INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN, 1/2020 (17): 42–52

PHYSICAL AND MECHANICAL PROPERTIES OF COMBINED WOOD-BASED PANELS WITH PARTICIPATION OF PARTICLES FROM VINE STICKS IN CORE LAYER

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ABSTRACT

The growing needs for wood and the impact of forest ecosystems on the climate of the planet require the rational use of wood raw material. One possible way to "save" forests is to increase the use of agricultural lignocellulosic residues. The research efforts of scientists around the world are aimed at improving the properties of wood-based panels and to increase the share of agricultural residues in that production.

In laboratory conditions were produced three-layer combined wood-based panels with a face layer of wood fibers and a core layer of wood and vine sticks particles. The participation of vine stick particles in the core layer was: 0; 15; 30 and 45%. As binder was used urea-formaldehyde resin. The content of resin in core layer was 8; 10; and 12%. The properties of the panels with and without participation of vine particles were compared. The final data for physical and mechanical properties of the panels, with participation of vine particles, were processed by the methods of regression analyze.

In the result of conducted study was established and analyzed the influence of the participation of particles from vine stick and resin content on the physical and mechanical properties of combined wood-based panels.

Key words: combined tree-layered wood-based panes, wood fibres, vine sticks particles, physical and mechanical properties.

INTRODUCTION

Wood raw material is increasingly in short supply (FAO). The small-sized woods find limited application in solid-wood materials (Trichkov N. and Antov, P. 2005), but are a main raw material in the production of wood-based panels (Thoemen, H. et al. 2010). Another advantage of wood-based panels is the possibility of utilization of non-wood lignocellulosic raw material in their composition (Mihajlova J 2012 a; Mihajlova, J. 2012 b).

During the cultivation and management of the vineyards every year there are waste of about 200 kg per 1 dekare of vine sticks (Abrasheva, P. et al. 2008). The anatomical and chemical composition of vine sticks is very close to that of wood and when creating a suitable technology for their utilization as raw material for the production of wood-based panels, they would be an alternative source of raw material.

Every year the production of wood-based panels increases (Neykov, N. et al 2018; FAO), which increases the consumption of wood raw material. These require the search for alternative sources of raw materials. According to a number of studies, vine sticks are proving to be a very suitable raw material for the production of wood-based panels (Georgius, A. et al. 2002; Yosifov, N. et al. 2001; Mehmet, Y. et al 2014). The concentration of the vine sticks, their quantities and the way they are collected and stored are also a factor that influences their suitability for industrial processing (Mihailova J. et al 2008). In the contemporary cultivation of vineyards, mechanization has been introduced for the collection and removal of vine rods from the field, which greatly helps to reduce the cost of collecting of vine sticks (Rangelov, B and Nikov, M. 2005).

In the production of combined wood-based panels, the aim is to be improved some of their properties. The use of wood fibers in the face layers of the panels aims to improve their bending strength and modulus of elasticity, as well as to reduce the roughness of the face layers. This improvement of the properties of the product on the one hand, leads on the other hand to increase of production costs of the panels. The use of vine particles aims both to save wood raw material and to reduce the cost of raw material.

The aim of the study is to establish how the participation of wood fibers and the percentage of vine particles in the core layer affect the physical and mechanical properties of wood-based panels.

MATERIALS AND METHODS

In laboratory conditions were produced three-layer combined wood-based panels with face layers of wood fibers and a core layer of wood and vine particles, Figure 1.

A) B) C)

Figure 1: Materials used for the production of combined wood-based panels A) wood fibres; B) wood particles; C) vine particles

The amount of vine particles in the core layer was from 0 to 45%. The ratio of face to core layer (FL:CL) was 40:60. Wood fibers were composed from 70% hardwood and 30% softwood. The bulk density of the pulp was 29 kg.m^{-3}. The fractional composition of the particles is given in table 1.

