RESEARCH ON THE CHARACTERISTICS OF LABORATORY MADE PLYWOOD

Violeta Jakimovska Popovska, Iliev Borce
S.S. Cyril and Methodius University Skopje, Macedonia

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ABSTRACT:

The aim of the researches presented in this paper is to study some physical and mechanical characteristics of laboratory made plywood. One part of the research includes the study of the plywood 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, four models of laboratory nine-layered 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 of the position of the veneers with a thickness of 3,2 mm around the central axis (axis of symmetry). All four models are overlaid with phenol formaldehyde-resin impregnated paper that is bonded during the hot pressing process. One additional model without surface protection of phenol formaldehyde-resin impregnated paper is made as replica of one of the four models. This model is made in order to see the differences in physical properties of overlaid and non-overlaid plywood. Pure water-soluble phenol-formaldehyde resin is used as plywood binder. The evaluation of the models quality was made on the base of the obtained data from the tests of some of their physical and mechanical properties such as thickness swelling and water absorption after immersion in water for the period of 24 h, bending strength in length and width direction of the panel. The tests of these properties were carried out according to the national MKS standards. The research results showed that all tested models of plywood meet and exceed the defined values of physical and mechanical properties in accordance with the requirements of the standard MKS D.C5.043 for structural plywood used in construction.

1. INTRODUCTION

Wooden composites are intensively used in modern construction, as materials for indoor and outdoor application, as well as for structural or non-structural uses. Plywood is one of the major types of wood composite materials for structural use.

In developed European countries and on the American Continent the use of wood composites in the construction of wooden buildings is on a significant level. In North America, wood composite materials represent more than 40 % of the materials that are used in construction of residential buildings (Winandy, 2006).

Plywood is characterized with excellent strength characteristics, stiffness and dimensional stability, which is the result of the cross-laminated layup of veneers in the plywood structure. The form of these panels allows its application in many areas where materials of large formats are required. Plywood is utilized for many applications in constructions: as a part of engineered wood products such as webs for wood-I joists, for siding, sheathing, flooring or roofing.

The utilization of plywood in modern construction requires higher physical and mechanical properties. One part of the research includes the study of the plywood 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.

By making certain laboratory plywood models with changed position of the layers in plywood structure, some optimised plywood composition with improved physical and mechanical properties can be provided (Jakimovska Popovska, 2011).

2. MATERIALS AND METHODS OF THE EXPERIMENTAL WORK

For the realization of the research four models of laboratory plywood with nine-layers 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 modeling 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 (axis of symmetry). 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.

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.

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=1,8 MN/m^2; temperature of hot plates - T=155ºC and pressing time - t=20 min.

Dimensions of the panels are 580×580×17 mm. The humidity of the panels is 8 %.

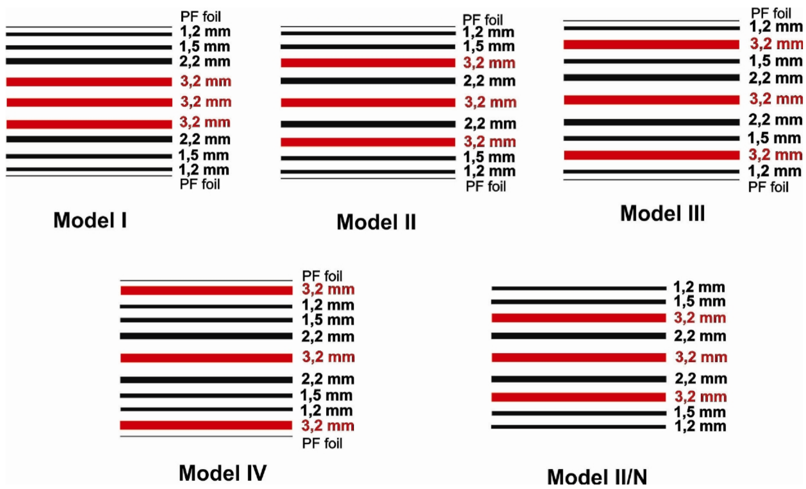

Figure 1. Pattern of the models structure

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

- Model I – nine-layered 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, overlaid with phenol formaldehyde-resin impregnated paper (γ=761,70 kg/m^3);

- Model II – nine-layered 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, overlaid with phenol formaldehyde-resin impregnated paper (γ=759,99 kg/m^3);
- Model III – nine-layered 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, overlaid with phenol formaldehyde-resin impregnated paper (γ=782,34 kg/m^3);
- Model IV – nine-layered 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), overlaid with phenol formaldehyde-resin impregnated paper (γ=785,90 kg/m^3);
- Model II/N – nine-layered 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), without surface phenol formaldehyde-resin impregnated paper.

