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INFLUENCE OF COMPOSITION AND NUMBER OF LAYERS OF POPLAR PLYWOOD (*Populus euramericana*) ON BENDING STRENGTH AND MODULUS OF ELASTICITY

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ABSTRACT

In this paper the influence of composition and number of layers for ten poplar plywood boards of different thicknesses to bending strength and modulus of elasticity has been investigated. Results showed that with both increasing of plywood thickness and number of layers, density, bending strength and modulus of elasticity in lengthwise direction have been decreed, while in crosswise direction, bending strength and modulus of elasticity increased until 18 mm thickness and after that decreased. Analysis showed that with increasing both of number of layers and veneers thickness in plywood composition, the difference of examined properties in lengthwise and crosswise directions decreased. The plywood composition decreasing also influenced on anisotropy: as the difference in percentage part of veneer thickness in crosswise v.s. lengthwise direction decreased, so the difference in bending strength and modulus of elasticity decreased.

Key words: poplar plywood, bending strength, modulus of elasticity, anisotropy

1. INTRODUCTION

Plywood panels are produced of at least three glued veneer layers with different orientation of adjacent veneer layers. Thanks to crossing of adjacent veneer layers, (common, in direction of 90 degrees) the final product is less susceptible to shrinking, swelling, splitting, and warping compared to initial wood spices. Among that, plywood panels have improved mechanical properties, stability, isotropy and they were more durable compared to massive wood (Nikolić 1971).

The main factors influencing to plywood panels properties are: wood species (Biblis 1999, Constant et al. 2003, Bal and Bektas 2014...), type of adhesive (Cremonini and Pizzi 1999, Grindl and Muller 2006, Zdravković and Stanković 1997...), pressing parameters (Nikolić 1971, Bekhta et al. 2012...), veneer quality (Neese et al. 2004, DeVallance et al. 2007...) and veneer preparing (Aydin and Colak 2002, Dai et al. 2003...). Baldassino et al. (1998), considered the influence of plywood lay-up to its mechanical properties in two directions (according to wood fibers orientation in plywoods outer layers).

The aim of this research was to determine on which way both construction of plywood panels and number of veneer layers influenced on board isotropy measured by bending strength (MOR) and modulus of elasticity (MOE) in two cross directions.

2. METERIALS AND METHODS

In this experiment the plywood panels of different thicknesses produced by standard production process (Hot-Press Schedule: synthesized UF adhesive, pressure 1MPa, pressing temperature 135^{o}C, pressing time 1 min/mm of total plywood thickness), were randomly chosen from production batches of company ``Novi drvni kombinat`` from Sremska Mitrovica. Thicknesses and plywood panels lay-up are shown in Table 1. For lengthwise layers veneer thicknesses were 2; 2.2 and 3mm, and for crosswise layers veneer thicknesses were 1.5; 2.2 and 3mm. All plywood panels were slightly thicker than their nominal thickness, because of calculated over measure (of 6 to 8% for pressing losses) and around 1 mm for finishing.

Table 1. *Plywood panels thicknesses and constructions*

Nominal thickness (mm)	Number of layers	Plywood panel lay-up*
4	3	2 + 1.5 + 2 ‖ ⊥ ‖
6	3	2.5 + 2.2 + 2.5 ‖ ⊥ ‖
8	5	2 + 1.5 + 2.5 + 1.5 + 2 ‖ ⊥ ‖ ⊥ ‖
9	5	2 + 2.2 + 2 + 2.2 + 2 ‖ ⊥ ‖ ⊥ ‖
10	5	2 + 2.2 + 3 + 2.2 + 2 ‖ ⊥ ‖ ⊥ ‖
12	5	3 + 2.2 + 3 + 2.2 + 3 ‖ ⊥ ‖ ⊥ ‖
15	7	2.5 + 2.2 + 2.5 + 2.2 + 2.5 + 2.2 + 2.5 ‖ ⊥ ‖ ⊥ ‖ ⊥ ‖
18	9	2 + 2.2 + 2 + 2.2 + 3 + 2.2 + 2 + 2.2 + 2 ‖ ⊥ ‖ ⊥ ‖ ⊥ ‖ ⊥ ‖
20	9	2.5 + 2.2 + 2.5 + 2.2 + 3 + 2.2 + 2.5 + 2.2 + 2.5 ‖ ⊥ ‖ ⊥ ‖ ⊥ ‖ ⊥ ‖
28	11	2.5 + 3 + 3 + 3 + 2.5 + 3 + 2.5 + 3 + 3 + 3 + 2.5 ‖ ⊥ ‖ ⊥ ‖ ⊥ ‖ ⊥ ‖ ⊥ ‖

*Symbols ‖, ⊥ refers to the direction of other veneer layers.

