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WATER RESISTANCE OF PLYWOOD BONDED WITH ALCOHOL-SOLUBLE PHENOL-FORMALDEHYDE RESIN

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ABSTRACT

The aim of the research presented in this paper is to study the water resistance of experimental plywood bonded with alcohol-soluble phenol-formaldehyde resin. The evaluation of water resistance is made on the basis of the obtained data for the changes of the physical properties of plywood after exposure to prolonged water treatment. Tests for the thickness swelling, volume swelling and water absorption are made after immersion in water for prolonged period in controlled laboratory conditions. The measuring of thickness, length, width and mass of plywood specimens for determination of these properties is made after immersion in water for the period of 1 day (24 hours) to 52 days (1248 hours).

The experimental plywood model was made from peeled beech veneers. Pure alcohol-soluble phenol-formaldehyde resin is used as plywood binder.

The research results showed that the plywood model has uniform density; it is dimensionally stable during and after prolonged water treatment, without any deformations of the shape of the test specimens. The changes of the values of thickness and volume swelling, as well as the values of water absorption in the analyzed period are proportional to change of the duration of the period of water treatment. According to the obtained data from the tests of these properties the plywood model meets the requirements of the standard for load-bearing plywood for use in construction.

Key words: plywood, alcohol-soluble phenol-formaldehyde resin, water resistance, thickness swelling, water absorption, dimensional stability

1. INTRODUCTION

Panels made on the basis of wood in different forms and dimensions (from solid wood, wood particles, wood fibers etc.) bonded with thermoreactive resins as binders (aminoplasts, base-catalyzed phenolplasts or its modifications) nowadays are widely used in construction. Because of the increased need of different types of wood-based panels in construction, as well as because of the insufficiency of raw material for production of these panels, intense researches in this field are made in order to obtain panels that can meet the modern exploitation requirements.

Plywood panels with its characteristics are most durable wood-based panels for constructional needs. These panels are considerate as constructional material with highest performance, so its application is on a significant level. Basically plywood panels were used in construction for formwork, but today its application as structural or non-structural materials in building of wooden constructions is on high level. Because of its high mechanical properties, decreased anisotropy and possibility to receive and distribute loads, these panels are used in many applications

such as: flooring, siding, shear walls, roofing, insulation etc.

The physical properties of plywood panels are also very important. These properties have impact on other properties, so during determination of the plywood quality a special attention is paid on them.

Plywood characteristics mostly depend on wood species used for veneer production, as well as on the type of the thermoractive resin used for veneer bonding. When plywood is made from common wood raw material for veneer production (mostly the beech in our circumstances), than the resin is the key factor for achieving improved physical and mechanical characteristics of these panels, dimensional stability, consistency on prolonged water impact, humidity, heat, chemical agents and weathering.

One of the solutions for achieving high mechanical and physical properties of plywood for use in construction can be found in application of alcohol-soluble phenol-formaldehyde resin as plywood binder. Referring to this, the research presented in this paper elaborates the possibility for production of water-resistant multilayer plywood with alcohol-soluble phenol-formaldehyde resin as binder. Particular tests of the physical properties of this plywood model are made in order to determinate the consistency on prolonged water impact as well as the dimensional stability.

2. EXPERIMENTAL METHODS

For the realization of the research experimental plywood with nine-layers is made. Plywood is made from beech peeled veneers with thickness of 1,5 and 1,85 mm.

The veneers with thickness of 1,5 mm runs parallel to the longitudinal axis of the panel, while the veneers with thickness of 1,85 mm runs perpendicular to this axis. The orientation of adjacent layers in plywood structure is at right angle, which means that the grain direction of the surface layers is parallel to the length of the panel. The central layer of plywood model represents a veneer sheet with thickness of 1,85 mm, oriented perpendicular to the face grain of the panel.

The configuration of plywood structure is shown on figure 1.

The humidity of the veneers measured by gravimetric method is 9,77 %.

Pure alcohol-soluble phenol-formaldehyde resin is used as plywood binder which is a product of company "Fenoplast 99" OOD, Ruse, Republic of Bulgaria. The resin is supplied under the name RFE-2 and has the following characteristics: form - brown-reddish viscous liquid, content of dry matters - 51 %, viscosity by Vz4/20 °C – 33 s, gel time at temperature of 150°C – 96 s.

