Original scientific paper
Received:28.09.2022
Accepted:18.11.2022
UDK: 674.815.017-026.562

JANKA HARDNESS OF PLYWOOD REINFORCED WITH FIBERGLASS PREPREGS

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ABSTRACT

Plywood properties can be enhanced by applying different non-wood materials in its structure.

The aim of this research is to study the Janka hardness of experimental plywood reinforced with fibergalss fabrics pre-impregnated with alcohol-soluble phenol-formaldehyde resin.

Plywood models were made of eleven layers of peeled beech veneers with thickness of 1,5 mm and 1,85 mm. Alcohol-soluble phenol-formaldehyde resin was used as plywood binder. The pre-impregnated fabrics (fiberglass prepregs) were incorporated as layers in the plywood structure. Different models of reinforced plywood were made by change of the position of the reinforcing layers in the structure of the panel. One additional model was made without reinforcements as comparing plywood model.

Tests for plywood hardness according to Janka were done on each plywood model.

The research results showed that the values of Janka hardness are affected by use of glassfiber prepregs as reinforcements in plywood structure.

Keywords: plywood, reinforcement, pre-impregnated fiberglass fabric, prepreg, alcohol-soluble phenol-formaldehyde resin, Janka hardness.

1. INTRODUCTION

Plywood panels are characterized with high strength to weight ratio, decreased anisotropy compared to solid wood, as well as possibility to receive and distribute loads. Because of these characteristics, plywood is used in many applications in construction of wooden buildings, such as flooring, siding, roofing, shear walls etc. Plywood is also used in production of engineered wood flooring.

Plywood is a key material for floors in construction of transport equipment. Plywood panels compete for the same usages as light metals and composite materials thanks to its light weight, strength, firmness and hardiness (Lukkaroinen, Metsa wood, 2008). Other materials cannot be turned into sufficiently light products that would still meet the technical criteria as economically as plywood (Lukkaroinen, 2008).

Plywood hardness is an important property when plywood is used as flooring material in construction as well as in transport industry.

Plywood properties can be improved by reinforcing the plywood structure (Jakimovska Popovska and Iliev, 2019). This reinforcement can be achieved by application of non-wood materials, especially fiber-reinforced polymers in plywood structure. (Davalos et al., 2000; Hardeo and Karunasena, 2002; Choi et al., 2011; Zīke and Kalniņš, 2011, Xu et al., 1996, Xu et al., 1998, Brezović et al., 2002, Brezović et al., 2003, Brezović et al., 2010, Biblis and Carino, 2000, Hrázský and Král, 2007, Maniņš and Zīke, 2011). Kohl et al. (2013) studied the influence of different types of technical fabrics embedded in the adhesive layer of plywood. Jakimovska Popovska and Iliev (2021) studied the Janka hardness of plywood reinforced with cotton prepregs.

Fiberglass prepregs can be used as reinforcement materials of plywood structure (Jakimovska Popovska, 2014).

The aim of this research is to study the Janka hardness of experimental plywood reinforced with fiberglass fabrics pre-impregnated with alcohol-soluble phenol-formaldehyde resin.

2. EXPERIMENTAL METHODS

For realizarion of the research different models of reinforced plywood were made by inserting reinforcement layers of pre-impregnated fiberglass fabrics (fiberglass prepreg) into the adhesive layers of the panels. By changing the position of the reinforcements in the plywood structure, four models of eleven-layered reinforced plywood were made from beech peeled veneers with thickness of 1,5 and 1,85 mm. In plywood structure, the veneers with thickness of 1,5 mm ran parallel to the longitudinal axis of the panel, while the veneers with thickness of 1,85 mm ran perpendicular to this axis. The orientation of the adjacent layers in plywood structure was at right angle, which means that the grain direction of the surface layers is parallel to the length of the panel. The moisture content of the veneers used in plywood was 9,77 %.

For comparison of the results, one control model of plywood was made without reinforcements.

In three of the plywood models, each reinforcement layer consists of four sheets of fiberglass prepreg placed one on top of the other and inserted into the panel structure symmetrically on both sides with respect to its axis of symmetry. This means that the structure of these three models incorporates a total of eight sheets of fiberglass prepreg. Modeling is done by changing the position of reinforcement layers in different adhesive layers throughout the panel structure. The composition and cross-section of plywood models is shown on Figure 1.

