



Substituting spruce with larch, alder and birch in strand board manufacture

Tomáš Pipiška¹ · Pavlo Bekhta^{1,2} · Jozef Ráhel¹ · Marek Nociar¹ · Michal Šulák¹ · Pavel Král¹ · Roman Réh³ · Rastislav Igaz⁴ · Ľuboš Krišťák⁴ · Miroslav Jopek⁵

Received: 24 August 2025 / Accepted: 10 March 2026 / Published online: 30 April 2026
© The Author(s) 2026

Abstract

The composition of manufactured wood-based boards is influenced by variations in the availability of input materials caused by changes in forestry practice. The effect of substituting the ubiquitous Norway spruce (*Picea abies* L. Karst) was studied in manufacturing single-layer oriented-strand boards (OSBs) with larch (*Larix decidua*), alder (*Alnus glutinosa* (L.) Gaertn.) and birch (*Betula pendula*) at compositions of 10, 15 and 20%. The boards with 3% pMDI resin and 0.5% wax were made and their standard physical, mechanical and thermophysical properties were measured. Strands made from the broadleaf wood species (alder and birch) were wider than those from spruce, and lower wood density was associated with a higher slenderness ratio. The slenderness and flatness ratios of alder strands were 9.6% and 33.3% higher than those of spruce, 54.2% and 100.0% higher than those of larch, and 45.1% and 44.0% higher than those of birch. Substituting 10–20% of spruce strands with larch, alder, or birch improved the dimensional stability and mechanical properties of the boards. All boards met the EN 300 (for OSB/3) requirements for bending strength, internal bond strength, and thickness swelling, whereas modulus of elasticity values met the standard in all cases except for boards containing 15% alder. Alder and larch are the most suitable alternative species for replacing spruce. The higher internal bond strength observed in mixed-species boards indicates potential for reducing adhesive consumption in OSB production.

1 Introduction

Norway spruce (*Picea abies* L. Karst) is one of the most widespread conifers in central Europe and also one of the most economically and ecologically important trees in the region. It accounts for 50% of the forest area of the Czech Republic, though its natural territory is only 11%; it typically favours higher altitudes—for example, in the European Alps (Čermák et al. 2021). Forestry has significantly expanded the range of spruce into natural broadleaved forest areas at low altitude in middle Europe; now only 20% of spruce trees are growing within their natural range (Klimo et al. 2000). Yet, the sustainability of spruce in its current range is being reduced by climate change and the effects of bark beetle (Schlyter et al. 2006) and this is driving changes in forestry, with different management approaches and different species cultivated (Neuner et al. 2015).

European forests volumetrically comprise 29.6% pine (*Pinus*), 23.0% spruce (*Picea*), 11.9% beech (*Fagus*), 10.0% oak (*Quercus*), 6.6% birch (*Betula*), 3.2% fir (*Abies*) and 15.7% other species (Köhl et al. 2020), a list that suggests potential for species currently underutilised in wood-based

✉ Tomáš Pipiška
tpipiska@gmail.com

¹ Department of Wood Science and Technology, Faculty of Forestry and Wood Technology, Mendel University in Brno, Zemědělská 1665/1, 613 00 Brno, Czech Republic

² Department of Furniture and Wood Products, Faculty of Wood Sciences and Technology, Technical University in Zvolen, T. G. Masaryka 24, 960 01 Zvolen, Slovakia

³ Department of Wood Technology, Faculty of Wood Sciences and Technology, Technical University in Zvolen, T. G. Masaryka 24, 960 01 Zvolen, Slovakia

⁴ Department of Physics, Electrical Engineering and Applied Mechanics, Faculty of Wood Sciences and Technology, Technical University in Zvolen, T. G. Masaryka 24, 960 01 Zvolen, Slovakia

⁵ Department of Metal Forming and Plastics, Faculty of Mechanical Engineering, Technical University in Brno, Antonínská 548/1, 601 90 Brno, Czech Republic

composite manufacture (Beck et al. 2009). OSB manufacture typically uses wood of only one species. In the Czech Republic this is often Norway spruce while in the USA it tends to be southern yellow pine (*Pinus echinata*) in the southern states and aspen (*Populus tremuloides*) in the north. The decision is an economic one, influenced by the availability of species close to the mill.

Oriented-strand board global production has seen recent growth. In the last 20 years, output has risen from 25.0 million m³ in 2003 to 41.7 million m³ in 2023 (Food and Agriculture Organization of the United Nations 2024). This increase in demand, accompanied by changes in forestry discussed above, has resulted in the Czech Republic in a shortage of spruce wood and a consequent impact on its price (Jandl 2020), creating opportunities for other wood species in OSB production. However, the addition of another wood species to the commonly used spruce could cause productivity problems due to the quality of the strands, the proportion of fine particles, the consumption of resin and so on.

A number of wood species for the production of OSBs was considered: Moso bamboo (*Phyllostachys pubescens*) (Sun et al. 2021), Betung bamboo (*Dendrocalamus asper* (Schultes.f)) (Febrianto et al. 2012), palm (Khoo et al. 2008; Ibrahim et al. 2022), western juniper (*Juniperus occidentalis*) (Pipíška et al. 2021), trembling aspen (*Populus tremuloides*) (Beck et al. 2009, 2010; Jin et al. 2009), different types of pine: Scots pine (*Pinus sylvestris*) (Ciobanu et al. 2014; Akyildiz et al. 2018; Lunguleasa et al. 2021), Loblolly pine (*Pinus taeda* L.) (Okino et al. 2004; Chiromito et al. 2016), jack pine (*Pinus banksiana*) (Zhuang et al. 2022) and black pine (*Pinus nigra* A.) (Akyildiz et al. 2018), fast-growing poplar (*Populus tremula*) (Ciobanu et al. 2014; Akrami et al. 2014, 2015; Dumitrascu et al. 2020; Lunguleasa et al. 2021), willow (*Salix alba*) (Ciobanu et al. 2014; Dumitrascu et al. 2020; Lunguleasa et al. 2021), kiri (*Paulownia tomentosa*) (Pham Van et al. 2021), fir (*Abies alba*) (Ciobanu et al. 2014; Akyildiz et al. 2018), beech (*Fagus sylvatica*) (Ciobanu et al. 2014; Akrami et al. 2014, 2015; Pham Van et al. 2021), balsam fir (*Abies balsamea*) (Zhuang et al. 2022) and black spruce (*Picea mariana* (Mill.)) (Zhuang et al. 2022).

A limited number of studies have been published on OSB production using larch (*Larix decidua*), alder (*Alnus glutinosa* (L.) Gaertn.) or birch (*Betula pendula*). In the work of Pipíška et al. (2024), juvenile wood from nine underutilised European wood species, including larch, alder and birch, were compared with Norway spruce in single-species OSB panels. Their comparison showed that almost all alternative woods exhibited less thickness swelling, most notably larch OSB, which swelled only 12.0% compared to 25.4% for spruce OSB. However, all wood species tested achieved a lower modulus of elasticity (MOE) and modulus of rupture (MOR) than those of spruce. Alder's relatively strong

performance was linked to its longer strand length (107 mm versus 83 mm for spruce). Beck et al. (2009, 2010) similarly demonstrated that paper birch (*Betula papyrifera*) OSB panels benefited from increased strand length and yielded greater MOE and MOR. In a further comparison of birch (*Betula pendula* Roth.), willow (*Salix alba* L.) and poplar (*Populus tremula* L.), Dumitrascu et al. (2020) reported the highest MOE values for birch panels—5665 MPa parallel and 4597 MPa perpendicular to the strand orientation.

