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NAIL WITHDRAWAL RESISTANCE OF COMPOSITE WOOD-BASED PANELS MADE FROM PARTICLEBOARD CORE AND CONSTRUCTIVE TWO-PLY CROSS-LAMINATED VENEERS

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ABSTRACT

This paper elaborates the nail withdrawal resistance of composite water-resistant wood-based panels for use in construction.

Three experimental panels were made by combining particleboards and constructive peeled veneers of beech, black pine and poplar with thickness of 1,5 and 3,2 mm. The core layer of composite panels was made from single-layer particleboard with thickness of 16 mm. Particleboards were overlaid on both sides with two-ply cross-laminated veneers.

Water-soluble phenol-formaldehyde resin was used for particle bonding and veneering.

The results from the research showed that the different veneer species used for particleboard overlay significantly impact the nail withdrawal resistance perpendicular to the plain of the composite panels. The highest mean value of this property is achieved in composite model made with beech veneers overlay.

According to the obtained values of nail withdrawal resistance, the composite panels can be used in construction.

Key words: composite wood-based panels, particleboard, veneer, beech, black pine, poplar, phenol formaldehyde resin, nail withdrawal resistance

1. INTRODUCTION

Composite wood-based panels represent a type of wood-based panels made as combination of particleboard and veneers. Researches in the field of wood-based panels are directed to finding methods and technical-technological solutions for production of stable panels with high physical and mechanical properties that can meet the requirements of modern construction.

Many authors have done researches of this kind of composite wood-based panels (Buyuksari 2012; Dimeski *et al.* 1996; Dimeski *et al.* 1997; Hse *et al.* 2012; Iliev *et al.* 2000; Iliev *et al.* 2005; Iliev *et al.* 2006; Iliev *et al.* 2010; Jakimovska Popovska *et al.* 2014; Miljković *et al.* 1997; Mihajlova *et al*. 2005; Norvydas and Minelga 2006).

Some of the researches are concerned with dimensional stability of the panels under water impact (Iliev 2006; Jakimovska Popovska *et al.* 2014; Mihajlova *et al.* 2005). Possibilities for improving the water resistance properties of composite panels were investigated by Hse *et al*. (2012).

Iliev (2000) and Norvydas and Minelga (2006) studied the impact of veneers number on the properties of composite panels.

The nail withdrawal resistance is an important property of composite wood-based panels for use in construction, which can shows the behavior of the assemblies of this kind of wood-based panels made with nails.

The aim of the research presented in this paper is to study the nail withdrawal resistance of composite wood-based panels made form particleboard core overlaid on both sides with two-ply cross-laminated veneers.

2. MATERIALS AND METHODS OF THE EXPERIMENTAL WORK

For realization of the research, three experimental composite wood-based panels were made by combining single-layered particleboard and peeled beech, black pine and poplar veneers. The core layer of composite panels represents a single-layer particleboard with thickness of 16 mm which was overlaid on both sides with two-ply cross-laminated beech/black pine/poplar veneers with thickness of 1,5 and 3,2 mm, where the veneers with thickness of 1,5 mm represent the surface layers of the panels.

The single-layered particleboards were made from beech particles. Water solution of phenol-formaldehyde resin was used as an adhesive for particle bonding. The resin has a density of 1,22 g/cm^3 at 20°C, 50,43% dry matters content, 0,30% content of free phenol, viscosity of 195 s by Ford at 20°C, pH value 11,0 and resin curing time of 97 s. For production of single-layered particleboards, a pure phenol formaldehyde resin with 16% dry matters content on dry wood basis was used. The mixture of particles for production of single-layered particleboards was obtained by mixing of equal weight ratios of particles for core and surface layer.

The particleboards were pressed under specific pressure of 25 kg/cm^2 (19 minutes under maximal specific pressure of 25 kg/cm^2 and 10 minutes under pressure of 12,5 kg/cm^2) at temperature of 155°C and pressing time of 30 minutes. The particleboards were made with dimensions of 560×455 mm^2 and thickness of 16 mm.

