PHYSICAL CHARACTERISTICS OF MULTILAYERED PLYWOOD MADE FROM BLACK PINE VENEERS

Violeta Jakimovska Popovska[1], Borche Iliev[1], Julia Mihajlova[2]
[1]Ss. Cyril and Methodius University in Skopje, R. of Macedonia, Faculty of Design and Technologies of Furniture and Interior-Skopje
jakimovska@fdtme.ukim.edu.mk; iliev@fdtme.ukim.edu.mk
[2]University of Forestry – Sofia, R. of Bulgaria
jmihajlova@yahoo.com

ABSTRACT

The research presented in the paper is directed to creating possibilities for production of multilayered plywood that are resistant to prolonged water impact, as well as to mutual impact of water and heat.

The aim of the conducted research consists of the possibility for production of stable multifunctional plywood made from coniferous raw material. For that purpose experimental multilayered plywood panels are made from peeled black pine veneers bonded with water-soluble phenol formaldehyde resin.

The experimental panels were subjected to standard laboratory tests in conditions of water regimes in order to define the water resistance and dimensional stability under water impact and mutual impact of water and heat, as well as to determine the degree of adhesion between the veneers.

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

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

INTRODUCTION

Plywood panels take high percent 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. The water resistant plywood made with additional protection to water and moisture is still irreplaceable in construction, shipbuilding and automotive industry.

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

Special consideration in plywood production is paid to improvement of their physical and mechanical properties. The researches are made in order to produce stable panels that will meet the modern exploitation requirements (Alam et al., 2012; Brezin et.al., 1996; Carvlho et.al., 2014; Dieste et al., 2008; Dimeski and Iliev, 1997; Iliev et al., 2004, 2007 and 2008; Jakimovska Popovska 2011, Jakimovska Popovska et al., 2013 and 2014; Jamalirad et al., 2011; Rahman et al., 2013; Trinh et al., 2012; Uisal et al., 2010; Zdravković et al., 2013). From the aspect of improvement of physical properties, special attention is paid on the researches of hygroscopic properties of plywood and their dimensional stability (Aziri, 2012; Aziri et. al., 2013; Brezin et al., 1996; Carvlho et.al., 2014; Dieste et al., 2008; Iliev et al., 2004, 2007 and 2008; Jakimovska Popovska, 2011; Jakimovska Popovska et al., 2013 and 2014; Jamalirad et al., 2011; Mihailova et al., 2005; Trinh et al., 2012; 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 (Brezin et al., 1996; Iliev et al., 2007; Mihailova et al., 2005; Zdravković et al., 2013).

2. METHOD OF THE EXPERIMENTAL WORK

The aim of the conducted research is studying the water impact on physical properties of seven-layer and nine-layer plywood. The water impact is analyzed trough the change of the thickness swelling and water absorption after immersion of the test specimens in water in the period of 96 hours, as well as trough the change of the density, water absorption, thickness swelling and volume swelling, after immersion of the 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 have been conducted on experimental seven and nine-layer water resistant plywood. The panels are made from peeled black pine veneers with thickness of 1,5; 2,2 and 3,2 mm and moisture content of 9,6 %.

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 have the following ratio: resin-72,46 %, filler – 10,87 %, water – 10,14 % and catalyst – 6,52 %.

The panels are made by combining the veneers with different thicknesses and by positioning the adjacent sheets at right angles. The prepared adhesive is spread 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 is 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.

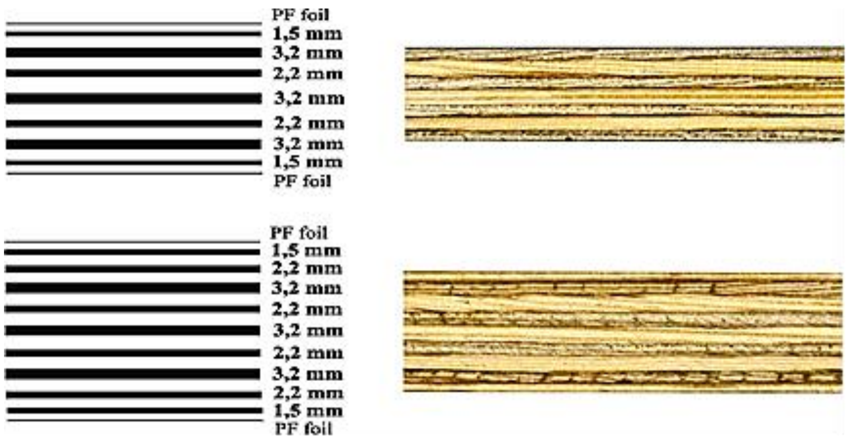


Figure 1: The patterns of seven-layer and nine-layer plywood panels

The panels are made in single-opening electric press with the fallowing 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 are 580×580 mm. The moisture content of the panels is 10 %.