In the structure of the first model, the reinforcements are positioned in the fifth and the sixth adhesive layer, i.e. next to the central veneer sheet, while in the structure of the second model they are inserted into the third and the eighth adhesive layer. In the third model, the reinforcements represent the surface layers of the panel (Figure 1). The fourth experimental model was made by inserting single sheets of fiberglass prepreg in each adhesive layer of the panel (Figure 1). Given that the structure of the plywood panels contains ten adhesive layers, the reinforcement of this model is done by inserting ten sheets of glassfiber prepreg.

In all models of reinforced plywood, the orientation of the wrap of the fabric is parallel to the grain direction of the surface veneers.

Fiberglass fabric used for plywood reinforcement is a product of the Taiwanese company “Taiwan Glass” and is procured by the company “Laminati Com” from Prilep. This fabric is supplied in the form of a roll, which after impregnation with a resin is cut into the required format.

The fabric is made of E-glass fibers with simple “plain" weaving. The threads of the fabric are made from bundles of approximately 408 continuous filaments with diameter of 9 microns (G mark). The weight of the bundles is 66 tex (tex = g / 1000 m). The threads are made of single bundles.

The technical characteristics of the fabric given by the manufacturer are shown in Table 1.

The threads that make up the wrap and fill of the fabric are identical.

Table 1. *The technical characteristics of the fiberglass fabric*

No	***Parameter***	***Result***
1	Wrap threads	ECG-75 1/0
2	Fill threads	ECG-75 1/0
3	Wrap density (threads /10 cm)	173/10 cm
4	Fill density (threads /10 cm)	122/10 cm
5	Surface mass of the fabric (g/m^2)	202±3
6	Thickness of the fabric (mm)	0,173±0,020
7	Tensile strength to wrap (dN)	> 41
8	Tensile strength to fill (dN)	> 31

Pure alcohol-soluble phenol-formaldehyde resin was used for pre-impregnation of fiberglass fabrics used as reinforcements of experimental plywood. The same resin was also used for veneer bonding.

The resin was a product of company “Fenoplast 99” OOD, Ruse, Republic of Bulgaria, 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. Methyl alcohol was used as resin solvent.

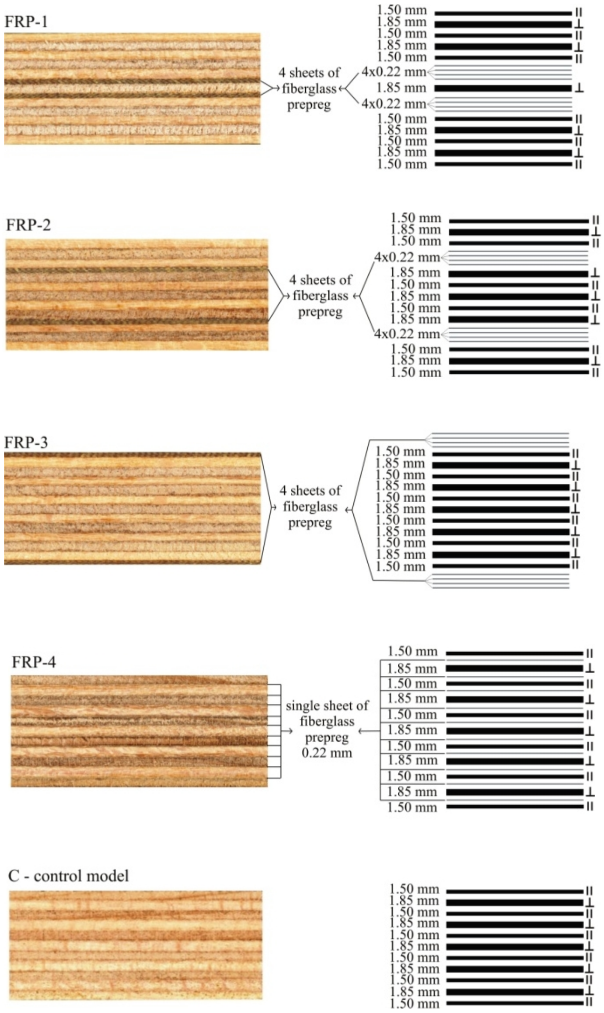

Figure 1. *Pattern and cross-section of plywood structure*

Pre-impregnation of the fabric was done on an impregnation machine, where the fabrics passed through a system of rollers that guided the fabric through the adhesive container so that it was applied double-sided to the fabric. In the later phase of impregnation, the impregnated fabric went through a drying section, where the process of polycondensation of the resin began, but not its complete hardening. The drying temperature was gradually increasing from 80 to 140ºC. Complete hardening of the resin occurred at the stage of pressing the plywood composition. The speed of the fabric passing through the impregnating machine was 2,5 m/min. At the exit of the drying section, the impregnated fabric was cut into the format corresponding to the dimensions of the plywood. The fiberglass fabric was pre-impregnated with resin in quantity of 140 g/m^2. The thickness of the prepreg was 0,22 mm.