Ethyl alcohol is used as resin solvent without adding filler and modifier. The binder with concentration of 51 % is applied in quantity of 180 g/m^2.

The panel is pressed in a hot press using the following parameters:

- specific pressure - P=1,8 kg/cm^2;
- temperature of hot plates - T=155ºC;
- pressing time - t=30 min.

After pressing process was completed, plywood is cooled to the ambient temperature of 20 ºC into the press for 30 minutes under reduced pressure. Cooling of plywood panel into the press is made by cooling the hot plates with circulating cold water into the plates. The plywood cooling was done in order to obtain flat panel and to reduce the warping and deformation of the pressed panel.

Density of the experimental plywood is 828,35 kg/m^3. The panel is made with dimensions of 1180×910×15,61 mm. The (moisture) water content of the panel is 8,86 %.

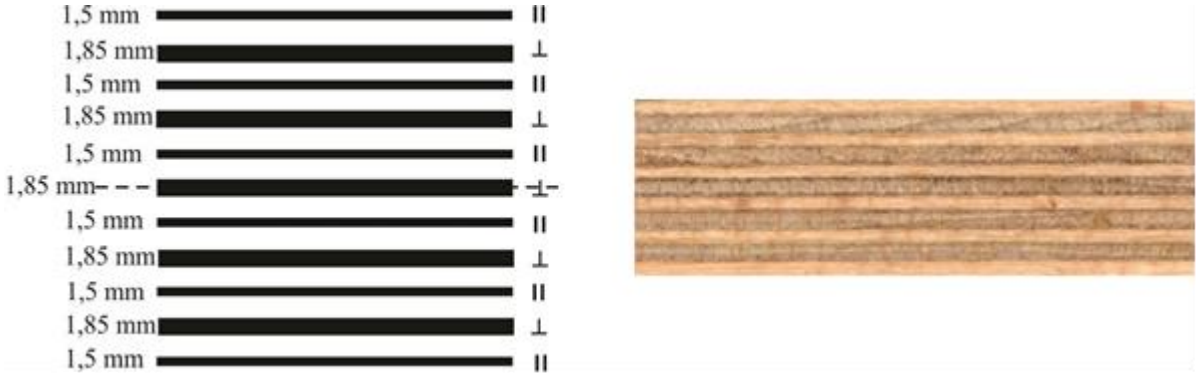

Figure 1: Pattern and cross-section of plywood structure

The evaluation of water resistance is made on the basis of the obtained data for the changes of the physical properties of plywood after exposure to prolonged water treatment. Tests for the thickness swelling, volume swelling and water absorption are made after immersion in water for prolonged period in controlled laboratory conditions. The measuring of thickness, length, width and mass of plywood test specimens for determination of these properties is made after immersion in water for the period of 1 day (24 hours) to 52 days (1248 hours). Control measurings were done in intervals of: 1 day, 2, 4, 6, 8, 12, 16, 24, 32, 42 and 52 days.

The test specimens with standard dimensions of 100×100 mm for research and analysis are made according to the national standard for wood-based panels MKS D.C8.100. The thickness swelling and water absorption of plywood are tested according to the national standard MKS D.C8.104.

In conducted research the statistical data analysis is made with confidence level of 95 %. The index of accuracy of statistical values for this kind of research is in the limit of 5 %.

3. RESULTS AND DISCUSSION

The results from the research of the changes of the physical properties of the experimental plywood are shown in tables 1, 2 and 3 and on figures 2, 3 and 4.

The analysis of the results from the research of the change of the plywood physical properties showed a tendency of increasing of the mean arithmetical values by the increasing of the duration of the treatment of the test specimens. Increasing of the values of all tested properties is intense in the initial period of treatment whereupon the maximal value is achieved in the final control measuring.