By substituting only a proportion of spruce strands with alternative wood species, it may be possible to improve some particular characteristics of an OSB without sacrificing its overall mechanical performance. For example, a mixture of aspen and birch strands with different vertical density profiles showed a 10% improvement in the bending (MOE) of a strand board (Jin et al. 2009). A mixture of strands, including 50% softwoods (spruce, fir, pine, larch), 25% beech and 25% low-density hardwood species (poplar, birch, willow, alder), was manufactured with different pressing parameters on an industrial continuous press (Ciobanu et al. 2014). Yet, studies on partial replacement – particularly involving larch, alder and birch—remain limited, despite these species' potential for future OSBs production in Central Europe. To address this deficiency, it was set out to investigate systematically the effects of substituting spruce strands with different proportions of larch, alder and birch on the resulting OSBs' physical, mechanical and, crucially, thermophysical properties.

2 Materials and methods

2.1 Materials

Juvenile logs (25–35 years old) were cut at the Habrůvka Forest District of the University Forest Enterprise, Mendel University in Brno with a diameter in the range of 100–150 mm from European larch (*Larix decidua*) – coded EL; alder (*Alnus glutinosa* (L.) Gaertn.) – coded AR; and birch (*Betula pendula*) – coded BI were split in half (for more accurate parallel orientation to the knife during the disintegration process) and cut to a length of 120 mm (the length of the final strands). All materials were immediately disintegrated into strands using a knife ring flaker (Maier MSF 1400, Dieffenbacher-CZ s.r.o., Czech Republic). Spruce strands were taken from standard production of OSBs in Kronospan, Jihlava (Czech Republic). The strands were dried in a kiln at 80 °C until they reached a moisture content (MC) of 4% ± 1%.

Polymeric 4,4-diphenyl methane diisocyanate (pMDI) resin (Ongronat® WO 2750; BorsodChem Zrt., Hungary) with a solid content of 100% and viscosity of 170–230 mPa·s,

was used to resinate the strands. A water-based paraffin wax emulsion (SVH 60; Dřevozpracující družstvo, Czech Republic) with a solid content of $60 \pm 2\%$ and a viscosity of approximately 24 mPa.s was also used.

2.2 Specimen manufacturing

Panels in which spruce strands were replaced with 10, 15 and 20% of larch, alder and birch strands were made (Table 1). For comparison, reference panels with only spruce strands were made. In total, this resulted in ten groups of panels. To produce single-layer OSBs, 3% pMDI resin by weight and 0.5% wax were used to resinate the strands. The resin was sprayed with an EL-4 model spinning disk atomiser (Coil Manufacturing, Surrey, BC, Canada) at a speed of 10,000 rpm. Three 12-mm thick panels with a target density of 600 kg/m^3 and dimensions of $600 \text{ mm} \times 600 \text{ mm}$ were made for each group. The OSB panels were formed without any attempt to orient the strands. The panels were pressed at a pressure of 3.5 MPa and a temperature of 180°C with 30 s of closing, 240 s in position and 80 s to vent with a continuous decrease in pressure.

2.3 Testing procedures

2.3.1 Dimensions of strands

Wooden blocks (made from logs) were measured, and the density of the raw material calculated. After strand manufacturing, all dimensions (thickness, width and length) were measured on 50 strands.

The specific surface values of the strands were calculated according to Moslemi (1974):

$$S_s = \frac{2}{t \cdot \rho}$$

where S_s is the specific surface (m^2/kg), t is the thickness of the strand (m) and ρ is the oven-dry wood density in the oven (kg/m^3).

The slenderness ratio (SR) is defined as the dimensionless ratio of the length and thickness of the strands and reflects the quality of the strands. Slenderness ratio is calculated according to Moslemi (1974):

$$SR = \frac{l}{t}$$

where l is the strand length (mm) and t is the strand thickness (mm).

The flatness ratio (FR) is defined as the dimensionless ratio of the width and thickness of the strands and is calculated according to Moslemi (1974):

$$FR = \frac{b}{t}$$

where b is the strand width (mm) and t is the strand thickness (mm).

2.3.2 Water contact angle measurement

Changes in the wettability of wood surfaces were determined by measuring the static contact angle using the sessile drop method. The evolution of the contact angle between a drop of deionised water and the test sample was tracked at intervals from the point at which the drop was laid on the surface (time steps of 5 s). Twelve sessile drops of $2 \mu\text{l}$ volume were used for the wettability evaluation of each wood species. A contact angle goniometer of SEE System E (Advex Instruments, Brno, Czech Republic) was used for the measurements.

2.3.3 Density and density profile

The density EN 323 (1994) was determined on five specimens cut from each panel (three panels for each group). Density profiles were measured on three $50 \text{ mm} \times 50 \text{ mm} \times 12 \text{ mm}$ specimens cut from each panel. Density profiles were obtained at intervals of 0.05 mm through the sample thickness using an X-ray density profile analyser (DPX300-LTE, IMAL, Italy), from which the average density profile was calculated.

2.3.4 Wood-water relations

Moisture content (MC) (EN 322 1993) was determined on 15 specimens for each group with dimensions of $50 \text{ mm} \times 50 \text{ mm}$. Thickness swelling (TS) (EN 317 1996)

Table 1 Manufacturing parameters of the strand boards produced for this study

Code of boards	Proportion of strands (wt. %)			
	Spruce	Larch	Alder	Birch
NS*	100	—	—	—
EL 10	90	10	—	—
EL 15	85	15	—	—
EL 20	80	20	—	—
AR 10	90	—	10	—
AR 15	85	—	15	—
AR 20	80	—	20	—
BI 10	90	—	—	10
BI 15	85	—	—	15
BI 20	80	—	—	20

*Reference board

and water absorption (WA) were measured on specimens with dimensions $50 \times 50 \text{ mm}^2$, after 24, 48 and 168 h of immersion in water.

TS (%) and WA (%) were calculated according to the following formulae:

$$TS = \frac{t_2 - t_1}{t_1} \cdot 100$$

$$WA = \frac{m_2 - m_1}{m_1} \cdot 100$$

where t_1 and m_1 —thickness (mm) and weight (g) of the test piece before immersion; and t_2 and m_2 —thickness (mm) and weight (g) of the test piece after immersion.

2.3.5 Mechanical properties

Mechanical testing was carried out using a Zwick® Z050 universal testing machine with testXpert v11.02 software and a 50 kN load cell (Zwick GmbH & Co. KG, Ulm, Germany). Three-point bending tests (EN 310 1993) were performed to determine the MOE and MOR of five specimens cut from each panel (three panels for each group), having dimensions of $290 \text{ mm} \times 50 \text{ mm}$, with a span of 240 mm. Internal bond (IB) strength was determined according to the EN 319 (1993) standard on 15 specimens for each group with dimensions $50 \text{ mm} \times 50 \text{ mm}$.

