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PHYSICAL CHARACTERISTICS OF MULTILAYERED PLYWOOD MADE FROM BEECH VENEERS

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ABSTRACT

The researches conducted were directed to production of stable multipurpose plywood from deciduous raw materials that are resistant to prolonged water impact, as well as to mutual impact of water and heat. For that purpose experimental seven-layer and nine-layer plywood panels were made from peeled beech veneers bonded with water-soluble phenol formaldehyde resin.

Water impact was analyzed in conditions of water regimes in order to define the change in thickness swelling and water absorption after immersion of test specimens in water for a period of 96 hours, and the change in density, volume, thickness swelling and water absorption after immersion of the test specimens in boiling water for 6 hours. Water impact on the degree of adhesion after 2 hours of immersion in water was also analyzed.

The research showed that panels are characterized by high stability during this kind of treatment. The panels showed consistency in form and dimensions, as well as consistency of adhesion in glue lines.

Key words: multilayered plywood, beech veneers, phenol formaldehyde resin, physical properties, resistance to water and heat

1. INTRODUCTION

Plywood panels take up high share in the total world production of wood based panels. That is due to the fact that these panels with their characteristics and properties still cannot be replaced with other wood based panels that are chipper and with similar characteristics to plywood. Water resistant plywood made with additional protection to water and moisture is still irreplaceable in construction, shipbuilding and automotive industry.

Attaining high level of plywood properties and improvement of plywood properties is a challenge in technological processes. Technological solutions that will eliminate the negative impacts on plywood properties are being intensively searched for. The selection of raw material, bonding components and technological parameters for plywood production affects immensely plywood quality.

Special consideration in plywood production is given to improvement of its physical and mechanical properties. Researches are made in order to produce stable panels that will meet the modern exploitation requirements (Almeida *et al.* 2013; Carvlho *et al.* 2014; Dieste *et al.* 2008; Dimeski and Iliev 1997; Iliev *et al.* 2004; Iliev *et al.* 2007; Iliev *et al.* 2008; Jakimovska Popovska 2011, Jakimovska Popovska *et al.* 2013; Jakimovska Popovska *et al.* 2014; Jamalirad *et al.* 2011; Uisal *et al.* 2010; Zdravković *et al.* 2013; Zdravković *et al.* 2014). From aspect of improvement of the physical properties, special attention is paid to studying the hygroscopic properties of plywood and its dimensional stability (Aziri 2012; Aziri *et. al.* 2013; Carvlho *et al.* 2014; Dieste *et al.* 2008; Iliev *et al.* 2004; Iliev *et al.* 2007; Iliev *et al.* 2008; Jakimovska Popovska 2011; Jakimovska Popovska *et al.*

2013; Jakimovska Popovska *et al.* 2014; Jamalirad *et al.* 2011; Mihailova *et al.* 2005; Miljković *et al.* 1997, Uisal *et al.* 2010; Zdravković *et al.* 2013).

One segment of the researches of plywood is directed to creating possibilities for production of multilayered plywood with enhanced physical properties that will be resistant to moisture, water and heat impact (Iliev *et al.* 2007; Mihailova *et al.* 2005; Zdravković *et al.* 2013).

2. METHOD OF THE EXPERIMENTAL WORK

The aim of the research conducted is studying water impact on physical properties of seven-layer and nine-layer plywood. Water impact was analyzed through change of thickness swelling and water absorption after immersion of test specimens in water for a period of 96 hours, as well as through change of density, water absorption, thickness swelling and volume swelling, after immersion of test specimens in boiling water for 6 hours. The degree of adhesion between the veneers after immersion in water for 2 hours has also been analyzed.

The researches were made on laboratory experimental seven-layer and nine-layer water-resistant plywood made from peeled beech veneers with thickness of 1,5; 2,2 and 3,2 mm. The moisture content of the veneers was 7,2%.

The seven-layer plywood was made with four longitudinally oriented veneer sheets (the first and the seventh as surface veneers with thickness of 1,5 mm, and the third and the fifth with thickness of 2,2 mm) and three perpendicularly oriented veneers with thickness of 3,2 mm. The nine-layer plywood was made with five longitudinally oriented veneers (the first and the ninth as surface veneers with thickness of 1,5 mm and the fifth and the seventh veneer with thickness of 3,2 mm) and four perpendicular veneers with thickness of 2,2 mm.