Table 1: Statistical values for relative water absorption of experimental plywood

Duration of water treatment [days]	No. of test specimens	x_{min} [%]	x_{max} [%]	x_{sr} [%]	$x_{sr}\pm f_{xsr}$ [%]	$s_x\pm f_s$ [%]	$V\pm f_v$ [%]	P_x [%]
1	5	19,22	21,99	20,47	20,47±0,53	1,18±0,37	5,75±1,82	2,57
2	5	25,46	28,10	26,73	26,73±0,47	1,05±0,33	3,94±1,25	1,76
3	5	29,73	32,04	30,84	30,84±0,46	1,03±0,33	3,34±1,06	1,49
4	5	32,38	34,78	33,64	33,64±0,48	1,07±0,34	3,19±1,01	1,43
6	5	35,57	38,61	37,01	37,01±0,56	1,25±0,40	3,38±1,07	1,51
8	5	37,48	40,49	38,88	38,88±0,55	1,23±0,39	3,17±1,00	1,42
12	5	39,17	41,98	40,51	40,51±0,55	1,23±0,39	3,04±0,96	1,36
16	5	40,48	43,27	42,02	42,02±0,61	1,36±0,43	3,24±1,03	1,45
24	5	41,64	44,29	43,24	43,24±0,63	1,40±0,44	3,25±1,03	1,45
32	5	43,44	46,66	45,29	45,29±0,67	1,51±0,48	3,33±1,05	1,49
42	5	45,24	48,55	47,14	47,14±0,70	1,55±0,49	3,30±1,04	1,48
52	5	46,75	50,20	48,70	48,70±0,70	1,57±0,50	3,22±1,02	1,44

The analysis of the obtained test results for the relative water absorption of experimental plywood (Table 1, Fig. 2) showed increasing of the mean arithmetical values of this property by prolongation of the duration of the water treatment. These values are within the limits of 20,47 % after immersion in water for 1 day (24 hours) to 48,70 % at the end of the water treatment of 52 days. Highest intensity of increasing of relative water absorption is achieved in the initial period of water treatment (period of 1 to 2 days). Such intensity of increasing of the values of this property continues for the period of immersion up to 8 days, after which the intensity of increasing of the relative water absorption is lower.

Increasing of the mean arithmetical value of relative water absorption for the period of 1 to 8 days is 89,94 %, while increasing for the period of 8 days to the end of the water treatment (52 days) is 25,26 %. The results from the measurings between the periods of 8 to 52 days showed that the increasing of the values between two successive measurings does not exceed 4,74 %.

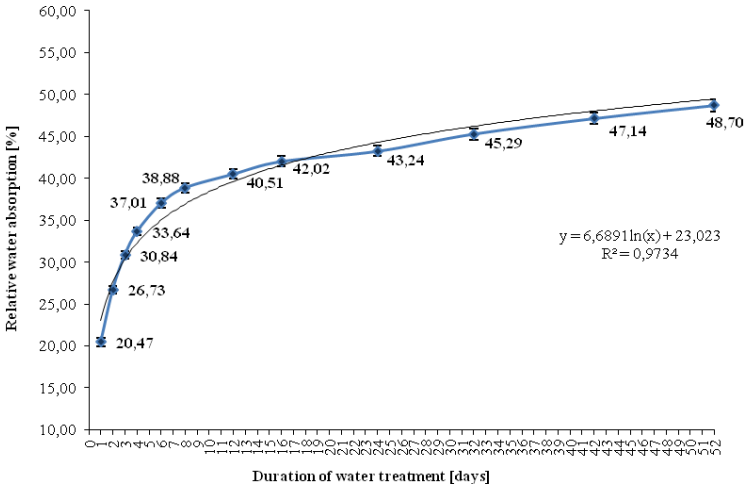

Figure 2; Increase of the mean arithmetical values of relative water absorption for period of 1 to 52 days