From randomly chosen plywood panels the samples have been cutted according to EN 310 (Figure 1). The samples have been tested on computer controlled automatic testing machine WT4, in Laboratory for Wood properties in Faculty of Forestry of Belgrade University.

Figure 1. *Appearance of probes for MOR and MOE testing according to EN 310*

After the MOR and MOE testing, from every probe the samples were cutted for determination of MC and plywood density (according to EN 322 and EN 323), at the moment of testing (Figure 2). The all statistics was calculated by standard SPSS software.

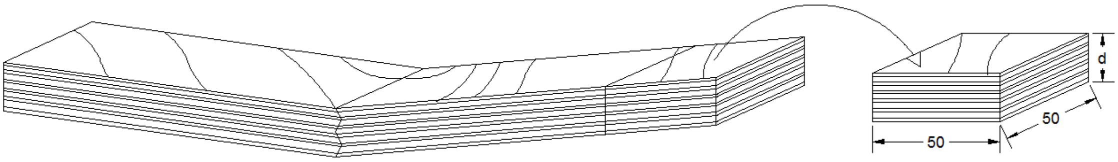


Figure 2. *Samples for determination of plywood MC and density*

3. RESULTS AND DISCUSSION

The main statistics for plywood moisture content (MC) and plywood density is presented in Tables 2 and 3. Besaide the average values ($\bar{x}$), the number of samples (N), standard deviation (SD), coefficient of variation (KOV) and standard error (SE) were presented.

Table 2. *Moisture content (MC) of plywood panels at the moment of testing (%)*

Plywood thickness (mm)	4	6	8	9	10	12	15	18	20	28
N	10	10	10	10	10	10	10	10	10	10
$\bar{x}$	**7.95**	**8.31**	**8.10**	**7.42**	**7.36**	**7.72**	**7.24**	**7.46**	**8.31**	**7.45**
SD	0.35	0.25	0.36	0.31	0.57	0.14	0.22	0.18	0.25	0.30
KOV	4.37	2.95	4.47	4.12	7.75	1.76	3.04	2.44	3.00	4.01
SE	0.11	0.08	0.11	0.10	0.18	0.04	0.07	0.06	0.08	0.09

Table 3. *Plywood panels density at the moment of testing (kg/m^3)*

Plywood thickness (mm)	4	6	8	9	10	12	15	18	20	28
N	10	10	10	10	10	10	10	10	10	10
$\bar{x}$	515.29	476.19	455.45	509.25	501.26	493.68	498.49	468.16	442.71	443.33
SD	51.20	19.43	13.75	16.93	19.69	20.12	20.59	16.37	9.96	14.75
KOV	9.94	4.08	3.02	3.32	3.93	4.07	4.13	3.50	2.25	3.33
SG	16.19	6.14	4.35	5.35	6.23	6.36	6.51	5.18	3.15	4.67

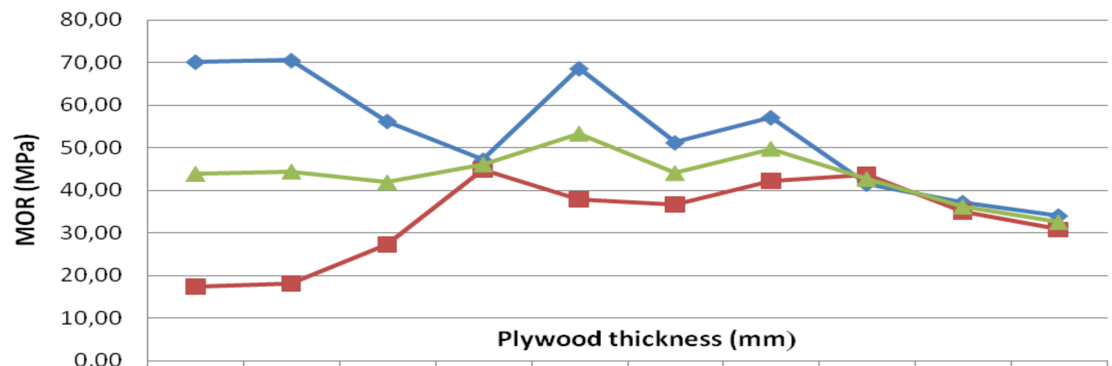
Table 2 showed that plywood MC at the moment of testing varied at little range of around 1% (min. 7.24%, max. 8.31%). Low values of all statistic parameters showed that plywood MC was pretty uniform, although most of them were below, or at the boundary of the lower limit of 10±2% prescribed by EN 322.