The orientation of the adjacent layers of veneers in panels' composition was at right angle. The grain direction of the surface veneers was parallel to the longitudinal axis of the panel.

The composition of the plywood panels is shown in table 1.

Table 1. *Composition of plywood panels*

Model	Panel thickness, mm	Number of veneers	Composition (thickness of veneers, mm)
I	15,20	7	1,5+3,2+2,2+3,2+2,2+3,2+1,5
II	18,83	9	1,5+2,2+3,2+2,2+3,2+2,2+3,2+2,2+1,5

Water-soluble phenol-formaldehyde resin with concentration of 47,3% was used for veneer bonding. The preparation of the adhesive was made with addition of wheat flour as filler and 20% water solution of NaOH as catalyst. The adhesive's compounds were with the following ratio: resin 72,46%, filler 10,87%, water 10,14% and catalyst 6,52%.

The panels were made by combining veneers with different thicknesses and by positioning the adjacent sheets at right angles. The prepared adhesive was spread manually on both sides of veneers, with thickness of 3,2 mm in seven-layer panels and on veneers with thickness of 2,2 mm in nine-layer panels in quantity of 180 g/m^2. The surface finish was made of phenol-formaldehyde foil (phenol-formaldehyde resin impregnated paper) with surface weight of 120 g/m^2.

The patterns of the panels are shown on figure 1.

The panels were made in single-opening electric press with the following technological parameters: specific pressure of 15 kg/cm^2, pressing temperature of 155°C and pressing time of 20 minutes. The dimensions of the panels were 580×580 mm. Moisture content of the panels was 10%.

According to the number and thickness of the veneer used for the panels, the following models were made:

- model I: seven-layered panel with thickness of 15,20 mm and density of 743,20 kg/m^3;
- model II: nine-layered panel with thickness of 18,83 mm and density of 757,21 kg/m^3.

Twelve test specimens with dimensions of 100×100 mm and two test specimens with dimensions of 200×100 mm from each model were made.

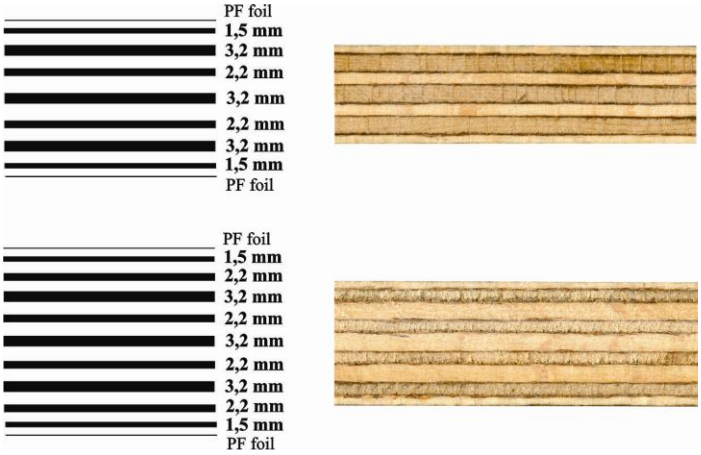


Figure 1. *Patterns and cross-sections of seven-layer and nine-layer plywood panels*

Water impact on the physical properties of the panels was studied on six test specimens with dimensions of 100×100 mm taken from each model. The test specimens were immersed in distillated water with temperature of 20±2ºC for a continuous period of 96 hours. Evaluation of the hygroscopy and dimensional stability of the panels was made on the basis of the properties that have direct impact on them, i.e., water absorption and thickness swelling. The changes of these properties were examined trough control measurings made in the period of 24, 48, 72 and 96 hours.

Mutual impact of water and heat on plywood physical properties (density, water absorption, thickness swelling and volume swelling) was studied on six test specimens with dimensions of 100×100 mm taken from each model. The test specimens were immersed in boiling water for 6 hours and after that were immersed in cold water with temperature of 20±5ºC for 2 hours. According to the national standard MKS D.A8.063, this treatment is appropriate for plywood type Tp 100 and bonding type UK-26 and UK-27.

