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RESEARCH ON MECHANICAL PROPERTIES OF BIRCH PLYWOOD WITH SPECIAL VENEER LAY-UP SCHEMES

Plywood is a wood-based panel material laminated of veneers where the grain direction is perpendicular in adjacent layers. The use of plywood can be extended if there is a possibility to use special lay-up schemes designed to improve mechanical properties which depend on the grain direction in the outer plies. This report contains results of research whose purpose was to determinate bending strength and modulus of elasticity of birch plywood types with special veneer lay-up schemes and of different width, bending flatwise and edgewise. Two special plywood types, 28 mm thick Spec1 and 30 mm thick Spec3, with different veneer lay-up schemes were selected for bending properties determination tests according to standard EN 789. Specimens were tested when the face veneer direction was parallel and then perpendicular to the specimens' longer axis. Moisture content and density were determined as well. This report contains the comparison of bending strength properties of special plywood specimen with different width and load direction. It was found that bending strength was significantly higher for narrower special plywood specimens, and bending strength of special plywood loaded edgewise was 4 % lower for Spec1 and 9.5 % lower for Spec3 than for flatwise loaded specimen of the same cross-sectional dimensions.

Keywords: birch plywood, veneer lay-up scheme, bending strength, edgewise load

Introduction

The plywood manufacturing industry is one of the most significant industries in the wood processing sector in Latvia. More than 90% of produced plywood is exported. In the first half of 2010 the plywood value in the forestry sector exports amounted to 9.5%. The biggest plywood manufacturer in Latvia is Latvijas Finieris Company, which in a period of crisis tries to increase its turnover by developing specific products with higher added value.

The main products of Latvijas Finieris Company are Riga Ply and plywood with different surface laminations. The plywood is produced with common lay-up

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scheme that requires one thickness of veneers which are arranged so that the grain direction is perpendicular in all adjacent layers. Choosing the default plywood construction causes to size stability in a changing conditions and similar mechanical properties in both directions - parallel and perpendicular to the longitude. This applies more to plywood of the thickness over 18 mm that is relatively more homogenous. The thinner the plywood is, the bigger differences in mechanical properties between plywood of the same thickness and of different face veneer grain direction appear. Therefore, the face veneer direction defines this material's suitability.

Proceeding the plywood mechanical properties dependence on veneer layer orientation, is able to made material with of the required characteristics in any direction to longitude. Manufacturers designed many plywood types combining veneers of different thicknesses and made of various wood species [Hrazsky, Kral 2005]. The special plywood types produced in Latvia are composed of similar veneers using special lay-up schemes. Unlike the case of Riga Ply type, mechanical properties of special construction plywood are less studied.

Plywood as a wood material is heterogeneous, so it can be assumed that the plywood specimen's strength is mostly related to veneer natural flaws, e.g. knots. It is obvious that the larger the specimen area under load is, the greater the probability of occurrence of knot or other flaw is, but the resulting strength values are applied to whole specimen. The standard methods for panel material bending strength properties determination require specimens of the width of 300 mm, but the used plywood details often are narrower. The use of special plywood can be extended if there is a possibility to use plywood for products of small cross-sectional dimensions or to use waste material from plywood processing (mostly cut-offs). Hence, the dependence of strength properties on specimen's width should be studied.

There are other possibilities to extend the application of special plywood. For example, special construction plywood as a material is similar to laminated veneer lumber (LVL), which is designed for use edgewise. Therefore, research on the strength properties of edgewise loaded special plywood should be useful as well.

The purpose of this report is to test birch plywood types with special veneer lay-up schemes and compare values of bending strength and modulus of elasticity determined for plywood species of different widths and at bending flatwise and edgewise.

Plywood manufacture

The production process of special construction plywood in Latvijas Finieris Company's plywood mills is the same as Riga Ply production process, except the lay--up stage. The plywood is made of birch (*betula sp.*) rotary cut veneers of the thickness of 1.45 mm after drying. The plywood is laminated with phenol-formaldehyde glue. The glue is mixed using resin SFŽ-3014 and mixture Prefere 24J688 containing resin polymerisation accelerator and filler-plasticiser. Lamination parameters are:

– glue spread rate 180 g·m^{-2},
– press temperature 150 ^{o}C,
– press pressure 2.0 MPa,
– full pressure time is equal to 360 s + 30 s per 1 mm of panel thickness,
– pressure decreasing time 120 s.

