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WATER IMPACT ON INCREMENT OF THE PHYSICAL CHARACTERISTICS OF MULTILAYERD PLYWOOD MADE FROM BEECH VENEERS

Basri Aziri[1], Violeta Jakimovska Popovska[2], Borche Iliev[2]

[1]*Ministry of Agriculture, Forestry and Water Economy, Skopje, Republic of Macedonia*
e-mail: basri-aziri@hotmal.com;
[2]*Ss. Cyril and Methodius University in Skopje, Republic of Macedonia,*
Faculty of Design and Technologies of Furniture and Interior – Skopje,
e-mail: jakimovska@fdtme.ukim.edu.mk; iliev@fdtme.ukim.edu.mk

ABSTRACT

The researches presented in the paper are made on experimental eleven-layer and fourteen-layer plywood made from beech peeled veneers with thickness of 1,5 and 1,8 mm, overlaid with phenol-formaldehyde resin impregnated paper with surface weight of 120 g/m^2, as well as on experimental nine-layer plywood made from beech peeled veneers with thickness of 2,2 and 3,2 mm without surface protection.

Phenol-formaldehyde resin with 47,10% dry matter content was used for veneer bonding, applied in quantity of 180 g/m^2.

The criterion for evaluation of hygroscopic characteristics and dimensional stability of plywood is the increment of the physical properties that have a direct impact, i.e.: density, volume, thickness swelling and water absorption. The increment of the mean arithmetical values of these properties was traced for time interval of 1248 hours.

The research results showed that the panels are characterized by uniform density, stability in volume, without any deformation of the shape and dimensions of the test specimens. The changes in the physical properties for the period analyzed are proportional to the changes in the duration of the treating period of the test specimens. From the aspect of the analyzed physical properties, the panels are consistent on water impact and have dimensional stability, so they meet the requirements for application in high humidity condition and weathering.

Key words: plywood, physical properties, changes of physical properties, water-resistance, dimensional stability

1. INTRODUCTION

Worldwide, plywood takes a great percentage of the total world production of wood-based panels. This is due to the fact that these panels with their characteristics still cannot be replaced by other types of panels. On the other hand, plywood made with surface protection (protection against water impact, increased humidity and weathering) still is an indispensable product in construction, shipbuilding and automotive industry. These advantages give the plywood production promising development and prosperity.

Beside the fact that plywood is a very stable material during exposure to the effects of air moisture, water and weathering, a special attention is being paid to the production of plywood panels, all that with a view to improving their physical and mechanical properties. These panels are constantly subjected to researches in order to produce stable panels that can meet the modern exploitation requirements. From the aspect of improving their properties, special attention is paid to research of hygroscopic properties and their impact on the dimensional stability of the panels. The hygroscopic properties have impact on other plywood properties. This means that the variations of hygroscopic properties cause variations in other properties of the panels, which reflect on the quality of the panels and their use value.

Related to the above mentioned, researchers from different world regions have studied the physical properties of different types of plywood in order to produce dimensionally stable panels. Almeida *et al.* (2013) give data on water absorption and thickness swelling of commercial plywood made from pine veneers after being immersed in water for 24 hours. Aziri (2012) studied the changes of the physical properties of different types of wood-based panels after their 52-day immersion in water. Aziri *et al.* (2013) give the values of water absorption and thickness swelling of multilayer plywood made from black pine veneers after a 52-day water treatment. Barboutis *et al.* (2011) give the results for thickness swelling after 24 hours of three-layer plywood made from three layers of haven and poplar. The values of thickness swelling and water absorption for 24 hours of commercial multilayer beech plywood are given by Dimeski *et al.* (1997). Hrazsky *et al.* (2010) studied the stability of the shape of water-resistant panels made from thermally treated pine and spruce veneers. Results for the changes in water absorption and thickness swelling of water-resistant plywood made from beech and black pine veneers after water treatment of 72 hours, as well as comparative results for water absorption and thickness swelling of water-resistant plywood, water resistant particleboards and solid wood after 72 hours, are given by Iliev *et al.* (2004) and Iliev *et al.* (2008). There are literature data on water absorption and thickness swelling of multilayer water-resistant beech plywood after 72 hours water treatment in relation to the structure of the plywood cross-section (Jakimovska Popovska 2011, Jakimovska Popovska *et al.* 2013). Jakimovska Popovska *et al.* (2014) give the results for water absorption and thickness swelling of beech plywood bonded with alcohol-soluble phenol-formaldehyde resin after immersion in water for 52 days.