The thickness swelling and water absorption of plywood panels are tested according to the national standard MKS D.C8.104, while the bending strength of plywood is tested according to MKS D.A8.068/85. This property is tested in two directions, i.e., parallel and perpendicular to the face grain of the panel.

3. Results of the research and discussion

3.1. Results of the relative water absorption for the period of 24 hours

Table 1. Statistical values of relative water absorption for the period of 24 hours

Model	No. of test specimens	X_{min} [%]	X_{max} [%]	X_{sr} [%]	$X_{sr}\pm f_{xsr}$ [%]	$\sigma\pm f_\sigma$ [%]	$V\pm f_V$ [%]	P_x [%]
I	5	25.70	32.93	29.72	29,72±1,18	2,63±0,83	8,85±2,80	3.96
II	5	19.68	25.53	22.93	22,93±1,11	2,48±0,78	10,82±3,46	4.84
III	5	25.25	30.29	28.69	28,69±0,89	2,00±0,63	6,95±2,20	3.11
IV	5	26.37	31.28	27.73	27,73±0,90	2,02±0,64	7,30±2,31	3.26
II/N	10	27.22	36.86	32.43	32,43±0,92	2,90±0,65	8,93±2,00	2.82

The mean values of the relative water absorption for the period of 24 hours are within the limits of 22,93 % in model II to 32,43 % in model II/N. The ratio of the values of these two models shows that overlaying the panels with phenol formaldehyde-resin impregnated paper reduces the relative water absorption by about 30 %.

The analysis of the values of relative water absorption showed that models I and III have higher values of this property compared to models II and IV.

3.2. Results of the relative thickness swelling for the period of 24 hours

Table 2. Statistical values of relative thickness swelling for the period of 24 hours

Model	No. of test specimens	X_{min} [%]	X_{max} [%]	X_{sr} [%]	$X_{sr}\pm f_{xsr}$ [%]	$\sigma\pm f_\sigma$ [%]	$V\pm f_V$ [%]	P_x [%]
I	5	8.53	10.66	9.58	9,58±0,36	0,80±0,25	8,35±2,64	3.73
II	5	8.35	9.33	8.90	8,90±0,16	0,36±0,11	4,08±1,29	1.82
III	5	8.61	9.96	9.46	9,46±0,28	0,63±0,20	6,68±2,11	2.99
IV	5	8.55	10.28	8.96	8,96±0,33	0,75±0,24	8,32±2,63	3.72
II/N	10	8.95	12.19	9.95	9,95±0,29	0,91±0,20	9,19±2,06	2.91

The analysis of the obtained test results of the laboratory models showed that the mean values of relative thickness swelling for 24 hours are within the limits of 8,90 % in model II to 9,95 % in model

II/N. It was expected that the non-overlaid model II/N will have a higher value of thickness swelling compared to the other models that have surface finish with phenol formaldehyde-resin impregnated paper.

The values of this property for all models vary in tight limits. It can be noticed that the first and the third models have approximately equal values, as well as the values of the second and fourth model. Models I and III have higher values for 5,28 to 7,64 % compared to the values of models II and IV.

The values of relative thickness swelling for the immersion period of 24 hours are in all models bellow the limit of 12 % defined as national standard MKS D.C5.032 for wood-based panels for the use in construction.

3.3.Results of testing the bending strength of plywood models

Table 3. Statistical values of bending strength parallel to the face grain of the panel

Model	No. of test specimens	X_{min} [N/mm^2]	X_{max} [N/mm^2]	X_{sr} [N/mm^2]	$X_{sr}\pm f_{xsr}$ [N/mm^2]	$\sigma\pm f_\sigma$ [N/mm^2]	$V\pm f_v$ [%]	P_x [%]
I	5	62.58	68.89	66.71	66,71±1,16	2,59±0,82	3,88±1,23	1.73
II	5	92.96	102.77	99.71	99,71±1,78	3,99±1,26	4,00±1,27	1.79
III	5	60.57	71.04	64.16	64,16±1,92	4,28±1,35	6,68±2,11	2.99
IV	5	86.07	108.20	94.13	94,13±3,85	8,60±2,72	9,14±2,89	4.09

According to the test results of the bending strength parallel to the face grain of the panel presented in table 3, following grouping can be done. The values of the 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 are 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.

