Utilization of spruce (*Picea abies* [L.] Karst.) and beech (*Fagus sylvatica L.*) wood in plywood production using different processing pressures

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ABSTRACT: In this research the spruce plywood board and combined spruce-beech plywood board were prepared in laboratory conditions using two levels of processing pressure. The bending properties in perpendicular and longitudinal direction were measured and compressibility and density were specified. Considering the obtained results, there was found an overall increase of the bending properties in spruce plywood manufactured by the higher pressure and a decline of properties perpendicular to the grain in combined spruce-beech plywood board. On the other hand, combined spruce-beech plywood boards produced by the common processing pressure performed better than both types of spruce plywood.

Keywords: composite; compression; veneer; density profile

Wood as a raw material, including its natural features, is utilized in the wood panel industry in various veneer based materials. In the form of plywood it can take a part for instance in the building branches (Stephen et al. 2005). The plywood as a material itself preserves the advantages of wood such as considerable weight or comparable mechanical properties and widely mitigates the disadvantages of natural anisotropy at the same time. Details of production techniques, advantages and disadvantages of these panels were widely described in many literature sources (Baldwin 1995; Walker et al. 2006; Thoemen et al. 2010; Forest Product Laboratory 2010).

Strength properties of plywood boards are considered as sufficient in many fields; however, it is not suitable for using in structural applications where high strength characteristics are required. Various approaches to achieve better mechanical performance have been revealed, for example the concept of wood densification has been known since the late 19th century (Kollmann et al. 1975). This process was found to be successful in increasing the strength properties. A similar approach was found viable in the field of plywood production when a roller press, compressing each veneer separately, compressed each ply before the plywood assembly, and certain properties were modified (Bekhta et al. 2009). The compressed veneers were also used in the lamination of fibreboard (Buyuksan et al. 2012) to achieve better bending properties. Moreover, veneer compression was found to positively affect the adhesive consumption (Bekhta, Marutzky 2007). Although density may play an important role, the properties vary according to the changed material species in the compact boards as well. Properties of various combined plywood based materials were reported already (Adin et al. 2004; Shukla, Kamdem 2007; Kral et al. 2014). It was found that a change of material can optimize the properties of commonly produced panels and provide additional attributes. In our research we propose to densify the plywood boards, however in a step when the compact pre-assembled panel is pressed by a press. We will increase the processing pressure and observe the influence on

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the bending properties, compressibility and overall density of boards. At the same time we have a goal to observe the effect of such a treatment using different species. We propose to produce a traditional spruce plywood board and an additional novel type of the combined, spruce-beech plywood board and observe the mechanical performances. In our research the following hypotheses are formulated: (1) the bending properties of plywood boards are increased through the increased processing pressure; (2) the combined plywood boards are a viable alternative to the traditional plywood boards.

MATERIAL AND METHODS

Sample preparation. According to the research design (Table 1), plywood panels in different pressure conditions were produced. The spruce veneers and beech veneers were used in plywood composites (Fig. 1). The plywood panels were produced in a hydraulic press under the following conditions; the spruce plywood boards were pressed at 1.6 N·mm^{-2} (SPR 1.6) and 3.2 N·mm^{-2} (SPR 3.2) and combined plywood board with beech surface layers was pressed at 1.9 N·mm^{-2} (COMB 1.9) and 3.8 N·mm^{-2} (COMB 3.8). The veneers for plywood board production were supplied by the plywood producer DIAS.EU from Uherský Ostroh. The lower value of the pressure is defined according to recommended processing of industrial production and the second pressure is double. All boards were separately pressed in a hydraulic press at a temperature of 130°C for 10 min. Urea formaldehyde (UF) resin "PREFERE 4170" (UF) provided by Dynea™ and "KORNOADD HL 100" hardener were used for gluing in an amount of 120 g·m^{-2}. The boards of 600 × 600 mm in size were produced and they were trimmed to the final dimension of 500 × 500 afterwards. All boards were conditioned and sampled afterwards, in accordance with EN 326-1.

Table 1. Plan of layers utilized in plywood board manufacturing (layer 1–5 in 2.5 mm)

Board	SPR 1.6	COMB 1.9	SPR 3.2	COMB 3.8
Processing pressure (N·mm^{-2})	1.6	1.9	3.2	3.8
Layer 1		beech	beech	beech
Layer 2				
Layer 3	spruce	spruce	spruce	spruce
Layer4				
Layer 5		beech	beech	beech