The veneer lamination quality belongs to the 3. class according to EN 314-1 and EN 314-2 standards. The bonding quality of special construction plywood is not influenced by glue seams of plies of the same grain direction, because glue seams of perpendicular plies are much weaker.

Then panels are sanded. The thickness of the face veneers is 0.9±0.1 mm. The panel surface foiled with phenol-formaldehyde film of the density of 120 g·m^{-2}. One face of the panel is smooth (side F) and the other has wire mesh pattern (side W). The pattern on side W is used to increase the abrasion resistance of the surface.

Mechanical properties were determined for two types of special plywood: Spec1 and Spec3. Both types were special constructions. Their veneer lay-up schemes are given in table 1. The face veneers of both plywood types were WGE grade. In Spec1 and Spec3 three and four of the outer plies parallel to the panel's longer axis, respectively, were BB grade. The adjusted perpendicular outer plies were WG grade. BB and WG grades are equal to III and IV grade, respectively, according to EN 635-2 standard. WGE are special WG grade veneers prepared for foiling, in which all splits, knot holes, picks, imprints and holes are repaired.

Table 1. Veneer lay-up schemes and dimensions of specimens
Tabela 1. Systemy układu fornirów i wymiary próbek

<table>
<tr><th>Plywood type
Rodzaj sklejki</th><th>Number of layers
Liczba warstw</th><th>Veneer lay-up scheme*
System układu fornirów</th><th>Testing direction
Kierunek badania</th><th>Height or thickness, mm
Wysokość lub grubość, mm</th><th>Width, mm
Szerokość, mm</th></tr>
<tr><td rowspan="3">Spec1</td><td rowspan="3">20</td><td rowspan="3">_|||_|_|_||_|_|_|||_</td><td>flatwise
płasko</td><td>28</td><td>50</td></tr>
<tr><td>flatwise
płasko</td><td>28</td><td>200</td></tr>
<tr><td>edgewise
bokiem</td><td>50</td><td>28</td></tr>
<tr><td rowspan="2">Spec3</td><td rowspan="2">22</td><td rowspan="2">||_|||_|_|_||_|_|||_||</td><td>flatwise
płasko</td><td>30</td><td>50</td></tr>
<tr><td>edgewise
bokiem</td><td>50</td><td>30</td></tr>
</table>

* | - veneer of the grain direction parallel to the longer axis; _ - veneer of the grain direction perpendicular to the longer axis
** | - fornir o orientacji włókien równoległej do dłuższej osi; _ - fornir o orientacji włókien prostopadłej do dłuższej osi*

Test methods

The specimens were taken from separate panels. Panels of both plywood types were selected from one batch. Ten specimens were selected for every specimen group. The dimensions of the specimens were determined according to EN 325 standard.

Static bending strength and modulus of elasticity at bending values were determined according to EN 789 standard. This method is based on 4-point load of specimen which involves constant bending moment without shear stress influence in a specimen failure zone. The bending strength test primary scheme is presented in fig. 1. To determine the above-mentioned values a testing machine Zwick Z100/TLS3 was used.

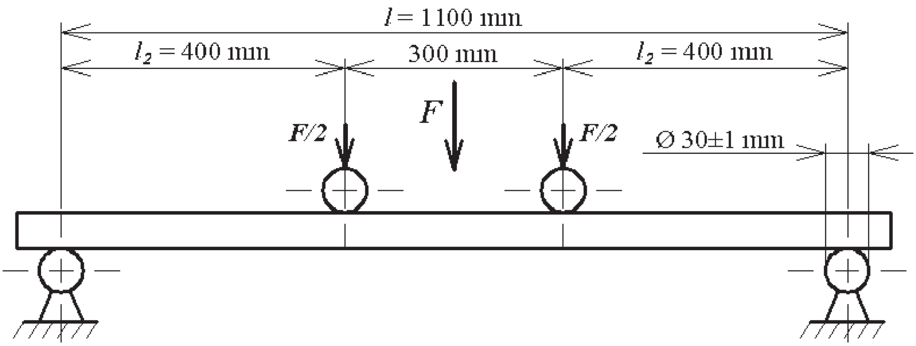

Fig. 1. Bending strength test primary scheme:
l – distance between supports; l_2 – distance between point of load and support; F – load
Rys. 1 Podstawowy schemat testu wytrzymałości na zginanie:
l – odległość między podporami; l_2 – odległość między punktem obciążenia a podporą; F – obciążenie

For bending flatwise half of the specimens in every group were tested with side F upwards, the other specimens were tested with side W upwards.

