IMPACT OF VENEER LAYOUTS ON PLYWOOD BENDING PROPERTIES

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ABSTRACT

The research presented in this paper includes the study of the plywood bending properties through a change of the position of the layers in the structure of the panel around the central axis, without changing the number and the thickness of the veneers.

For studying this impact, experimental models of nine-layer plywood are made. The models are made from peeled beech veneers with thickness of 1,2; 1,5; 2,2 and 3,2 mm.

The modeling is made on the basis of changing the position of veneers with thickness of 3,2 mm around the central axis (axis of symmetry).

Pure water-soluble phenol-formaldehyde resin is used as plywood binder.

The bending strength and modulus of elasticity in bending of the plywood panels is tested in two directions, parallel and perpendicular to the face grain.

The research results showed that the tested plywood models meet the defined values of bending properties in accordance with the requirements of the MKS standard for structural plywood for use in construction. The different layouts of veneer sheets in panel structure gives opportunities for production of panels with different strength characteristics.

Key words: plywood, veneers, bending properties, changes, position, layers.

1. INTRODUCTION

Plywood is one of the major types of wood composite materials for structural use for indoor and outdoor application. The cross-laminated layup of layers of veneers gives plywood excellent strength characteristics, stiffness and dimensional stability. The form of these panels allows its application in many areas where materials in large formats are required. Plywood has high strength to weight ratios and it is very cost effective to use in structural applications such as: flooring, siding, roofing, shear walls, formwork and engineered wood products.

Plywood application in modern construction requires higher mechanical properties of this material. Improvement of mechanical properties of plywood can be made by changing the thickness of the outer layers (Kljak et al. 2006), by reinforcement made from synthetic fibers (Xu et al., 1998; Biblis et al., 2000; Brezović et al., 2002, 2003, 2010; Hráskỳ and Král, 2007; Choi et al., 2011), as well as by changing the positions of veneers in plywood structure (Jakimovska Popovska and Iliev, 2013). Trough combining the veneers with diffetrernt thickness, plywood with adequate characteristic for its application can be obtained (Hráskỳ and Král, 2006).

One segment of the researches of plywood includes the study of the plywood properties through a change of the position of the layers (veneer layouts) in the structure of the panel around the central axis, without changing the number and the thickness of the veneers.

Research on plywood bending strength and modulus of elasticity in bending in relation to their construction (structure) was carried out by Hráskỳ and Král (2005). By making certain experimental plywood models with different veneer layouts in plywood structure, some optimized plywood composition with improved mechanical properties can be provided (Jakimovska Popovska, 2011).

The aim of the research presented in the paper is to study the impact of veneer layouts on plywood bending properties, through the change of the position of the veneers in plywood structure around the central axis of the plywood panel, without changing the number and the thickness of the veneers.

2. MATERIALS AND METHODS OF THE EXPERIMENTAL WORK

For the realization of the research four experimental nine-layer plywood models are made. Each model has the same number of veneer sheets of each thickness class: three veneer sheets with a thickness of 3,2 mm and two veneer sheets with a thickness of 2,2; 1,5 and 1,2 mm.

The modelling is made on the basis of changing the position of veneers with a thickness of 3,2 mm around the central axis of the panel. The central layer of each model represents a veneer sheet with thickness of 3,2 mm, oriented parallel to the face grain of the panel.

In the first model the veneers with thickness of 3,2 mm are positioned next to the central veneer sheet. In the other models their position moves to the surface of the panel, so that in the fourth model these veneers build the surface layers of the panel (figure 1).

The orientation of adjacent layers in plywood structure is at right angle, which means that in all models the grain direction of the surface layers is parallel to the longitudinal axis of the panel.

Pure water-soluble phenol-formaldehyde resin with concentration of 47,10 % is used as plywood binder, applied in quantity of 180 g/m^2.