Table 1: Fractional composition of wood and vine sticks particles

Fraction, mm	Vine particles		Wood particles	
	Mass, g	Percentage, %	Mass, g	Percentage, %
above 4.0	0	0	10.0	10.0
4.0 ÷ 2.0	79.2	79.2	38.0	38.0
2.0 ÷ 1.0	18.0	18.0	38.8	38.8
1.0 ÷ 0.5	2.6	2.6	7.7	7.7
0.5 ÷ 0.2	0.6	0.6	2.0	2.0
below 0.2	0.2	0.2	1.4	1.4
Total:	100 g	100 %	100 g	100 %

The moisture content of wood fibres was 11.0%, of wood particles – 10.4% and of vine particles 8.5%. The target density of the panels was 700 kg.m^{-3} and the dimensions of the panels were 500x500x16 mm. One-component urea-formaldehyde resin powder "Sadecol P410", class E_1 was used as a binder. The percentage of resin in face layers was 10% and in core layers was 8%, 10% and

12%. The concentration of adhesive solution was 55%. The hot-pressing was done in a laboratory hydraulic press PMC ST 100 of the company "Manni-S.PA" – Italy. The regime of hot-pressing was as follow: 1^{st} stage – specific pressure 2.5 MPa and pressing time of 1 minutes; 2^{nd} stage – specific pressure 1.2 MPa and pressing time of 5 minutes; 3^{rd} stage – specific pressure 0.6 MPa and pressing time of 2 minutes. The hole pressing time was 8 minutes, i.e. the press factor was 30 $s.mm^{-1}$. Three types of panels were produced according to the amount of binder in the core layer: type A panel with 8% resin content, type B with 10% resin content and type C with 12% resin content. From each type of panels were produced 4 modifications with the participation of vine sticks particles in the core layer as follow: 0%, 15%, 30% and 45%.

After acclimatization for 24 hours, the laboratory panels were cut into test specimens according to EN 325 and EN 326-1. The physical and mechanical properties of the combined panels were determined according to the EN 310, EN 311, EN 312, EN 317, EN 319, EN 322 and EN 323.

For each property were tested 10 samples and the main statistical indicators were determined – mean value (average), standard deviation, probability (p-value). The results for the properties of the panels were processed by the methods of regression analyze through specialized software – *QStatLab* version 6.0.

The general type of regression, experimentally-statistical, model is (Vuchkov, I. and Stoianov, St. 1980):

$$\hat{Y} = B_0 + B_1.X_1 + B_2.X_2 + B_{12}.X_1.X_2 + B_{11}X_1^2 + B_{22}.X_2^2, \quad (1)$$

where $\hat{Y}$ it is predicted by the equation output value;

B_0, B_1, B_2, B_{12}, B_{11}, B_{22} – regression coefficients;

X_1, X_2 – content of vine particles and resin content in core layer.

RESULTS AND DISCUSSION

The results, for each property of the panels, obtained from test samples were processed by the methods of variation statistics. For all samples, p-value was below 0.05, therefore the results are statistically significant at α 0.05 and can be used for analyze of the studied factors.

The density of the produced combined panels varied from 690 to 710 $kg.m^{-3}$. Therefore, the variation in this property is below 3% and should not affect the results of the study. After acclimatization the moisture content of the panels varied in very small range – from 7.01 to 7.56%. So this property also should not affect the results of the study.

The water absorption and swelling in thickness of the panels with standard deviation for every test are presented in Table 2. The water absorption of the panels is influenced by the core layer, where the distances between the particles allow water to enter between them. The face layers, which are from wood fibers, should not be affected, as they are very dense (over 1000 $kg.m^{-3}$).

Table 2: Physical properties of combined wood-based panels

Panel №	Content of vine particles *Px*, %	Water absorption *A*, %			Swelling in thickness *Gt*, %		
		Type of panel			Type of panel		
		A	B	C	A	B	C
1.	0	112.0±4.5	97.0±4.6	95.0±3.7	38.0±1.7	29.0±1.9	27.8±1.0
2.	15	113.5±4.8	116.0±8.6	93.8±5.4	39.8±5.9	32.0±2.0	25.5±0.8
3.	30	106.0±6.3	96.0±3.2	99.0±5.1	38.0±1.8	30.8±1.8	28.0±4.4
4.	45	114.0±4.0	97.8±4.6	87.0±4.6	37.9±3.0	29.9±2.2	25.9±0.9

The regression models for the influence of the content of vine particles and UF resin in core layer on water absorption and swelling in the thickness of the panels are given in Table 3.

