Dimensional Stability of OSB Panels Subjected to Variable Relative Humidity: Core Layer Made with Fine Wood Chips

Radosław Mirski,* Adam Derkowski, and Dorota Dziurka

The purpose of this study was to determine the dimensional stability of oriented strand boards (OSBs) with the core layer made of fine wood chips when the boards were exposed to air of variable relative humidity (30%, 65%, and 85%). The share of fine wood chips, intended for the particleboard core layer or originating from comminution of unrefined particleboards, accounted for 50% or 100% of the core layer mass. This study revealed much greater changes in the length of the board's shorter axis, regardless of the type of fine wood chips in the core layer. These changes increased with an increasing share of this type of chips in the core layer. More pronounced changes in thickness were observed for particleboards containing 50% of the fine chips. The research also showed that the relative changes in linear dimensions were slightly smaller in OSBs containing 50% of wood chips from the comminution of unrefined particleboards than in the boards with a core layer made from wood chips designed for this purpose.

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

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

INTRODUCTION

The ever-increasing demand for wood-based materials coincides with the concept of increasing forest resources and reducing the predatory acquisition of wood. Therefore, reasonable use of wood resources is a crucial element of a modern timber industry. To achieve their specific characteristics, OSB panels must be manufactured using high-quality strand chips, which can be obtained only by cutting proper quality wood (Geimer *et al.* 1975, Keiser 1987; Mayers 2001). Moreover, the cutting process yields not only the strand chips, but also fine fractions that constitute from a few to a dozen or so percent of the obtained chips. Initially, it was assumed that very fine wood chips would become the material for particleboard production. However, as can be concluded from numerous publications, including this one, fine wood chips from a subscreen fraction or from other sources may be used as complementary material for the core layer of boards (Brinkmann 1979; Barnes 2001; Mirski and Dziurka 2011a and b; Mirski *et al.* 2012; Han *et al.* 2006).

An inherent feature of wood materials is the variability of their linear dimensions with changes in relative humidity. As roof sheathing or construction materials, OSB panels are very often exposed not only to temperature changes, but also to changes in relative humidity; they can also be directly exposed to water. This is why there are many studies that investigate the degree of the board deformations and their connection with less desirable mechanical properties or links to production-related factors (Han *et al.* 2007; Wu and Lee 2002; Wu and Piao 1999; Wu and Suchsland 1996; Wu 1999).

The previously demonstrated possibility of replacing the strand chips with fine chips, allowing for the production of boards that meet the mechanical requirements for OSB/3, did not guarantee good dimensional stability. Significantly increased board thickness contributes to the deformation of the joints in the wooden structures, which may result in their diminished load capacity. When OSB panels are used as sheathing elements, the changes in their length and width become increasingly important. Dimensional stability of the panel elements, or knowledge concerning the changes in their properties during use, will allow the design of wooden structures, ensuring safe operation without the need for applying too strict safety factors.

Therefore, the aim of this study was to determine the effect of the type and amount of fine wood chips in the core layer of OSB on the degree of linear deformations caused by the exposure to air of variable humidity.

MATERIAL AND METHODS

This study involved industrial strand chips (OSB), industrial wood chips designed for the core layer of particleboards (PB), and wood chips resulting from the comminution of unrefined particleboards of P2 type (Eco). Both industrial and recycled wood chips were obtained from pine *(Pinus sylvestris* L.) wood. The fractional content of fine wood chips and their dimensions are shown in Fig. 1 and Table 1.

