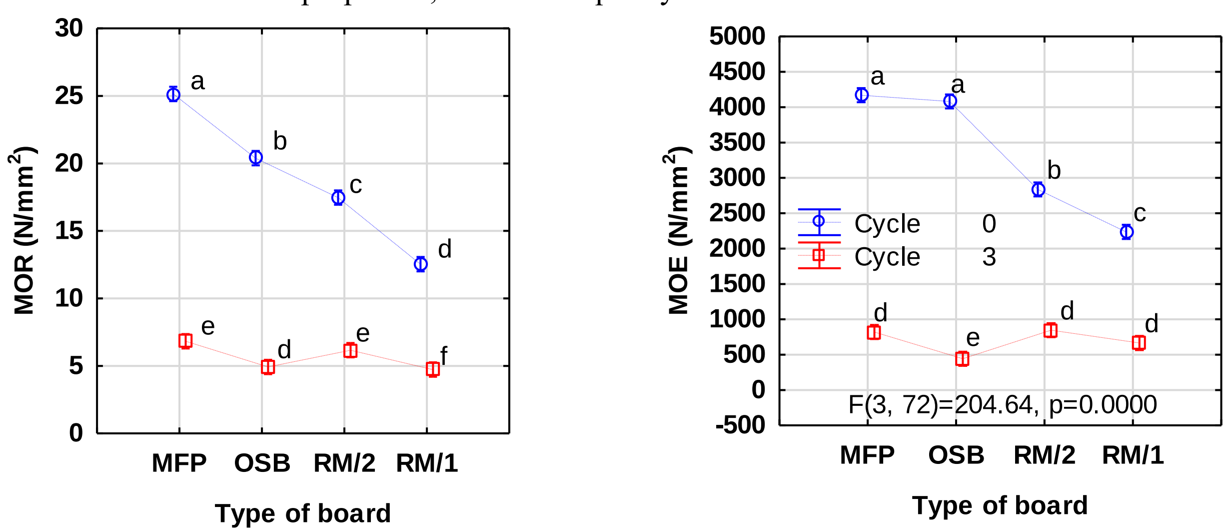

Fig. 5. Effects of number of cycles and board types on bending strength and MOE of boards undergoing V313 test

Table 2. Selected Properties of the Investigated Boards after Cycles of the V313 Test

Board type	Conditioning cycle	MC (%)	IB (N/mm²)		TS (%)		WA (%)	
MFP	1	7.04	0.45	0.04	8.83	1.07	63.6	4.73
	2	7.25	0.36	0.03	8.35	1.19	70.5	3.09
	3	7.30	0.31	0.03	8.93	0.75	85.1	1.92
OSB/3	1	6.98	0.13	0.02	12.7	2.07	108	6.22
	2	7.07	0.11	0.03	12.7	1.61	113	5.91
	3	7.08	0.10	0.02	12.3	1.17	121	6.53
RM/1	3	7.29	0.13	0.02	9.69	0.89	124	9.21
RM/2	3	7.06	0.20	0.02	9.68	1.20	117	4.44

An increase in thickness observed for the OSB/3 board was much greater than in the other boards. This resulted not only in a significant reduction in mechanical properties of these boards, but also in low quality of the board surface, manifested by numerous chips loosely bound to the board structure. These chips fell off from the sample surface readily after a slight damage. The nature of changes in thickness was similar to that of linear ones and depended on the number of cycles. The changes appeared to be closely related to the density in boards made of fine chips (MFP and RM) (Fig. 6).