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

– Model I: seven-layered panel with thickness of 13 mm and density of 737,41 kg/m^3;
– Model II: nine-layered panel with thickness of 16 mm and density of 750,64 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.

The 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±2 ºC in continued period of 96 hours. The evaluation of the hygroscopy and dimensional stability of the panels is 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 are examined trough control measuring made in the period of 24, 48, 72 and 96 hours.

The 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±5 ºC for 2 hours. According to the national standard MKS D.A8.063/85 this treatment is appropriate for plywood type TP 100 and bonding type UK-26 and UK-27.

The 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 is parallel to the face grain of the panel. The test specimens were immersed in boiling water for 2 hours and than in cold water with temperature of 20±5 ºC for 2 hours. According to the national standard MKS D.A1.072/72 the degree of adhesion was tested with special device with chisel that has slightly curved knife-edge and it is used for separation of the veneers one from another (Fig. 2). According to the same standard, the evaluation of the degree of adhesion is made on the base of the percent of wood failure after separation of the adjacent veneer layers. The bigger percent of wood failure is equivalent to higher degree of adhesion.

The evaluation of the degree of adhesion is made on the basis of the visual comparison between the wood failure surfaces and photos that are enclosed in the standard MKS D.A1.072/72. The photos represent the degree of adhesion from 0 to 9. According to the standard MKS D.C5.041/82 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.

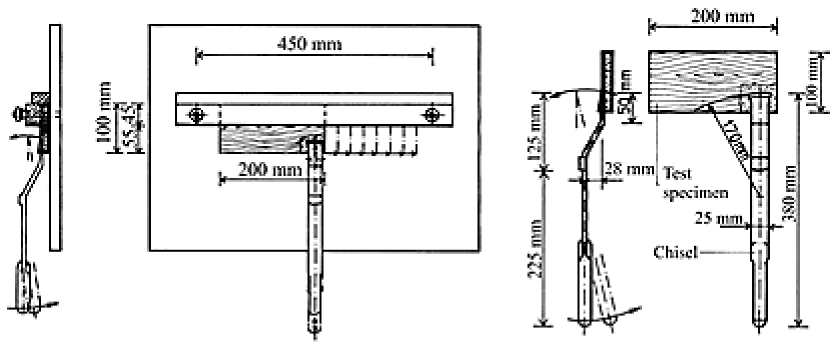
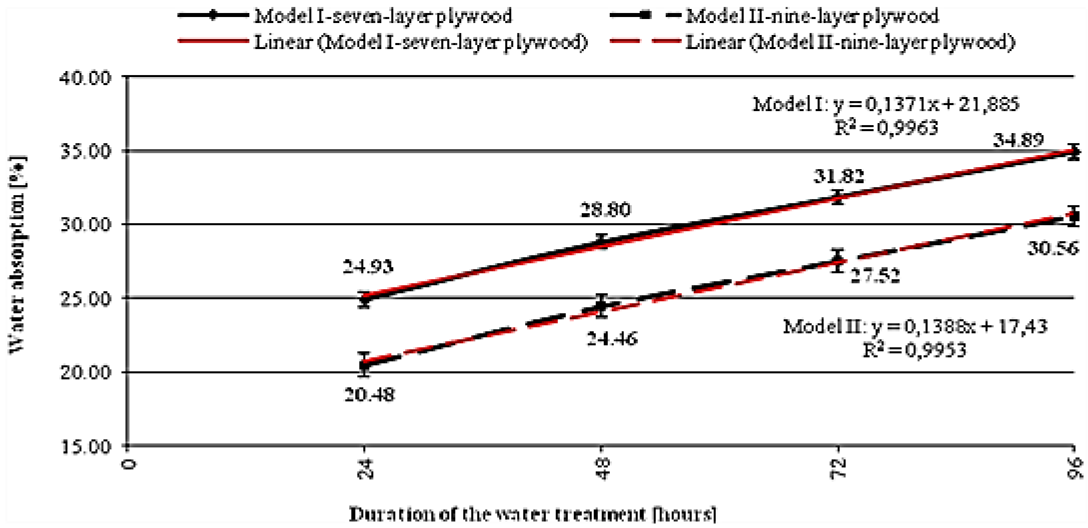