Similar researches for changes in water absorption and thickness swelling of different types of plywood panels intended for different application have also been conducted by other authors. Jamalirad *et al.* (2011) give the results for water absorption and thickness swelling for 2 and 24 hours of three-layer plywood made from red beech heart wood. Mihailova *et al.* (2005) give the values of water absorption and thickness swelling after 72 hours water treatment of nine-layer water-resistant beech and pine plywood. Reinprecht *et al.* (2011) studied the water absorption and thickness swelling after 2 and 24 hours water treatment of three-layer beech plywood. Vasileiou *et al.* (2011) give the results for thickness swelling after 24 hours for three-layer poplar plywood. Zdravković *et al.* (2013) studied the change of the water content and thickness swelling for the period of seven days of three-layer and fife-layer plywood made from no modified, modified and combined poplar plywood. Zdravković *et al*. (2014) give the results for water absorption and thickness swelling after 24 and 48 hours water treatment for commercial beech multilayer plywood for application in automotive industry.

Because of the importance of hygroscopic and other physical properties of plywood, the researches in this paper are directed to study of water impact on changes in the physical properties of different types of multilayer plywood after prolonged water treatment. The experimental researches should help in selection of the materials, technology and technological parameters for production of water-resistant plywood in order to produce dimensionally stable panels intended for application in high humidity conditions and weathering.

2. METHOD OF THE EXPERIMENTAL WORK

The aim of the researches conducted is studying water impact on change of the physical properties of multilayer plywood during prolonged treatment with water. Water impact was analyzed on standard test specimens in controlled laboratory conditions trough change of the density, volume, thickness swelling and water absorption.

The researches were made on experimental eleven-layer and fourteen-layer plywood made from beech peeled veneers with thickness of 1,5 and 1,8 mm, overlaid with phenol-formaldehyde resin impregnated paper, as well as on experimental nine-layer plywood made from beech peeled veneers with thickness of 2,2 and 3,2 mm without surface protection. The panels were made by combining the veneers with two thicknesses.

The eleven-layer plywood was made with six longitudinally oriented veneers with thickness of 1,5 mm and five perpendicularly oriented veneers with thickness of 1,85 mm. The orientation of the adjacent layers of veneers in plywood structure was at right angle. The grain direction of the surface veneers was parallel to the longitudinal axis of the panel. The binder was applied on both sides of the odd veneers of the panel cross section.

The fourteen-layer water-resistant plywood was made with eight longitudinally oriented veneers with thickness of 1,5 mm and six perpendicularly oriented veneers with thickness of 1,85 mm. The orientation of the adjacent layers of veneers in plywood structure is at right angle, with the exception of the two central layers (the seventh and the eight veneer layer) which had grain direction parallel to each other. These veneers were also parallel to the surface layers of the panel. The grain direction of the surface veneers was parallel to the longitudinal axis of the panel. The binder was applied on the inner side of each veneer sheet.

The nine-layer plywood was made with five longitudinally oriented veneers with thickness of 2,2 mm and four perpendicularly oriented veneers with thickness of 3,2 mm. The orientation of the adjacent layers of veneers in plywood structure was at right angle. The grain direction of the surface veneers was parallel to the longitudinal axis of the panel. The binder was applied on both sides of the odd veneers of the panel cross section.

The composition of plywood panels is shown on table 1.

Table 1. *Composition of plywood panels*

Model	Panel thickness, mm	Number of veneers	Composition (thickness of veneers, mm)
A	17	11	1,5+1,8+1,5+1,8+1,5+1,8+1,5+1,8+1,5+1,8+1,5
B	20	14	1,5+1,8+1,5+1,8+1,5+1,8+1,5+1,5+1,8+1,5+1,8+1,5+1,8+1,5
C	19	9	2,2+3,2+2,2+3,2+2,2+3,2+2,2+3,2+2,2

In plywood models, veneer bonding was made with water-soluble phenol-formaldehyde resin with 47,10% dry matter content. The binder was applied in quantity of 180 g/m^2 with gluing machine (adhesive type TP 20, class 1). The surface protection of the eleven-layer and fourteen-layer plywood was made with phenol-formaldehyde resin impregnated paper with surface weight of 120 g/m^2 bonded during the hot pressing process. Pressing was made in single-opening hot press with temperature of the hot plates of 155°C, specific pressure of 18 kg/cm^2 and pressing time of 30 min for the eleven-layer and fourteen-layer plywood and 25 minutes for the nine-layer plywood.