2.3.6 Thermophysical properties

Thermal conductivity, thermal diffusivity and specific heat capacity were measured by the pulse transient method (PTM), using RTB 1.02, a thermophysical tester developed at the Slovak Academy of Sciences (Štofanič et al. 2007). Twelve samples of each group were used for the thermal properties measurement. The samples were cut to dimensions of $100 \times 100 \times 12 \text{ mm}^3$. The pair of samples was clamped between two copper heat exchange plates. A thin plane heat source made from flexible nickel foil sandwiched between the wooden samples was used to generate the heat pulse. The time-dependent thermal response was recorded by thermocouples situated on the opposite sides of the test sample. Three repeated measurements were taken on each pair with the thermocouple at different locations on the sample surface, thus removing the effect of surface irregularities. The whole setup was housed inside a thermostat chamber (Lauda RK20), which stabilised the temperature with an accuracy of $\pm 0.02 \text{ K}$. Measurements were taken in the normal laboratory atmosphere (there was no vacuum).

2.4 Statistical analysis

The data were processed in Statistica 10 software (StatSoft Inc., USA) and evaluated using a one-factor analysis of variance (Anova), completed with Tukey's honest significance test (HSD test).

3 Results and discussion

3.1 Dimensions of strands

Sieve analysis (Fig. 1) revealed the relative distribution of the size fractions of strands made from the wood species under test. As shown in Fig. 1, larch, alder and birch produced a higher proportion of large strands (fraction over 20 mm) and a lower proportion of fine strands (fractions < 1 mm) than spruce wood. The results of the strand measurements are presented in Table 2, which includes the dimensions (length, width and thickness), slenderness ratio (SR) and flatness ratio (FR) of the samples. Significant differences in strand size and aspect ratios were observed among the wood species. On average, alder wood strands were shorter and thinner than spruce, whereas larch and birch strands were longer and thicker. Alder, larch and birch strands were wider than those of spruce. The same equipment and identical disintegration process parameters were used to produce strands from all wood species. Therefore, the observed differences in strand size, geometry, and particle size distribution are not attributable to variations in the disintegration process or equipment. Instead, these differences are most likely related to inherent species-specific characteristics, such as variations in wood density, morphological structure and mechanical performance, which influence strand formation behavior. The SR and FR values of alder strands were 9.6% and 33.3% higher than spruce; 54.2% and 100.0% higher than larch; and 45.1% and 44.0% higher than birch, respectively. These differences in strand geometry may significantly influence the mechanical performance of the manufactured boards, particularly their bending strength. Therefore, it can be anticipated that substituting spruce with alder may lead to an improvement in the bending strength of the boards.

Considering the geometry and wetting properties of the wood strands, alder appears to be the most comparable with spruce. Alder showed similar wetting behaviour (Fig. 2) and had a nearly identical density to spruce. From a technological viewpoint, substituting spruce with alder would require minimal adjustments, as the mass of alder strands required to achieve a given board density would be effectively the same as that of spruce strands.

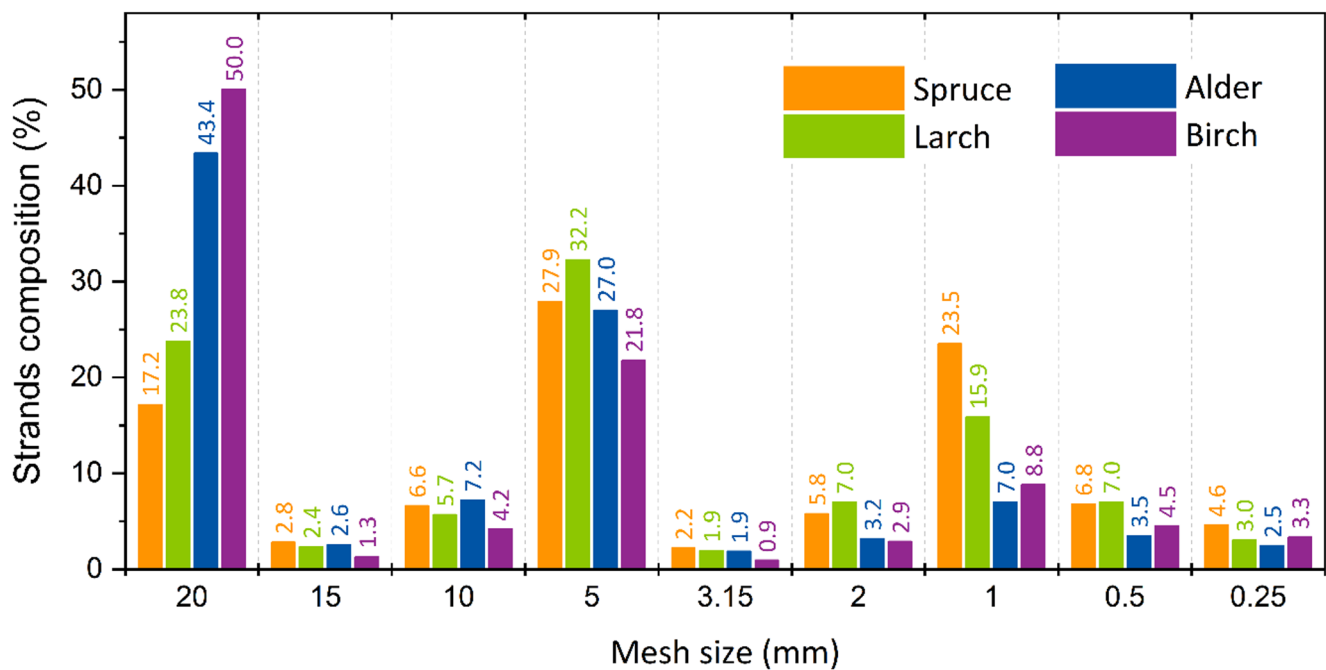


Fig. 1 Sieve analysis – percentage representation of spruce, larch, alder and birch strands

Table 2 Average strand dimensions

Wood species	Thickness (mm)	Width (mm)	Length (mm)	Slenderness ratio	Flatness ratio	Specific surface (m ² /kg)
Norway spruce (NS)*	0.63 (0.20)	16.8 (8.4)	85 (27)	135	27	8.1
European larch (EL)	1.03 (0.46)	18.2 (11.5)	99 (29)	96	18	4.1
Alder (AR)	0.56 (0.15)	20.4 (12.1)	83 (26)	148	36	8.8
Birch (BI)	0.97 (0.52)	24.4 (14.0)	99 (24)	102	25	4.1

* Reference. Numbers in parentheses represent the standard deviation

Larch strands had less favourable geometric characteristics than spruce and alder; however, they had better wetting performance than the other species (Fig. 2). This enhanced wettability partially compensates for the inferior geometry. Furthermore, the density of larch was comparable to that of spruce and alder, supporting its potential use as an alternative. In contrast, birch strands showed less favourable geometry but better wetting behaviour than spruce and comparable with alder (Fig. 2). Its higher density also resulted in reduced compressibility of the strand mat and inferior inter-strand contact during board formation. Consequently, when targeting the same board density, a lower mass of birch strands would be required, which may affect the properties of the resulting board.