Specimen conditioning was conducted according to EN 789 standard. Moisture content and density were determined for all specimens. Moisture content was determined using weighing method according to EN 322 standard and density was determined according to EN 323 standard.

Descriptive values were calculated using the method described in EN 326-1 standard. The compared parameters were checked for significance of value difference according to EN 326-2 standard. For comparison of bending strength values for edgewise tested plywood and LVL, the specimens' height factor was taken into consideration according to EN 14374 standard.

Mechanical properties comparison

The results of determination of moisture content and density values for the specimens are given in table 2 and 3. The significance of the difference in moisture content values and density values was checked for all specimen groups. No significant difference in moisture content and density values between any of the compared specimen groups at 95% probability level (t-test with $p < 0.05$) was observed.

Table 2. Physical and mechanical properties of Spec1 and Spec3 plywood specimen tested flatwise
Tabela 2. Właściwości fizyczne i mechaniczne próbek sklejki Spec1 i Spec3badanych na płasko

Statistical value *Wartość statystyczna*	Bending strength *Wytrzymałość na zginanie* f_m, N·mm^{-2}		Modulus of elasticity *Moduł sprężystości podłużnej* E, N·mm^{-2}		Moisture content *Wilgotność* W, %		Density *Gęstość* ρ, kg·m^{-3}	
	⊥*	‖**	⊥	‖	⊥	‖	⊥	‖
50 mm wide Spec1 *Spec1 szerokość 50 mm*								
Mean value *Średnia*	86.3	38.0	10 899	5 575	9.0	8.0	745	712
Standard deviation *Odchylenie standardowe*	3.4	6.1	141	545	0.2	0.2	13	18
Variation coefficient, % *Współczynnik zmienności, %*	3.9 %	16.2 %	1.3 %	9.8 %	2.2 %	2.7 %	1.7 %	2.6 %
5% quantile *kwantyl 5%*	81.0	30.0	10 710	5134	-	-	-	-
200 mm wide Spec1 *Spec1 szerokość 200 mm*								
Mean value *Średnia*	68.3	-	10 881	-	9.4	-	-	-
Standard deviation *Odchylenie standardowe*	5.7	-	780	-	1.4	-	-	-
Variation coefficient, % *Współczynnik zmienności, %*	8.3 %	-	6.4 %	-	15.2 %	-	-	-
5% quantile *kwantyl 5%*	61.2	-	9 846	-	-	-	-	-
50 mm wide Spec3 *Spec3 szerokość 50 mm*								
Mean value *Średnia*	33.4	85.7	4 101	11 726	8.6	7.9	718	707
Standard deviation *Odchylenie standardowe*	4.4	8.0	474	595	0.3	0.2	17	14
Variation coefficient, % *Współczynnik zmienności, %*	13.2 %	9.3 %	11.6 %	5.1 %	4.0 %	2.2 %	2.4 %	2.0 %
5% quantile *kwantyl 5%*	27.1	77.5	3 397	11 056	-	-	-	-

Table 2. Continued
Tabela 2. Ciąg dalszy

300 mm wide Spec1*** *Spec1 szerokość 300 mm****								
Mean value *Średnia*	29.6	63.7	5 685	10 930	-	-	-	-
Standard deviation *Odchylenie standardowe*	7.7	11.7	1 194	1 594	-	-	-	-
300 mm wide Spec3*** *Spec3 szerokość 300 mm****								
Mean value *Średnia*	67.6	22.8	11 836	4 095	-	-	-	-
Standard deviation *Odchylenie standardowe*	13	6	1 828	721	-	-	-	-

* ⊥ – face veneer of perpendicular grain direction; ** || – face veneer of parallel grain direction
* ⊥ – *okleina o prostopadłej orientacji włókien; ** || – okleina o równoległej orientacji włókien*
*** Zudrags, Ludvigsone-Rudzite 2008

Table 2 presents the results of statistical processing of data obtained for flatwise tested Spec1 and Spec3 plywood.