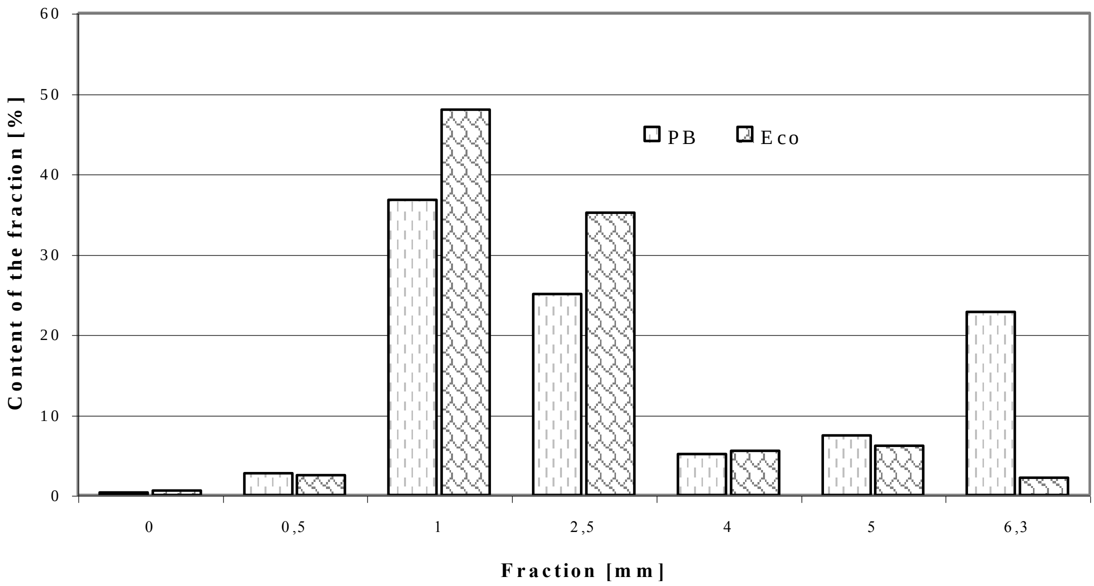

Fig. 1. Fractional composition of small chips (PB – chips intended for the core layer of particleboards, Eco – chips produced by comminution of unrefined particleboards)

Table 1. Basic Parameters of the Chips Used for the OSB Production

Fraction mesh mm	Eco					PB				
	l	*b*	*a*	$\lambda = \frac{l}{a}$	$\psi = \frac{b}{a}$	*l*	*b*	*a*	$\lambda = \frac{l}{a}$	$\psi = \frac{b}{a}$
0.5	3.6	0.89	0.3	12	3.0	6.72	0.58	0.17	40	3.4
1	5.64	1.81	0.7	8	2.6	10.71	1.19	0.52	21	2.3
2.5	7.77	3.42	1.3	6	2.6	14.22	2.02	0.62	23	3.3
4	7.96	4.72	2	4	2.4	18.65	2.41	0.80	23	3.0
5	8.71	5.62	2.2	4	2.6	20.64	2.36	0.77	27	3.1
6.3	9.75	6.83	2.6	4	2.6	27.22	2.42	0.77	35	3.1

l, *b*, *a* – length, width, thickness, mm
λ – Slenderness ratio
ψ – Flatness

Average dimensions of the chips from individual screens were calculated for 100 random chips, except for Eco chips from the screen 6.3, where only 20 pieces were retained. As can be concluded from the presented data, in both types of chips the dominant fractions were those remaining on the screen of 1- and 2.5-mm mesh, but in the case of PB chips, almost a quarter of the mass could be identified as the chips remaining on the screen of 6.3-mm mesh.

Polymeric isocyanate (pMDI) was used as a binding agent, and no water-resistance agents were employed.

Three-layer OSB panels of 1:2:1 type (face:core:face) were produced. The outer layers were always made of strand chips, and the core layer also contained fine wood chips that constituted 50% or 100% of its mass. In previous works, it has been noted that changes in such properties as the static bending strength and modulus of elasticity determined for the shorter axis and tensile strength perpendicular to the planes are proportional to the share of fine wood chips in the core layer and that the share of fine chips in this layer only slightly affects the mechanical properties of a board, determined for the longer axis (Mirski and Dziurka 2011a, b). The moisture content for strand chips and PB chips was about 6.0%, and for the Eco chips it was 5.6%. The outer layers were glued at a treatment level of 15.34 $kg{\cdot}m^{-3}$, and the core layer was glued at 15.34 $kg{\cdot}m^{-3}$, 16.52 $kg{\cdot}m^{-3}$, and 17.70 $kg{\cdot}m^{-3}$, for 0%, 50%, and 100% fine chip contents, respectively. The control board was the laboratory board containing only strand chips in its core layer (OSB/P), and its properties were also compared to those of an industrial OSB/3. For each variant, five 15-mm-thick experimental boards with a nominal density of 590 $kg{\cdot}m^{-3}$ were manufactured.

Batches of both types of chips to be used in the core and face layers were resinated in a laboratory small-speed gluing machine and then the cake was formed manually, while trying to maintain orientation directions as much as possible.

OSBs produced in this way were tested based on relevant standards, and the following characteristics were assessed:

- Modulus of rigidity (MOR) and modulus of elasticity (MOE) according to EN 310 (1993);
- Internal bond strength (IB) according to EN 319 (1993);
- Swelling after 24 h according to EN 317 (1993).

Samples of the boards used for determining specific properties were acquired in accordance with EN 326-1 (1994). To facilitate the assessment of the physical and mechanical properties, the initial average values of such parameters as: MOR, MOE, IB, and TS were brought to a single predetermined density of 590 kg/m^3, thus modifying the method proposed by Yemele *et al*. (2008),

$$X' = (X \times 590)/\text{determined sample density} \qquad (1)$$

where X is the actual MOR, MOR, IB, or TS, while the X' values are the respective properties recalculated into the density of 590 kg/m^3

Changes in the linear dimensions of the boards caused by relative humidity fluctuations were performed according to the EN 318 (2002) standard. However, taking into account the results of our previous studies, the changes in humidity were applied according to the standard only for set #2, and the number of stages was increased to 12. It was found that the deformation of linear dimensions for this set was always higher than for set # 1 (Mirski and Dziurka 2013). The calculations of dimensional changes were made assuming 65% relative humidity as a reference value, and the concept of a stage was introduced. A complete course of the conditioning process is shown in Table 2.