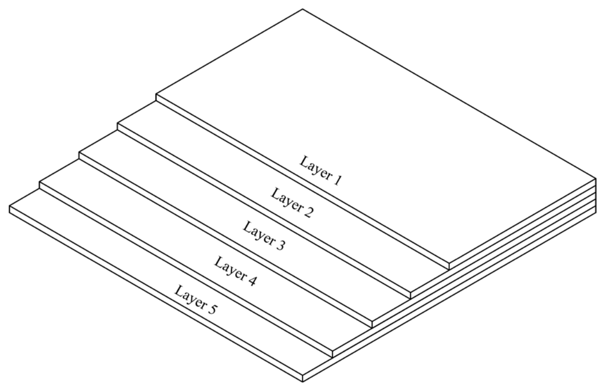

Fig. 1. Layers in plywood board

Testing methods. The mechanical properties were measured employing a ZWICKZ050® universal testing machine with testXpert V11.02 software (Zwick GmbH & Co. KG, Ulm, Germany). The basic mechanical properties using standardized methods were obtained. The bending properties (EN 310) and density (EN 323) were measured. All samples were conditioned in a climate chamber obtaining 9% moisture content. On top of it compressibility as a difference between total veneer thicknesses before and after compression was measured manually with a calliper (Eq. 1).

$$C = \frac{t_1 - t_2}{t_1} \times 100\ (\%) \qquad (1)$$

where:

t_1 – thickness before the pressing of plywood,

t_2 – total thickness after the plywood pressing process.

The samples were cut according to Fig. 2, where longitudinal direction and direction across the grain was considered. Eight bending samples and 16 samples for density measurement were as-

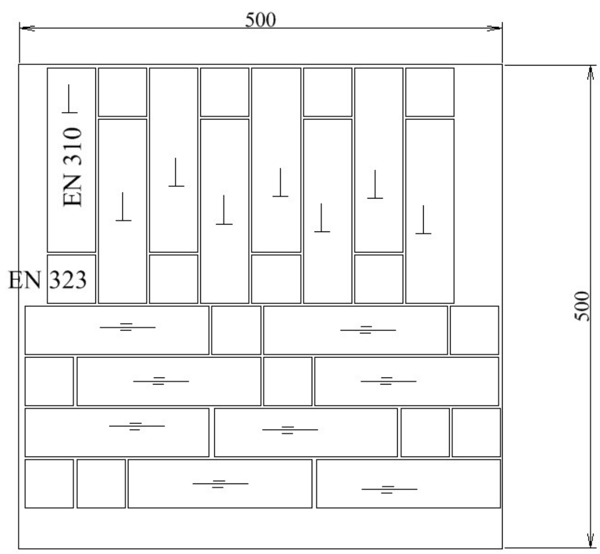

Fig. 2. Cutting plan of the samples from a single board

sessed in the evaluation of each board type. The measured data was analysed using the STATISTICA 10 software (SPSS, Tulsa, USA). First, an exploratory data analysis (EDA) was carried out and normal distribution of data was confirmed. All data was then evaluated by analysis of variance (ANOVA) with post-hoc Duncan's test to distinguish the level of statistical significance.

RESULTS AND DISCUSSION

Compressibility and density

Results of compressibility and density are shown in Table 2. The compressibility was found to be increased along with higher pressure within the same plywood board types. The compressibility of SPR 1.6 was 15% and was doubled with higher pressure, the panels with beech veneer in the face layer performed likewise. Although the density behaved similarly, different evaluation is provided by a comparison of spruce plywood and spruce-beech plywood. Considering the normal, i.e. lower processing pressure, no difference in compressibility between SPR 1.6 and COMB 1.6 was found out. On the other hand, differences in density were obtained. The density of SPR 3.2 compared to SPR 1.6 was increased by 17% and the density of COMB 3.8 compared to COMB 1.9 was increased by 11%. An insignificant difference in the density level was found out between SPR 3.2 and COMB 1.6. The lowest density was measured with SPR 1.6 and the highest with COMB 3.8. The higher density (+16%) of COMB 1.9 was achieved due to different veneer composition. Using the higher pressure, the compressibility of COMB 3.8 was found insignificantly higher compared to SPR 3.2, however density was increased by 9%.

Bending properties

The bending properties were measured in both directions of plywood, i.e. perpendicular to the grain and across the grain. All tests followed standard procedures of EN310. The descriptive statistics of bending properties is in Table 2 and 3. The perpendicular direction of the results is marked by "//" and longitudinal by "=".

Table 2. Descriptive statistics

	SPR 1.6[b]	SPR 3.2*[c]	COMB 1.9*[b]	COMB 3.8*[c]
Compressibility (%)				
Mean value	14.856	31.187	18.355	34.355
SD	0.691	0.432	0.172	0.128
x_{min}	13.732	28.365	17.589	34.971
x_{max}	18.187	34.410	19.662	38.432
Density (kg·m^{-3})				
Mean value	576.185	675.434	666.752	742.344
SD	23.041	20.249	25.110	23.601
x_{min}	541.436	641.987	634.863	712.552
x_{max}	642.001	712.000	732.003	847.001
Modulus of rupture (MOR) (N·mm^{-2})				
Mean value	42.778[a]	49.385	58.385	42.863[a]
SD	2.821	2.182	1.464	3.156
x_{min}	38.854	44.848	54.301	40.401
x_{max}	46.195	53.900	305.325	48.402
Modulus of elasticity (MOE) (N·mm^{-2})				
Mean value	3,216.482	3,796.582	5,488.643	4,380.105
SD	113.561	105.654	92.131	106.300
x_{min}	3,061.493	3,636.553	5,327.852	4,158.458
x_{max}	3,429.502	4,006.121	5,689.368	4,610.003