The veneers and fiberglass prepregs were assembled in plywood composition. Pure alcohol-soluble phenol-formaldehyde resin with concentration of 51 % was used as plywood binder, applied on the veneers in quantity of 180 g/m^2. The panels were pressed in a hot press under specific pressure of 1,8 kg/cm^2, at temperature of 155ºC for 30 min.

After pressing process was completed, plywood panels were cooled to the ambient temperature of 20ºC into the press for 30 minutes under reduced pressure in order to get flat panel and to reduce its warping and deformation.

Plywood models were made in the following dimensions: 1180×910×d mm. Moisture content of the panels was 8,3 %.

The denotations of the experimental plywood models have the following meanings:

- model FRP-1 – eleven-layer plywood reinforced with four sheets of fiberglass prepreg on both sides of the central axis, positioned in the fifth and in the sixth adhesive layer of the panel (d=16.69 mm; γ=929.01 kg/m3);
- model FRP-2 – eleven-layer plywood reinforced with four sheets of fiberglass prepreg on both sides of the central axis, positioned in the third and in the eighth adhesive layer of the panel (d=16.15 mm; γ=934.88 kg/m3);
- model FRP-3 – eleven-layer plywood reinforced with four sheets of fiberglass prepreg on each surface of the panel (d=16.38 mm; γ=939.67 kg/m3);
- model FRP-4 – eleven-layer plywood reinforced with single sheets of pre-impregnated fabric in each adhesive layer of the panel (d=17.32 mm; γ=959.33 kg/m3).
- model C – control model of eleven-layer plywood without reinforcements (d=15.70 mm; γ=822.69 kg/m3).

The Janka hardness of the experimental plywood was tested on the test specimens with dimensions of 100×100 mm. The tests were performed at two measuring points, positioned diagonally in the corners of the face and the back of the test specimens. Thereby, the measuring points on the back of the test specimens were positioned in opposite angles in relation to the measuring points on the face of the test specimens.

The hardness was tested by pressing a stainless hemisphere on the surface of the test specimen, which, when entering the surface of the test specimen, leaves an impression in the form of a calotte with an area of 1 cm^2. The ratio between the force used and the surface of the calotte represents the hardness of the panel.

The data obtained were statistically analyzed. One way ANOVA was used to determine the significance of the effect of the fiberglass prepreg reinforcements on plywood hardness. Tukey's test was applied to evaluate the statistical significance between the mean values of Janka's hardness of plywood with different layouts of reinforcement (different plywood models). The tests were conducted at 0,05 probability level.

Statistical software SPSS Statistic was used for statistical analysis of the data obtained.

3. RESULTS AND DISCUSSION

The results obtained from the tests of Janka hardness of the experimental plywood models are shown in Table 2.

Table 2. *Statistical values for Janka hardness of experimental plywood*

Model	*N*	*Mean (N/mm^2)*	*Std. Deviation (N/mm^2)*	*Std. Error (N/mm^2)*	*95% Confidence Interval for Mean (N/mm^2)*		*Min (N/mm^2)*	*Max (N/mm^2)*
					Lower Bound	*Upper Bound*		
FRP-1	5	173,78[a]	5,07	2,27	167,49	180,08	166,89	179,52
FRP-2	5	151,61[b]	14,42	6,45	133,71	169,52	134,64	173,27
FRP-3	5	151,49[b]	13,74	6,14	134,44	168,55	141,14	167,26
FRP-4	5	171,45[a]	8,54	3,82	160,86	182,05	162,85	184,92
C	5	127,41[c]	5,36	2,40	120,75	134,06	119,56	133,42

The mean values with the same letters are not significantly different at 0,05 probability level

The highest value of plywood hardness is achieved in model FRP-1 in wihich the fiberglass reinforcements are positioned next to the central veneer. Compared to the control model, the mean value of Janka hardness of model FRP-1 is higher by 36,4 %. Within the reinforced plywood models, the lowest value of this property is obtained in the model in which the reinforcement layers are positioned as surface layers of plywood (model FRP-3).

Compared to the mean values of hardness in models FRP-2, FRP-3 and FRP-4, the highest value obtained in model FRP-1 is higher by 14,6 %, 14,7 % and 1,4 %, respectively. The obtained values of Janka hardness in models FRP-2 and FRP-3 are approximately the same, wheres model FRP-2 has higher value compared to model FRP-3 by only 0,08%.