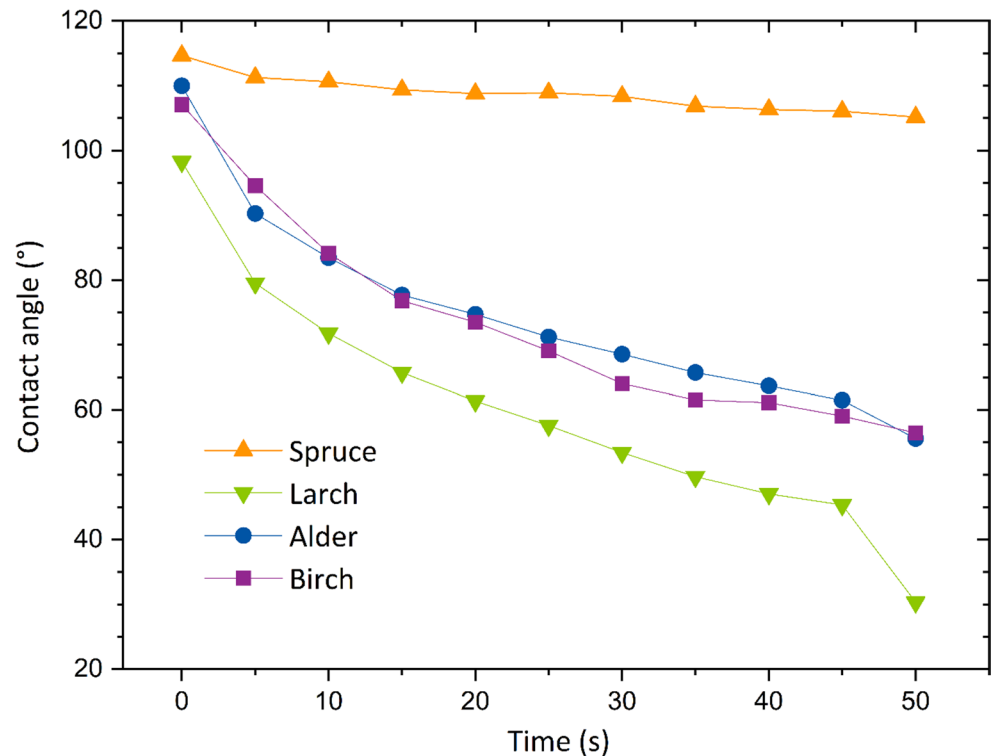
3.2 Density and density profile

The final mean density of the strand boards group ranged from 615 kg/m³ for AR 20 to 694 kg/m³ for EL 15 (Table 3). The target density was 600 kg/m³ and all average densities exceeded this value. However, there was no significant

difference between the densities of the boards made from spruce (reference) and any mixture of larch, alder or birch with spruce. The higher average density of the panels was mainly observed in the larch and birch, which may have been caused by the higher density of the wood and the easier densification of the strands of these wood species.

Large relative standard deviations in strand board densities (4–6%) can be attributed to both natural variance of wood material and the insufficient size of the tested specimen (50×50 mm²) with respect to the small number of substituted strands. The small size of the test specimen increases the variance of the average number of substituted strands expected to be found in the cut specimen. According to our simple statistical analysis, for a single cut specimen, the variance of substituted strands can be as much as 50%. For a more precise analysis of OSB with mixed wood strand content, it would be advisable to measure density on larger volume samples. It was adopted a statistical averaging by measuring five specimens cut from the same board.

The measured vertical density profiles (VDPs) of the boards produced were consistent with Kelly (1977), with the

Fig. 2 Contact angle measurement**Table 3** Physical properties of strand boards

Code of boards	Density of raw material (kg/m ³)	Density (kg/m ³)	Moisture content (%)
NS*	392 (12)	650 (27) A, B, C	9.7 (0.1) B, C, D
EL 10	470 (37)	667 (39) B, C	9.3 (0.2) A
EL 15		694 (21) C	9.5 (0.1) A, B
EL 20		661 (39) A, B, C	9.6 (0.1) B
AR 10		630 (26) A, B	9.6 (0.3) B
AR 15	407 (33)	668 (35) B, C	9.6 (0.1) B
AR 20		615 (33) A	9.7 (0.3) B, C
BI 10	509 (23)	650 (32) A, B, C	10.0 (0.3) E
BI 15		655 (36) A, B, C	10.0 (0.1) D, E
BI 20		667 (40) B, C	9.9 (0.2) C, D, E

*Reference. Means with the same letter in the column do not differ statistically by the Tukey test ($\alpha = 0.05$). Numbers in parentheses represent the standard deviation

typical U shape in which higher densities are in the face layers and lower density is in the core layer (Fig. 3). Nevertheless, as shown in Table 3, the average densities of all panels did not differ significantly. Panels with 15% of larch, alder and birch showed lower surface density in VDPs. Beck et al. (2010) showed the VDP of paper birch OSB without high peaks on the surfaces of the panels, which was influenced by the pressing parameters.

3.3 Wood–water interaction

The TS values after 24, 48 and 168 h of immersion for strand boards made by replacing spruce strands with larch, alder and birch strands were consistent except for AR 20 (Table 4). Similar trends between the groups were observed after 24, 48 and 168 h of immersion. After 24 h of immersion, the TS values for the AR 15 and AR 20 panels met the 15% minimum requirement of the European standard EN 300 (2006) for OSB/3. The inclusion of less than 20% of larch, alder or birch strands in the strand board did not influence the TS. Pipiška et al. (2024) observed that strand boards made of 100% larch, alder and birch showed lower average values for TS after 24 and 48 h compared to spruce strand boards; however, only larch panels swelled less than spruce.

Similarly, the only significant difference in average WA values after 24, 48 and 168 h of immersion was shown by the decrease in AR 20 and increase in BI 15 (Table 5). After 48 h, alder strand boards showed lower average WA than the reference panels which may have been caused by the speed of the water absorption of alder wood. It is possible to claim the same conclusion as for TS, that the replacement of less than 20% of strands with larch, alder or birch does not influence the WA. Pipiška et al. (2024) observed on the 100% panels made out of the larch, alder and birch that only larch absorbs significantly less water than spruce strand board.