Table 3: Data from regression analysis for water absorption and swelling in thicknesses of combined wood-based panels

Indicator of the regression model \ Panel property	Water Absorption	Swelling in thickness
Free member B_0	202.93	191.38
Coefficient of linear member B_1	−1.94	−1.43
Coefficient of linear member B_2	−8.29	−23.59
Coefficient of interaction B_{12}	0.02	0.10
Coefficient of square member B_{11}	0.03	0.01
Coefficient of square member B_{22}	0.12	0.84
Coefficient of determination R^2	0.81	0.95

The variation of water absorption of the combined panels is presented in Figure 2.

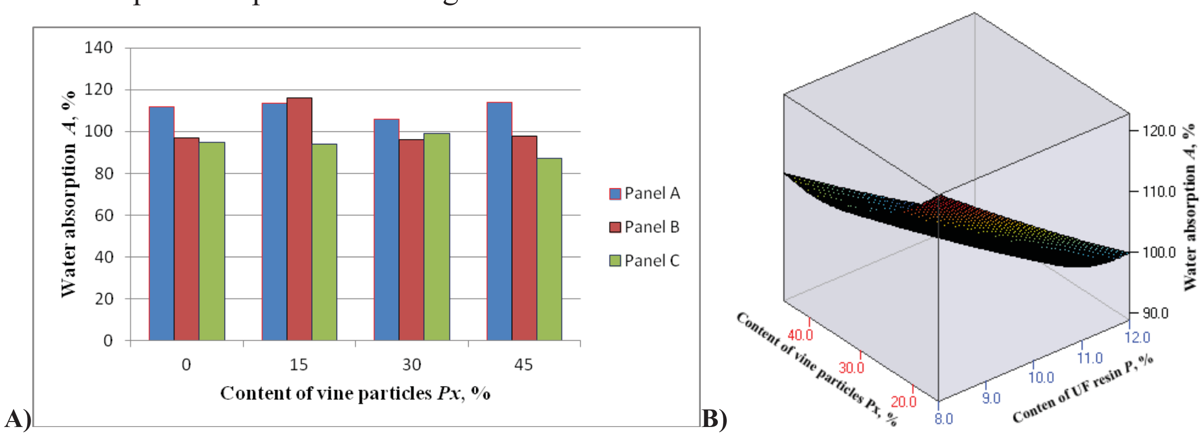


Figure 2: Water absorption of combined wood-based panels
A) Water absorption of different types of panels; B) Influence of the content of vine particles and UF resin on water absorption

The water absorption of the combined panels Type A was from 106 to 123.5%. The lowest water absorption was at 30% content of vine particles, and the highest – at 15% content of vine particles. Due to the small amount of binder (8%) the water absorption exceeds 100%.

There is no clear trend for the influence of vine particles on the water absorption of Type B panels. The lowest water absorption was at 30% content of vine particles – 96%, and the highest at 15% content, respectively 116%. The difference between the two values is 21%. For Type C panels, the lowest water absorption was at 45% content of vine particles and it was 87%, and the highest was at 30% content of vine particles – 99%, which is an increase in water absorption by 14%. The average water absorption was 93%.

From the results it become clear that the addition of vine particles in the core layer does not increase the water absorption of the panels, and the increase of the resin from 8% to 12% leads to a decrease in the water absorption.

Both the face and the core layers of the panels take part in the swelling of the thickness. As the face layers of the panels had the same resin content (10%), their swelling in thickness should be approximately the same. So it can be concluded that the variation in thickness is due to the core layer.

In the analysis of the combined effect of the two factors on the water absorption of the panels with the participation of vine particles the influence of the content of UF resin is significantly greater. With an increase in the content of resin in the core layer from 8 to 12%, a significant improvement in water absorption is observed. The dependence is close to the linear one. After the improvement of the water absorption with the increase of the content of vine particles in the core layer from 15 to 30%, no significant change in the values of the property is observed at further increase of the content of vine particles. In general, all panels have a relatively high water absorption, which most likely can be compensated by increasing the temperature of hot-pressing at maintaining a press factor from 30 s.mm^{-1}.