Mutual impact of water and heat on the degree of adhesion between the veneers was studied on two test specimens with dimensions of 200×100 mm taken from each model. The length of the test specimens was parallel to the face grain of the panel. The test specimens were immersed in boiling water for 2 hours and then in cold water with temperature of 20±5ºC for 2 hours. According to the national standard MKS D.A1.072, the degree of adhesion was tested with a special device with chisel that has slightly curved knife-edge and is used for separation of the veneers one from another (fig. 2). According to the standard mentioned above, evaluation of the degree of adhesion was made on basis of the percentage of wood failure after separation of the adjacent veneer layers. Higher percentage of wood failure was equivalent to higher degree of adhesion.

Evaluation of the degree of adhesion was made on basis of the visual comparison between wood failure surfaces and the photos contained in the standard MKS D.A1.072. The photos represent the degree of adhesion from 0 to 9. According to standard MKS D.C5.041 for plywood, the mean value of the degree of adhesion of plywood type Tp 100 should be at least 4, while the value of the degree of adhesion in individual glue lines between two adjacent layers should be at least 3.

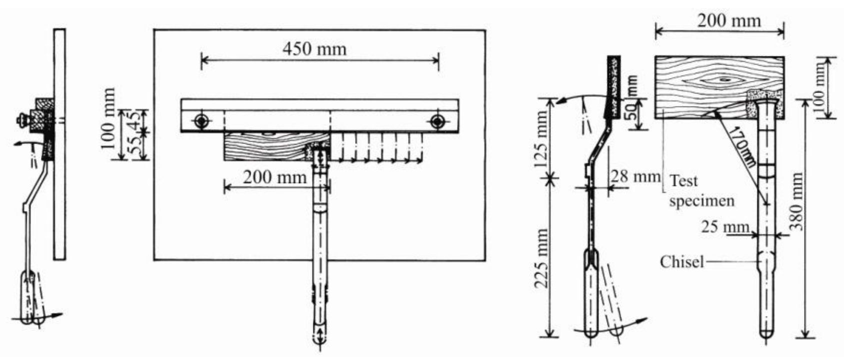


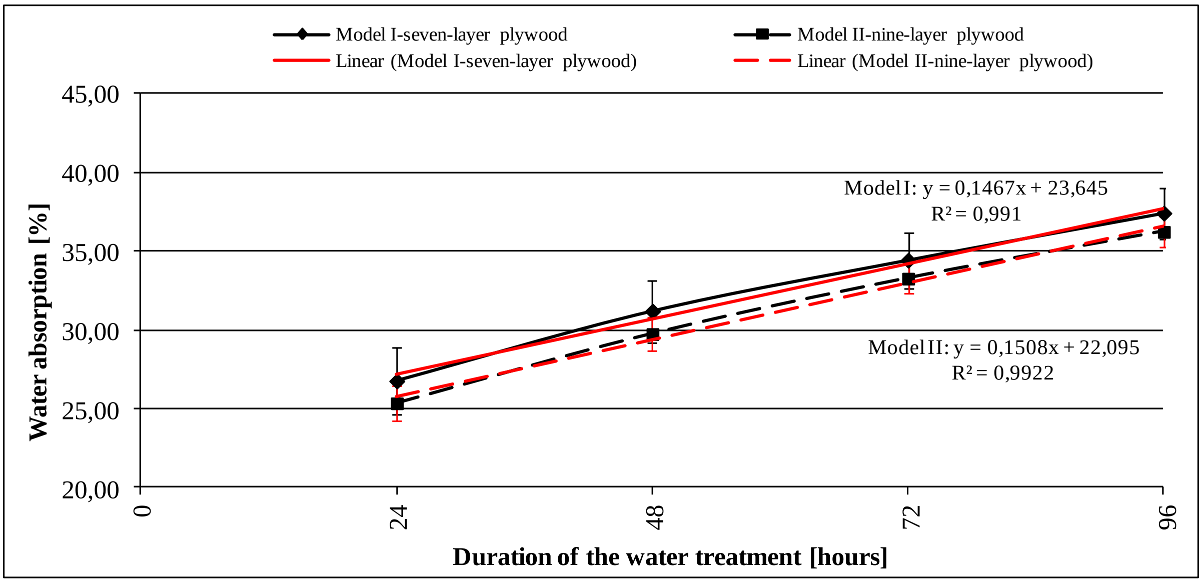
Figure 2. *Device with chisel for testing the degree of adhesion*

3. RESULTS AND DISCUSION

The values of relative water absorption for the analyzed period of immersion up to 96 hours were rising by increasing the duration of water treatment of the test specimens. The dynamics of increasing of the relative water absorption for immersion period of up to 96 hours are shown in figure 3.