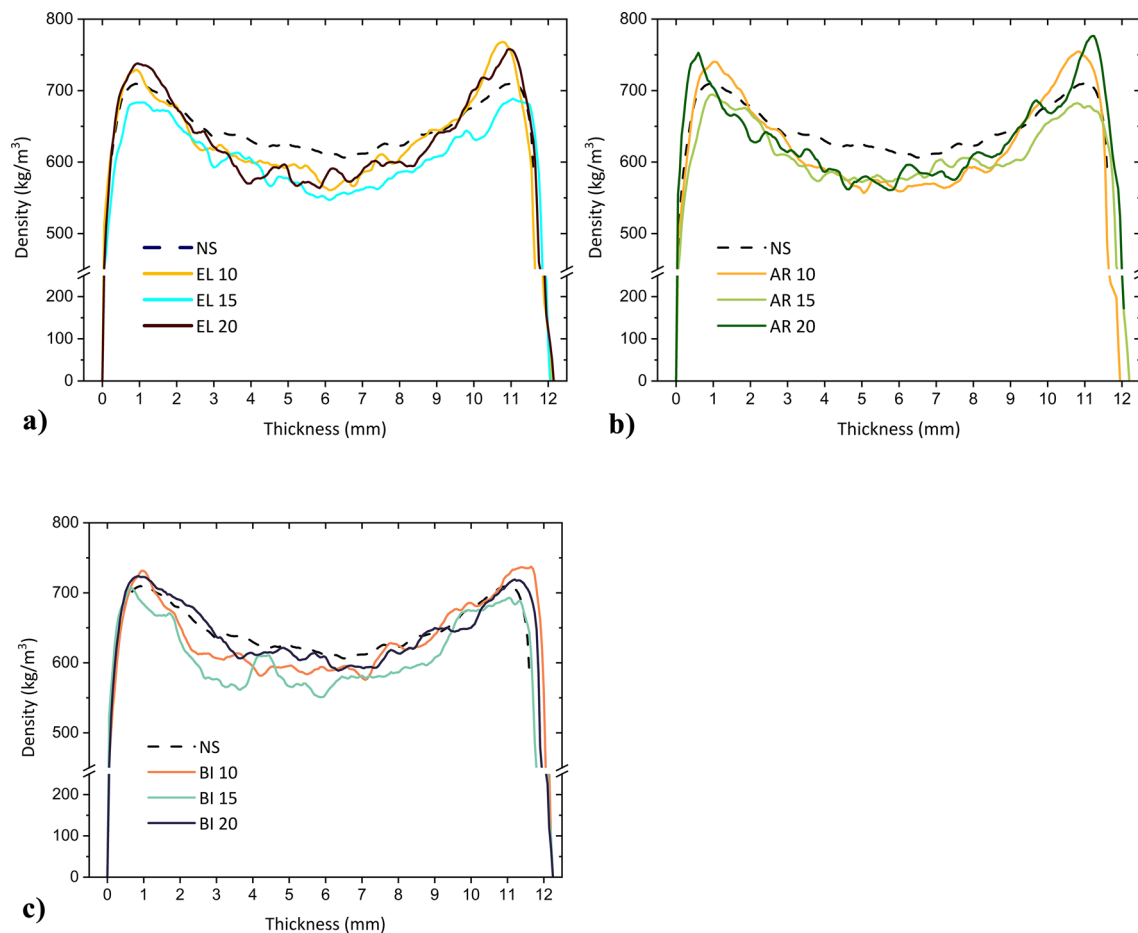


Fig. 3 Vertical density profile for strand boards in which spruce strands are replaced by those of larch (a), alder (b) and birch (c) in varying proportions

Table 4 Thickness swelling of strand boards

Code of boards	TS 24 h (%)	TS 48 h (%)	TS 168 h (%)
NS*	17.6 (3.9) B	22.6 (4.1) B	27.6 (4.9) A, B
EL 10	15.8 (3.9) B	24.0 (3.3) B	27.1 (3.6) A, B
EL 15	15.9 (3.6) B	26.0 (3.4) B	31.3 (4.7) B
EL 20	15.1 (4.1) B	23.1 (2.8) B	29.7 (4.1) A, B
AR 10	16.5 (3.8) B	23.5 (2.7) B	31.0 (4.4) B
AR 15	14.3 (2.9) B	22.4 (3.1) B	28.4 (3.7) A, B
AR 20	9.9 (1.4) A	17.7 (2.2) A	25.8 (3.2) A
BI 10	16.6 (3.7) B	24.0 (2.6) B	29.0 (3.3) A, B
BI 15	17.0 (3.3) B	22.8 (2.0) B	29.5 (3.4) A, B
BI 20	16.0 (3.0) B	24.3 (3.3) B	31.9 (4.1) B

*Reference. Means with the same letter in the column do not differ statistically by the Tukey test ($\alpha=0.05$). The numbers in parentheses represent the standard deviation

3.4 Mechanical properties of panels

Strand boards produced by replacing spruce strands with larch, alder and birch exhibited the same average MOR and MOE values as the reference samples made from 100%

spruce strands (Figs. 4 and 5). The highest MOR value of 28.4 MPa was found for panels with 10% of birch (BI 10) and the lowest value, 20.8 MPa, was observed on the panels with 15% of alder (AR 15) (Fig. 4). Although higher panel density is generally associated with higher MOR, the differences observed in this study did not follow this trend, as panels with lower density did not consistently exhibit lower MOR values. The lower MOR of the specimen AR 15 may have been caused by the lower surface densities shown at VDP on these specimens. A generally similar trend in changes in the average values of MOR and MOE was observed. The lowest value of MOE (3400 MPa) was observed for AR 15 and the highest (4415 MPa) for EL 15 (Fig. 5). All average MOR values exceeded the minimum requirements of 20 MPa specified in EN 300 (2006) for OSB/3. All average MOE values, except for AR 15 (3400 MPa), exceeded the minimum requirements of 3,500 MPa for OSB/3 EN 300 (2006).

Dumitrascu et al. (2020), examining birch OSBs, found MOR average values of 33 and 36 MPa (perpendicular and

Table 5 Water absorption of strand boards

Code of boards	WA 24 h (%)	WA 48 h (%)	WA 168 h (%)
NS*	43.2 (4.4) B, C	67.1 (6.5) D, E	92.0 (5.9) A
EL 10	42.6 (5.0) B, C	59.7 (5.7) B, C, D	95.1 (6.6) A
EL 15	46.6 (7.6) B, C, D	65.8 (8.9) C, D, E	98.8 (8.8) A
EL 20	41.5 (5.8) B, C	59.4 (8.4) B, C, D	93.4 (7.6) A
AR 10	40.0 (4.3) A, B	52.9 (4.8) A, B	92.0 (6.3) A
AR 15	41.2 (3.4) A, B, C	57.0 (5.4) A, B, C	96.5 (5.7) A
AR 20	32.8 (3.6) A	49.4 (5.3) A	89.1 (6.4) A
BI 10	49.5 (7.8) C, D	66.9 (7.6) D, E	99.1 (8.5) A
BI 15	54.3 (11.4) D	70.6 (11.4) E	97.7 (12.3) A
BI 20	48.6 (9.7) B, C, D	64.5 (9.1) C, D, E	91.5 (9.3) A

* Reference. Means with the same letter in the column do not differ statistically by the Tukey test ($\alpha=0.05$). The numbers in parentheses represent the standard deviation

parallel direction), which is higher than the values in this study, which ranged from 22 to 28 MPa according to the proportion of birch strands. In the same study, MOE reached 4597 and 5665 MPa (perpendicular and parallel direction), which is also higher than the values in this study of 3682 to 4328 MPa according to the proportion of birch. In the study, Dumitrascu et al. (2020), made 100% birch OSBs, which may have caused the differences in the MOR and MOE.

Higher average IB values were observed in boards made from 10–20% larch, alder and birch (Fig. 6). The average IB values ranged from 0.41 MPa for the reference panels

(NS) to 0.70 MPa for the ones made from 20% alder (AR 20). These results show that the use of strands with higher density led to higher IB values than the reference panels made from 100% spruce strands. The IB values of all panels met the standard requirements, and showed adequate bonding between different wood species and spruce strands. All boards met the European standard EN 300 (2006) OSB/3 requirement of 0.32 MPa.

Beck et al. (2009) found higher values of IB ranging from 0.70 to 0.82 MPa in birch oriented strand lumber, where the density was 650 kg/m³. The IB of birch panels ranging from 0.53 to 0.60 MPa is comparable to the other study of OSBs made from paper birch, which reported average values from 0.45 to 0.68 MPa, varying with the amount of resin used (Beck et al. 2010). Average IB strength values in a study by Pipiška et al. (2024) of 100% larch, alder and birch panels were higher than 0.6 MPa, partially corresponding with our results, especially for larch and alder. However, when it comes to birch strand boards, it seems that more than 20% birch should be used to improve IB values.