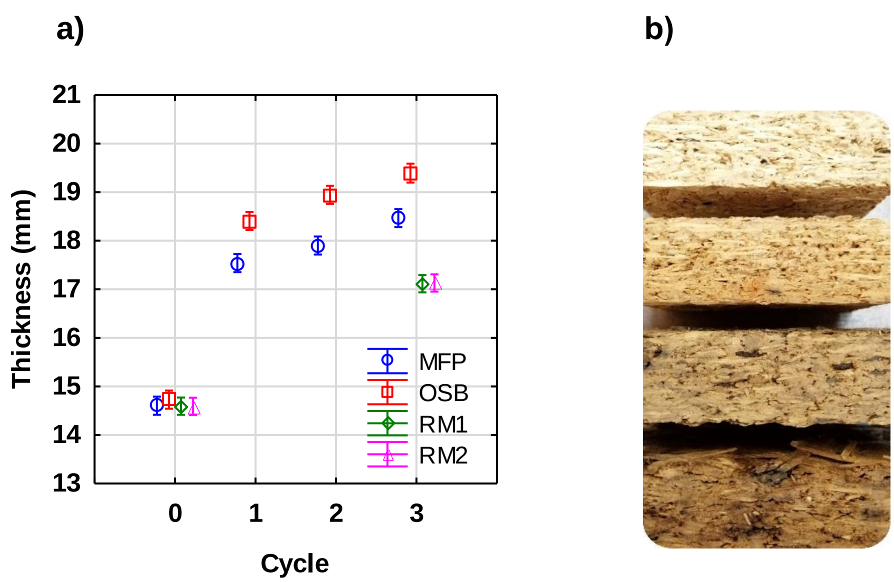

Fig. 6. a): Effects of number of cycles and board types on thickness undergoing V313 test; and b): Appearance of boards after 3 cycles: from above RM1, RM2, MFP, OSB boards (in the scale approx. 2:1)

Table 3 shows the results for relative changes in thickness and length of the tested boards. Average values of relative changes in thickness and length of the OSB/3 boards were comparable to the results of previous studies in OSB boards (Mirski and Dziurka 2013, Mirski *et al.* 2013), while a relative change in thickness of the MFP boards was close to average for both directions in the OSB/3 boards. The laboratory boards demonstrated significantly smaller changes in their thickness, when compared with the other two types of boards, as confirmed by the post-hoc analysis (ANOVA F(4, 119)=34.214, p=0.0000). This may possibly be an effect of much lower density of these boards, particularly of their core, which possibly attenuated an increase in thickness of individual chips due to its looser structure. However, as demonstrated previously, changes caused by water were strongly associated with quantity of wood in the board volume. Relative changes in length of the studied boards differed statically between each other (F(4, 35) = 7.4722, p = 0.00018). This was caused mainly by small and very large changes determined for the longest and the shorter axes of the OSB board, respectively. The laboratory boards, intended as substitutes of the studied industrial boards, showed relative changes in length similar to MFP boards.

Table 3. Relative Changes in Thickness and Length Expressed as a Change in Board Moisture Content

Parameter		Sample				
		MFP	RM/1	RM/2	OSB/3 II	OSB/3 _I_
Relative change in thickness/change MC (%/%)	Mean	0.814	0.479	0.531	0.892	0.696
	SD	0.16	0.12	0.10	0.22	0.11
	HSD	a	c	c	a	b
Relative change in length/change MC (mm/m/%)	Mean	0.25	0.23	0.22	0.18	0.30
	SD	0.056	0.035	0.025	0.058	0.062
	HSD	b,a*	c,b	c,b	c	a

Note: SD – Standard deviation; Letters denote homogeneous groups; and consecutive letters denote increasing values

CONCLUSIONS

1. The MFP boards had a higher resistance to the aging test (V313) than OSB/3 boards, and this was possibly related to the quality of chips used for their production. This may be confirmed by the fact that the laboratory boards, although of different structure, yet containing chips of similar dimensions, behaved in a similar way. Although in general these chips can be considered as material of lower quality, requiring higher levels of gluing, yet boards of this type better endured difficult conditions of the V313 tests.
2. The greatest decrease in the analyzed parameters was visible already after the first cycle, and corresponded to 65% to 75% of changes observed during the entire study.
3. The observed changes in mechanical properties were the greatest for the shorter axis of the OSB board, and the smallest for the main axis of the MFP board.
4. The relative change in thickness of the MPF board was similar to the average change in thickness of the OSB/3 board. The laboratory boards featured smaller change in their thickness, and this possibly resulted from their low core density, compensating for chip deformation caused by moisture.
5. Boards manufactured from fine chips were characterized by similar changes in their length. The OSB/3 boards showed significant alterations in their relative change in length, depending on the orientation axis, as already demonstrated in previous studies. However, relative changes in length of the MFP board were greater by 28% than changes determined for the longer axis of the OSB boards.
6. After additional protection of chips with paraffin, these boards are expected to be a

good substitute for MFP and OSB construction boards, because they fulfill the requirements for mechanical properties.