The panels are pressed in a hot press using the following parameters: specific pressure – P=18 kg/cm^2; pressing temperature – T=155 ºC and pressing time – t=20 min.

The panels are overlaid with phenol formaldehyde-resin impregnated paper with a surface weight of 120 g/m^2. The paper is bonded during the hot pressing process. Plywood overlaying with this paper is made in order to improve the water resistance of plywood, considering the fact that these plywood panels are intended for application in construction where can be exposed to high humidity conditions. Previuos researches (Iliev 2004) showed that overlaying wood-based composite panels with resin impregnated paper does not couse significant differences in bending strength and modulus of elasticity in bending compared to non-overlaid panels with the same structure.

The plywood models are made in the following dimensions: 580×580×17 mm. The moisture content of the panels is 8 %.

The denotations of the experimental plywood models have the following meaning:

- Model I – nine-layer plywood in which the veneers with thickness of 3,2 mm are positioned in the fourth, fifth (central) and in the sixth layer of the panel (γ=761,70 kg/m^3);
- Model II – nine-layer plywood in which the veneers with thickness of 3,2 mm are positioned in the third, fifth (central) and in the seventh layer of the panel (γ=759,99 kg/m^3);
- Model III – nine-layer plywood in which the veneers with thickness of 3,2 mm are positioned in the second, fifth (central) and in the eighth layer of the panel (γ=782,34 kg/m^3);
- Model IV – nine-layer plywood in which the veneers with thickness of

3,2 mm are positioned in the surface layers and in the central layer of the panel (first, fifth-central and ninth layer) (γ=785,90 kg/m^3).

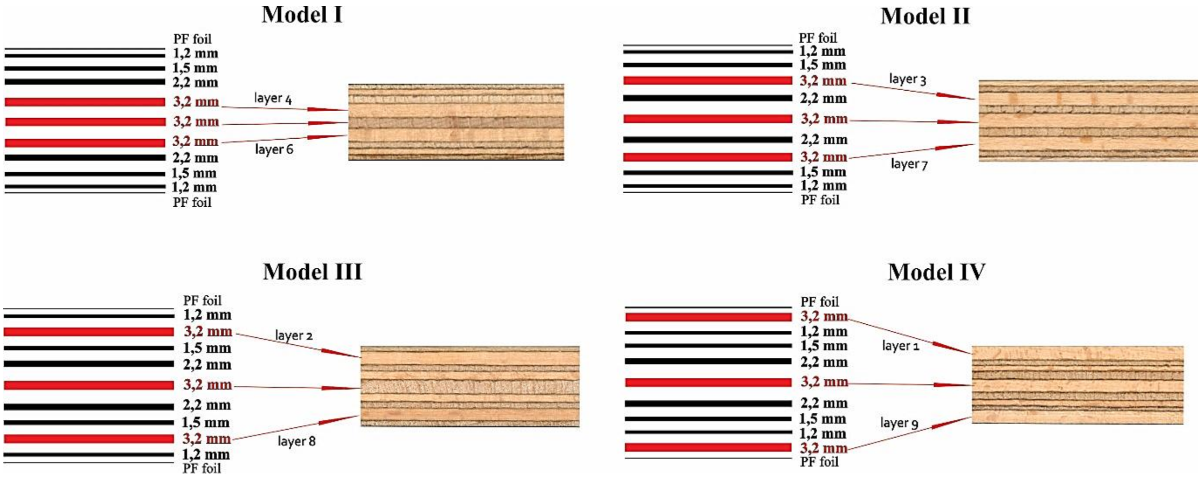

Figure 1: Pattern and cross-section of plywood models

The plywood bending strength and modulus of elasticity in bending are tested according to MKS D.A8.068/85. These properties are tested in two directions, i.e., parallel and perpendicular to the face grain of the panel.