3.5 Thermophysical properties

OSB is a structurally engineered wood product characterised by its heterogeneous internal structure, pronounced inhomogeneity and elevated surface porosity, including variable surface texture; all of these properties significantly influence its thermophysical behaviour (Sugahara et al. 2022; Núñez-Decap et al. 2025). In the present study, the

Fig. 4 Bending strength (MOR) of strand boards made by replacing spruce

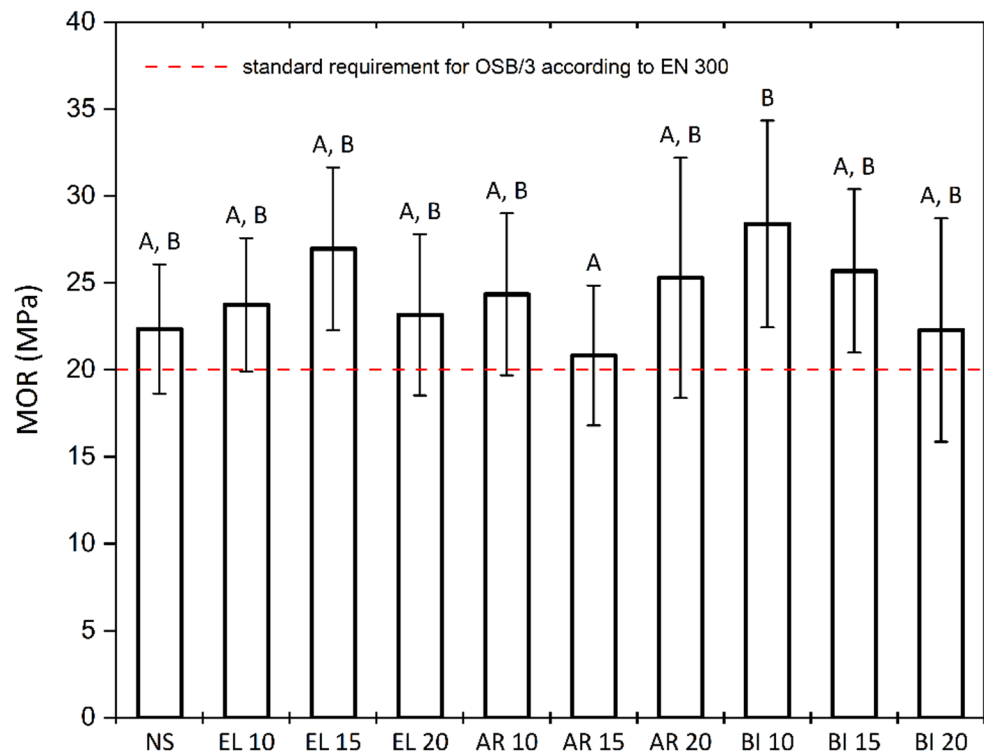


Fig. 5 Modulus of elasticity (MOE) of strand boards made by replacing spruce

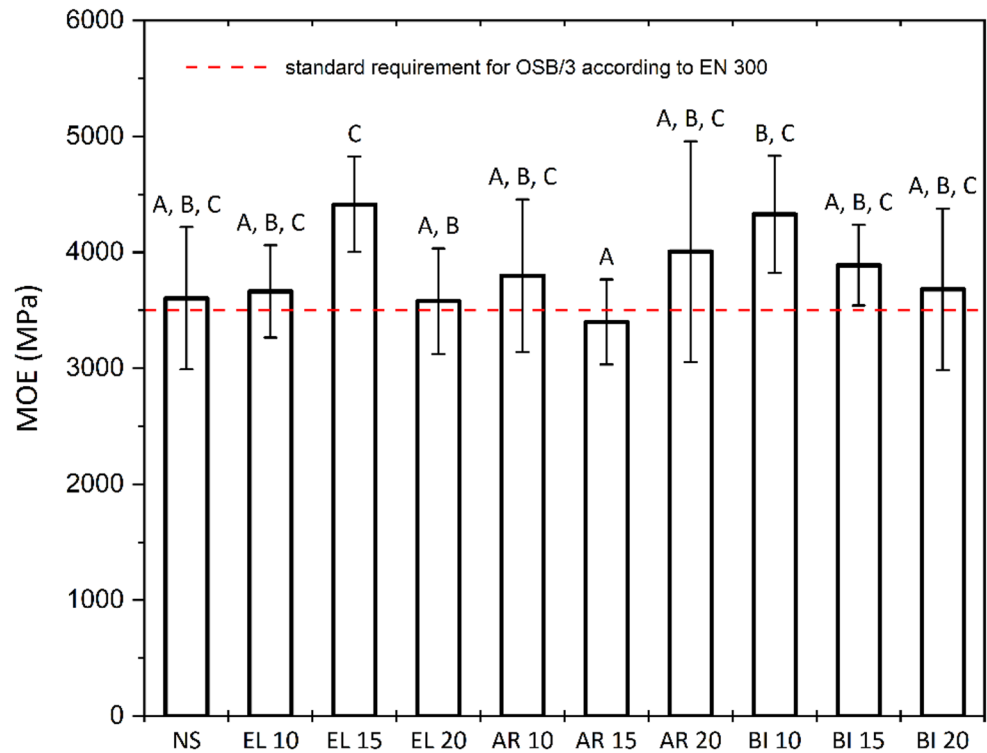
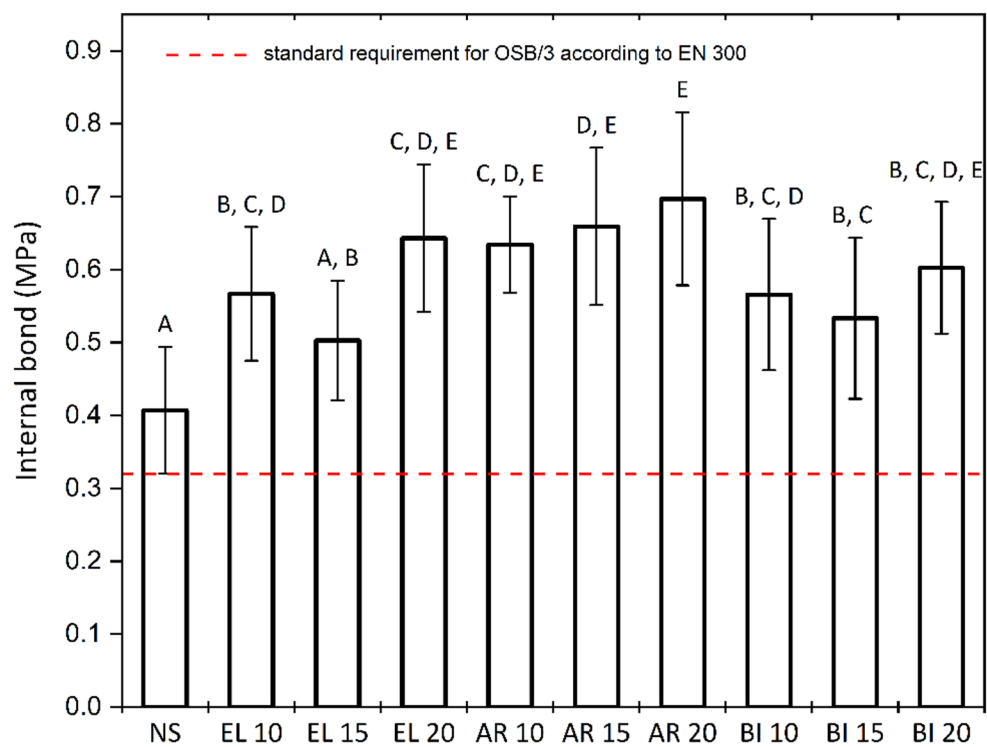


Fig. 6 Internal bond (IB) of strand boards made by replacing spruce



inherent heterogeneous nature of standard OSB was further enhanced by partially substituting spruce with particles of higher density. The impact of this on the final thermophysical properties of the boards is summarised in Table 6.