The effect of different participation of vine particles in core layer of the panels on swelling in thickness is presented in Figure 2.

The variation of swelling in thickness of the combined panels is presented in Figure 3.

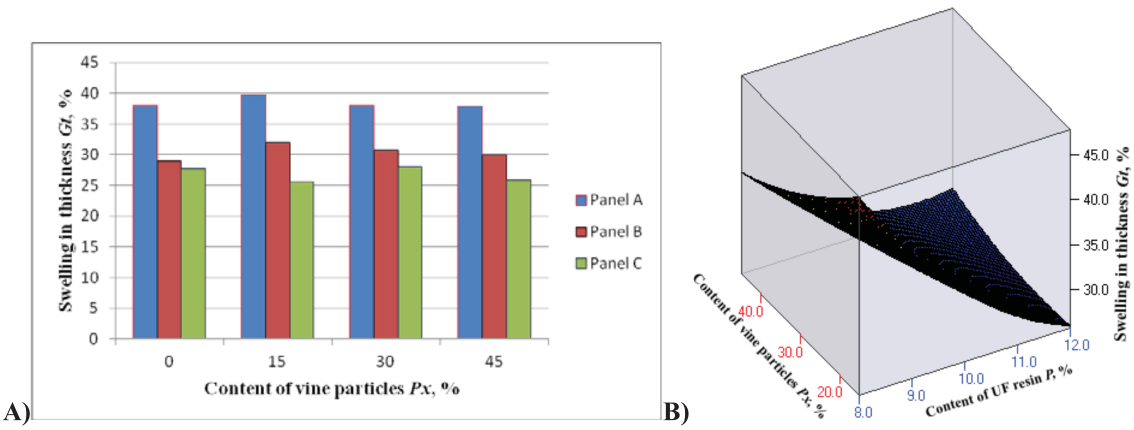


Figure 3: Swelling in thickness of combined wood-based panels
A) Swelling in thickness of different types of panels; B) Influence of the content of vine particles and UF resin on swelling in thickness

The results show that the addition of vine particles in Type A panels does not have a significant effect on the swelling in thickness due to the fact that at 0; 30 and 45% content of vine particles, swelling in thickness is close to 38%. The swelling in thickness for Type B panels was from 29%, at 0% participation of vine particles, to 31% at 15% participation of vine particles. This makes an increase of 6% for this property. The average swelling in thickness was about 30%. The swelling in thickness in Type C panels was in the range from 25%, at 15% content of vine particles, to 28% at 30% participation of vine particles. The average swelling in thickness is about 27%.

The data shows clear that the swelling in thickness decrease with increase of the resin content from 8 to 12%. The improvement of that property is with 28%.

When analyzing the combined influence of the factors, a significantly greater effect of the increase in content of UF resin was again found. However, the increased content of vine particles also has a positive effect on the swelling in thickness of the panels. This can be due both to the presence of bark in the vine particles and to their less swelling in thickness compared to one of wood particles.

The mechanical properties of the produced panels with standard deviation for every test are presented in Table 4.

Table 4: Mechanical properties of combined wood-based panels

Panel №	Content of vine particles *Px*, %	Bending strength *fm*, $N.mm^{-2}$			Modulus f elasticity *Em*, $N.mm^{-2}$			IB strength *ft*, $N.mm^{-2}$		
		Type of panel			Type of panel			Type of panel		
		A	B	C	A	B	C	A	B	C
1.	0	18.8± 2.7	18.0± 1.9	18.9± 2.3	2300± 174	2400± 201	2300± 330	0.31± 0.04	0.48± 0.06	0.52± 0.07
2.	15	15.0± 1.7	17.8± 2.9	19.7± 2.5	2000± 224	2300± 203	2400± 305	0.13± 0.03	0.32± 0.05	0.56± 0.04
3.	30	16.8± 2.4	18.8± 2.8	20.0± 2.4	2300± 260	2300± 295	2400± 232	0.24± 0.06	0.36± 0.07	0.50± 0.07
4.	45	15.5± 1.2	16.8± 2.0	19.0± 1.7	2100± 191	2200± 240	2400± 255	0.24± 0.06	0.36± 0.03	0.56± 0.07

The regression models for the influence of the content of vine particles and UF resin in core layer on studied mechanical properties of the panels are given in Table 5.