Table 2. Course of the Conditioning Process

Stage	Degree	Air parameters	Stage	Degree	Air parameters
0	0	20°C, 65% RH	III	6	20°C, 65% RH
	1*	20°C, 85% RH		7	20°C, 30% RH
I	2*	20°C, 65% RH	IV	8	20°C, 65% RH
	3*	20°C, 30% RH		9	20°C, 85% RH
II	4	20°C, 65% RH	V	10	20°C,65% RH
	5	20°C, 85% RH		11	20°C, 30% RH
-	-	-	-	12	20°C, 65% RH

* - degrees assumed in standard EN 318 (2002)

Relative dimensional changes were determined using the following formulas (2 and 3),

$$\delta l_{65,X} = \frac{l_{xn} - l_{65(n-1)}}{l_{65(n-1)}} \times 1000 \quad [\text{mm/m}] \tag{2}$$

$$\delta t_{65,X} = \frac{t_{xn} - t_{65(n-1)}}{t_{65(n-1)}} \times 100 \quad [\%] \tag{3}$$

where X is the value of relative humidity after which relative changes in length or thickness were determined, n is the degree (n = 1, 3, 5, 7, 9, 11), $\delta l_{65,x}$ is the relative change in length at a change in relative humidity from 65% to X, and $\delta t_{65,x}$ is the relative change in thickness at a change in relative humidity from 65% to X.

Relative changes in length and thickness are shown with respect to board moisture content changes caused by individual seasoning steps. This seems to be a more objective approach, as during seasoning, the boards achieve similar, albeit different moisture contents. Furthermore, absolute values were used when assessing the statistical impact of wood chip type and their share in the core layer.

A preliminary statistical analysis was performed using an Excel spreadsheet (2000), and Dixon's Q test to reject the outliers. More advanced analysis was carried out with a dedicated Statistica software, version 9 and 10. The analysis was mainly based on the ANOVA module that allowed for an easy assessment of several levels of a single factor, as well as a number of factors at different levels, and not multiple comparisons of only two levels of a single factor or two features.

RESULTS AND DISCUSSION

Properties of the Tested Board

Properties of the boards are presented in Table 3. As can be seen from the collected data, the properties of OSB/P and OSB/3 panels are similar. Replacing strand chips within the core layer with fine wood chips reduced both the static bending strength and tensile strength perpendicular to the board plane.

Changes in linear dimensions of the investigated OSBs caused by relative humidity fluctuations are shown in Tables 4 through 6. As evidenced by the data gathered in Table 4, the changes in length for stages 0 to 4 were much greater for the laboratory OSB/P than for the industrial OSB/3.

Table 3. Characteristics of the Tested OSB

Property	Testing method	Unit	Numerical value					
			OSB/P	OSB/3	50%-PB	100%-PB	50%-Eco	100%-Eco
ρ	EN 323	kg/m^3	620	600	590	610	610	590
TS'	EN 317	%	26.2	8.7	27.4	30.8	27.7	24.9
MOR' II	EN 310	N/mm^2	32.3	34	34.4	32.1	33	3102
MOR' ⊥	EN 310	N/mm^2	21.3	23.3	18.2	14.1	17.1	8.9
MOE' II	EN 310	N/mm^2	5450	5740	6020	5580	5750	5690
MOE' ⊥	EN 310	N/mm^2	2650	3370	2300	1930	2210	1380
IB'	EN 319	N/mm^2	0.66	0.64	0.66	0.57	0.47	0.43

Table 4. Effect of Changes in Relative Humidity on Changes in Linear Dimensions of Laboratory and Industrial OSB

Stage	Relative change in length / change in humidity – longer axis		Relative change in length / change in humidity – shorter axis		Relative change in thickness / change in humidity	
	δ_l[mm/m/%]	υ^* [%]	δ_l[mm/m/%]	υ [%]	δ_t[%/%]	υ [%]
Board OSB/3						
0	0.134	16.5	-	-	0.82	6.4
I	-0.172	-10.0	-	-	-0.32	-11.5
II	0.134	14.4	-	-	0.33	13.1
III	-0.130	-14.0	-	-	-0.62	-7.9
IV	0.190	9.5	-	-	0.74	12.6
V	-0.237	-8.4	-	-	-0.59	-11.4
Board OSB/P						
0	0.209	16.4	0.305	16.2	0.93	12.7
I	-0.217	-10.0	-0.247	-7.3	-0.49	-7.0
II	0.185	19.0	0.124	15.3	0.45	13.4
III	-0.193	-6.6	-0.200	-15.2	-0.61	-7.3
IV	0.105	17.7	0.195	9.8	0.75	7.2
V	-0.223	-9.9	-0.211	-15.5	-0.59	-11.6

* coefficient of variation

The OSB/P exhibited about 30% greater length deformation than OSB/3. It is worth mentioning that the currently marketed industrial board used in the study is characterized by relatively large changes in length, compared to boards of the same thickness evaluated several years earlier (Mirski *et al.* 2007). However, even though none of the agents improving its hydrophobic properties were used during production of the laboratory OSB/P, it was still very resistant to changes in humidity.