Only the AR 15, AR 20 and BI 20 samples showed a statistically significantly higher thermal conductivity λ than

the reference ($p < 0.05$). However, absolute λ differences were very small (~ 0.01 W/m·K) in our study. For context, a typical OSB (around 650 kg/m³) has $\lambda \approx 0.130$ W/m·K, and the literature reports values of approximately 0.13 to 0.17 W/m·K depending on the method of processing. Thus, the observed difference of ~ 0.01 W/m·K corresponds only

Table 6 Thermophysical properties of strand boards made by replacing spruce

Code of boards	Thermal conductivity λ [W/(m·K)]	Thermal diffusivity α (mm ² /s)	Specific heat capacity c_p [J/(kg·K)]
NS*	0.123 (0.005) A, B	1.40 (0.07) A	1,375 (58) A
EL 10	0.131 (0.004) C, D	1.40 (0.05) A	1,456 (26) B
EL 15	0.130 (0.007) C, D	1.37 (0.03) A	1,475 (23) B
EL 20	0.130 (0.003) C, D	1.39 (0.03) A	1,467 (37) B
AR 10	0.122 (0.005) A	1.37 (0.03) A	1,433 (47) A, B
AR 15	0.135 (0.003) D	1.36 (0.08) A	1,442 (68) A, B
AR 20	0.129 (0.003) B, C, D	1.36 (0.04) A	1,429 (41) B
BI 10	0.126 (0.004) A, B, C	1.37 (0.04) A	1,458 (32) B
BI 15	0.131 (0.003) C, D	1.38 (0.06) A	1,464 (49) B
BI 20	0.133 (0.006) D	1.39 (0.04) A	1,457 (33) B

*Reference. Means with the same letter in the column do not differ statistically by the Tukey test ($\alpha=0.05$). The numbers in parentheses represent the standard deviation

to 1/4 variability of λ between OSBs. Neither did the thermal diffusivity α show any statistically significant difference between groups. This was expected, since $\alpha=\lambda/(\rho \cdot c_p)$ and our small λ changes (and compensating density/ c_p changes) yielded negligible variation. In the literature, α for wood-based composites is generally reported as insensitive to modest density/moisture differences.

On the other hand, modified OSB groups gave higher numbers for specific heat capacity c_p than the reference. The higher c_p was statistically significant ($p<0.05$) for all groups, except for AR 10 and AR 20, where the variance of the measured data was too high. The modestly higher specific heat is advantageous for thermal performance when boards are used in timber construction. Materials with higher c_p can store more heat per unit mass (Sulttan et al. 2024). The greater heat capacity in our boards means they had slightly greater thermal inertia: they would absorb or release more heat for a given temperature change (Araya Olguin 2021). This improved heat storage can help stabilise indoor temperatures and buffer thermal fluctuations. Thus, the greater c_p observed, though only slightly so, represents a beneficial side effect of using denser wood strands in OSB composition.

4 Conclusion

Strands made out of broadleaf wood species (alder, birch) are wider than spruce and larch, which can improve their bending properties and usability. A negative relationship between the density of the raw material and the slenderness ratio of strands was found.

There is a potential to decrease WA in OSBs by incorporating more alder wood. At the same time, the TS of boards made with larch, alder or birch strands was no greater than spruce boards.

The higher values of IB shows potential for reducing the amount of resin used in making OSBs by incorporating higher density strands.

Replacing less than 20% of spruce strands with larch, alder or birch strands had no influence on the physical and mechanical properties of the resulting boards. Our general conclusion is that it is possible to replace a smaller amount of spruce strands with other wood species without any negative impact on the final properties of the panels. Based on our results, it was hypothesised that more high-density strands can reduce the need for adhesive in making panels.

Based on a comprehensive assessment of strand geometry and wettability and the resulting board properties, the suitability of alternative wood species to replace spruce can be ranked as follows: alder, followed by larch and birch (alternatively, larch, followed by alder and birch), depending on the relative importance assigned to each parameter.

Acknowledgements This research was supported by the Ministry of Education, Youth and Sports of the Czech Republic under project No. INTER-EXCELLENCE - LUASK22094 and Slovak Research and Development Agency under contract Nos. SK-CZ-RD-21-0100 and APVV-19-0269. The EU NextGenerationEU supported this work through the Recovery and Resilience Plan for Slovakia under project No. 09I03-03-V01-00124.

Author contributions T.P: Conceptualization, Methodology, Investigation, Supervision, Project administration, Writing – original draft preparation; P.B: Writing – original draft preparation, Writing – review & editing, Methodology, Investigation, Supervision; J.R: Methodology, Investigation, Writing – review & editing; M.N: Methodology, Investigation, Writing – review & editing; M.Š: Methodology, Investigation, Writing – review & editing; P.K: Writing – review & editing; R.R: Methodology, Investigation, Writing – review & editing; R.I: Methodology, Investigation, Writing – review & editing; L.K: Methodology, Investigation, Writing – review & editing; M.J: Methodology, Investigation, Writing – review & editing; All authors have read and agreed to the published version of the manuscript.

Funding Open access publishing supported by the institutions participating in the CzechELib Transformative Agreement.

Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declare no competing interests.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate

