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Properties of compressed laminated beech wood by bending stress

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Abstract: *Properties of compressed laminated beech wood by bending stress.* Beech is one of the most important, an economic plants. In furniture is mainly used in the manufacture of bentwood furniture for its very good flexibility. For its better use is necessary to know its original characteristics and properties obtained by the modification. In our work we are focused on examining the mechanical properties of compressed laminated wood made from beech. We investigated bending strength and modulus of elasticity at bending of native (non-compressed) wood, compressed (densified) wood and laminated beech wood glued with polyurethane adhesive.

Compressed laminated wood has better mechanical properties than non – treated wood.

Keywords: beech, pressing, density, compressed (densified) wood, degree of compaction, laminated wood, bending strength, modulus of elasticity

INTRODUCTION

Wood is a material used in various ways; it is characterised with various properties dependent on wood species. Despite of all the positive properties of native wood, wood is treated according to applied technological methods of wood processing and the purpose if utilization of the wood. One of possible ways of enlarging wood utilization is to modify its mechanical properties by increasing its density. By increasing wood density is possible to improve strength properties of wood (Chuchrjanskij 1953).

In our research we aimed at change of mechanical properties of beech wood *(Fagus silvatica)* by pressing and laminating. We evaluated the influence of chosen factors on bending strength and modulus of elasticity. Wood was pressed to three levels of compression. At layered – laminated wood we combined layers of pressed and non-pressed wood (native massive wood).

MATERIAL AND METHODS

To research chosen mechanical characteristics (bending strength and modulus of elasticity) of beech wood we prepared three basic sets:

a) non-treated massive wood (native wood)
b) treated massive wood by pressing (compressed wood),
c) layered – laminated wood.

Reference material for pressed and laminated wood was native massive beech wood.

Pressing treatment was processed at radial direction into three degree of compaction – 30, 40, and 50 % from initial thickness, with no consequent stabilisation in the press (fig. 1). Wood moisture content at pressing was 16 %, and before bending test the moisture was conditioned to the value of 12 %.

By the reason to evaluate wood density changes when pressed, the values of density before pressing and after pressing were measured.

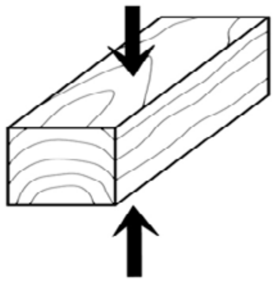

Fig. 1 Pressing of beech block in radial direction

Laminated wood was made from three layers in various combinations of compressed and non-compressed wood. We prepared five sets – combinations of laminated wood layers:

- all layers from native wood (type N),
- all layers from compressed wood (type Z),
- laminated wood with one layer from compressed wood in top, middle, or down layer (type VL, type SL, type SPL),
- laminated wood with two layers of compressed wood in outer layers (type KL).

Way of lying is figured in fig. 2. Thickness of individual layers – lamellas was 8.33 mm and they were glued together with the adhesive Jowat Power PUR 687.40 at ambient temperature in one-storey press.

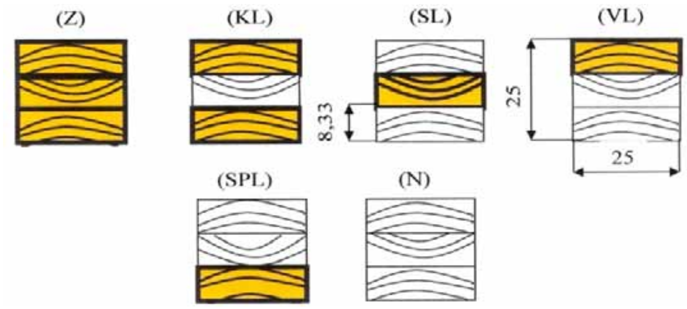

Fig. 2 Combinations of three-layer laminated beech wood [Grznárik 2011]
compressed lamella (Z) non- compressed lamella (N)

Specimen dimensions for bending test were 25 x 25 x 550 mm. Bending test was done according to test scheme represented in fig. 3.