Only for a few stages, and mainly for the longer axis, did the observed deformation values exceed the requirements of the EN 12872 standard (0.2 mm/m/% for the longer axis and 0.3 mm/m/% for the shorter axis). Moreover, even when these values were exceeded, the changes in length for the shorter and longer axis were not as significant as in previous studies of industrial OSB/3 and OSB/4 (Mirski and Dziurka 2013), or even boards containing materials other than strand chips in the core layer (Tables 5 and 6). This is probably because of the manual production of the board and excessive attention to wood chip orientation in the individual layers.

Table 5. Effect of Changes in Relative Humidity on Changes in Linear Dimensions of the Laboratory OSB with the Core Layer made of Chips Intended for the Core Layer of Particleboards

Stage	Relative change in length / change in humidity – longer axis		Relative change in length / change in humidity – shorter axis		Relative change in thickness / change in humidity	
	δ_l[mm/m/%]	υ^* [%]	δ_l[mm/m/%]	υ [%]	δ_t[%/%]	υ [%]
Board OSB/P – 50% PB						
0	0.246	14.8	0.442	14.9	1.02	10.0
I	-0.226	-11.7	-0.329	-8.7	-0.47	-14.6
II	0.132	17.0	0.197	13.8	0.62	13.7
III	-0.158	-23.4	-0.456	-15.5	-0.72	-13.1
IV	0.137	14.7	0.236	12.0	0.76	14.3
V	-0.208	-11.9	-0.284	-15.0	-0.62	-9.2
Board OSB/P – 100% PB						
0	0.160	17.1	0.656	8.5	1.01	14.6
I	-0.216	-13.6	-0.518	-9.2	-0.53	-17.7
II	0.099	22.3	0.291	14.4	0.53	17.2
III	-0.158	-17.9	-0.417	-9.7	-0.62	-6.5
IV	0.095	14.1	0.350	8.5	0.73	14.5
V	-0.165	-13.2	-0.419	-19.2	-0.66	-16.0

* coefficient of variation

Table 6. Effect of Changes in Relative Humidity on Changes in Linear Dimensions of the Laboratory OSB with the Core Layer made of Chips Originating From the Fragmentation of Unrefined Particleboard

Stage	Relative change in length / change in humidity – longer axis		Relative change in length / change in humidity – shorter axis		Relative change in thickness / change in humidity	
	δ_l[mm/m/%]	υ^* [%]	δ_l[mm/m/%]	υ [%]	δ_t[%/%]	υ [%]
Board OSB/P – 50% Eco						
0	0.204	13.0	0.400	14.4	0.98	11.5
I	-0.236	-11.9	-0.335	-12.1	-0.54	-14.6
II	0.162	17.1	0.176	11.5	0.56	15.0
III	-0.176	-11.5	-0.303	-17.8	-0.65	-7.0
IV	0.125	15.3	0.223	15.5	0.79	15.0
V	-0.223	-14.3	-0.286	-15.2	-0.62	-11.0
Board OSB/P – 100% Eco						
0	0.170	15.4	0.870	14.0	0.88	18.9
I	-0.213	-12.6	-0.694	-14.4	-0.44	-13.9
II	0.080	22.4	0.840	20.5	0.60	14.7
III	-0.149	-19.5	-0.634	-12.6	-0.64	-9.4
IV	0.192	15.6	0.932	18.5	0.75	10.4
V	-0.202	-10.4	-0.640	-12.2	-0.54	-14.9

* coefficient of variation

The effect of both the type and quantity of fine wood chips in the core layer of the investigated OSB on the relative change in the board length caused by varying air humidity is quite difficult to assess. This is because the largest length variation for stage zero and the longer axis was found for boards whose core layer contained a 50% admixture of the wood chips intended for the particleboard core layer, and for the shorter axis for the board whose core layer was made exclusively of Eco chips. The smallest changes were observed for the OSB/P variant - 100% PB for the longer axis, and OSB/P -

50% Eco for the shorter axis.

In the seasoning schedule used, the first stage is called desorption, as specified by the EN 318 standard. Regarding the longer axis, at this desorption stage, the boards containing 100% fine wood chips in the core layer showed similar length deformation to the control boards, and in those with a 50% share of fine wood chips, the deformation was only about 5 to 8% greater than OSB/P. These relationships were completely different in the case of the shorter axis. Irrespective of the type and quantity of fine chips in the core layer, the length variations were much greater than those observed for the control board. In addition, the boards containing only fine chips in the core layer experienced greater deformations than those in which only 50% of the strand chips were replaced with fine chips. The behavior of boards triggered by varying air humidity corresponded with their strength test results. An increased share of fine chips in the core layer was accompanied by markedly reduced static bending strength and modulus of elasticity for the shorter axis, while the changes in the longer axis were negligible. Moreover, similar to the case of the control board, but unlike the industrial board, the deformations were smaller for stages IV and V than for stages 0 and I, which means that more wetting and drying cycles lead to lower sensitivity of the laboratory board to air humidity variations, regardless of the type of core layer material.