The analysis of variance of the obtained data for the Janka hardness (ANOVA: F (4; 20)=16,804; p<<0,001) showed that the differences between the mean value of this property of at least two models are statistically significant, which means that reinforcement of plywood with fiberglass prepregs has significant impact on this property. The conducted post-hoc Tukey's test for multiple comparison between models showed that there are statistically significant differences in the mean value of this property between the control model C and all reinforced models. Within the reinforced plywood models, the differences between models FRP-1 and FRP-4, as well as between FRP-2 and FRP-3, are not statistically significant. The values in models FRP-1 and FRP-4 substantially differ compared to the values in models FRP-2 and FRP-3.

Table 3. *Anova for significance of the effect of fiberglass prepreg reinforcements on plywood hardness*

ANOVA					
Janka Hardness					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7043,047	4	1760,762	16,804	0,000
Within Groups	2095,691	20	104,785		
Total	9138,739	24			

Table 4. *Tukey's test for statistical significance between the mean values of Janka's hardness of different plywood models*

Model		N	Subset for alpha = 0.05		
			1	2	3
Tukey HSD[a]	C	5	127,41		
	FRP-3	5		151,49	
	FRP-2	5		151,61	
	FRP-4	5			171,45
	FRP-1	5			173,78
	Sig.		1,000	1,000	0,996

Means for groups in homogeneous subsets are displayed

a. Uses Harmonic Mean Sample Size = 5.000

Jakimovska Popovska and Iliev (2021) give the values within the limits of 144,26 N/mm^2 to 207,06 N/mm^2 for Janka hardness of plywood reinforced with cotton prepregs. Plywood model reinforced with fiberglass prepreg as a surface layers of the panel (model FRP-3) has higher value of hardness compared to plywood reinforced with cotton prepreg as surface layers. The other fiberglass reinforced plywood models (FRP-1, FRP-2, FRP-4) have lower values of Janka hardness compared to the values that give Jakimovska Popovska and Iliev (2021) for plywood reinforced with cotton prepregs.

The values obtained of Janka hardness of reinforced models are higher compared to the values of this property of non-reinforced plywood listed in literature. Iliev (2000) gives the values of Janka hardness of 88,54 N/mm^2 for nine-layered beech plywood and 98,11 N/mm^2 for seven-layered beech plywood. The same author for nine-layered and seven-layered black pine plywood gives the values of 73,00 N/mm^2 and 81,75 N/mm^2, respectively. Jakimovska Popovska (2011) gives the values of Janka hardness of nine-layered beech plywood within the limits of 86,13 N/mm^2 to 93,69 N/mm^2.

The test specimens for testing Janka hardness are shown in figure 2.

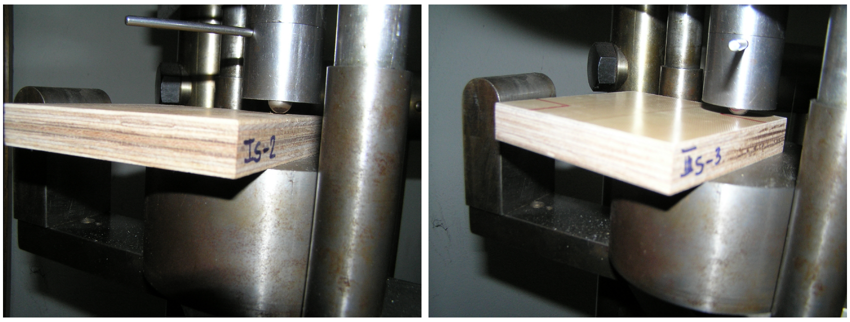

Figure 2. *Test specimens for testing the Janka hardness*

4. CONCLUSIONS

Based on the research conducted, a conclusion can be drawn that application of preimpregnated fiberglass fabric in the structure of plywood significantly increases its hardness.

The position of the fiberglass reinforcements in the plywood structure has impact on the plywood hardness. By reinforcing the plywood structure with fiberglass prepregs positioned next to the central veneer layer of plywood, the hardness is increased by 36,4 %, compared to the control model of non-reinforced plywood. This kind of reinforcement, compared to the other reinforced models, is most favorable regarding the plywood hardness. Moving the fiberglass reinforcement layers to the surface of the plywood decreases the values of plywood hardness.

When choosing an adequate reinforced plywood model, the other physical and mechanical properties of plywood should also be taken into consideration, depending on the type of loads that the panel will be exposed to during its exploitation period.

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