The values of relative water absorption are within the limits of the values for this property listed in available literature. Iliev (2007) for water treatment in duration of 24 to 72 hours (1 to 3 days) gives the values of 32,82 to 42,92 % for seven-layered beech plywood overlaid with phenol-formaldehyde foil. Iliev *et al*. (2008) for the same period of water treatment gives the values of 31,97 to 41,16 % for relative water absorption of nine-layer beech plywood overlaid with phenol-formaldehyde foil. Jakomovska Popovska (2011) gives the values within the limits of 32,43 to 44,34 % after water treatment in the period of 1 to 3 days of laboratory nine-layered beech plywood. Jamalirad *et al.* (2011) for 1 day immersion in water gives the values within the limits of 35 to 50 % for relative water absorption of three-layer plywood made from UV irradiation treated red-heart beech veneers. Reinprecht *et al*. (2011) for the same period of water treatment gives the value of 47,1 % for relative water absorption of three-layer beech plywood overlaid with decorative beech veneer. Aziri (2012) gives the value of 33,26 % for relative water absorption of laboratory made nine-layered beech plywood after immersion in water for 1 day and 65,66 % after immersion in water for 52 days. Trinh *et al.* (2012) gives the values within the limits of 55 to 60 % for relative water absorption of beech plywood after immersion/oven drying cycling test. Each cycle was consisted of immersion in water for 24 hours, soaking under vacuum for 1 hour, storing under water for 20 hours and oven drying to 0 % moistrure content. Aziri *et al.* (2013) gives the values of 26,76 to 53,27 % for relative water absorption of seven-layered beech plywood overlaid with phenol-formaldehyde foil for immersion period of 1 to 52 days.

Table 2: Statistical values for relative thickness swelling of experimental plywood

Duration of water treatment [days]	No. of test specimens	x_{min}	x_{max}	x_{sr}	$x_{sr}\pm f_{xsr}$	$s_x\pm f_s$	$V\pm f_v$	P_x
		[%]	[%]	[%]	[%]	[%]	[%]	[%]
1	5	6,82	7,47	7,18	7,18±0,12	0,27±0,09	3,81±1,21	1,70
2	5	7,86	8,62	8,31	8,31±0,14	0,31±0,10	3,70±1,17	1,65
3	5	8,24	9,16	8,83	8,83±0,16	0,36±0,11	4,07±1,29	1,82
4	5	8,74	9,60	9,29	9,29±0,16	0,35±0,11	3,82±1,21	1,71
6	5	9,27	10,14	9,81	9,81±0,16	0,36±0,11	3,65±1,15	1,63
8	5	9,70	10,36	10,07	10,07±0,12	0,27±0,08	2,64±0,84	1,18
12	5	9,96	10,53	10,21	10,21±0,11	0,24±0,07	2,31±0,73	1,03
16	5	10,10	10,83	10,37	10,37±0,14	0,30±0,10	2,92±0,92	1,31
24	5	10,19	10,94	10,51	10,51±0,14	0,32±0,10	3,07±0,97	1,37
32	5	10,27	10,99	10,59	10,59±0,13	0,30±0,09	2,82±0,89	1,26
42	5	10,35	11,10	10,67	10,67±0,15	0,33±0,10	3,06±0,97	1,37
52	5	10,42	11,11	10,70	10,70±0,14	0,31±0,10	2,87±0,91	1,28