The plywood panels were made with dimensions of 580×580 mm. The moisture content of the panels was 8,90% for the eleven-layer plywood, 8,54% for the fourteen-layer plywood and 8,53% for the nine-layer plywood.

Depending on the number of the veneers used for plywood manufacturing, the following plywood models were made:

- model A: eleven-layer plywood with surface protection on both sides, panel thickness of 17 mm and density of 806,65 kg/m^3;
- model B: fourteen-layer plywood with surface protection on both sides, panel thickness of 20 mm and density of 798,13 kg/m^3;
- model C: nine-layer plywood without surface protection, with thickness of 19 mm and density of 706,11 kg/m^3.

After manufacturing, the panels were left for acclimatization for period of 24 hours, after which they were cut in test specimens in accordance with the national standards for testing the physical properties of the panels.

The test specimens were made in compliance with the national standard for wood-based panels MKS D.C8.100. Test specimens with standard dimensions of 100×100 mm were made from the panels. Six test specimens from each model were taken.

Before testing, the test specimens were conditioned to constant mass in an atmosphere with a relative humidity of 65±5% and a temperature of 20±2ºC.

During the laboratory research, the length and the width of the test specimens were measured with digital schubler at the middle of the test specimens at one measuring point for the length and one for the width, with accuracy of the measurements of 0,01 mm. The thickness of the test specimens was measured at five measuring points with mechanical comparator with accuracy of 0,01 mm. The weight of the test specimens was measured with digital balance with accuracy of measurements of 0,01 g.

The treatment of the test specimens in water regime was made by their full immersion in distillated water in special bath, continuously for a period of 1248 hours (52 days). The water temperature during the whole treatment was within the limits of 19 to 22°C.

The criterion for evaluation of the hygroscopic characteristics and dimensional stability of plywood was the increment of the properties that have a direct impact, i.e.: density, volume, thickness swelling and water absorption. The increment of these properties was monitored and recorded by control measuring in intervals of: 24, 48, 72, 96, 144, 192, 288, 384, 576, 768, 1008 and 1248 hours. For each tested property for each panel, after each successive measuring of the mean arithmetical values, variation-statistical coefficients were calculated: mean arithmetical value (X_{mean}), standard deviation (S_x), coefficient of variation (V_x), error of the mean arithmetical value (m_x) and the index of correctness (P_x). Researches of the changes of density, humidity, thickness swelling and water absorption were made in accordance with national standards: MKS D.A8.062/85, MKS D.A8.064/85 and MKS D.C8.104/83.

3. RESULTS FROM THE RESEARCH AND ANALYSIS

The results from the researches conducted are shown in table 2 (for increment of density), table 3 (for increment of volume), table 4 (for increment of thickness swelling) and in table 5 (for increment of water absorption). The increment of the mean arithmetical values in experimental models is also shown in figure 1 (for density), figure 2 (for volume), figure 3 (for thickness swelling) and in figure 4 (for water absorption).

The results from the research for the increment of the density show a tendency of increment in the mean values for the analyzed period by increasing the duration of the water treatment. Increase of the mean arithmetical value is proportional to prolongation of the duration of the treatment of the test specimens. The increasing of the values is intense in the initial period of treatment, whereupon the maximal value is achieved in the final control measuring. This tendency is noticed in all models. The highest increment of the mean arithmetical values was achieved in model C (50,44%).