*$P < 0.05$; [a–c] values having the same letter are not significantly different (Duncan's test)

Table 3. Descriptive statistics of MOR and MOE in direction longitudinal to the grain (in N·mm^{-2})

	SPR 1.6^{b}	SPR 3.2^{*c}	COMB 1.9^{*b}	COMB 3.8^{*c}
Modulus of rupture (MOR)				
Mean value	82.723	87.189^{a}	87.381^{a}	98.165
SD	1.652	1.911	2.601	2.392
x_{min}	80.222	83.843	83.081	90.812
x_{max}	85.181	89.769	90.711	101.291
Modulus of elasticity (MOE)				
Mean value	10,020.852^{b}	12,115.186	8,776.352	10,020.112^{b}
SD	150.321	196.634	175.521	183.771
x_{min}	9,840.623	11,761.073	8,467.078	9,691.057
x_{max}	10,246.465	12,409.942	9,039.275	10,295.649

*$P < 0.05$; $^{a-c}$ values having the same letter are not significantly different (Duncan's test)

Bending properties perpendicular to the grain

Using the higher pressure, an increase of MOR and MOE in spruce plywood boards and an increase of MOR and MOE in combined plywood boards perpendicular to the grain were found, on the other hand, COMB//3.8 shows a decrease of MOR and MOE with doubled pressure. The most significant increase (+14%) of MOR perpendicular to the grain was presented by SPR//1.6. The MOR of COMB//1.9 was decreased by 25% with doubled pressure. The MOE of spruce in the same direction was increased by 18% when using the higher pressure, nevertheless, the COMB//3.8 presented a decrease by 20%. Comparing COMB//1.9 with the spruce plywood boards, COMB//1.9 performed better, the values of MOR were higher (+35%) compared to SPR//1.6 and MOE was also found higher (+70%); compared to SPR//3.2 MOR was higher as well (+19%) and MOE showed the higher value of +45%. Compared to SPR//1.6 and SPR//3.2 MOR of COMB//3.8 was significantly decreased, and MOE was higher.

Bending properties in longitudinal direction

The bending properties of both tested materials were significantly increased. The MOR of spruce was increased by 5% when the processing pressure was doubled; the MOE was then increased by +21%. The MOR of combined material performed similarly: an increase +13% and an increase of MOE by +14%. Comparing the material between the produced types, i.e. combined plywood and spruce plywood, the combined plywood in longitudinal direction performed better considering MOR. COMB = 1.9 compared to SPR = 1.6 was higher by +5%, compared to SPR = 3.2 it provided the same result, on the other hand, the MOE was lower in both comparisons. COMB = 3.8 compared to SPR = 1.6, the MOR was higher (+18%) and compared to SPR = 3.2 it was higher by +12%. The MOE was found similar to SPR = 1.6 and lower than SPR = 3.2.

DISCUSSION

According to results the spruce plywood boards were found to be more prone to densification when using the higher pressure. This behaviour is assigned to the spruce wood itself, which is more compressible than beech wood, however the combined plywood provided density on the same level as SPR 3.2 when using the recommended, i.e. lower pressure. The bending properties are increased by using the higher pressure in the case of spruce plywood boards; the assumption of a positive influence of increased pressure is supported. The increased pressure probably caused a partial distortion of the short fibre structure on top layers in beech wood, which resulted in a decrease of MOR and MOE perpendicular to the grain. Nevertheless, bending properties in longitudinal direction were increased. Our results are consistent with similar research where alteration of the pressing procedure was used to optimize the properties as well (Bekhta et al. 2007, 2009; Shukla et al. 2007). Our research results of properties connected with species alteration partially correspond with the research of Adin et al. (2004) and Shukla et al. (2007), where the properties were varied through the change of material composition in veneer-based product as well. Therefore even our results and especially properties connected with different species in layers of plywood may provide viable alternatives of plywood product. At the end the density may provide some limits in usage. The types of combined plywood show higher density than SPR 1.6, however the properties are significantly higher (ANOVA, $P < 0.05$) compared to both spruce plywood board types. Furthermore, compared to SPR 3.2, COMB 1.9 is even more suitable as the final alternative product due to the same density (ANOVA, $P > 0.05$) and better bending properties. Although the higher density is seen as a disadvantage, several methods have been introduced. For instance Král et al. (2014) used the cork layer in plywood to optimize the bending property-density relation.

CONCLUSION

A significant positive effect of increased pressure was found as exerted on the bending properties of spruce plywood boards and of combined plywood boards in longitudinal direction.

The bending properties of combined plywood boards in perpendicular direction were decreased when using the higher processing pressure and increased in longitudinal direction.

The combined plywood board COMB 1.9 performed better than both types of spruce plywood boards, on the other hand, the density was increased compared to SPR 1.6.

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