The values of water absorption in the analyzed period of 96 hours increase with increment in the time of immersion of the test specimens in water, and they are as follows: for 24 hours, 26,76% in the first model and 25,34% in the second model; for 48 hours, 31,19% in the first model and 29,74% in the second model; for 72 hours, 34,43% in the first model and 33,26% in the second model and for 96 hours, 37,42% in the first model and 36,23% in the second model (fig. 3). The first model has higher values of water absorption compared to the second model.

The obtained values for relative water absorption of experimental plywood models are within the limits of the data listed in available literature.



Ɪ-error of the mean value ($\pm f_{xmean}$)

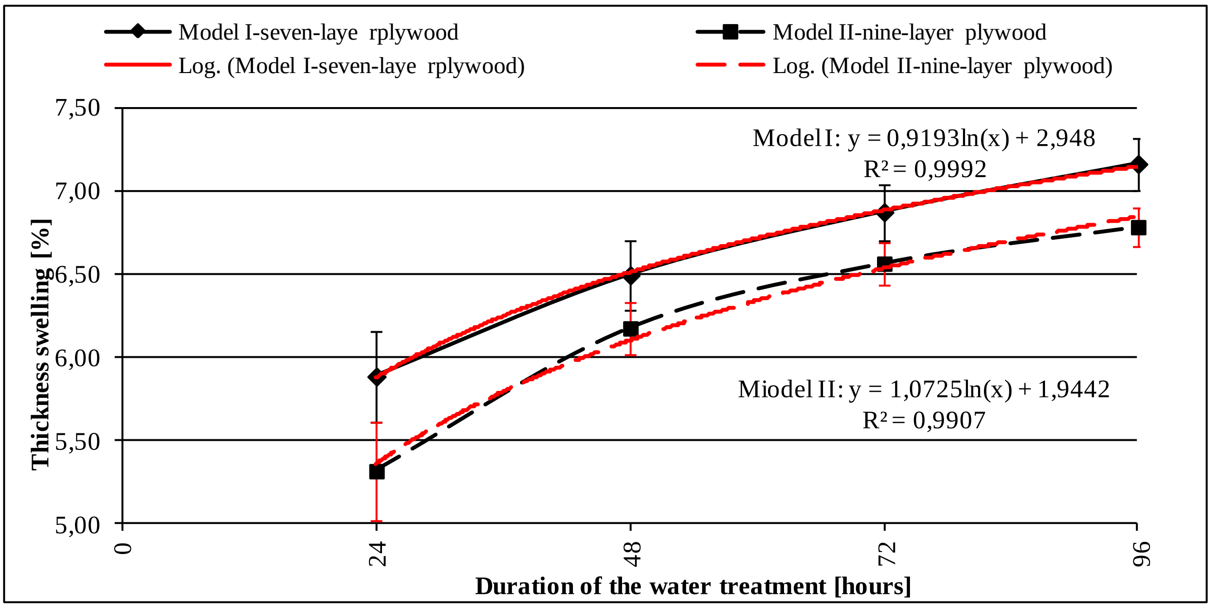
Figure 3. *Dynamics of increments in relative water absorption after immersion in water of up to 96 hours*

Test results for relative thickness swelling showed that the change in the value of this property for the analyzed period of 96 hours is proportional to the change of the duration of the water treatment of test specimens. The dynamics of increments in relative thickness swelling for immersion period of up to 96 hours are shown on figure 4.

The values of thickness swelling after 24 hours in both experimental models (5,88% in model I and 5,31% in model II) meet the requirements of the standard MKS D.C5.032 which defines the maximal value of 12% for relative thickness swelling of wood based panels after immersion in water for 24 hours.

By prolongation of water treatment after 24 hours, the values of this property are increasing, so after immersion for 48 hours the relative thickness swelling of model I increased by 11,97%, while the value of model II grew by 14,99%. After 72-hour immersion in water, the rise in the mean values of thickness swelling compared to the 24-hour immersion values was by 16,84% in the first model and by 23,54% in the second model. After completed cycle of immersion of up to 96 hours, the increment in the mean values, compared to the initial value (24 hours) was 21,77% in the first model and 27,68% in the second model (fig. 4). During the whole period of water treatment, the values of thickness swelling of model I (seven-layer plywood) were higher when compared to the values of model II (nine-layer plywood).