The obtained data were statistically analyzed. One way ANOVA (analysis of variance) was used to determine the significance of the effect of veneer layouts on plywood bending properties. Shapiro-Wilk test for normality of the obtained data was applied and Levene's test for homogeneity of variances was applied. Tukey's test was applied to evaluate the statistical significance between mean values of the properties of plywood with different veneer layouts (different plywood models).

Statistical software SPSS Statistic was used for statistical analysis of the obtained data.

3. RESULTS AND DISCUSSION

According to the test results of the bending strength and modulus of elasticity in bending parallel to the face grain of the panel (Tabl. 1 and 2), following grouping can be done. The values of these properties of models I and III are within similar limits, as well as the values of models II and IV whereupon the difference in values between two groups is obvious. The mean value of bending strength in models II and IV are higher for 41,10 to 55,41 % compared to the mean value in models I and III. Models II and IV have higher values of modulus of elasticity compared to models I and III for 40,74 to 58,89 %.

The analysis of variance of the obtained data for bending strength (ANOVA: F (3; 16) = 58,61; p=0,000) and modulus of elasticity in bending parallel to the face grain (ANOVA: F (3;16) = 291,78; p=0,000) showed that the differences between the mean values of these properties of at least two plywood models are statistically significant. The conducted post-hoc Tukey's test for multiple comparison between models showed that there are statistically significant differences in the mean values of these properties of models I and III compared to models II and IV. The differences in the mean values of bending strength between model I and model III, as well as between model II and model IV are small and they are not statistically significant, whereto the model I has higher value of bending strength parallel to the face grain for 3,97 % compared to model III, while model II compared to model IV has higher value for 5,74 %. This means that the position of the veneers with a thickness of 3,2 mm in plywood structure, i.e., their moving to the surfaces layers of the panel, does not have significant impact on the bending strength parallel to the face grain.

In relation to the modulus of elasticity in bending parallel to the face grain, the differences in the mean values of this property between model II and model IV are not statistically significant, while the differences in the mean value between model I and all other plywood models, as well as between model III and all other plywood models are statistically significant.

The difference in the values of bending strength and modulus of elasticity in bending parallel to the face grain between the two groups of models results from the orientation of the veneers in the plywood structure, particularly of the veneers with a thickness of 3,2 mm, as they occupy the biggest percentage of the thickness of the panel.

In models I and III, two of the three veneer sheets with a thickness of 3,2 mm are oriented perpendicular to the length of the test specimen (perpendicular to the span-loading), while in models II and IV all three veneers with thickness of 3,2 mm are oriented parallel to the length of the test specimen. The bigger number of longitudinally oriented veneers with thickness of 3,2 mm is a reason for the higher values of bending strength and modulus of elasticity in bending parallel to the face grain in models II and IV compared to models I and III. In models II and IV a bigger percentage of the thickness of the panel is occupied by the veneers oriented parallel to the length of the test specimen.

Table 1: Statistical data for bending strength parallel to the face grain of plywood

Model	*No. of test spec.*	X_{min} *[N/mm²]*	X_{max} *[N/mm²]*	X_{mean} *[N/mm²]*	$X_{mean} \pm f_{xmean}$ *[N/mm²]*	$s \pm f_s$ *[N/mm²]*	$V \pm f_v$ *[%]*
I	5	62,58	68,89	66,71[a]	66,71±1,16	2,59±0,82	3,88±1,23
II	5	92,96	102,77	99,71[b]	99,71±1,78	3,99±1,26	4,00±1,27
III	5	60,57	71,04	64,16[a]	64,16±1,92	4,28±1,35	6,68±2,11
IV	5	86,07	108,20	94,13[b]	94,13±3,85	8,60±2,72	9,14±2,89

The mean values with the same letters are not significantly different at 0,05 probability level

Table 2: Statistical data for modulus of elasticity in bending parallel to the face grain of plywood