Table 5: Data from regression analysis for mechanical properties of combined wood-based panels

Panel property / Indicator of the regression model	Bending strength	Modulus of elasticity	IB strength
Free member B_0	3.16	1158	0.212
Coefficient of linear member B_1	0.42	39.65	0.012
Coefficient of linear member B_2	2.19	61.23	-0.013
Coefficient of interaction B_{12}	−0.01	−0.62	0.001
Coefficient of square member B_{11}	−0.04	−0.57	−
Coefficient of square member B_{22}	−0.01	0.95	0.006
Coefficient of determination R^2	0.94	0.82	0.93

In graphical form the studied dependences are presented in Figure 4, Figure 5 and Figure 6.

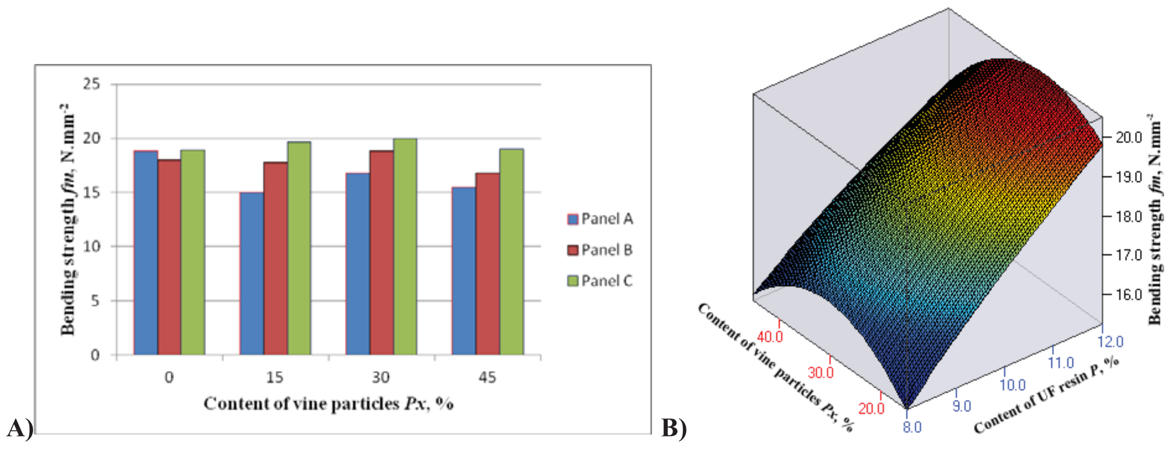


Figure 4: Bending strength of combined wood-based panels
A) Bending strength of different types of panels; B) Influence of the content of vine particles and UF resin on bending strength

Type A panels had highest bending strength of 19 N.mm^{-2} at 0% participation of vine particles, and the lowest – 15 N.mm^{-2}, at 15% participation of vine particles. With increasing the participation of vine particles, the tendency to decrease the bending strength is clearly visible. The panels meet the requirements of EN 312 for boards type P1, P2, P3 and P4 for general purpose, respectively for interior furnishing (including furniture) in dry environment and for panels for non-load-bearing structures in a humid environment.

Panels Type B have a maximum bending strength of 19 N.mm^{-2} at 0% and 30% content of vine particles, and the lowest (17 N.mm^{-2}) – at 45% content of vine particles, ie; the reduction in strength is 11%. With increasing participation of vine particles there is a clear tendency for reduction of bending strength. The panels meet the requirements of EN 312 for boards type P1, P2, P3, P4 and P5 for general use, for interior furnishing (including furniture) in a dry environment, for panels for non-load-bearing structures in a humid environment and for load-bearing tiles structures for use in humid environments.