Multivariate statistical analysis ANOVA confirmed previous observations. Irrespective of the type of chips in the core layer, the length variations were much smaller for the longer axis than for the shorter axis (Fig. 2a). No correlation was found between the type of the chips in the inner layer and the board axes. Relative length variations specified for the longer and shorter axis of the control OSB/P were very similar; in the boards containing chips intended for the core layer of a traditional particleboard (PB), the changes were approximately 2.3 times greater, and in the boards containing chips originating from the comminution of unrefined particleboard, they were almost 2.9 times larger (Fig. 2b).

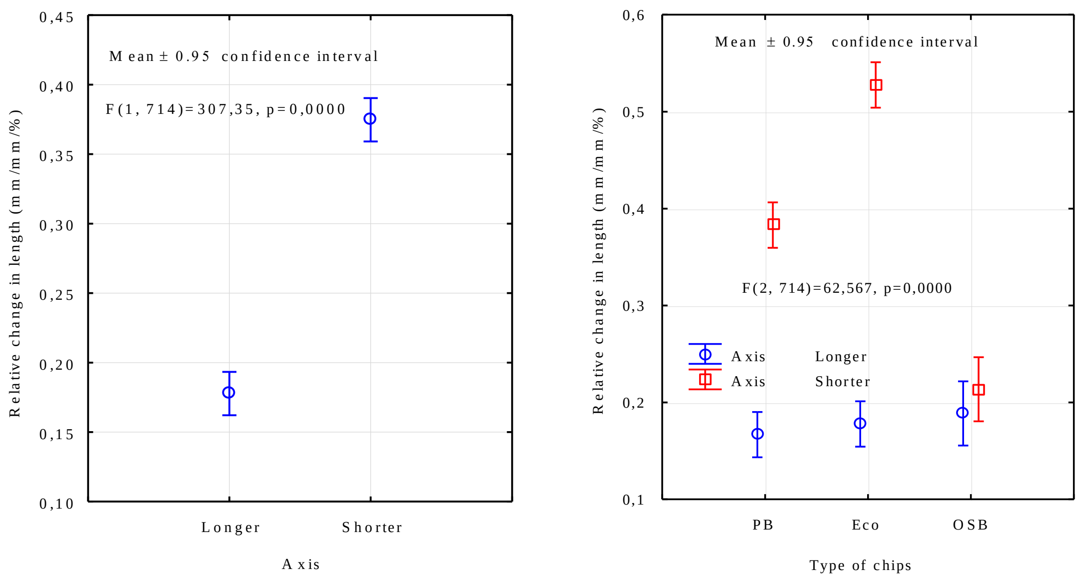

Fig. 2. Effect of the type of chips in the OSB core layer on the change in length triggered by changes in humidity; a) importance of the board axis, and b) relationship between the type of chips and the board axis

Such reaction of the boards may be attributed to the geometry of the chips used in the study and the method of board formation. PB chips are more slender than those resulting from the comminution of P2 board, and they can be more easily oriented. Moreover, their perpendicular orientation in relation to the outer layers probably allowed for limiting the length gain of these layers. Much shorter and thus less slender Eco chips were unable to restrict the dimensional changes in the outer layers, thus the changes in the dimensions specified for the shorter axis of the boards produced from these chips were so large. In addition, the perceived relationships were consistent with those obtained by Han *et al.* (2006).

The data presented in Fig. 3a show that an elevated share of fine wood chips in the core layer is accompanied by the reduced dimensional stability of OSB, as determined by length variations. This situation is mainly due to the changes in the length of the board, whose core layer contains only chips from the comminution of a particleboard (100% Eco, Fig. 3b). No statistically significant difference (at α = 0.05) concerning length changes in the boards containing 50% of fine chips in the core layer was found (F (1. 286) = 2.2091, p = 0.13830).