The particleboards overlay was made with two veneer sheets on each side of the panels. Beech, black pine and poplar veneers with thickness of 1,5 and 3,2 mm were used for overlaying. The orientation of the adjacent veneers was at right angle, where the surface veneers with thickness of 1,5 mm were oriented parallel to the longitudinal axis of the particleboard. A water-soluble phenol-formaldehyde resin with the following characteristics was used for veneer bonding: density at 20°C 1,201 g/cm^3, dry matters 48,85%, content of free phenol 0,21%, viscosity by Ford at 20°C 165 s, pH value 11,12, resin curing time (120°C) 108 s. Wheat flour was used as filler and 15% water solution of $Ca(OH)_2$ as catalyst. The binder was applied on both sides on the inner veneers with thickness of 3,2 mm in quantity of 180 g/m^2.

The veneering was made in a hot press using the following parameters: specific pressure of 15 kg/cm^2, pressing temperature of 155°C and pressing time of 20 minutes.

The composite panels were overlaid with phenol-formaldehyde resin impregnated paper during the hot pressing process. The panels produced had dimensions of 545×435 mm^2, with thickness from 23,00 to 23,37 mm depending on the model and moisture content of 8,5%.

Applying this methodology, three models of composite wood-based panels were made:

- model B: water-resistant composite panel made of particleboard core overlaid with two-ply cross-laminated beech peeled veneers with surface protection of phenol-formaldehyde resin impregnated paper;
- model BP: water-resistant composite panel made of particleboard core overlaid with two-ply cross-laminated black pine peeled veneers with surface protection of phenol-formaldehyde resin impregnated paper;
- model P: water-resistant composite panel made of particleboard core overlaid with two-ply cross-laminated poplar peeled veneers with surface protection of phenol-formaldehyde resin impregnated paper;

Configuration of panels' structure is shown in figure 1.

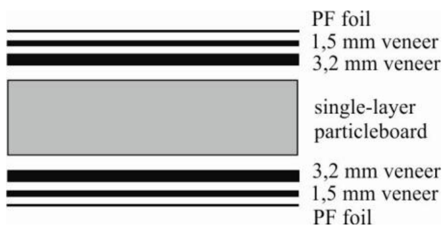

Figure 1. *Composition of composite panels*

Nail withdrawal resistance of composite panels was tested according to MKS D.C8.111/82. This property was tested in two directions: perpendicular to the plane of the panel, i.e., when the nail was driven in the surface of the panel and in plain of the panel (the nail was driven in the panel's edge).

Nine test specimens of each model were made with dimensions of 100×50×d mm. Nails with diameter of 2 mm and length of 45 mm were used for these tests. When the nails were driven into the surface of the panel, the free length of the nail above the surface of the test specimen was 4/10 of nail's length, while when the nails were driven in to the edge of the panel, the depth of the nail driving into the test specimen was 1,2×d. Because of the limited number of test specimens, the same test specimens were used for testing withdrawal resistance in both direction of the panel, so one nail was driven into the surface of the test specimen and two nails into the edge of the specimen. The tests were performed on universal testing machine, measuring the maximal force of withdrawal.

The specific nail withdrawal resistance perpendicular to the plane of the panel was calculated using the following equation:

$$K_{\perp}=\frac{F}{d\times\pi\times d_1}\ [\text{N/mm}^2],$$

where F is maximal force of nail withdrawal [N], d is diameter of the nails [mm] and d_1 is the thickness of the panel [mm].

The specific nail withdrawal resistance parallel to the plane of the panel was calculated using the following equation:

$$K_{\parallel}=\frac{F}{d\times\pi\times l}\ [\text{N/mm}^2],$$

where F is maximal force of nail withdrawal [N]; d is diameter of the nails [mm] and l is the depth of driving of the nail into the panel's edge [mm].