ACKNOWLEDGMENTS

The authors are grateful for the support of the National Centre for Research and Development, BIOSTRATEG3/344303/14/NCBR/2018.

The paper was partially financed within the framework of Ministry of Science and Higher Education programme "Regional Initiative of Excellence" in years 2019-2022, Project No. 005/RID/2018/19.

REFERENCES CITED

Barnes, D. (2000). "An integrated model of the effect of processing parameters on the strength properties of oriented strand wood products," *For. Prod. J.* 50(11-12), 33-42.

Barnes, D. (2001). "A model of the effect of stand length and stand thickness on the strength properties of oriented wood composites," *For. Prod. J.* 51(2), 36-46.

Chen, S., Du, C., and Wellwood, R. (2008). "Analysis of strand characteristics and alignment of commercial OSB panels," *For. Prod. J.* 58(6), 94-98.

Cheng, Y., Guan, M. J., and Zhang, Q. S. (2012). "Selected physical and mechanical properties of bamboo and poplar composite OSB with different hybrid ratios," *Key Engineering Materials*, 517, 87-95.

Concise Statistical Yearbook of Poland (2018), (www.stat.gov.pl), accessed June 12th, 2019.

Derkowski, A., Mirski, R., Dziurka, D., and Popyk, W. (2014). "Possibility of using accelerated aging tests to assess the performance of OSBs exposed to environmental conditions," *BioResources* 9(2), 3536-3549. DOI: 10.15376/biores.9.2.3536-3549

Dziurka, D., and Mirski, R. (2014). "Properties of liquid and polycondensed UF resin modified with pMDI," *Drvna Industrija* 65(2), 115-119.

EN 1087-1 (1995). "Particleboards - Determination of moisture resistance – Boil test," European Committee for Standardization, Brussels, Belgium.

EN 300 (2006). "Oriented Strand Boards (OSB). Definitions, classification and specifications," European Committee for Standardization, Brussels, Belgium.

EN 309 (2005). "Particleboards. Definition and classification," European Committee for Standardization, Brussels, Belgium.

EN 310 (1993). "Wood-based panels. Determination of modulus of elasticity in bending and of bending strength," European Committee for Standardization, Brussels, Belgium.

EN 312 (2010). "Particleboards. Specifications," European Committee for Standardization, Brussels, Belgium.

EN 317 (1993). "Particleboards and fibreboards. Determination of swelling in thickness after immersion in water," European Committee for Standardization, Brussels, Belgium.

EN 318 (2002). "Wood-based panels. Determination of dimensional changes associated with changes in relative humidity," European Committee for Standardization,