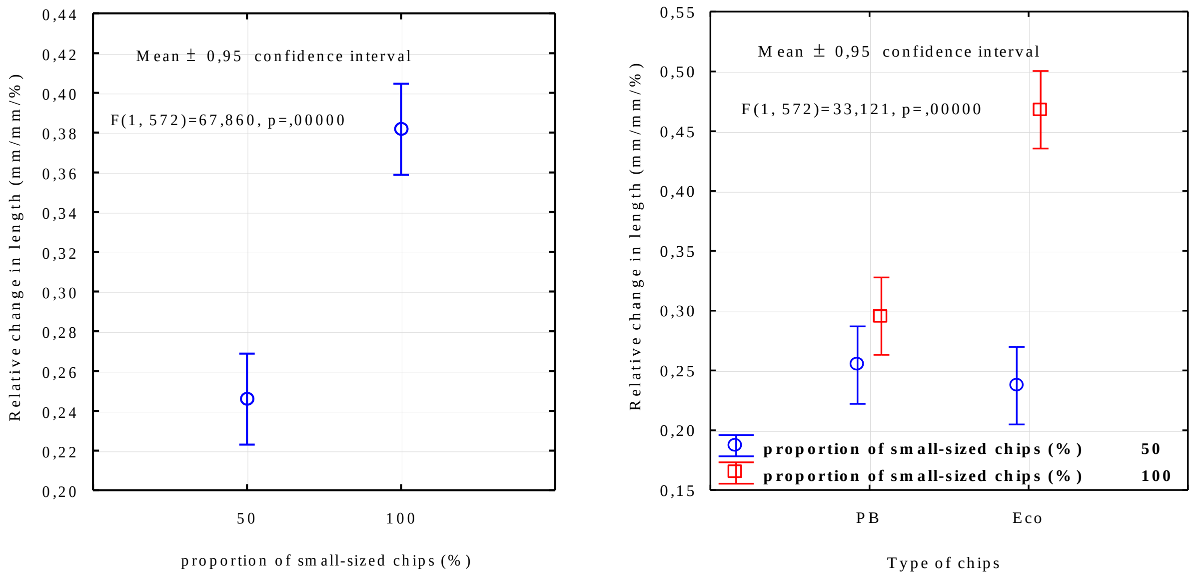

Fig. 3. Effect of the type of chips in the OSB core layer on the changes in length observed for various humidity conditions (analysis only for Eco PB chips); a) effect of fine chips share, and b) relationship between the chips type and share

More pronounced changes in the length of the boards with the core layer containing exclusively Eco chips were probably due to the chips quality. Those chips were in fact chunks of boards, in many cases consisting of several glued pieces of wood, and their shape and anatomical direction of wood were hard to determine. Moreover, the UF resin used for the manufacture of furniture boards was not only significantly less susceptible to changes in moisture content, but it also provided weaker adhesive joint. This was confirmed by MOR and MOE calculated for the shorter axis (Table 1). Therefore, the core layer made of these chips significantly better reflected the changes occurring in the outer layers of OSBs.

However, the data presented in Fig. 4 demonstrated that if a 50% admixture of fine chips in the core layer is intended, the preferred option is chips from the comminution of unrefined P2 furniture board.

The relative changes in OSB/P thickness, with respect to the percentage change in humidity for the first three stages of seasoning, were about 15% to 55% greater than for industrial OSB/3 (Table 4). At the next stages, the values are very similar for both types of boards. Considering the relatively low values of the coefficients of variation, it should be concluded that these boards behaved identically under the studied conditions, although the hydrophobicity of the laboratory board was in no way enhanced.

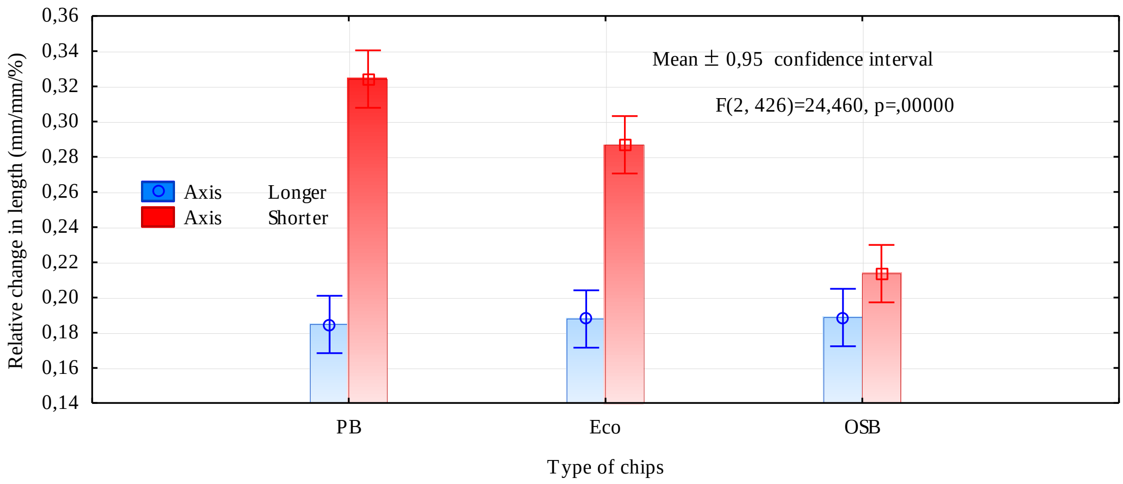

Fig. 4. Effect of the type of axis on the change in length for the boards containing 50% of fine chips (PB and Eco) or only strand chips (OSB) in the core layer

Because the variations in thickness were calculated in relation to the board thickness at the previous stage of seasoning, it is possible that actual changes taking place in the boards during their seasoning at subsequent stages were to some degree obscured. Intensive changes in board thickness at stages II and 0 associated with the absorption of moisture from the air damaged the board structure that was created during compression and led to permanent deformations that were no longer compensated for by the desorption processes.