The test specimens for determination of nail withdrawal resistance are shown in figures 2 and 3.

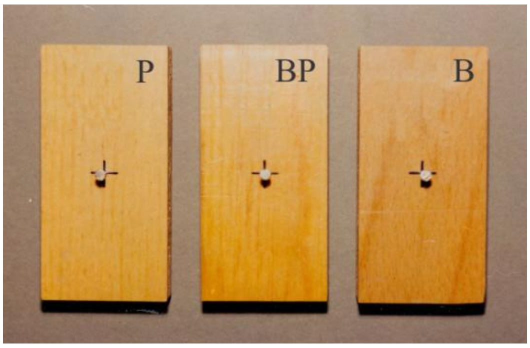

Figure 2. *Test specimens for determination of nail withdrawal resistance perpendicular to the plane of composite panels*

Figure 3. *Test specimens for determination of nail withdrawal resistance parallel to the plane of composite panels*

The obtained data were statistically analyzed. One way ANOVA was used to determinate the significance of the effect of veneer type on panel's nail withdrawal resistance perpendicular to the plane of the panel. Shapiro-Wilk test for normality of the data obtained was applied and Levene's test for homogeneity of variances was applied. Tukey's test was applied to evaluate the statistical significances between mean values of the property of composite panels with different veneer types (different panel models).

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

3. RESULTS AND DISCUSSION

The results for the density of composite panels are shown in table 1 and 2. The ANOVA (F(2,24)=21,46; p=0,000) and Tukey's test for density of the composite panels showed that there is statistical differences in density of the composite model made with poplar veneers compared to models made with beech and black pine veneers. The highest mean value of density was achieved in composite model that was overlaid with beech veneers (740,78 kg/m^3), while the lowest value was achieved in the model made with poplar veneers (657,11 kg/m^3).

Table 1. *Statistical data for density of composite panels*

Model	***N***	***Mean***	***Min***	***Max***	***95% Confidence Interval for Mean***		***Std. Deviation***	***Std. Error***
		kg/m^3	***kg/m^3***	***kg/m^3***	***Lower Bound***	***Upper Bound***	***kg/m^3***	***kg/m^3***
A	9	740,78[a]	699,00	788,00	717,47	764,08	30,32	10,11
B	9	723,56[a]	692,00	744,00	710,74	736,37	16,67	5,56
C	9	657,11[b]	611,00	706,00	629,84	684,38	35,48	11,83

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

Table 2. *Results for the ANOVA of the data obtained for density of composite panels*

ANOVA					
Density					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	35134,741	2	17567,370	21,460	0,000
Within Groups	19646,667	24	818,611		
Total	54781,407	26			

The results for the nail withdrawal resistance perpendicular to the plain of the panels are shown in table 3 and 4. The analysis of variance of the data obtained for nail withdrawal resistance perpendicular to the plain of the panel (ANOVA: F (2; 24)=11,935; p=0,000) showed that the differences between the mean values of this property of at least two models are statistically significant, which means that wood species used for particleboard overlay has a considerable 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 values of this property between model B and the other two composite models (BP and P). The differences in the mean values of nail withdrawal resistance perpendicular to the plain of the panel between model BP and model P are not statistically significant.

The highest mean value of this property was achieved in the composite model that was overlaid with beech veneers (B), while the lowest value was achieved in the model made with poplar veneers (P). These values correspond with the values of density of the composite models.

The results for the nail withdrawal resistance parallel to the plain of the panels are shown in table 5 and 6. The analysis of variance of the obtained data for the nail withdrawal resistance parallel to the plain of the panel (ANOVA: F (2; 24)=3,101; p=0,063) showed that there are no statistically significant differences between the mean values of this property of all composite models. This was expected due to the fact that all composite models are made with the same core layer of single-layer particleboard, i.e. in all models the nail withdrawal resistance parallel to the plain of the panel was tested in the particleboard core layer, which is the same in all models.