Figure 2: Device with chisel for testing the degree of adhesion

3. RESULTS AND DISCUSION

The values of relative water absorption for the analyzed period of immersion up to 96 hours increase with the increase of the duration of the water treatment of the test specimens. The dynamics of increasing of the relative water absorption for the immersion period up to 96 hours are shown on figure 3.

During the whole period of water treatment the values of water absorption of model I (seven-layer plywood) are higher compared to the values of model II (nine-layer plywood). By prolongation of the water treatment after 24 hours, the values of this property increase, so after immersion for 48 hours the relative water absorption of model I is increased for 15,52 %, while the value of model II is increased for 19,43 %. The highest intensity of increasing of this property in both models is achieved in the period between 24 and 48 hours immersion in water. After this period, the intensity of increasing is lower and in the period between 48 and 72 hours the increment in the value of model I is 10,49 % and in model II 12,51 %. Such lower intensity of increasing continues in the next period of immersion between 72 and 96 hours, when the increment in the value of model I is 9,64 % and the increment in the value of model II is 11,05 %.



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

Figure 3: Dynamic of increasing of the relative water absorption after immersion in water up to 96 hours

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

Dimeski et al. (1997) gives the values of 15,67 % and 18,29 % for relative water absorption after 24 hours of seven-layer and nine-layer beech plywood bonded with phenol-formaldehyde resin and overlaid with phenol-formaldehyde foil.

Iliev et al. (2004) studied the water absorption of beech and black pine plywood bonded with phenol-formaldehyde resin and overlaid with phenol-formaldehyde foil. The measurings were done after immersion in water for 24, 48 and 72 hours. The authors give the following values for this property: for 24 hours immersion – 25,05 % for seven-layer beech plywood, 26,96 % for nine-layer beech plywood, 23,92 % for seven-layer black pine plywood and 23,07 % for nine-layer black pine plywood; for 48 hours immersion - 29,13 % for seven-layer beech plywood, 34,42 % for nine-layer beech plywood, 29,74 % for seven-layer black pine plywood and 28,01 % for nine-layer black pine plywood; for 72 hours immersion – 33,66 % for seven-layer beech plywood, 36,45 % for nine-layer beech plywood, 33,82 % for seven-layer black pine plywood and 32,27 % for nine-layer black pine plywood.

Mihailova et al. (2005) give the following values of the water absorption of nine-layer beech and black pine plywood bonded with phenol-formaldehyde resin and overlaid with phenol-formaldehyde foil: 36,64 %, 41,51 % and 42,12 % for relative water absorption of beech plywood after immersion for 24, 48 and 72 hours, respectively; 38,08 %, 41,99 % and 42,12 % for relative water absorption of black pine plywood after immersion for 24, 48 and 72 hours, respectively.

Zdravković et al. (2013) studied the impact of the variation in the air humidity on the water absorption of three-layer plywood panels made from thermally treated and untreated poplar veneers, bonded with melamine urea formaldehyde resin. After 7-days treatment in closed containers above water, authors give the values in the limits of ≈ 12 % to ≈ 19 % depend on the plywood model. After 7-weeks treatment for the same property the authors give the values in the limits of ≈ 16,5 % to ≈ 24 % depend on the plywood model.

Brezin et al. (1996a) studied the water absorption of plywood made by combination of beech and poplar veneers bonded with phenol-formaldehyde resin and overlaid with phenol-formaldehyde foil. Depend on the plywood model the authors give the values in the limits of 31 to 45 %.

Brezin et al. (1996b) studied the water absorption of fire-retardant plywood made from lime tree and poplar veneers bonded with urea-formaldehyde and phenol-formaldehyde resin. The authors give the following values for plywood bonded with urea formaldehyde resin: lime tree plywood – 59,7 % for 5 mm thick plywood and 51,2 % for 10 mm thick plywood; poplar plywood – 60,14 % for 5 mm thick plywood and 42,75 % for 10 mm thick plywood. For plywood bonded with phenol-formaldehyde resin, the authors give the following values: 51,5 % and 41,09 % for 5 mm and 10 mm thick lime tree plywood, respectively; 57,5 % and 38,02 % for 5 mm and 10 mm thick poplar plywood, respectively.