The plywood density fluctuated from minimum of 442 kg/m^3 to maximum of 515 kg/m^3 with increased variation in the case of plywood of 4mm thickness. The main trend was that as plywood thickness increased so and their density decreased. So the highest plywood density was noted in case of plywood thickness of 4 mm, and the smallest plywood density was noted in case of plywood thickness of 20 and 28 mm. This could bee explained as consequence of lower plywood thickness loss of thicker plywoods during the pressing (piezzo-thermic effect; Nikolić, 1988). One-way ANOVA and Bonferroni post hoc test showed significant influence of plywood thickness to plywood density (F (9.90) = 13.845, p=.05). Regarding increased variation of density in case of plywood thickness of 4 mm, tested plywood panels did not have homogeneous variance: Levene test (F(9.90)=5.978, p=.05).

Bonferroni post hoc test showed exactly that the most of tested plywood panels had significantly smaller density than board thickness of 4 mm and greater than boards of 20 and 28 mm.

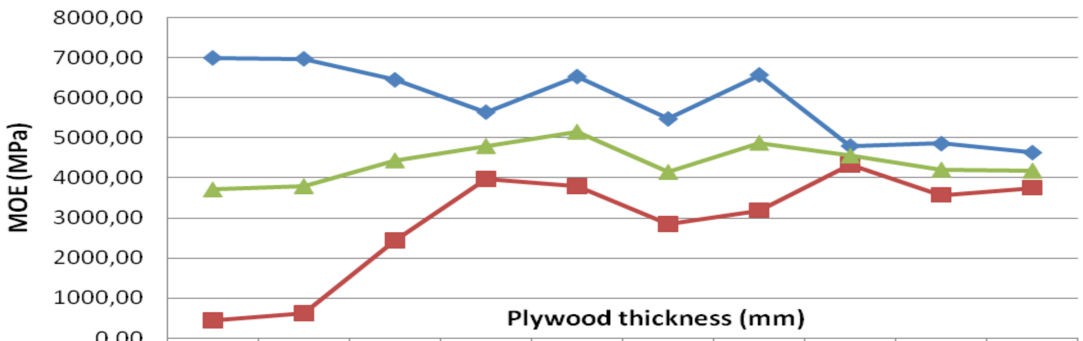
Figures 3 and 4 presents bending strength (MOR) and modulus of elasticity (MOE) of tested plywoods. Among the average values of MOR and MOE in lengthwise and crosswise directions for each plywood thickness, the average values in these two directions have been showed. Generally, the main trend was that in the case of lengthwise direction, both MOR and MOE decreased with increasing of plywood thickness. In the case of crosswise direction, both MOR and MOE increased until plywood thickness of 18 mm and then decreased. It was distinctly that difference between lengthwise and crosswise directions was the biggest in case of the smallest plywood thicknesses and the smallest in case of the biggest plywood thicknesses. Exception relative to this trend was in the case of plywood thickness of 9 mm.

Examining plywoods lay-up data (Table 1) it is obvious that there is significant difference in overall veneer thickness oriented in lengthwise direction v.s. crosswise direction. By subtracting oversize for finishing of 1 mm from overall veneers thickness in lengthwise direction (only outer lengthwise veneers have been sanded) graphs shown in Fig. 3 and 4 could be explained (Table 4).
The overall pressing losses are excluded on purpose, because such kind of calculation does not consider individual veneer layers, but only assembled veneers. Someone can only assume that there was consequence of higher pressing losses i outer veneer layers.



	4	6	8	9	10	12	15	18	20	28
MOR ǁ	70,20	70,56	56,26	47,16	68,64	51,26	57,14	41,57	37,21	34,06
MOR ⊥	17,44	18,18	27,40	44,94	37,92	36,77	42,28	43,69	35,03	30,85
Average	43,82	44,37	41,83	46,05	53,28	44,02	49,71	42,63	36,12	32,46

***Figure 3**. Bending strength (MOR) of poplar plywoods of different thicknesses*



	4	6	8	9	10	12	15	18	20	28
MOE ǁ	7011,7	6988,4	6462,0	5654,4	6545,0	5483,9	6586,4	4805,8	4865,0	4640,7
MOE ⊥	434,85	623,76	2441,8	3964,5	3787,2	2836,2	3189,5	4331,1	3570,5	3751,1
Average	3723,3	3806,0	4451,9	4809,5	5166,1	4160,1	4887,9	4568,4	4217,8	4195,9

***Figure 4.** Modulus of elasticity (MOE) of poplar plywoods of different thicknesses*

Table 4. *Difference in veneer thickness among lengthwise and crosswise direction*

Thickness (mm)		**4**	**6**	**8**	**9**	**10**	**12**	**15**	**18**	**20**	**28**
No. of layers		3	3	5	5	5	5	7	9	9	11
Sum in mm	ǁ	3	4	5,5	5	6	8	9	10	12	15
	⊥	1.5	2.2	3	4.4	4.4	4.4	6.6	8.8	8.8	15
Difference in mm		1,5	1.8	2.5	0.6	1.6	3.6	2.4	1.2	3.2	0
Share in %	ǁ	66.66	64.51	64.71	53.19	57.69	64.52	57.69	53.19	57.69	50.00
	⊥	33.33	35.49	35.29	46.81	42.31	35.48	42.31	46.81	42.31	50.00