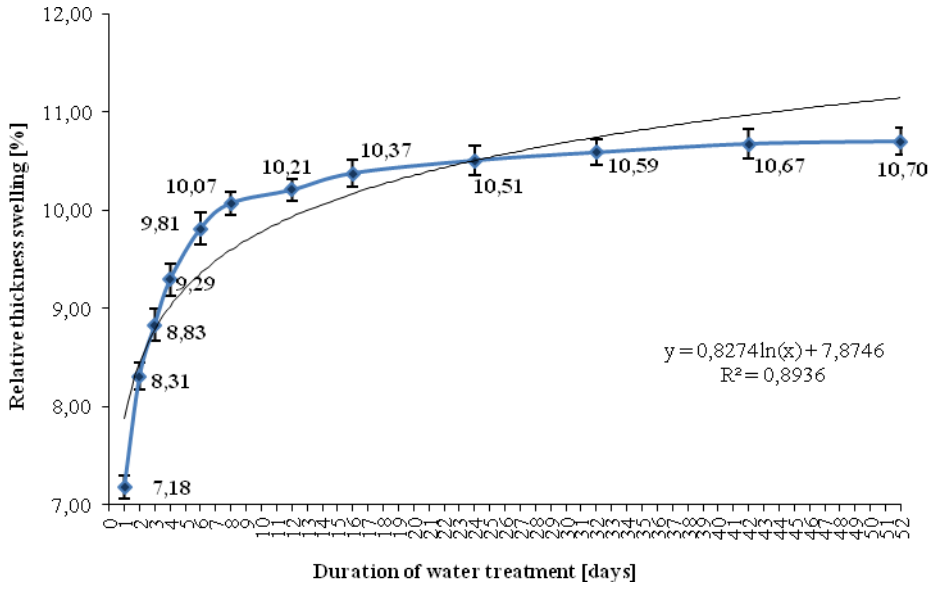

Figure 3: Increase of the mean arithmetical values of relative thickness swelling for period of 1 to 52 days

The analysis of the obtained test results for the relative thickness swelling of experimental plywood (Table 2, Fig. 3) showed increasing of the mean arithmetical values of this property by prolongation of the duration of the water treatment. The mean arithmetical values of this property are within the limits of 7,18 % for the immersion period of 1 day to 10,70 % at the end of the water treatment of 52 days.

Highest intensity of increasing of relative thickness swelling is achieved in the initial period of water treatment (period of 1 to 2 days) in which period the increasing of the value of this property is 15,74 %. Increasing of the values of relative thickness swelling continues with high intensity for the period of immersion up to 8 days, after which the intensity of increasing is lower.

Increasing of the mean arithmetical value of relative thickness swelling for the period of 1 to 8 days is 40,25 %, while increasing for the period of 8 days to the end of the water treatment of 52 days is 6,25 %. The results from the measurings between the periods of 8 days to 52 days showed that the increasing of the values between two successive measurings does not exceed 1,57 %.

The national standard MKS D.C5.032 for wood-based panels for use in construction defines 12 % as a limit of relative thickness swelling for immersion period of 24 hours. According to the tests results the experimental plywood meet the requirements of this standard. After full water treatment in the period of 52 days the plywood model does not exceed the value of 12 %. This shows that the plywood model is dimensionally stable to water impact, which is one of the requirements for plywood application in high humidity conditions and for structural use in construction.

The obtained test results for relative thickness swelling correspond with the results of similar research known in listed literature. Iliev (2007) for immersion period of 1 to 3 days gives the values of 6,94 to 7,54 % for seven-layer beech plywood overlaid with phenol-formaldehyde foil. Iliev *et al.* (2008) for the same period of water treatment gives the values of 6,88 to 7,15 % for relative water absorption of nine-layer beech plywood overlaid with phenol-formaldehyde foil. Jakomovska Popovska (2011) for water treatment of laboratory nine-layer beech plywood

in the period of 1 day to 3 days gives the values within the limits of 9,95 to 11,06 %. Dieste *et al.* (2008) gives the values within the limits of 7 to 10 % for relative thickness swelling of five-layer beech plywood after 10 cycles of soaking/oven drying. The cycles were consisted of 1 hour saturation in water under vacuum at 80 mbar, immersion in water for 16 hours and oven drying to 0 % moisture content. When the beech veneers used for plywood manufacturing were modified with 1.3-dimethylol-4.5-dihydroxyethylenеurea, the values for thickness swelling were in the limits of 4 to 6 % (Dieste *et al.* 2008). Jamalirad *et al.* (2011) for 1 day immersion in water gives the values within the limits of 8 to 14 % for relative thickness swelling of three-layer plywood made from UV irradiation treated red-heart beech veneers. Reinprecht *et al*. (2011) for the same period of water treatment gives the value of 8,3 % for relative thickness swelling of three-layer beech plywood overlaid with decorative beech veneer. Aziri (2012) gives the value of 6,85 % for relative thickness swelling of laboratory made nine-layered beech plywood after immersion of 1 day and 8,68 % after immersion of 52 days. Trinh *et al.* (2012) gives the values within the limits of 8 to 9 % for relative thickness swelling of beech plywood after immersion/oven drying cycling test. Aziri *et al.* (2013) gives the values of 5,31 to 8,00 % for relative thickness swelling of seven-layered beech plywood overlaid with phenol-formaldehyde foil for immersion period of 1 to 52 days.