Table 2. *Values for increment of density for a period of 0 to 1248 hours*

Model	Initial value (before treatment) [kg/m³]	Value after 24 hours [kg/m³]	Final value (1248 hours) [kg/m³]	Increment in absolute values [kg/m³]	Increment in relative values [%]
A	806,65	914,28	1063,09	256,44	31,79
B	798,13	896,04	1058,57	260,44	32,63
C	706,11	878,07	1062,30	356,19	50,44

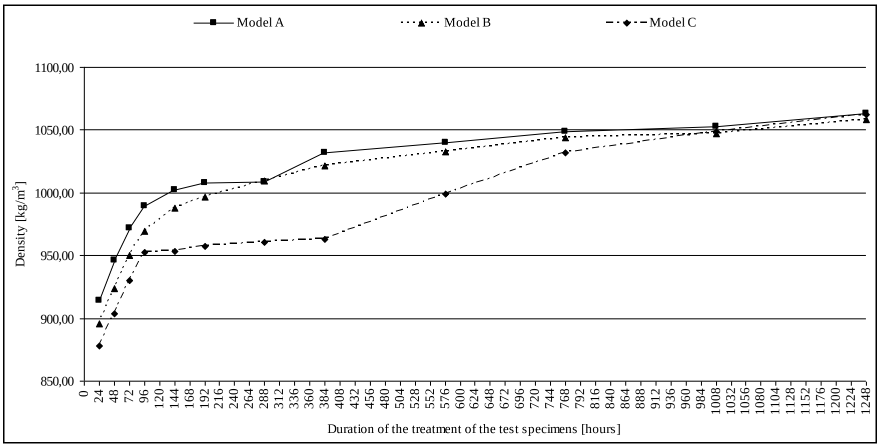

Figure 1. *Increment of mean arithmetical values of density for a period of 24 to 1248 hours*

How the duration of the water treatment affects the increment of the volume of the experimental panels can be seen from the data shown in table 3 and in figure 2. In all the models, the increment of mean arithmetical values of the volume is proportional to increment of the duration of the treatment of the test specimens. Increment in volume, as well as increment in density is intense in the initial period of treatment. After this period, mean arithmetical values rise with weaker intensity, whereupon the maximal mean value in all three models is achieved in the final control measuring after 1248 hours. The highest increment of mean arithmetical values is achieved in model B (11,30%).

Table 3. *Values for increment in volume for a period of 0 to 1248 hours*

Model	Initial value (before treatment) [cm^3]	Value after 24 hours [cm^3]	Final value (1248 hours) [cm^3]	Increment in absolute values [cm^3]	Increment in relative values [%]
A	165,40	176,57	182,58	17,18	10,39
B	199,59	213,39	222,14	22,55	11,30
C	193,62	207,45	213,19	19,57	10,11

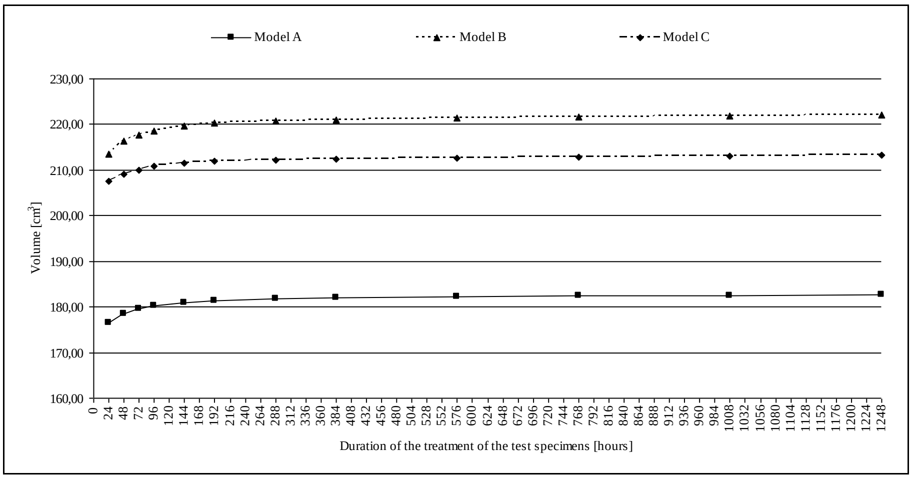

Figure 2. *Increment of mean arithmetical values of volume for a period of 24 to 1248 hours*

The relationship between the duration of immersion of the test specimens in water and the increment of the thickness swelling of plywood models in analyzed period can be seen from the data shown in table 4 and in figure 3. As the data show, in all models, the increment of the mean arithmetical values of this property is proportional to the increment of the duration of the treatment of the test specimens in the period analyzed. The increment of the mean arithmetical values is intense in the initial period of treatment up to the control measuring after 288 hours, whereupon the intensity of the increment is successively lower up to the final control measuring. This tendency is noticed in all models. The highest value of the mean arithmetical value of the thickness swelling after 24 hours immersion in water (6,85%) is achieved in model C, while after immersion in water for 1248 hours in model B (10,49%). The highest increment of the mean arithmetical values is achieved in model C (58,94%).