if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Akrami A, Barbu MC, Fruehwald A (2014) Characterization of properties of oriented strand boards from beech and poplar. *Eur J Wood Wood Prod* 72:393–398. <https://doi.org/10.1007/s00107-014-0793-9>
- Akrami A, Fruehwald A, Barbu MC (2015) Supplementing pine with European beech and poplar in oriented strand boards. *Wood Mater Sci Eng* 10(4):313–318. <https://doi.org/10.1080/17480272.2014.942880>
- Akyildiz MH, Dogan K, Kaymakci A (2018) The impact of density and mixture ratio of melamine on some properties of oriented strand board. *Maderas Cienc Tecnol* 20(3):417–430. <https://doi.org/10.4067/S0718-221X2018005031201>
- Araya Olguin RJ (2021) Moisture transport and changes in mechanical properties in oriented strand board: experimental and modeling. In: A thesis for the degree of Master of Science. University of Alberta
- Beck K, Cloutier A, Alexander S, Beauregard R (2010) Comparison of mechanical properties of oriented strand board made from trembling aspen and paper birch. *Eur J Wood Wood Prod* 68(1):27–33. <https://doi.org/10.1007/s00107-009-0350-0>
- Beck K, Cloutier A, Salenikovitch A, Beauregard R (2009) Effect of strand geometry and wood species on strandboard mechanical properties. *Wood Fiber Sci*: 267–278
- Čermák P, Mikita T, Kadavý J, Trnka M (2021) Evaluating recent and future climatic suitability for the cultivation of Norway spruce in the Czech Republic in comparison with observed tree cover loss between 2001 and 2020. *Forests* 12(12):1687. <https://doi.org/10.3390/f12121687>
- Chiromito EMS, Campos CI, Ferreira BS, Christoforo AL, Lahr FAR (2016) Mechanical properties of wood panels produced with wood strands with three different lengths. *Sci For* 44:175–180
- Ciobanu VD, Zeleniuc O, Dumitrascu AE, Lepadatescu B, Iancu B (2014) The influence of speed and press factor on oriented strand board performance in continuous press. *BioResources* 9(4):6805–6816
- Dumitrascu AE, Lunguleasa A, Salca EA, Ciobanu VD (2020) Evaluation of selected properties of oriented strand boards made from fast growing wood species. *BioResources* 15(1):199–210. <https://doi.org/10.15376/biores.15.1.199-210>
- EN 300 (2006) Oriented strand boards (OSB)—definitions, classification and specifications. European Committee for Standardization, Brussels
- EN 310 (1993) Wood-based panels—determination of modulus of elasticity in bending and of bending strength. European Committee for Standardization, Brussels
- EN 317 (1996) Particleboards and fibreboards—determination of swelling in thickness after immersion in water. European Committee for Standardization, Brussels
- EN 319 (1993) Particleboards and fibreboards—determination of tensile strength perpendicular to the plane of the board. European Committee for Standardization, Brussels
- EN 322 (1993) Wood-based panels—determination of moisture content. European Committee for Standardization: Brussels
- EN 323 (1993) Wood-based panels—determination of density. European Committee for Standardization, Brussels
- Febrianto F, Sahroni Hidayat W, Bakar ES, Kwon GJ, Kwon JH, Kim NH (2012) Properties of oriented strand board made from Betung bamboo (*Dendrocalamus asper* (Schultes. f) Backer ex Heyne). *Wood Sci Technol* 46, 53–62. <https://doi.org/10.1007/s00226-010-0385-8>
- Food and Agriculture Organisation of the United Nations, FAOSTAT Data (2024). Available online: <https://www.fao.org/faostat/en/#data/FO>
- Ibrahim NI, SaifulAzry SOA, Sultan MTH, Fajobi AO, Lee SH, Ilyas RA (2022) Oriented strand board from oil palm biomass. In: *Oil Palm Biomass for Composite Panels* (pp. 267–281). Elsevier. <https://doi.org/10.1016/B978-0-12-823852-3.00006-4>
- Jandl R (2020) Climate-induced challenges of Norway spruce in Northern Austria. *Trees for People* 1:100008
- Jin J, Dai C, Hsu WE, Yu C (2009) Properties of strand boards with uniform and conventional vertical density profiles. *Wood Sci Technol* 43(7–8):559–574. <https://doi.org/10.1007/s00226-009-0248-3>
- Kelly MW (1977) Critical literature review of relationships between processing parameters and physical properties of particleboard. In: *Gen. Tech. Rep. FPL-10*. US Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, pp. 10
- Khoo KC, Rahim S, Yoichi T, Koh MP, Mohd Nor MY (2008) Oriented strand board from oil palm stem. In: *Utilisation of Oil Palm Tree: Strategizing for Commercial Exploitation*
- Klimo E, Hager H, Kulhavy J (2000) Spruce monocultures in Central Europe: problems and prospects. European Forest Institute, Joensuu
- Köhl M, Linser S, Prins K (2020) State of Europe's forests 2020. Ministerial Conference on the Protection of Forests in Europe. FOREST EUROPE Liaison Unit, Bratislava
- Lunguleasa A, Dumitrascu AE, Spirchez C, Ciobanu VD (2021) Influence of the strand characteristics on the properties of oriented strand boards obtained from resinous and broad-leaved fast-growing species. *Appl Sci Basel* 11(4):1784. <https://doi.org/10.3390/app11041784>
- Moslemi AA (1974) Particleboard, vol. 1: materials. Southern Illinois University Press, Carbondale, pp. 256
- Neuner S, Albrecht A, Cullmann D, Engels F, Griess VC, Hahn WA, Hanewinkel M, Härtl F, Kölling C, Staupendahl K, Knoke T (2015) Survival of Norway spruce remains higher in mixed stands under a dryer and warmer climate. *Glob Change Biol* 21(2):935–946. <https://doi.org/10.1111/gcb.12751>
- Núñez-Decap M, Díaz-Stuardo F, Vidal-Vega M, Opazo-Carlsson C, Moya-Rojas B, Hernández-Castillo V (2025) Preliminary investigation of the properties of oriented strand boards produced using green adhesives. *Buildings* 15(10):1702. <https://doi.org/10.3390/buildings15101702>
- Okino EYA, Teixeira DE, De Souza MR, Santana MAE, De Sousa ME (2004) Properties of oriented strandboard made of wood species from Brazilian planted forests: Part 1: 80 mm-long strands of *Pinus taeda* L. *Holz Roh Werkst* 62(3):221–224. <https://doi.org/10.1007/s00107-004-0472-3>
- Pham VT, Schöpper C, Klüppel A, Mai C (2021) Effect of wood and panel density on the properties of lightweight strand boards. *Wood Mater Sci Eng* 16(4):237–245. <https://doi.org/10.1080/17480272.2019.1705906>
- Pipiška T, Leavengood S, Kamke FA, Král P (2021) Properties of the Western Juniper (*Juniperus occidentalis*) strandboard. *BioResources* 16(2):2853–2860. <https://doi.org/10.15376/biores.16.2.2853-2860>
- Pipiška T, Nociar M, Král P, Ráhel' J, Bekhta P, Réh R, Křišťák L, Jopek M, Pijáková B, Wimmer R, Šernek M (2024) Characterization of randomly oriented strand boards manufactured from juvenile wood

- of underutilized wood species. *Eur J Wood Wood Prod* 82(4):927–941. <https://doi.org/10.1007/s00107-024-02080-4>
- Schlyter P, Stjernquist I, Barring L, Jönsson AM, Nilsson C (2006) Assessment of the impacts of climate change and weather extremes on boreal forests in northern Europe, focusing on Norway spruce. *Clim Res* 31(1):75–84. <https://doi.org/10.3354/cr031075>
- Štofanik V, Markovič M, Boháč V, Dieška P, Kubičár Ľ (2007) RT-Lab-the equipment for measuring thermophysical properties by transient methods. *Meas Sci Rev* 7(3):15–18
- Sugahara ES, Arroyo FN, De Campos CI, Botelho EC, Christoforo AL, Costa ML, Lahr FAR (2022) Thermal treatment of OSB panels: a systematic and bibliometric overview. *Eur J Wood Wood Prod* 80(6):1293–1307. <https://doi.org/10.1007/s00107-022-01849-9>
- Sulttan S, Nabipour H, Rohani S (2024) Heat release rate of oriented strand board through cone calorimetry test: a numerical analysis. *Eur J Wood Wood Prod* 82(3):871–884. <https://doi.org/10.1007/s00107-023-02036-0>
- Sun Y, Yu W, Wei X, Ge L, Guo Z, Zhang Y (2021) Bamboo strand-based structural composite lumber: influence of technological parameters on physico-mechanical properties. *Constr Build Mater* 271:121795. <https://doi.org/10.1016/j.conbuildmat.2020.121795>
- Zhuang B, Cloutier A, Koubaa A (2022) Physical and mechanical properties of oriented strand board made from Eastern Canadian softwood species. *Forests* 13(4):523. <https://doi.org/10.3390/f13040523>

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.