The results of flatwise tests of Spec1 and Spec3 plywood of the widths of 50 and 200 mm are discussed together with another research results for 300 mm wide specimen [Zudrags, Ludvigsone-Rudzite 2008]. In every tested group the bending strength value for 50 mm wide specimen was higher than the bending strength value for wider specimens.

The mean value of bending strength determined for 50 mm wide Spec1 plywood specimens with perpendicular face veneer grain direction was 86.3 $N \cdot mm^{-2}$, which was 26 and 38% higher than the mean values for specimens of the widths of 200 and 300 mm, respectively.

The mean value of bending strength for 50 mm wide Spec1 plywood specimens with parallel face veneer grain direction was 38 $N \cdot mm^{-2}$, which was 35% higher than that value for specimens of the width of 300 mm.

The mean value of bending strength determined for 50 mm wide Spec3 specimens with parallel face veneer grain direction was 85.7 $N \cdot mm^{-2}$, which was 25% higher than that value for specimens of the width of 300 mm.

The mean value of bending strength for 50 mm wide Spec3 specimens with perpendicular face veneer grain direction was 33.4 $N \cdot mm^{-2}$, which was 44% higher than that value for specimens of the width of 300 mm.

The difference in the mean values of modulus of elasticity at bending determined for each previously compared Spec1 and Spec3 plywood specimen groups was insignificant.

Table 3. Physical and mechanical properties of Spec1 and Spec3 plywood specimen tested edgewise

Tabela 3. Właściwości fizyczne i mechaniczne próbek sklejki Spec1 i Spec3 badanych bokiem

Statistical value *Wartość statystyczna*	Bending strength *Wytrzymałość na zginanie* f_m, N·mm^{-2}	Modulus of elasticity *Moduł sprężystości podłużnej* E, N·mm^{-2}	Moisture content *Wilgotność* W, %	Density *Gęstość* ρ, kg·m^{-3}
Spec1 with face veneer of perpendicular grain direction *Spec1 z okleiną o prostopadłej orientacji włókien*				
Mean value *Średnia*	82.7	10 660	9.0	741
Standard deviation *Odchylenie standardowe*	4.1	362	0.3	15
Variation coefficient, % *Współczynnik zmienności, %*	5.0 %	3.4 %	3.8 %	2 %
5% quantile *kwantyl 5%*	77.2	10 108	-	-
Spec1 with face veneer of parallel grain direction *Spec1 z okleiną o równoległej orientacji włókien*				
Mean value *Średnia*	42.8	6 431	8.6	733
Standard deviation *Odchylenie standardowe*	2.7	216	0.2	8
Variation coefficient, % *Współczynnik zmienności, %*	6.2 %	3.4 %	2.0 %	1.1 %
5% quantile *kwantyl 5%*	39.4	6 127	-	-
Spec3 with face veneer of parallel grain direction *Spec3 z okleiną o równoległej orientacji włókien*				
Mean value *Średnia*	77.6	10 199	9.1	-
Standard deviation *Odchylenie standardowe*	5.9	783	0.5	-
Variation coefficient, % *Współczynnik zmienności, %*	7.6 %	7.7 %	5.1 %	-
5% quantile *kwantyl 5%*	69	9 437	-	-
Spec3 with face veneer of perpendicular grain direction *Spec3 z okleiną o prostopadłej orientacji włókien*				
Mean value *Średnia*	42.1	6 061	9.0	736
Standard deviation *Odchylenie standardowe*	4.1	361	1.0	16
Variation coefficient, % *Współczynnik zmienności, %*	9.7 %	6.0 %	10.8 %	2.2 %
5% quantile *kwantyl 5%*	36.6	5 530	-	-

Table 3 presents the results of statistical processing of data obtained for edgewise tested Spec1 and Spec3 plywood.

The mean value of bending strength determined for edgewise tested Spec1 plywood specimens with perpendicular face veneer grain direction was 82.7 $N\cdot mm^{-2}$ and of modulus of elasticity 10660 $N\cdot mm^{-2}$. Those values were 4 and 2% lower, respectively, than the values for flatwise tested specimens (table 2).

The mean value of bending strength for edgewise tested Spec1 specimens with parallel face veneer grain direction was 42.8 $N\cdot mm^{-2}$ and of modulus of elasticity 6431 $N\cdot mm^{-2}$. Those values were 13 and 15% higher, respectively, than the values for flatwise tested specimens.