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 three experimental models meet the requirements of this standard for 24 hours immersion in water, as well as after complete treatment of 1248 hours. Accordingly, it can be stated that plywood panels are dimensionally stable during prolonged water treatment, which is one of the prerequisite for their application in high humidity conditions and weathering.

Table 4. *Values for increment in relative thickness swelling for a period of 24 to 1248 hours*

Model	Initial value (24 hours) [%]	Final value (1248 hours) [%]	Increment in absolute values [%]	Increment in relative values [%]
A	6,46	9,29	2,83	43,81
B	6,60	10,49	3,89	58,94
C	6,85	8,68	1,83	26,72

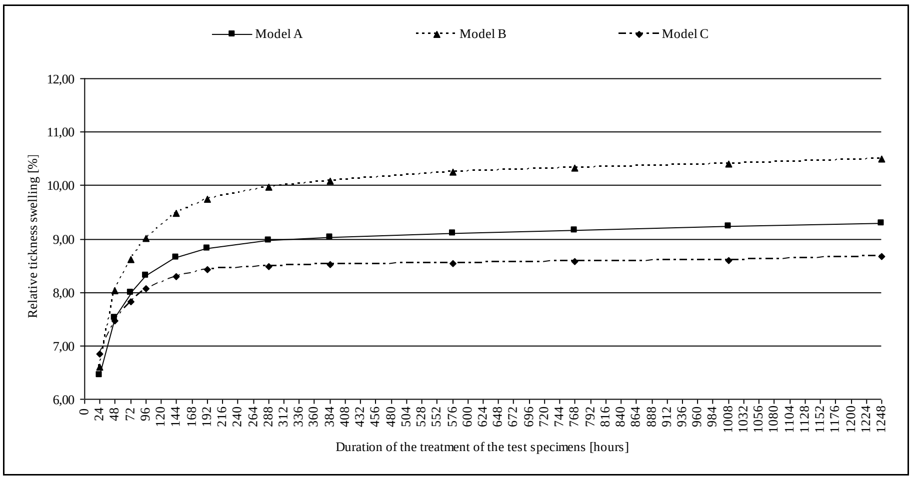

Figure 3. *Increment of mean arithmetical values of relative thickness swelling for a period of 24 to 1248 hours*

The increment of water absorption in all experimental models is proportional to increment in duration of the treatment of the test specimens in the period analyzed, as can be seen from the data given in table 5 and in figure 4. The increment of the mean arithmetical values of this property is intense in the initial period of treatment, whereupon the intensity of the increment gets successively lower, up to the final control measuring. This tendency is noticed in all models. The highest value of the mean arithmetical value of water absorption after 24 hours immersion in water (33,26%) is achieved in model C, as well as after 1248 hours (65,66%). The highest increment of the mean arithmetical values is achieved in model B (136,26%).

The results showed that in model A and B water absorption in the period analyzed exceeds the limit of 100%, while in model C the value is below 100% at the end of the water treatment after 1248 hours.

The analysis of the increment of the mean arithmetical values for the density, volume, thickness swelling and water absorption, shows that general conclusion cannot be drawn for the impact of the number and the thickness of the veneers in the structure of the panel, as well as of the use of surface protection, on the change of the physical properties in the period analyzed. The small differences between the models in the mean values after the first and the final measuring, as well as the differences between the models in the increment of the values confirm this statement.

Table 5. *Values for increment in relative water absorption for a period of 24 to 1248 hours*

Model	Initial value (24 hours) [%]	Final value (1248 hours) [%]	Increment in absolute values [%]	Increment in relative values [%]
A	21,01	45,49	24,48	116,52
B	20,05	47,37	27,32	136,26
C	33,26	65,66	32,40	97,41