Model	*No. of test spec.*	X_{min} *[N/mm²]*	X_{max} *[N/mm²]*	X_{mean} *[N/mm²]*	$X_{mean} \pm f_{xmean}$ *[N/mm²]*	$s \pm f_s$ *[N/mm²]*	$V \pm f_v$ *[%]*
I	5	6950,32	7342,37	7161,66[b]	7161,66±76,75	171,63±54,27	2,40±0,76
II	5	9608,90	10404,91	10157,91[a]	10157,91±144,20	322,43±101,96	3,17±1,00
III	5	6266,89	6654,62	6405,22[c]	6405,22±68,73	153,69±48,60	2,40±0,76
IV	5	9639,46	10500,27	10079,47[a]	10079,47±144,03	322,06±101,85	3,20±1,01

The mean values with the same letters are not significantly different at 0,05 probability level

This ratio of the values is consistent with the so-called “Parallel ply theory”, which explains the differences in strength characteristics in the length and the width directions of plywood panels, which results from the alternating grain direction of individual veneers in plywood structure [Structural plywood & LVL design manual, 2009]. According to this theory veneers with grain direction parallel to the span, carry all of the bending from the applied load to the supports, while the veneers with grain direction perpendicular to the span are assumed not to contribute to the strength [Structural plywood & LVL design manual, 2009].

The obtained values of bending strength and modulus of elasticity in bending parallel to the face grain of the panel are within the limits of the values for this property listed in available literature. Dimeski and Iliev (1997) give values of 78,36 and 67,68 N/mm^2 for bending strength of seven-layer and nine-layer beech plywood respectively. Iliev (2000) gives a value of 84,25 N/mm^2 for seven-layer and 96,51 N/mm^2 for nine-layer beech plywood. Hráskỳ and Král (2005) give the values of 75,81 N/mm^2 for bending strength and 18456 N/mm^2 for modulus of elasticity in bending of nine-layer beech plywood. The same authors for eleven and thirteen-layer beech plywood give the values of 86,74 and 78,07 N/mm^2 for bending strength and 21969 and 21015 N/mm^2 for modulus of elasticity in bending parallel to the face grain of the plywood panels. Kljak et al. (2006) give the values of 92,35 and 9924,29 N/mm^2 for bending strength and modulus of elasticity in bending parallel to the face grain of multi-ply beech plywood. Dieste et al. (2008) for bending strength and modulus of elasticity in bending parallel to the face grain of five-layer beech plywood give the values of 87,46 and 10000 N/mm^2 respectively. Bal and Bektap (2014) give the values of 80,2 and 8258 N/mm^2 for bending strength and modulus of elasticity in bending parallel to the face grain of five-layer beech plywood bonded with phenol-formaldehyde resin.

The obtained values of bending strength parallel to the face grain of the panel of all models exceed the value of 40 N/mm^2 defined in the standard MKS D.C5.043 for structural plywood for use in construction. The same standard defines the minimal value of 7000 N/mm^2 for modulus of elasticity in bending parallel to the face grain. With exception of model III, all other plywood models meet the requirement of this standard in relation to the modulus of elasticity.

The test results of the bending strength and modulus of elasticity in bending perpendicular to the face grain of the panel are shown in tables 3 and 4.

Table 3: Statistical data for bending strength perpendicular to the face grain of plywood

Model	*No. of test spec.*	X_{min} *[N/mm^2]*	X_{max} *[N/mm^2]*	X_{mean} *[N/mm^2]*	$X_{mean} \pm f_{xmean}$ *[N/mm^2]*	$s \pm f_s$ *[N/mm^2]*	$V \pm f_v$ *[%]*
I	5	68,23	73,91	71,34^a	71,34±0,91	2,03±0,64	2,85±0,90
II	5	59,32	66,44	63,74^b	63,74±1,40	3,13±0,99	4,91±1,55
III	5	78,64	89,95	83,87^c	83,87±2,44	5,46±1,73	6,51±2,06
IV	5	41,08	45,34	43,79^d	43,79±0,78	1,75±0,55	4,00±1,26