This assumption was confirmed by the results of relative thickness change specified for stage 0 for the other investigated boards (Table 5 and 6). In all studied boards, the greatest changes in thickness were observed for the 0 seasoning stage. As can be seen in Fig. 5, relative variations in thickness, specified for boards containing fine chips in the core layer, were much greater than for the control OSB/P.

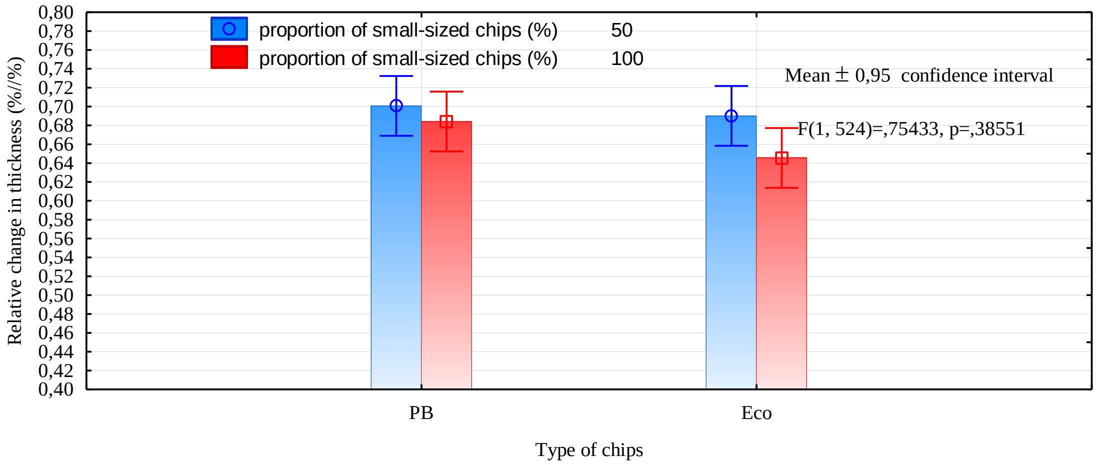

Fig. 5. Effect of type and share of fine chips in the core layer of OSB on the relative change of the board thickness, recalculated for 1% change in the board moisture content

The differences in values should be regarded as significant for the analyzed system. However, the results of the Tukey's test determined that there were no statistical differences between the relative change in thickness specified for the boards containing chips designed for the core layer of a traditional particleboard or chips resulting from the comminution of finished particleboards (Tukey HSD test {PB/Eco} = 0.2758) and boards containing Eco chips and the control boards (Tukey HSD test {OSB/Eco} = 0.17289).

As evidenced by the data presented in Fig. 5, increasing the fine chip content in the core layer limits the thickness variations of OSBs subjected to cyclic changes of humidity, and much better board thickness stability is obtained for chips from the comminution of the finished particleboard. This seems to be consistent with the expectations for this study, as those chips had already been glued with resin supplemented with paraffin emulsion. However, when the change in relative board thickness resulting from the complete seasoning process was determined, *i.e.*, covering the stages from 0 to 12, it turned out that in the boards containing 50% of fine chips in the core layer, the thickness gain was much smaller than in those whose core layer was made exclusively of fine chips (Fig. 6). It was also found that boards containing strand chips (OSB) or a 50% admixture of fine chips in their core layer exhibited similar thickness deformations over the complete seasoning period ($F(2.63)=2.5505$, $p=0.08608$).

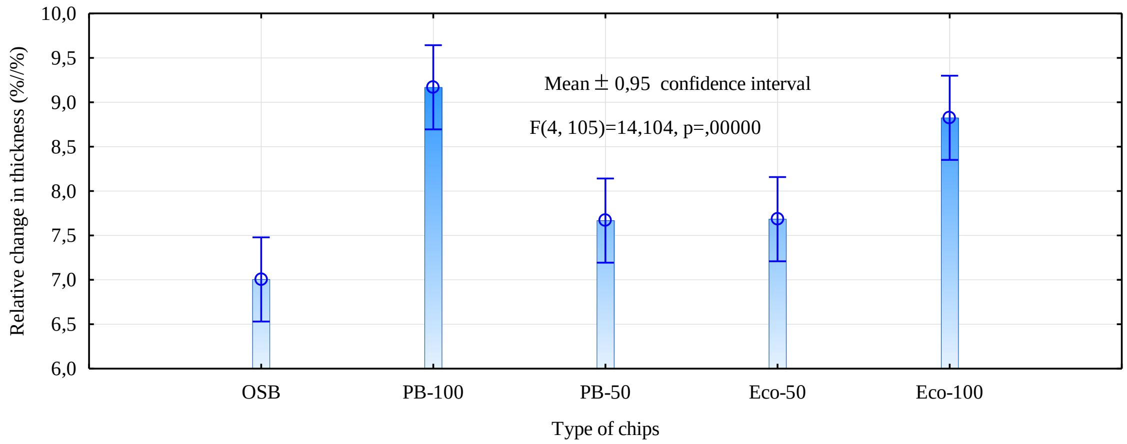

Fig. 6. Relative change in thickness of laboratory OSB determined over the entire seasoning process