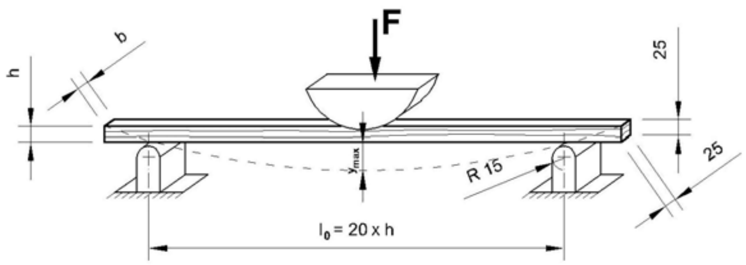

Fig. 3 Bending test

Based on the bending test results we found out the values for calculation of limit of strength and limit of modulus of elasticity according to the relations 1 and 2:

- bending strength:

$$\sigma_o = \frac{3.\ F_{max}\ .l_o}{2.b.h^2} \quad [MPa] \qquad (1)$$

where: F_{max} – force at failure of specimen [N],
l_0 – distance between supports [mm],
b – width of specimen [mm],
h – thickness of specimen [mm].

- modulus of elasticity:

$$E = \frac{(F_{40} - F_{10})\ .\ l^3_o}{4\ .\ b\ .\ h^3\ .\ (y_{40} - y_{10})} \quad [MPa] \qquad (2)$$

where: F_{40} – 40 % from maximal force [N],
F_{10} – 10 % from maximal force [N],
y_{40} – deflection corresponding to force F_{40} [mm],
y_{10} – deflection corresponding to force F_{10} [mm].

RESULTS AND DISCUSION

Increase of wood density was confirmed by pressing of massive beech wood in radial direction at three levels of compression and wood moisture content of 16 %. Increasing the degree of compaction of massive beech wood the density increases. When compared with density of non-pressed beech wood – native wood (ρ_{12} = 680 kg.m^{-3}), at first degree of compaction (30 %) density increased by 15.7 %, at second degree of compaction (40 %) the increase was by 23.2 %, and at third degree of pressing (50 %), the increase was as by 26.7 % and wood density reached the value of ρ_{12} = 896 kg.m^{-3} (Tab. 1).

By compression not only density was changed, but also mechanical properties of massive beech wood. **Bending strength** of massive beech wood across the fibre in radial direction increased with increasing density. At non-treated massive wood we reached the value of the strength σ_{12} = 132.8 MPa. At compression of 30 % the increase was by 11.7 % and strength reached the value σ_{12} = 148.34 MPa. Another increase of degree of compaction to 40 % resulted in density increase by 13.4 % in comparison with non-treated wood and strength reached the value σ_{12} = 150.55 MPa. The highest values of strength increase were reached at 50 % compression of beech wood. The strength increased by 16.2 % to the value of 154.37 MPa (Tab.1).

Modulus of elasticity was not influenced much by compression of wood. The highest increase was reached at 40 % compression, by 10.4 % compared to native wood. Modulus of elasticity increased from E_{12} = 18 364 MPa (non-treated wood) to E_{12} = 20 281 MPa. At 50 % compression the increase was only by 7.4 % what indicates to the fact that probably some failure in the wood structure happen and stiffness is decreased.

Tab. 1 Monitored properties of massive and laminated beech wood (m. c. = 12 %)

Matter		Degree of compaction [%]	Density ρ_{12} [kg.m^{-3}]	Bending strength σ_{12} [MPa]	Modulus of elasticity E_{12} [MPa]
Massive wood	Non-pressed	-	707,36	132,81	18364
	Pressed	30	818,38	148,34	19139
		40	871,55	150,55	20281
		50	896,4	154,37	19727
Laminated wood - **N**	Non-pressed	-	711,8	135,88	16481
Laminated wood - **Z**	Pressed	30	835,69	148,75	16324
		40	871,32	154,47	16356
		50	897,19	151,15	16881
Laminated wood - **SPL**	N N Z	30	750,52	141,63	16503
		40	755,29	138,76	15472
		50	758,4	139,62	13683
Laminated wood - **VL**	Z N N	30	752,73	147,48	18687
		40	756,63	147,44	15403
		50	765,4	143,22	15462
Laminated wood - **SL**	N Z N	30	755,07	135,53	15651
		40	762,29	139,4	14408
		50	747,82	142,09	15661
Laminated wood - **KL**	Z N Z	30	777,23	154,14	18147
		40	803,94	150,25	16746
		50	833,1	160,96	18507