Table 3. *Statistical data for nail withdrawal resistance perpendicular to the plain of the composite panels*

Model	N	Mean	Min	Max	95% Confidence Interval for Mean		Std, Deviation	Std, Error
		N/mm^2	N/mm^2	N/mm^2	Lower Bound	Upper Bound	N/mm^2	N/mm^2
A	9	5,68[a]	4,54	6,56	5,09	6,27	0,77	0,26
B	9	4,73[b]	3,80	6,29	4,11	5,34	0,80	0,27
C	9	4,04[b]	3,20	4,93	3,60	4,47	0,56	0,19

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

Table 4. *Results for the ANOVA of the obtained data for nail withdrawal resistance perpendicular to the plain of the composite panels*

ANOVA					
nail withdrawal resistance-perpendicular					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	12,260	2	6,130	11,935	0,000
Within Groups	12,327	24	0,514		
Total	24,587	26			

Table 5. *Statistical data for nail withdrawal resistance parallel to the plain of the composite panels*

Model	N	Mean	Min	Max	95% Confidence Interval for Mean		Std, Deviation	Std, Error
		N/mm^2	N/mm^2	N/mm^2	Lower Bound	Upper Bound	N/mm^2	N/mm^2
A	9	2,81	2,23	3,70	2,50	3,12	0,41	0,14
B	9	2,90	2,53	3,18	2,74	3,07	0,22	0,07
C	9	2,58	2,25	2,80	2,46	2,70	0,16	0,05

There are no statistically significant differences between the mean values at 0,05 probability level

Table 6. *Results for the ANOVA of the obtained data for nail withdrawal resistance parallel to the plain of the composite panels*

ANOVA					
nail withdrawal resistance-parallel					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	,490	2	0,245	3,101	0,063
Within Groups	1,897	24	0,079		
Total	2,387	26			

The obtained values of nail withdrawal resistance of the experimental composite panels are within the limits of the values listed in available literature from similar researches. Iliev (2000) gives the values in the limits of 4,39 to 5,62 N/mm^2 for nail withdrawal resistance perpendicular to the plain of the composite panels made with two-ply cross-laminated beech veneers and values in the limits of 4,68 and 5,56 N/mm^2 for the composite panels made with single beech veneer overlay. The same author for the nail withdrawal resistance parallel to the plain of the panel gives the values within the limits of 3,55 to 4,12 N/mm^2 for composite panels made with single beech veneer overlay and values within the limits of 2,70 to 3,91 N/mm^2 for composite panels made with two-ply cross-laminated beech veneers. Miljković *et al.* (1997) give the value of 4,72 N/mm^2 for nail withdrawal resistance perpendicular to the plain of the composite panel made with two-ply cross-laminated black pine veneers. Dimeski *et al.* (1997) give the value of 4,04 N/mm^2 for nail withdrawal resistance parallel to the plain of the composite panels made with two-ply cross-laminated poplar veneers.

Miljković (1991) defined the values within the limits of 2,4 to 3,6 N/mm^2 for the nail withdrawal resistance perpendicular to the plain of the particleboard panel and the values within the limits of 1,2 to 1,8 N/mm^2 for the nail withdrawal resistance parallel to the plain of the particleboard panel. The values obtained for this property of the experimental composite wood-based panels exceed these values.

4. CONCLUSIONS

On basis of the results obtained from the research conducted, it can be concluded that composite wood-based panels made with peeled constructive veneers for particleboard overlay are suitable for structural application in construction.

The wood specie used for particleboard overlay (beech, black pine or poplar) has significant impact on the values of nail withdrawal resistance perpendicular to the plain of the composite wood-based panels. The highest mean value of this property was achieved in composite model made with beech veneer overlay, which is in accordance with the highest value of density of this model.

According to the values obtained of nail withdrawal resistance, composite panels can be used in construction.

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