According to the standard MKS D.C5.032 which defines 12% as maximal value for thickness swelling after immersion in water for 24 hours for different types of wood-based panels, all experimental models proved to meet the requirements of this standard for 24 hours immersion in water, as well as after complete treatment of 96 hours. Accordingly, it can be stated that plywood panels are dimensionally stable during prolonged water treatment, which is one of the prerequisites for their application in high humidity conditions and weathering.



I-error of the mean value (±f_{xmean})

Figure 4. *Dynamics of increments in relative thickness swelling after immersion in water of up to 96 hours*

Based on the results of the research conducted and literature cited, it can be noticed that the values of experimental researched models correspond with the data from relevant literature. The models show dimensional stability under water impact, which is one of the requirements for their application in high humid conditions and weathering.

Resistance of plywood under water and heat impact is physical property that can help in defining the dimensional stability of exterior type plywood. For that reason, the experimental models were subjected to tests with treatment in boiling water in order to define the consistency of density, volume, thickness swelling and water absorption. The test results are shown in tables 2, 3, 4 and 5.

Test results presented in tables 2, 3, 4 and 5 show that after immersion in boiling water for 6 hours, higher values of the tested properties were achieved in model I (seven-layer plywood) compared to model II (nine-layer plywood). Compared to model II, the obtained values of density, water absorption, thickness swelling and volume swelling in model I were higher by 0,16%, 5,80%, 4,55% and 1,64%, respectively.

The value of relative water absorption after immersion for 6 hours in boiling water in model I is higher by 147,95 % compared to the value of relative water absorption of the same model after immersion in cold water for 24 hours, and higher by 77,31 % compared the value of relative water absorption after immersion in cold water for 96 hours. The value of relative water absorption after immersion for 6 hours in boiling water in model II is higher by 147,47 % and 73,09 % compared to the value of relative water absorption of the same model after immersion in cold water for 24 hours and higher by 73,09 % compared to the value of relative water absorption after immersion in cold water for 96 hours.

Compared to the values of relative thickness swelling after 24 hours immersion in cold water, the values of this property after immersion for 6 hours in boiling water were higher by 44,56% in model I and by 53,11% in model II. Compared to the values of the relative thickness swelling after 96 hours immersion in cold water, the values of this property after immersion for 6 hours in boiling water were higher by 18,71% and by19,91% in model I and model II respectively.

Mihailova *et al.* (2005) give the values of 47,25% and 64,53% for relative water absorption after 2 hours immersion in boiling water of nine-layer beech and black pine plywood, respectively. The plywood models were bonded with phenol-formaldehyde resin and overlaid with phenol-formaldehyde foil. The same authors give the values of 8,33% and 21,47% for relative thickness swelling of beech and black pine plywood, respectively.

Visual analysis of the form and structure of the test specimens after treatment in boiling water for 6 hours showed that there were no deformations and structural changes. No checks, warping or delaminating of the veneers of the test specimens were noticed (fig. 5)..

Table 2. *Statistical values for density of plywood models after treatment in boiling water for 6 hours*

Model	*No. of test specim.*	X_{min}	X_{max}	X_{mean}	$X_{mean} \pm fx_{mean}$	$S \pm fs$	$V \pm fv$	*Px*
		[kg/m³]	*[kg/m³]*	*[kg/m³]*	*[kg/m³]*	*[kg/m³]*	*[%]*	*[%]*
I	6	1098,60	1153,66	1130,68	1130,68±16,63	28,64±11,69	2,53±1,03	1,46
II	6	1123,87	1132,87	1128,82	1128,82±2,64	4,57±1,86	0,40±0,17	0,23

Table 3. *Statistical values for relative water absorption of plywood models after treatment in boiling water for 6 hours*

Model	*No. of test specim.*	X_{min}	X_{max}	X_{mean}	$X_{mean} \pm fx_{mean}$	$S \pm fs$	$V \pm fv$	*Px*
		[%]	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*
I	6	61,64	72,02	66,35	66,35±3,03	5,25±2,15	7,92±3,23	4,57
II	6	61,52	65,01	62,71	62,71±1,15	1,99±0,81	3,18±1,30	1,84

Table 4. *Statistical values for relative thickness swelling of plywood models after treatment in boiling water for 6 hours*