Table 3: Statistical values for relative volume swelling of experimental plywood

Duration of water treatment [days]	No. of test specimens	x_{min} [%]	x_{max} [%]	x_{sr} [%]	$x_{sr}\pm f_{xsr}$ [%]	$s_x\pm f_s$ [%]	$V\pm f_v$ [%]	P_x [%]
1	5	7,12	7,81	7,49	7,49±0,13	0,28±0,09	3,74±1,18	1,67
2	5	8,16	8,99	8,62	8,62±0,15	0,32±0,10	3,76±1,19	1,68
3	5	8,59	9,54	9,17	9,17±0,16	0,37±0,12	3,98±1,26	1,78
4	5	9,12	9,98	9,64	9,64±0,16	0,35±0,11	3,68±1,16	1,64
6	5	9,65	10,52	10,17	10,17±0,16	0,37±0,12	3,60±1,14	1,61
8	5	10,11	10,77	10,44	10,44±0,13	0,28±0,09	2,68±0,85	1,20
12	5	10,33	10,94	10,58	10,58±0,11	0,25±0,08	2,41±0,76	1,08
16	5	10,50	11,26	10,76	10,76±0,15	0,33±0,11	3,10±0,98	1,39
24	5	10,60	11,37	10,90	10,90±0,15	0,34±0,11	3,15±1,00	1,41
32	5	10,69	11,43	10,98	10,98±0,14	0,32±0,10	2,92±0,92	1,31
42	5	10,78	11,53	11,08	11,08±0,15	0,34±0,11	3,08±0,97	1,38
52	5	10,86	11,58	11,12	11,12±0,14	0,32±0,10	2,88±0,91	1,29

The analysis of the obtained test results for the relative volume swelling of experimental plywood (Table 3, Fig. 4) showed increasing of the mean arithmetical values of this property by prolongation of the duration of the water treatment. The mean arithmetical values of this property are within the limits of 7,49 % for the immersion period of 1 day to 11,12 % at the end of the water treatment of 52 days.

Highest intensity of increasing of relative volume swelling is achieved in the initial period of water treatment (period of 1 to 2 days) in which period the increasing of the value of this property is 15,08 %. Increasing of the values of relative volume swelling continues with high intensity for the period of

immersion up to 8 days, after which the intensity of increasing is lower.

Increasing of the mean arithmetical value of relative volume swelling for the period of 1 to 8 days is 39,38 %, while increasing for the period of 8 days to the end of the water treatment of 52 days is 6,51 %. The results from the measurings between the periods of 8 days to 52 days showed that the increasing of the values between two successive measurings does not exceed 1,70 %.

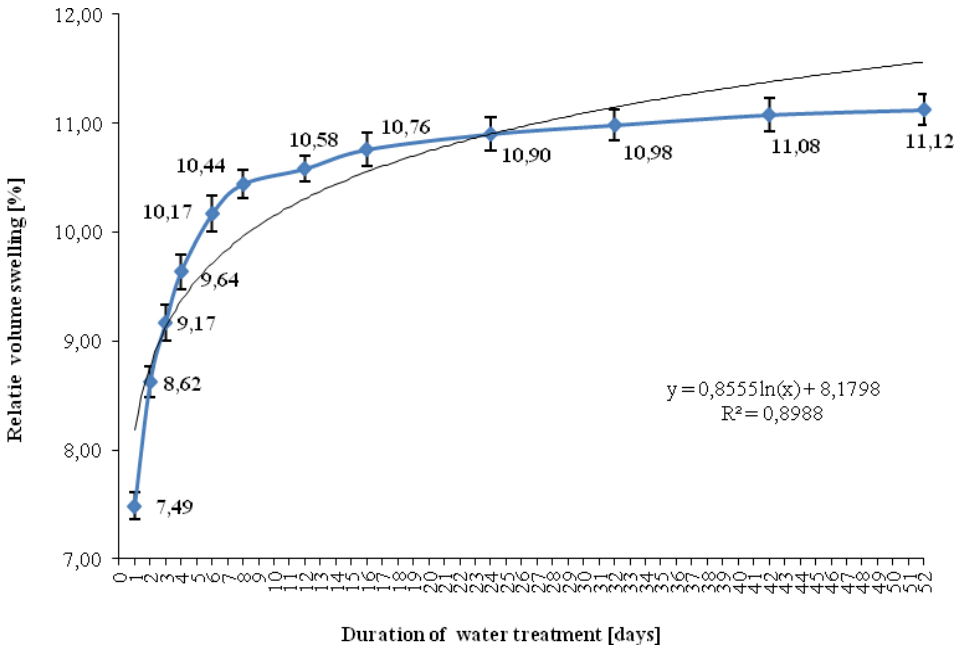

Figure 4: Increase of the mean arithmetical values of relative volume swelling for period of 1 to 52 days