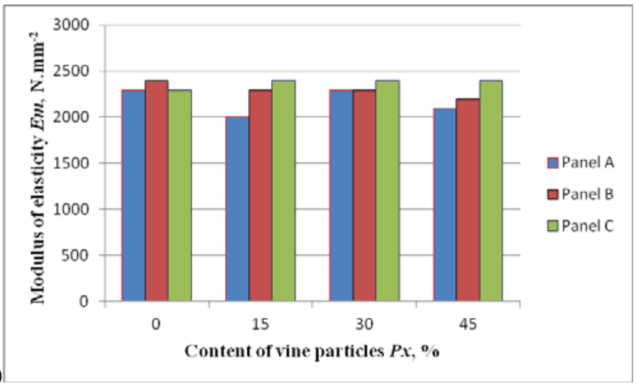
The produced panels Type C had the highest bending strength (20 N.mm^{-2}) at 15% and 30% content of vine particles, and the lowest (19 N.mm^{-2}) – at 0 and 45% content of vine particles. The panels meet the requirements of EN 312 for board types P1, P2, P3, P4 and P5, and the panelss with 15 and 30% participation of vine particles also meet the requirements for boards type P6 – for load-bearing structures with increased load resistance for use in humid environment

Of the two studied factors, the content of UF resin in the core layer has a greater influence on the bending strength. As the binder content increases, an improvement in bending strength is observed as the dependence is close to linear one. When only 15% vine particles are introduced into the core layer is observed a decrease in bending strength of the panels. This was followed, albeit to a lesser extent, by an improvement in the values of the property and a further decline when content of vine particle is more then 30%. This can be explained by an improvement in the homogeneity of the core layer with an increase in the content of vine particles and a subsequent greater fragility of the panels with a transition of 30%content of vine particles.

It should be noted that the core layer has little influence on bending strength of the panels and achieved high values for this property are due to the wood fibers used in face layers.

High values have been achieved and for the modulus of elasticity in bending of the combined panels and this is also due to the wood fibers used in the face layers, Figure 5.

A)



B)

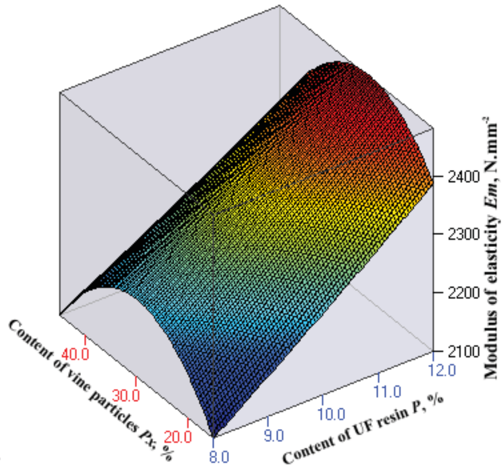


Figure 5: Modulus of elasticity of combined wood-based panels
A) Modulus of elasticity of different types of panels; B) Influence of the content of vine particles and UF resin on modulus of elasticity

The vine particles in the core layer have some influence on the modulus of elasticity, as for panels Type A it was 2300 N.mm^{-2} at 0% and decreases by 8% – up to 2100 N.mm^{-2} at 30% content of vine particles.

At panels Type B with the increase of the vine particles from 0% to 45%, the modulus decreases again by 8%, respectively from 2400 N.mm^{-2} to 2200 N.mm^{-2}.

The results for panels Type C show that as the resin in the core layer increases, the modulus of elasticity increases to 2400 N.mm^{-2}, and that the increase in the participation of vine particles does not affect it.

Panels Type A meet the requirements of EN 312 for boards type P1, P2 and P3. The resulting Type B panels meet the requirements of EN 312 for board type P1, P2, P3 and P4, while Type C panels show the highest modulus of elasticity.

Again, of the two factors studied, the influence on the modulus of elasticity of the resin content is significantly stronger. As with bending strength, the dependence is close to linear. The picture of the influence of the content of vine particles is also repeated. After deterioration of the modulus of elasticity when replacing wood with particles from vine sticks, there is a slight improvement with a repeated decrease in the values of the property.

IB strength of combined wood-based panels is presented in Figure 6.