Jakimovska Popovska et al. (2013a) give the values in the limits of 22,93 % to 29,72 % for relative water absorption for 24 hours of beech plywood bonded with phenol-formaldehyde resin and overlaid with phenol-formaldehyde foil. The value for non-overlaid plywood was 32,43 %.

Jakimovska Popovska et al. (2013b) studied the relative water absorption of beech plywood bonded with alcohol-soluble phenol-formaldehyde resin after immersion in water for the period up to 1248 hours. The mean values of this property were in the limits of 20,47 % for 24 hours immersion to 48,70 % for 1248 hours immersion in water.

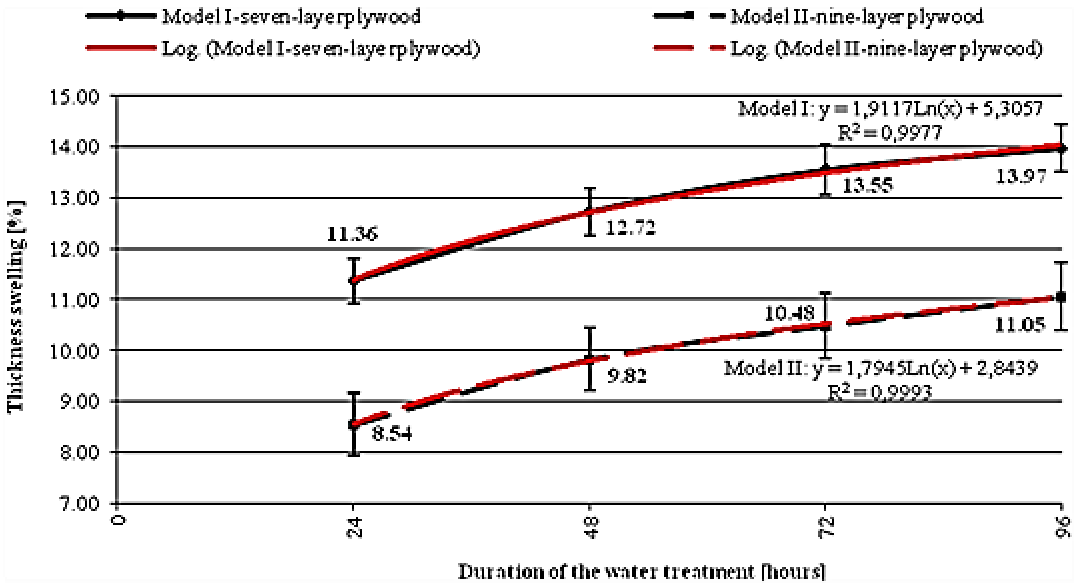
Carvalho et al. (2014) studied the water absorption after 24 hours immersion in water of plywood made form pine veneers *(Pinus oocarpa)*, bonded with tannin-based adhesive. Depend on the ratio between tannin adhesive and phenol-formaldehyde adhesive (from 0 to 100 %), the values of the water absorption were in the limits of 57,3 to 55,9 %.

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

The values of the thickness swelling after 24 hours in both experimental models (11,36 % in model I and 8,54 % in model II) meet the requirement of the standard MKS D.C5.032/83 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 the 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 is increased for 11,97 %, while the value of model II is increased for 14,99 %. The highest intensity of increasing of this property in both models is achieved in the period between 24 and 48 hours immersion in water. After this period, the intensity of increasing is lower and in the period between 48 and 72 hours is about twice lower compared to the increasing in the previous period of immersion between 24 and 48 hours. Such lower intensity of increasing continues in the next period of immersion between 72 and 96 hours.

During the whole period of water treatment the values of thickness swelling of model I (seven-layer plywood) are higher compared to the values of model II (nine-layer plywood).