From the obtained test results of relative volume swelling of experimental plywood it can be seen that the increasing of the relative volume swelling is very similar to the increasing of the relative thickness swelling. This is due to the fact that the volume swelling of plywood primary is a result of the swelling in thickness. The changes of the dimensions of the plywood in length and width direction are minor and these changes do not have a big effect on volume swelling of the plywood panel. The biggest changes in length and width dimensions of the plywood panel occur after initial period of 1 day of immersion in water. After this period of immersion there are almost no changes in these dimensions of the panel.

The values of relative volume swelling are similar to the values of this property listed in available literature. Aziri *et al.* (2013) gives the values of 6,24 % for relative volume swelling of seven-layered beech plywood overlaid with phenol-formaldehyde foil after immersion period of 1 day and 9,50 % after immersion period of 52 days. The same authors (2013) give the values of 5,70 % and 9,35 % for nine-layered beech plywood for immersion period of 1 day and 52 days, respectively.

From the analysis of the results from the research of the change of the plywood physical properties a general statement can be made, according to which there is a tendency of increasing of the mean arithmetical values

of all properties by the increasing of the duration of the treatment of the test specimens. Increasing of the values of all tested properties is intense in the initial period of treatment whereupon the maximal value is achieved in the final measuring.

The visual analysis of plywood test specimens after completed water treatment of 52 days showed that there were no deformations, delaminating and warping of the plywood test specimens. The stability of the form and the structure of the panel after prolonged water impact show that high-quality plywood is made durable for application in high humidity conditions.

The analysis of the data given in the tables 1, 2 and 3 made trough the index of accuracy (Px) showed that in measurings for water absorption, thickness swelling and volume swelling after 52 days the values of the index of accuracy are less than 5 %, i.e., the values are within the limits of 1,03 to 2,57 %. These values point to the constataion that the measurings for these physical dimensions are accurate.

The data from the research showed that in all tested properties the mean arithmetical values are in the limits of normal distribution of the values of $x_{sr} \pm 3\sigma$. This constatation go for the confirmation of the constatation for the accuracy of the measuring.

4. CONCLUSIONS

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

- The experimental plywood model represents a stable material with a density that exceeds the requirements of the national standard for structural plywood for use in construction. The high density of plywood is basic prerequisite for good dimensional stability of the material.
- The research results showed that the plywood model is dimensionally stable during and after prolonged water treatment, without any deformations of the shape of the test specimens.
- From the obtained test results for water absorption, thickness swelling and volume swelling of the plywood model it can be concluded that the experimental plywood model is resistant to water impact, which is one of the requirements for plywood application in high humidity conditions and for structural use in construction. Plywood water resistance can be additionally improved by overlaying the panel with phenol-formaldehyde resin impregnated paper.
- According to the tests results of the physical properties the experimental plywood meet the requirements of the national standard and can be used as load-bearing panel in construction. After full water treatment in the period of 52 days the plywood model does not exceed the limitation value of 12 % for thickness swelling defined by the standard. This shows that the connections in the wooden constructions made from this kind of panels exposed to extreme and prolonged water impact will not suffer serious deformations and displacements, which is one of the basic prerequisite for panels' structural use in constructions.
- The analysis of the research results showed that after analyzed period of treatment of 52 days the maximum value of the physical properties is not achieved, i.e. the values still have increasing tendency. The maximum value of the certain physical property can be defined only by continuing the

experiment in the period of time over 52 days.

- The realized research has scientific and practical meaning. This kind of research can help in selection of materials and defining the technological parameters for production of dimensionally stable water-resistant plywood durable for application in construction in high humidity conditions.

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