Model	*No. of test specim.*	X_{min}	X_{max}	X_{mean}	$X_{mean} \pm fx_{mean}$	$S \pm fs$	$V \pm fv$	*Px*
		[%]	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*
I	6	8,44	8,58	8,50	8,50±0,04	0,08±0,03	0,89±0,36	0,52
II	6	7,64	8,74	8,13	8,13±0,32	0,56±0,23	6,89±2,81	3,98

Table 5. *Statistical values for relative volume swelling of plywood models after treatment in boiling water for 6 hours*

Model	*No. of test specim.*	X_{min}	X_{max}	X_{mean}	$X_{mean} \pm fx_{mean}$	$S \pm fs$	$V \pm fv$	*Px*
		[%]	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*
I	6	9,25	9,37	9,29	9,29±0,04	0,07±0,03	0,75±0,31	0,43
II	6	8,58	9,91	9,14	9,14±0,40	0,69±0,28	7,56±3,09	4,36

The values obtained for degree of adhesion (tab. 6) showed that both models have similar mean values for this property (4,17 in model I and 4,25 in model II), that exceed the limitation mean value of 4 defined by the standards MKS D.C5.040 and 41. According to these standards, plywood models meet the requirements for exterior type of plywood Tp 100. The obtained degree of adhesion is a guarantee for consistency in the glue lines.

High bonding quality can be seen through comparison of the results obtained with the data presented in available literature. Dimeski and Iliev (1997) give values of degree of adhesion within the limits of 1,54 to 2,67 for beech plywood bonded with phenol-formaldehyde resin and values within the limits of 0,83 to 1,42 for combined panels veneered with poplar veneers bonded with phenol-formaldehyde resin. Iliev *et al.* (2007) give the values of 5 and 5,69 for seven and nine-layer black pine plywood bonded with phenol-formaldehyde resin, respectively. The same authors give the values of 4,58 and 4,25 for seven and nine-layer beech plywood, respectively. Jakimovska Popovska (2011) gives the value of 6,42 for degree of adhesion after 6-hour immersion in boiling water of nine-layer beech plywood bonded with phenol-formaldehyde resin. Miljković *et al.* (1997) give values within the limits of 2,42 to 2,58.for degree of adhesion of combined panels veneered with black pine veneers

Based on analysis of the values obtained from the research, it can be said that in the experimental model a standard degree of adhesion was obtained, which guarantees a consistency of the glue line. Experimental panels are characterized by consistency in the shape and dimensions during prolonged water and heat impact. There was not any self-delamination of the adjacent veneers, which indicates a good quality of adhesion.

Wood failure during determination of the degree of adhesion is presented on figure 6. This kind of wood failure surfaces are compared to those presented in the photos enclosed in standard MKS D.A1.072.

Table 6. *Values of degree of adhesion*

Model	*Test specim.*	*Degree of adhesion in glue line*								*Mean value*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	
I	1	5	5	3	4	4	4	/	/	4,17
	2	4	4	4	4	6	3	/	/	
II	1	4	6	4	4	6	5	3	3	4,25
	2	4	5	4	5	4	3	4	4	

Figure 5. *Test specimens of seven and nine-layer plywood models after 6 hours immersion in boiling water*

Figure 6. *Characteristic wood failure surfaces during determination of the degree of adhesion of plywood models*

4. CONCLUSIONS

On basis of the research accomplished, the following conclusions and recommendation can be drawn:

- from research of thickness swelling and of mutual impact of water and heat, it can be concluded that the panels showed a great dimensional stability. There was not anyt self-delaminating of the veneers, warping or other deformations.

- according to the physical properties tested, the panels meet the requirements of the national standards for use in construction and can be recommended for application in high humidity conditions, heat influence, weathering etc.
- the values of degree of adhesion between veneers showed consistency in form and dimensions of the panels under impact of water and heat. The values of this property guarantee panel consistency in conditions of variable humidity, heat and weathering.
- according to the results from the tested physical properties, it can be concluded that the investigated beech plywood panels meet the requirements of the national standard for plywood for structural use in construction, as well as for load-bearing and non load-bearing elements in floorings, wall and roof constructions.
- the results from the research showed that an adequate selection of materials and technological parameters for production of beech veneers plywood is made, which guarantee production of plywood with enhanced physical characteristics for use in different conditions of exploitation.

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