The biggest difference of examined properties (MOR around 50 MPa and MOE around 6500 MPa) has been calculated in the case of two smallest plywood thicknesses (4 and 6 mm), with share of veneer thickness in lengthwise direction around 65% and in crosswise direction around 35%. The next board of 8 mm thickness has almost the same share of veneer thickness in lengthwise direction as previous, but difference in examined properties was smaller (MOR around 30 MPa and MOE around 4000 MPa). It could be explained considering number of veneer layers: the plywood of 8 mm thickness was composed of 5 layers while plywoods of 4 and 6 mm thicknesses were composed of 3 layers. Those results indicated that as number of layers increased so plywood isotropy has been improved (Figures 3 and 4).

In the case of 9 mm plywood thickness the calculated values for MOR were almost the same in the lengthwise and crosswise direction, while the calculated differences for MOE were significantly smaller than for thinner plywoods (around 1700 MPa). These values correspond to reduction of share of veneer thickness in lengthwise direction (around 53%), and increase of shear in crosswise direction (around 47%) (Table 4). In the case of 10 mm plywood thickness, the difference of veneer share in lengthwise direction v.s. crosswise direction was increased (58% - 42%) what contributed to the slightly smaller values of MOR and MOE in crosswise direction, but increasing of MOR in the first place, and MOE in lengthwise direction was unexpected high.

That increasing of number of veneer layers in the plywood construction was not only cause of isotropy improvement it can be seen from analyzed differences of properties in the case of plywood thickness of 12 mm. In this plywood thickness the veneer share of both directions was almost identical as plywood thickness of 8 mm, but the difference of properties in the case of plywood thickness of 12 mm was even smaller (MOR around 14 MPa and MOE around 2600 MPa, v.s. MOR around 30 MPa and MOE around 4000 MPa, for plywood thickness of 8 mm). As both plywood panels have 5 layers in their construction, logical explanation is that number of veneer layers and veneer thickness simultaneously affected to the isotropy improvement.

The difference of MOR and MOE in lengthwise direction and crosswise direction for plywood panel of 15 mm thickness was almost the same as for panel of 12 mm thickness. That was unexpected, because it does not follow the trend of decreasing the difference of observed properties with increasing of number of layers. With the further increasing of plywood thickness, MOR in both directions approaching each other as and MOE, so in the case of plywood thickness of 18, 20 and 28 mm they are quite uniform (Figures 3 and 4). Further increasing of plywood thickness and number of veneer layers probably would follow this trend.

Average values of MOR and MOE (green lines on Figures 3 and 4) indicated that values for MOE were quite uniform, but in the case of MOR there was noticeable decline after plywood thickness of 18 mm. This decreasing of MOR is probably consequence of statistically proven decreasing of plywood density for 20 and 28 mm thicknesses. It could be also caused by uncontrolled veneer lathe checks which affect to the plywood rolling shear properties (Zdravković 1999), but it is not subject of this research. This effect of the plywood density to the MOE values was smaller, as the slope of the curves shows (Figures 3 and 4).

4. CONCLUSIONS

In this research the simultaneous influence of plywood thickness and veneer share in lengthwise direction v.s. crosswise direction on MOR and MOE has been investigated. Analyzed data showed that both increasing of plywood thickness and number of layers, lead to isotropy improvement.

The biggest differences between lengthwise and crosswise directions have been calculated in case of 3-layer plywood (MOR around 50 MPa and MOE around 6500 MPa) and the smallest in the case of 9-layer and 11-layer plywood panels (MOR 2-4 MPa and MOE 500-1300 MPa).
The plywood lay-up also affect to isotropy improvement. This is obvious in the case of plywood panels thickness 9 and 28 mm. On these boards veneer share of both directions was almost identical, so differences in MOR in those directions were 2.2 MPa and 3.2 MPa and in MOE were 1600 and 900 MPa respectively.

Generally it could be said that plywood density decreases as their thickness increases. The main trend in the case of lengthwise direction was that both MOR and MOE decreased with increasing of plywood thickness and the number of veneer layers. In the case of crosswise direction, both MOR and MOE increased until plywood thickness of 18 mm and then decreased. This decreasing of MOR is probably consequence of statistically proven decreasing of plywood density for 20 and 28 mm thicknesses. But it must be noticed that in the case of bigger plywood thicknesses there is more pronounced influence of stress-strain relationships in the tensile zone of plywood.

Also, this research refers to industrial production batch and presents actual state. If we would have been able to control veneer peeling process, veneer drying and pressing regime, the results might be different.

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