The mean value of bending strength determined for edgewise tested Spec3 specimens with perpendicular face veneer grain direction was 77.6 $N\cdot mm^{-2}$ and of modulus of elasticity 10199 $N\cdot mm^{-2}$. Those values were 9.5 and 13% lower, respectively, than the values for flatwise tested specimens (table 2).

The mean value of bending strength for edgewise tested Spec3 specimens with parallel face veneer grain direction was 42.1 $N\cdot mm^{-2}$ and of modulus of elasticity 6061 $N\cdot mm^{-2}$. Those values were 21 and 48% higher, respectively than the values for flatwise tested specimens.

The comparison of bending properties of tested plywood and 24.3 mm thick spruce LVL [Ranta-Maunus, Fonselius 2001] revealed that the values of bending strength for edgewise tested Spec1 plywood, for specimens with perpendicular and parallel face veneer grain direction, were 47% higher and 24% lower, respectively, than the LVL bending strength value. In the case of Spec3 plywood, for specimens with parallel and perpendicular face veneer grain direction, the values of bending strength were 38% higher and 25% lower, respectively, than the LVL bending strength value. The specimens' height factor was taken into account in the comparison. The height factor coefficient used in calculations was k_h=1.07.

Summary

The use of the special veneer lay-up scheme is the optimal way to enhance plywood's mechanical properties in one direction at the expense of decreasing them in another. This optimisation can be achieved without making any significant changes in technology in mills that produce plywood from veneers of one thickness.

The values of bending strength for both considered special construction plywood types were strongly influenced by the scaling factor. The values were significantly greater for narrower specimens of both types: with most of the layers with the grain direction parallel or perpendicular to the longer axis.

The values of modulus of elasticity at bending did not depend on the specimen's width for Spec1 and Spec3 plywood, and the differences in the modulus of elasticity mean values for separate plywood types were insignificant.

The use of the special construction plywood with small cross-sectional dimensions could be beneficial thanks to its mechanical properties values at edgewise bending which are good enough compared with mechanical properties of the same material loaded flatwise and with LVL mechanical properties.

References

Hrazsky J., Kral P. [2005]: Assessing the bending strength and modulus of elasticity in bending of exterior foiled plywood in relation to their construction. Journal of Forest Science [51]: 77–94

Ranta-Maunus A., Fonselius M. [2001]: Timber strength distributions. VTT Research Notes, Espoo

Zudrags K., Ludvigsone-Rudzite S. [2008]: Bending properties of special lay-up plywood. Nordic-Baltic Network in Wood Material Science and Engineering, Riga: 114 – 118

List of standards

EN 322. Wood-based panels. Determination of moisture content

EN 323. Wood-based panels. Determination of density

EN 325. Wood-based panels. Determination of dimensions of test pieces

EN 326-1. Wood-based panels. Sampling, cutting and inspection. Sampling and cutting of test pieces and expression of test results

EN 326-2. Wood-based panels. Sampling, cutting and inspection. Initial type testing and factory production control

EN 789. Timber structures. Test methods. Determination of mechanical properties of wood--based panels

EN 14358. Timber structures. Calculation of characteristic 5-percentile values and acceptance criteria for a sample

BADANIA WŁAŚCIWOŚCI MECHANICZNYCH WODOODPORNEJ SKLEJKI BRZOZOWEJ O ZRÓŻNICOWANYM UKŁADZIE FORNIRÓW

Streszczenie

Zakres stosowania sklejki może być rozszerzony dzięki poprawie jej właściwości mechanicznych, uzyskanej m.in. przez wprowadzenie nietypowych rozwiązań układu fornirów. Celem badań było określenie właściwości mechanicznych wodoodpornej sklejki brzozowej, okleinowanej błoną fenolową, a różniącej się budową zestawu. Zakres pracy obejmował badania wytrzymałości na zginanie i modułu sprężystości zgodnie z normą EN 789. Pomiary prowadzono wzdłuż i w poprzek włókien dla różnego rozstawu podpór ob-

ciążających oraz prostopadle do płaszczyzny sklejki i jej krawędzi. Oznaczono również wilgotność i gęstość sklejki. Na podstawie przeprowadzonych badań stwierdzono, że wytrzymałość na zginanie jest znacznie wyższa dla mniejszego rozstawu podpór.

Słowa kluczowe: sklejka brzozowa, budowa zestawu, wytrzymałość na zginanie, moduł sprężystości obciążenie