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

Figure 4: Dynamic of increasing of the relative thickness swelling after immersion in water up to 96 hours

Iliev et al. (2004) studied the thickness swelling of beech and black pine plywood bonded with phenol-formaldehyde resin and overlaid with phenol-formaldehyde foil. The measuring was done after immersion in water for 24, 48 and 72 hours. The authors give the following values for this property: for 24 hours immersion – 7,18 % for seven-layer beech plywood, 6,76 % for nine-layer beech plywood, 14,05 % for seven-layer black pine plywood and 13,29 % for nine-layer black pine plywood; for 48 hours immersion – 7,45 % for seven-layer beech plywood, 7,32 % for nine-layer beech plywood, 14,28 % for seven-layer black pine plywood and 14,40 % for nine-layer black pine plywood; for 72 hours immersion – 7,75 % for seven-layer beech plywood, 7,63 % for nine-layer beech plywood, 15,80 % for seven-layer black pine plywood and 14,92 % for nine-layer black pine plywood.

Mihailova et al. (2005) give the following values of the thickness swelling of nine-layer beech and black pine plywood bonded with phenol-formaldehyde resin and overlaid with phenol-formaldehyde foil: 5,01; 6,14 and 6,68 % for relative thickness swelling of beech plywood after immersion for 24, 48 and 72 hours, respectively; 15,09; 16,05 and 16,77 % for relative thickness swelling of black pine plywood after immersion for 24, 48 and 72 hours, respectively.

Zdravković et al. (2013) studied the impact of the variation in the air humidity on the thickness swelling of three-layer plywood panels made from thermally treated and untreated poplar veneers, bonded with melamine urea formaldehyde resin. After 7-days treatment in closed containers above water, authors give the values in the limits of ≈ 2,3 % to ≈ 4,1 % depend on the plywood model. After 7-weeks treatment for the same property the authors give the values in the limits of ≈ 3,3 % to ≈ 5,0 % depend on the plywood model.

Brezin et al. (1996a) studied the thickness swelling of plywood made by combination of beech and poplar veneers bonded with phenol-formaldehyde resin and overlaid with phenol-formaldehyde foil. Depend on the plywood models; the authors give the values in the limits of 5,1 to 8,5 %.

Brezin et al. (1996b) studied the thickness swelling of fire-retardant plywood made from lime tree and poplar veneers bonded with urea-formaldehyde and phenol-formaldehyde resin. The authors give the following values for plywood bonded with urea formaldehyde resin: lime tree plywood – 12,2 % for 5 mm thick plywood and 10,6 % for 10 mm thick plywood; poplar plywood – 13,45 % for 5 mm thick plywood and 9,5 % for 10 mm thick plywood. For plywood bonded with phenol-formaldehyde resin, the authors give the following values: 8,6 % and 6,03 % for 5 mm and 10 mm thick lime tree plywood, respectively; 8,17 % and 5,05 % for 5 mm and 10 mm thick poplar plywood, respectively.

Jakimovska Popovska et al. (2013a) give the values in the limits of 8,90 % to 9,58 % for relative thickness swelling for 24 hours of beech plywood bonded with phenol-formaldehyde resin and overlaid with phenol-formaldehyde foil. The value of non-overlaid plywood was 9,95 %.

Jakimovska Popovska et al. (2013b) studied the the thickness swelling of beech plywood bonded with alcohol-soluble phenol-formaldehyde resin after immersion in water for the period up to 1248 hours. The mean values of this property were in the limits of 7,18 % for 24 hours immersion to 10,70 % for 1248 hours immersion in water.

Carvalho et al. (2014) studied the thickness swelling after 24 hours immersion in water of plywood made form pine veneers

(Pinus oocarpa), bonded with tannin-based adhesive. Depend on the ratio between tannin adhesive and phenol-formaldehyde adhesive (from 0 to 100 %), the values of the thickness swelling were in the limits of 4,3 to 5,3 %.

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

The 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 1, 2, 3 and 4.

The test results presented in tables 1, 2, 3 and 4 showed that after immersion in boiling water for 6 hours the higher values of the tested properties are 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 are higher for 1,9 %, 17,82 %, 31,67 % and 29,93 %, respectively.

The value of the relative water absorption after immersion for 6 hours in boiling water in model I is higher for 202,81 % and 116,37 % compared to the value of the relative water absorption of the same model after immersion in cold water for 24 hours and 96 hours respectively. The value of the relative water absorption after immersion for 6 hours in boiling water in model II is higher for 212,84 % and 109,65 % compared to the value of the relative water absorption of the same model after immersion in cold water for 24 hours and 96 hours respectively.