The difference in the values 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 largest 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, 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 the bending strength 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.

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 difference in the mean values between model I and model III, as well as between model II and model IV is small, 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, has a small impact on the bending strength parallel to the face grain.

The force-deflection diagrams for all models are shown in figure 2.

The values of bending strength parallel to the face grain of the panel are for all models 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-layered and nine-layered beech plywood respectively. Iliev (2000) gives a value of 84,25 N/mm^2 for seven-layered and 96,51 N/mm^2 for nine-layered beech plywood.

The obtained values of bending strength parallel to the face grain of the panel of all models exceed the value of 40 N/mm2 defined in the standard MKS D.C5.043 for structural plywood for use in construction.

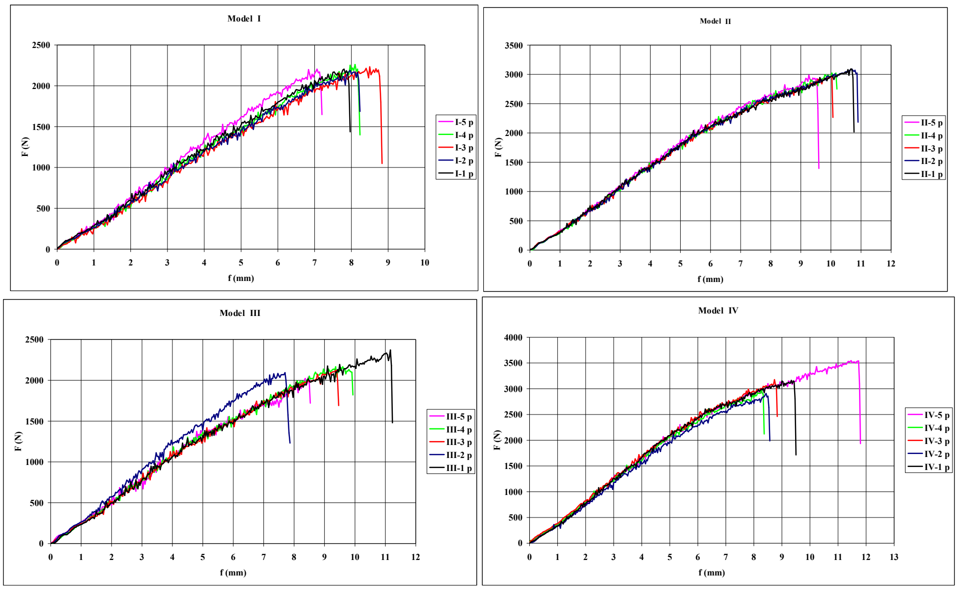

Figure 2. Force-deflection diagrams for models I, II, III and IV
(parallel to the face grain)

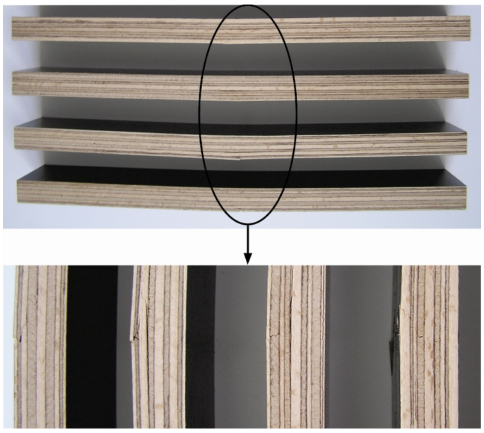

Figure 3. Standard deformation of the test specimens after determination of
bending strength of plywood parallel to the face grain

The test results of the bending strength perpendicular to the face grain of the panel are shown in table 4. The analysis of the obtained (table 4) 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 %.