The mean values with the same letters are not significantly different at 0,05 probability level

Table 4: Statistical data for modulus of elasticity in bending perpendicular to the face grain of plywood

Model	No. of test spec.	X_{min} [N/mm²]	X_{max} [N/mm²]	X_{mean} [N/mm²]	$X_{mean}\pm f_{xmean}$ [N/mm²]	$s\pm f_s$ [N/mm²]	$V\pm f_v$ [%]
I	5	6176,78	6509,06	6310,93[a]	6310,93±60,38	135,00±42,69	2,14±0,68
II	5	5444,28	5917,33	5702,22[b]	5702,22±89,39	199,89±63,21	3,51±1,11
III	5	7521,77	8493,64	8028,55[c]	8028,55±173,01	386,85±122,33	4,82±1,52
IV	5	3256,17	3549,63	3368,25[d]	3368,25±54,27	121,35±38,38	3,60±1,14

The mean values with the same letters are not significantly different at 0,05 probability level

The analysis of the obtained results for bending strength showed that models I and III have higher mean values of this property compared to models II and IV, whereto the mean value of model III is higher than the mean value of model IV for 91,53 %, while the mean value of model I compared to model II is higher for 11,92 %. Regarding the modulus of elasticity in bending, the mean value of model III is higher than the mean value of model IV for 138,36 %, while the mean value of model I compared to the mean value of model II is higher for 10,67 %.

The analysis of variance of the obtained data for bending strength (ANOVA: F (3;16) = 120,42; p=0,000) and modulus of elasticity in bending perpendicular to the face grain (ANOVA: F (3;16) = 333,66; p=0,000) showed that the differences between the mean values of these properties of at least two plywood models are statistically significant. The conducted post-hoc Tukey's test for multiple comparison between models showed that the differences in the values of these properties between all plywood models are statistically significant.

The different values of these properties in the different models are also a result of the orientation of the veneers with thickness of 3,2 mm in plywood structure. The highest values of bending strength perpendicular to the face grain of the panel are achieved in models that have more veneers with thickness of 3,2 mm running parallel to the length of the test specimen (model I and III). Models II and IV have all three veneers with thickness of 3,2 mm running perpendicular to the length of the test specimens.

Beside the orientation of the veneers, the position of the veneers, i.e., the veneer layouts in plywood structure has also impact on the values of bending strength and modulus of elasticity in bending perpendicular to the face grain of the panel. So, the model III has higher value of bending strength for 17,5 % and higher value of modulus of elasticity for 27,22 % compared to model I, while model II has a higher value of bending strength for 45,5 % and higher value of modulus of elasticity for 69,29 % compared to the value of model IV.

The failure mode of the test specimens after bending test of plywood models is shown on figure 2. The failure of plywood occurred mostly in surface layers of the tensile zone, which is one of the characteristic failures in bending stress (Hráskỳ and Král, 2005).

The obtained values of bending strength and modulus of elasticity in bending perpendicular to the face grain of the panel are within the limits of the values for this property listed in available literature. Hráskỳ and Král (2005) give the values of 55,68 N/mm² for bending strength and 9775 N/mm² for modulus of elasticity in bending of nine-layer beech plywood. The same authors for eleven and thirteen-layer beech plywood give the values of 70,71 and 65,62 N/mm² for bending strength and 14053 and 13774 N/mm² for modulus of elasticity in bending perpendicular to the face grain of the plywood panels. Kljak et al. (2006) give the values of 89,45 and 9333,31 N/mm^2 for bending strength and modulus of elasticity in bending perpendicular to the face grain of multi-ply beech plywood. Dieste et al. (2008) for bending strength and modulus of elasticity in bending perpendicular to the face grain of five-layer beech plywood give the values of 50 N/mm^2 and 3000 N/mm^2 respectively. Bal and Bektap (2014) give the values of 39,4 and 2640 N/mm^2 for bending strength and modulus of elasticity in bending perpendicular to the face grain of five-layer beech plywood bonded with phenol-formaldehyde resin.