CONCLUSIONS

1. The introduction of fine wood chips into the core layer of OSB reduced the dimensional stability of those boards, regardless of the origin of the fine chips. Decreasing dimensional stability mainly involved changes in thickness and length, specifically for the shorter axis.
2. The deterioration of OSB dimensional stability was greater with higher ratios of fine chips in the core layer.
3. Length and thickness deformations at individual stages of the seasoning process were slightly smaller for boards whose core layer contained 50% Eco chips than for those containing chips intended for the core layer of particleboards.
4. The thickness gain after the seasoning period was similar for boards containing 50% of any type of fine chips, and it was not different from the control board. For these reasons, both types of fine chips can be recommended as a possible substitute for strand chips in the core layer, but their share should not exceed 50% of the total chip weight in this layer.

ACKNOWLEDGMENTS

The authors are grateful for the support of the Polish Ministry of Science and Higher Education, Grant No. N N309 428138. “

REFERENCES CITED

Barnes, D. (2001). “A model of the effect of strand length and strand thickness on the strength properties of oriented wood composites,” *Forest Prod. J.* 51(2), 36-46.
Brinkmann, E. (1979). “OSB-Platten, ihre Eigenschaften, Verwendung und Herstellungstechnologie,” *Holz a. Roh- u. Werkst.* 37, 139-142.
CEN/TS 12872: 2000. “Wood-based panels – Guidance on the use of load-bearing boards in floors, walls and roofs.”
EN 310: 1993. “Wood-based panels: Determination of modulus of elasticity in bending and of bending strength.”
EN 317 : 1993. “Particleboards and fibreboards – Determination of swelling in thickness after immersion in water.”
EN 318: 2002. “Wood-based panels – Determination of dimensional changes associated with changes in relative humidity.”
EN 319: 1993. “Particleboards and fibreboards – Determination of tensile strength perpendicular to the plane of the board.”
EN 326-1: 1994. “Wood-based Panels – Sampling and cutting of test pieces and inspection.”
Geimer, R. L., Montrey, H. M., and Lehmann, W. F. (1975). “Effects of layer characteristics on the properties of three-layer particleboards,” *Forest Prod. J.* 25(3), 19-29.
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.
Keiser, J. (1987). “OSB-Entwicklung in Europa,” *Holz a. Roh-u. Werkst.* 10, 36-42.
Mayers, K. L. (2001). “Impact of strand geometry and orientation on mechanical properties of strand composites,” M.Sc.Thesis, Civil Engineering, Washington State University.
Mirski, R., and Dziurka, D. (2011a). “Applicability of strand substitution in the core of OSB,” *BioResources* 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,” *Forest Prod. J.* 61(6), 473-477.
Mirski, R., and Dziurka, D. (2013). “The effect of ambient conditions on dimensional stability of OSB/4,” *Wood Research* 58(1), 403-412.
Mirski, R., Derkowski, A., and Łęcka, J. (2007). “The effect of ambient conditions on dimensional stability of OSB/3,” *Ann. Warsaw Agricult. Univ.-SGGW, For. Wood Technol.* 62, 40-48.
Mirski, R., Dziurka, D., and Derkowski, A. (2012). “Application of chips designed for particleboard core in OSB as substitute for flakes,” *Lignocellulose* 1(1), 22-32.
Wu, Q. (1999). “In-plane dimensional stability of oriented strand panel: Effect of processing variables,” *Wood Fiber Sci.* 31(1), 28-40.
Wu, Q., and Lee, J.-N. (2002). “Thickness swelling of oriented strandboard under long-term cyclic humidity exposure condition,” *Wood Fiber Sci* 34(1), 125-139.

Wu, Q., and Piao, C. (1999). "Thickness swelling and its relationship to internal bond strength loss of commercial oriented strandboard," *Forest Prod. J.* 49(7/8), 50-55.
Wu, Q., and Suchsland, O. (1996). "Linear expansion and its relationship to moisture content change for commercial oriented strandboards," *Forest Prod. J.* 46(11/12), 79-83.
Yemele, N., Blanchet, M.C.P., Cloutier, A., Koubaa, A. (2008). "Effects of bark content and particle geometry on the physical and mechanical properties of particleboard made from black spruce and trembling aspen bark," *Forest Prod. J.* 58(11), 48-56.

Article submitted: August 14, 2013; Peer review completed: September 25, 2013; Revised version received: October 17, 2013; Accepted: October 18, 2013; Published: October 25, 2013.