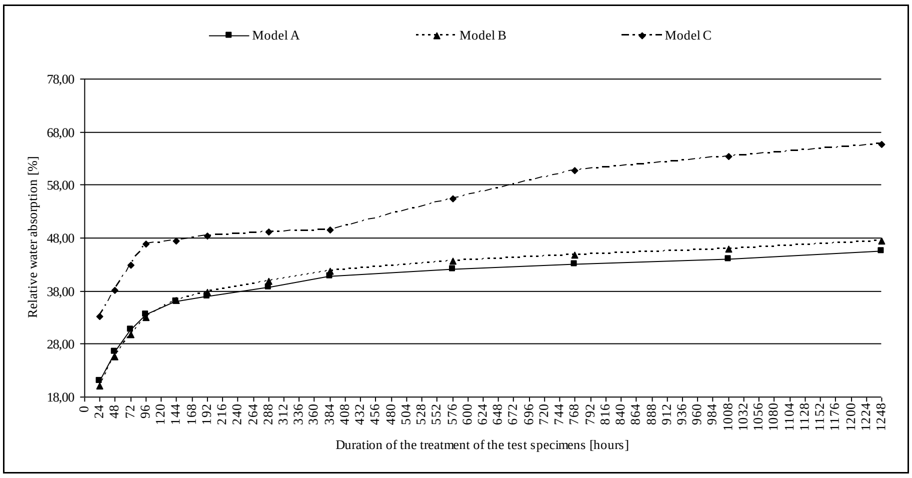

Figure 4. *Increment of mean arithmetical values of relative water absorption for a period of 24 to 1248 hours*

Visual analysis of the shape and the structure of the test specimens after completed experiment showed that there are no structural changes of the test specimens (fig. 5, 6 and 7). There was not noticeable warping or cracking of the test specimens, delamination of the veneers or any other deformation. The test specimens retained their form during the whole experiment.

It can be stated that the number and the thickness of the veneers, as well as the surface protection with phenol-formaldehyde foil, do not have an impact on the increment of the physical properties at longer immersion of the panels in water. Attention should be paid to the type and characteristics of the resin used for veneer bonding, technological parameters used for plywood manufacturing, as well as to the quality of beech veneers, which guarantee dimensional stability of the panels during prolonged water treatment. This statement is confirmed by the analysis of the results from the conducted experiment. In this context, it can be said that after finishing the treatment of immersion in water for 1248 hours in laboratory conditions, experimental models showed uniform density, stability in volume, without any deformation of the shape and dimensions. This confirms that plywood panels can be used in high humidity conditions and weathering as well as in similar conditions of exploitation.

Figure 5. *Cross-section of eleven-layer plywood overlaid with phenol-formaldehyde resin impregnated paper after 1248 hours water treatment (model A)*

Figure 6. *Cross-section of fourteen-layer plywood overlaid with phenol-formaldehyde resin impregnated paper after 1248 hours water treatment (model B)*

Figure 7. *Cross-section of nine-layer plywood without surface protection after 1248 hours water treatment (model C)*

4. CONCLUSIONS

On basis of the research conducted, the following major conclusions can be drawn:

1. Research of increment of the physical properties of three types of multilayer plywood showed that stable panels are made, which are characterized by uniform density, stability in volume, without any deformation of the shape and dimensions.
2. In all the models, the increment of the physical properties in the analyzed period is proportional to the increment of the duration of the treating period of the test specimens, i.e., the mean arithmetical value of the analyzed property increases proportionally to the increment of the duration of the water treatment. From aspect of the analyzed physical properties, the panels are consistent on water impact and have dimensional stability, so they meet the requirements for application in high humidity conditions and weathering.
3. The number and thickness of veneers, as well as the surface protection do not affect the increment of the physical properties after longer immersion of the panels in water. The quality of the plywood panels depends on the type and the characteristics of the resin used for veneer bonding, technological parameters used for plywood manufacturing, as well as on the quality of the beech veneers.
4. From aspect of dimensional stability, the panels showed good results. They are dimensionally stable and according to the tested properties, they meet the requirements of the national standard for use in high humidity conditions and weathering. The values from the research for the thickness swelling showed that the connecting points in wooden structures made from these panels exposed to prolonged water impact would not suffer serious deformations and displacements, which is the basic prerequisite for panels' structural use in constructions.
5. In experimental models for the analyzed period of treatment of 1248 hours the maximal value of the physical properties is not achieved, i.e. the values still have increasing tendency. The maximal value of certain physical properties can be defined only by continuing the experiment in the period of time over 1248 hours.
6. These researches have scientific and practical meaning. They can help in selection of materials, technology and technological parameters for production of multilayered water-resistant plywood, in order to produce dimensionally stable panels for use in high humidity conditions and weathering.

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