The obtained values of bending strength and modulus of elasticity in bending perpendicular to the face grain of the panel of all models exceed the values of 15 N/mm^2 for bending strength and 3000 N/mm^2 for modulus of elasticity in bending defined in the standard MKS D.C5.043 for structural plywood for use in construction.

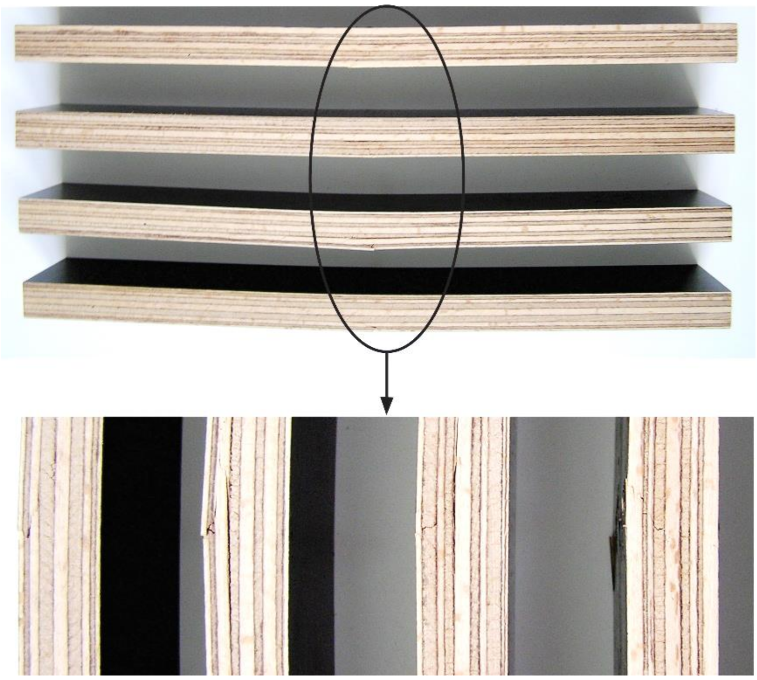

Figure 2: Failure mode of the test specimens of plywood models after bending test parallel to the face grain

4. CONCLUSIONS

On the basis of the realized researches the following conclusions can be drawn:

- Different veneer layouts in plywood structure have significant impact on plywood bending properties.
- The highest values of bending strength and modulus of elasticity in bending are achieved in plywood models in which the veneers with a thickness of 3,2 mm are oriented parallel to the span of the loaded panel. Therefore, the recommendation for use of configuration of models II and IV in those cases when the panels are exposed to bending parallel to the face grain of the panel. The relocation of longitudinally oriented veneers with thickness of 3,2 mm to the surface layers of the panel (model IV compared to model II) does not cause significant differences in the values of these properties between these two models.

- When the panels are loaded in bending in cross grain direction, or when a greater equality of the values of bending strength and modulus of elasticity in bending in both directions of the panel is required, then the configurations of models I and III are recommended. Thereto, by moving the longitudinally oriented veneers with thickness of 3,2 mm to the surface layers of the panel (model III compared to model I) the bending strength is increasing for about 17,5 %, while the modulus of elasticity in bending is increased for about 27 %. Therefore , it is recommended to use the configuration of model III when panel is exposed to this kind of loads. But, related to the greater equality of the values of these properties in both directions of the panel, then the configuration of model I is recommended.
- The production of plywood with different veneer layouts in panel structure gives opportunities for production of panels that can meet the different application requirements. Using the same veneer sheets in panel structure but with different layouts, panels with different strength characteristics required for installation in different constructions can be designed.
- The choice of particular plywood configuration will depend on the application area, i.e., the type of loads on which the panel is exposed during the exploitation period.

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