Our results at non-treated beech wood correspond with values given by others authors in the frame of natural variability of wood properties. At non-treated beech wood, Požgaj (1993) stated the density ρ_0 = 684 kg.m^{-3}, bending strength σ_{12} = 124 MPa and modulus of elasticity E_{12} = 12 966 MPa. Lexa (1952) stated the density ρ_{12} = 710 kg.m^{-3}, bending strength σ_{12} = 105 MPa and modulus of elasticity E_{12} = 15 000 MPa. Values for wood density ρ_{12} = 640 kg.m^{-3}, strength σ_{12} = 103 MPa and modulus of elasticity E_{12} = 11 900 MPa are given in Wood Handbook (1990).

Three layered **laminated beech wood** reaches higher values of mechanical properties when compared to massive wood. Laminated wood made from non-pressed lamellas by 2 % (σ_{12} = 136 MPa) and laminated wood made from pressed lamellas (40 %) by 16 % (σ_{12} = 154 MPa). From the view point of combinations of the layers, the best results were reached at laminated wood, where there were two layers from compressed wood (type KL); bending strength in the laminated was increased by 18 % to σ_{12} = 161 MPa and modulus of elasticity was increased to E_{12} = 18 507 MPa. Laminated wood composed from one layer of pressed wood and two layers of non-pressed wood markedly manifested itself only in type VL; strength increased by 11% (σ_{12} = 148 MPa). Other searched combinations of position of pressed layer in composition of three layered laminated wood increased the bending strength by 2 ÷ 7% when compared to the massive non-pressed wood (Tab. 1).

Increased mechanical properties were reached at laminated beech wood of type Lignostone, as well. Density in this case varied in the range $\rho = 800 \div 1\,350$ kg.m^{-3}, bending strength $\sigma = 140 \div 220$ MPa and modulus of elasticity
$E = 11\,000 \div 18\,000$ MPa (LIGNOSTONE®, 2009).

CONCLUSION

Wood modification by pressing and laminating enables to change wood properties to a certain extent.

1. By pressing, wood density is increased and mechanical properties are changed. There is no problem, without any pre-treatment, to compress beech wood by press to as for 50 % from its initial thickness without any stabilisation after pressing.
We obtained higher density by 27% ($\rho_{12} = 896$ kg.m^{-3}) and increased bending strength by 16% ($\sigma_{12} = 154$ MPa).

The modulus of elasticity was increased, as well. The highest value was reached at compression of 40 % when $E_{12} = 20\ 2081$ MPa, that means the increase by 10 %. Increasing degree of compaction as for to 50 % is possible, but we consider it to be a limit value at this way of treatment. It is confirmed by lower increase of modulus of elasticity – just by 7 % to the value of $E_{12} = 19\,727$ MPa.

2. Another possibility to improve mechanical properties of wood is layering of wood. Combination of position of one compressed layer in composition of three layered laminated wood we increased bending strength maximally by 11 % when compared to massive non-treated wood (σ_{12} = 147 MPa). Compressed layer was situated on top side – type VL. Combination of two compressed layers wit one non-pressed in the middle (type KL) reached the highest increase bending strength from al the tested combinations – by 18 % to the value of $\sigma_{12} = 161$ MPa.
Modulus of elasticity in tested compositions of laminated wood was lowered or increased only a little by 1 % to 2 % at types VL and KL.
The results have clearly shown that tested combinations of layering of compressed and non-compressed wood give laminated wood which is characterised by changed stiffness in comparison with native massive wood.

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Streszczenie: *Właściwości mechaniczne przy zginaniu prasowanego oraz warstwowego drewna buka.* Buk jest jednym z najważniejszych drzew pod względem ekonomicznym. Jest używany głównie przy produkcji mebli giętych, ze względu na doskonałą elastyczność. Aby lepiej wykorzystać tę własność, należy dokładniej zbadać ją w drewnie naturalnym, oraz zmodyfikowanym. Skoncentrowano się na własnościach mechanicznych bukowego drewna warstwowego. Testowano wytrzymałość na zginanie oraz moduł sprężystości drewna naturalnego, prasowanego oraz warstwowego, klejonego klejem poliuretanowym. Prasowane i warstwowe drewno ma lepsze własności mechaniczne niż drewno naturalne.

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