Compared to the values of the relative thickness swelling after 24 hours immersion in cold water, the values of this property after immersion for 6 hours in boiling water are higher for 69,45 % in model I and 71,19 % 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 are higher for 37,79 % in model I and 32,31 % in model II.

Mihailova et al. (2005) gives 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 the relative thickness swelling of beech and black pine plywood, respectively.

The visual analysis of the form and structure of the test specimens after the treatment in boiling water for 6 hours showed that there were no deformations and structural changes. There were not noticed any checks, warping or delaminating of the veneers of the test specimens (Fig. 5).

Table 1: Statistical values for the density of plywood models after treatment in boiling water for 6 hours

Model	*No. of test specim.*	X_{min} [kg/m^3]	X_{max} [kg/m^3]	X_{mean} [kg/m^3]	$X_{mean}\pm fx_{mean}$ [kg/m^3]	$S\pm fs$ [kg/m^3]	$V\pm fv$ [%]	Px [%]
I	6	1074,59	1080,14	1078,10	1078,10±1,76	3,05±1,25	0,28±0,12	0,16
II	6	1054,65	1074,82	1066,98	1066,98±6,24	10,81±4,41	1,01±0,41	0,59

Table 2: Statistical values for the relative water absorption of plywood models after treatment in boiling water

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	73,75	78,66	75,49	75,49±1,59	2,75±1,12	3,64±1,49	2,10
II	6	61,83	67,22	64,07	64,07±1,62	2,81±1,15	4,38±1,79	2,53

Table 3: Statistical values for the 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	17,22	21,56	19,25	19,25±1,26	2,19±0,89	11,35±4,69	6,55
II	6	12,66	16,96	14,62	14,62±1,25	2,17±0,89	14,86±6,20	8,58

Table 4: Statistical values for the 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	17,93	22,44	20,01	20,01±1,31	2,28±0,93	11,38±4,71	6,57
II	6	13,50	17,63	15,40	15,40±1,20	2,09±0,85	13,54±5,63	7,82

The obtained values for the degree of adhesion (Tab. 5) showed that both models have similar mean values for this property (5 in model I and 5,5 in model II) that exceed the limitation mean value of 4, which is defined by the standards MKS D.C5.040 and 41. According to these standards, plywood models meet the requirement for exterior type of plywood TP 100. The obtained degree of adhesion is a guarantee for consistency in the glue lines.

The high bonding quality can be seen trough comparison of the obtained results with the data presented in the available literature. Dimeski and Iliev (1997) give the values of degree of adhesion in the limits of 1,54 to 2,67 for beech plywood bonded with phenol-formaldehyde resin and the values in 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 the degree of adhesion after 6 hours immersion in boiling water of nine-layer beech plywood bonded with phenol-formaldehyde resin. Miljković et al. (1997) for the degree of adhesion of combined panels veneered with black pine veneers give the values in the limits of 2,42 to 2,58.

The wood failure during determination of the degree of adhesion is presented on figure 6. These kind of wood failure surfaces are compared to those presented in the photos enclosed in the standard MKS D.A1.072/72.

Table 5: Values of the degree of adhesion

Model	*Test specim.*	*Degree of adhesion in glue line*								*Mean value*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	
I	1	3	5	4	5	6	6	/	/	5,00
	2	8	6	6	3	4	4	/	/	
II	1	8	8	4	6	5	5	4	7	5,50
	2	5	5	4	4	6	6	4	7	

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 the basis of the realized research the following conclusions and recommendation can be drawn:

– From the aspect of the dimensional stability expressed mainly through the thickness swelling, the experimental panels showed good results. The panels are dimensionally stable and according to the results from the tested properties they meet the standard requirements for application in construction.

– From the research of the mutual impact of water and heat can be concluded that the panels showed a great dimensional stability, without self-delaminating of the veneers, warping or other deformations. The panels meet the requirements of the national standards and can be recommended for application in high humidity conditions, heat influence, weathering etc.

– The values of the degree of adhesion between veneers showed consistency in form and dimensions of the panels under impact of water and heat. The high values of this property guarantee panel consistency in conditions of variable humidity, heat and weathering.

– According to the results from the tested physical properties, the 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 conifer plywood is made, which guarantee production of plywood with enhanced physical characteristics for use in different conditions of exploitation.

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