Table 4. Statistical values of bending strength perpendicular to the face grain of the panel

Model	No. of test specimens	X_{min} [N/mm^2]	X_{max} [N/mm^2]	X_{sr} [N/mm^2]	$X_{sr}\pm f_{xsr}$ [N/mm^2]	$\sigma\pm f_\sigma$ [N/mm^2]	$V\pm f_v$ [%]	P_x [%]
I	5	68.23	73.91	71.34	71,34±0,91	2,03±0,64	2,85±0,90	1.27
II	5	59.32	66.44	63.74	63,74±1,40	3,13±0,99	4,91±1,55	2.20
III	5	78.64	89.95	83.87	83,87±2,44	5,46±1,73	6,51±2,06	2.91
IV	5	41.08	45.34	43.79	43,79±0,78	1,75±0,55	4,00±1,26	1.79

The different values of this property 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 in plywood structure has also some influence on the value of bending strength perpendicular to the face grain of the panel. So, the model III has higher value for 17,5 % compared to model I, while model II has a higher value for 45,5 % compared to the value of model IV.

The different orientation of the veneers with thickness of 3,2 mm also results in higher or lower values of bending strength parallel and perpendicular to the face grain within one model. The mean values of bending strength perpendicular to the face grain in model I and III are higher than the mean values of bending strength parallel to the face grain in these models.

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

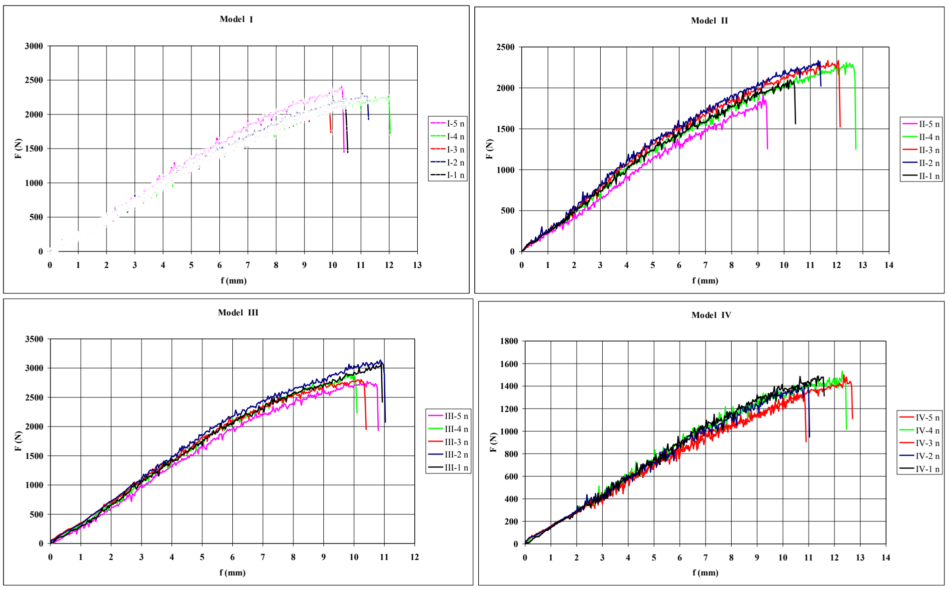

Figure. 4. Force-deflection diagrams for models I, II, III and IV (perpendicular to the face grain)

4. CONCLUSIONS

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

- All plywood models represent a stable material with a density that exceeds the requirements of the national standard for plywood used in construction. The high density of plywood is basic prerequisite for good dimensional stability and high mechanical properties of the material.
- From the obtained results for thickness swelling and water absorption of the plywood models it can be concluded that all models are dimensionally stable to water impact, which is one of the requirements for plywood application in high humidity conditions and for use in construction.
- The highest values of bending strength of plywood have the models where 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. By moving the longitudinally oriented veneers with thickness of 3,2 mm to the surface layers of the panel (model IV compared to model II) the bending strength is decreasing for about 6 %. Therefore, when choosing among these two models there is the recommendation for use of configuration of model II.
- When the panels are loaded in bending in cross grain direction, or when a greater equality of the values of this property 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 %. 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 this property in both direction of the panel, then the configuration of model I is recommended.
- The production of plywood with different layout of veneer sheets 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 depends on the application area, i.e., the type of loads on which the panel is exposed during the exploitation period.

5. REFERENCES

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