Brussels, Belgium.
EN 319 (1993). "Particleboards and fibreboards. Determination of tensile strength perpendicular to the plane of the board," European Committee for Standardization, Brussels, Belgium.
EN 321 (2002). "Wood-based panels. Determination of moisture resistance under cyclic test conditions," European Committee for Standardization, Brussels, Belgium.
Eurostat (2019). (https://ec.europa.eu/eurostat/data/database), accessed June 12th, 2019.
Fakhri, H. R., Semple, K. E., and Smith, G. D. (2006a). "Transverse permeability of OSB. Part I: The effects of core fines content and mat density on transverse permeability," *Wood Fiber Sci*. 38(3), 450-462.
Fakhri, H. R., Semple, K. E., and Smith, G. D. (2006b). "Transverse permeability of OSB. Part II. Modeling the effects of density and core fines content," *Wood Fiber Sci*. 38(3), 463-473.
Grand View Research (2019). (https://www.grandviewresearch.com/industry-analysis/wood-based-panel-market), accessed on June 12th, 2019
Han, G., Wu, Q., and Lu, J. Z. (2006). "Selected properties of wood strand and oriented strandboard from small diameter southern pine trees," *Wood Fiber Sci.* 38(4), 621-632.
Han, G., Wu, Q., and Lu, J. Z. (2007). "The influence of fines content and panel density on properties of mixed hardwood oriented strandboard," *Wood Fiber Sci.* 39(1), 2-15.
Irle, M. A., and Bolton, A. J. (1988). "Physical aspects of wood adhesive bond formation with formaldehyde based adhesives. Part II. Binder physical properties and particleboard durability," *Holzforschung* 42(1), 53-58. DOI: 10.1515/hfsg.1988.42.1.53
Mayers, K. L. (2001). *Impact of Strand Geometry and Orientation on Mechanical Properties of Strand Composites*, Master Thesis in Civil Engineering, Washington State University.
Miller, T., Creel, L. D., and Detlefsen, W. D. (2002). "Hybrid phenol-formaldehyde and polymeric isocyanate based adhesive and methods of synthesis and use," US Patent No. 6 478 998 2002.
Mirski, R., and Dziurka, D. (2011a). "Applicability of strand substitution in the core of OSB," *BioResources* 6(3), 3080-3086. DOI: 10.15376/biores.6.3.3080-3086
Mirski, R., and Dziurka, D. (2011b). "The utilization of chips from comminuted wood waste as a substitute for flakes in the oriented strand board core," *For. Prod. J.* 61(6), 473-478. DOI:10.13073/0015-7473-61.6.473
Mirski, R., and Dziurka, D. (2013). "The effect of ambient conditions on dimensional stability of OSB/4," *Wood Research* 58(1), 91-100.
Mirski, R., and Dziurka, D. (2015). "Low-density oriented strand boards," *BioResources* 10(6), 6388-6394. DOI: 10.15376/biores.10.4.6388-6394
Mirski, R., Derkowski A., and Dziurka, D. (2013). "Dimensional stability of OSB panels subjected to variable relative humidity: Core layer made with fine wood chips," *BioResources* 8(4), 6448-6459. DOI: 10.15376/biores.8.4.6448-6459
Mirski, R., Derkowski, A., and Dziurka, D. (2018). "Possibility of using fine wood strands for the production of P5 type building boards," *BioResources* 13(4), 7188-7196. DOI: 10.15376/biores.13.4.7188-7196
Mirski, R., Dziurka, D., and Czarnecki, R. (2016). "The possibility of replacing strands in the core layer of Oriented Strand Board by particles from the stems of rape (*Brassica napus* L. var. napus)," *BioResources* 11(4), 9273-9279. DOI:10.15376/biores.11.4.9273-9279

Mirski, R., Dziurka, D., and Derkowski, A. (2016). "Properties of oriented strand boards with external layers made of non-strand chips," *BioResources* 11(4), 8344-8354. DOI:10.15376/biores.11.4.8344-8354

Mirski, R., Dziurka, D., and Łęcka J. (2011). " Potential of shortening pressing time or reducing pressing temperature for plywood resinated with PF resin modified using alcohols and esters," *Eur. J. Wood Prod.* 69(2), 317-323. DOI: 10.1007/s00107-010-0436-8

Mirski, R., Dziurka, D., and Wieruszewski, M. (2015). "Properties of OSB boards after a few cycles of aging tests," *Wood Research* 60(4), 639-650.

Moriarty, Ch. J. (2002). "The effect of lab-made flakes on physical and mechanical property variability of laboratory flakeboard," *For. Prod. J.* 52(2), 69-73.

Pfleiderer (2019). (https://www.pfleiderer.com/pl/PM/Produkty-i-aplikacje/PremiumBoard/PremiumBoard-MFP-P5), accessed June 12th, 2019.

Pizzi, A. (1994). *Advanced Wood Adhesives Technology*, Marcel Dekker, Inc. New York, pp. 273-282.

Sellers, Jr. T. (1992). "Wood adhesives market builds a promising future on a profitable past," *Adhäsion Age* 35(10), 22-25.

Shupe, T. F., Hse, C. Y., and Price, E. W. (2001). "Flake orientation effects on physical and mechanical properties of sweetgum flakeboard," *For. Prod. J.* 51(9), 38-43.

Sumardi, I., Ono, K., and Suzuki, S. (2007). "Effect of board density and layer structure on the mechanical properties of bamboo oriented strandboard," *J. Wood Sci.* 53, 510-515. DOI: 10.1007/s10086-007-0893-9

Wang, S., and Winistorfer, P. M. (2000). "Fundamentals of vertical density profile formation in wood composites. Part II. Methodology of vertical density formation under dynamic conditions," *Wood Fiber Sci*. 32, 220-238.

Article submitted: December 13, 2019; Peer review completed: February 13, 2020; Revised version received: February 20, 2020; Accepted: February 22, 2020; Published: February 26, 2020.
DOI: 10.15376/biores.15.2.2680-2690