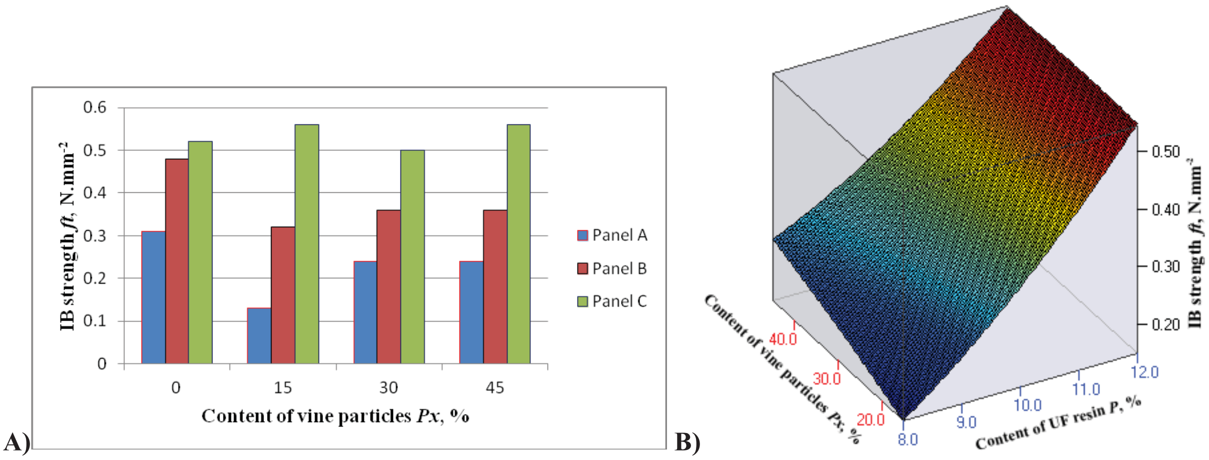


Figure 6: Internal bond strength of combined wood-based panels
A) Internal bond strength of different types of panels; B) Influence of the content of vine particles and UF resin on internal bond strength

IB strength of panels Type A decreases from 0.31 N.mm^{-2} at 0% participation of vine particles to 0.24 N.mm^{-2} at 30% and 45% content of vine particles, i.e. the participation of vine particles in the core layer of the panels leads to reduction of IB strength by 23%. Panels Type A does not meet the requirements of EN 312 for boards type P2.

Panels Type B had IB strength from 0.48 N.mm^{-2} at 0% participation of vine particles to 0.36 N.mm^{-2} at 30% and 45% participation of vine particles, i.e. the participation of vine particles in the core layer is the reason for the decrease in strength by 25%. Excluding the IB strength at 15% participation of vine particles (0.32 N.mm^{-2}) the remaining panels meet the requirements of EN 312 for boards type P1 and P2.

Panels Type C had IB strength over 0.5 N.mm^{-2}, i.e. they meet the requirements of EN 312 for boards type P1, P2 and P3 for non-bearing structures in humid environments.

For panels Type A and B, the participation of vine particles leads to a decrease in the IB strength of up to 25%, but when the resin content increases to 12% in panels Type C, the participation of vine particles does not reduce significantly the IB strength.

In general, there is a significant deterioration of IB strength even when replacing 15% of wood particles with vine ones. This is most likely due to the violation of the homogeneity of the core layer, the characteristics of vine particles and the introduction of bark with them. Subsequently, with an increase in the content of vine particles from 15 to 45%, a slight improvement in IB strength is observed. This improvement should be due to an improvement in the homogeneity of the layer. However, all panels with participation of vine particles have significantly worse IB strength than panels composed only from wood raw material. The increase of the resin content in core layer from 8 to 12% has a very strong positive effect on IB strength and at least partially compensates for the negative effect on the property from participation of vine particles.

CONCLUSIONS

Conducted experimental study have shown that the participation of particles from vine sticks in core layer of combined wood-based panels leads to a reduction in water absorption of the panels. Vine particles swell less than particles from wood, which leads to a decrease in swelling in thickness of the panels with increasing of the percentage of vine particles. The increase of resin content in core layer leads to improvement of all properties of the panels.

Mainly due to face layers of wood fibres the produced panels have very good modulus of elasticity and bending strength. The introduction of particles from vine sticks leads to a slight deterioration of these properties, which is significantly compensated by increase of resin content. The participation of vine particles in the panels have a main negative effect on IB strength, but this effect is again neutralized by increasing the resin content in the core layer.

In conclusion the structure of the panels with face layers of wood fibers and core layer of wood and vine particles uses better properties of fibreboards and at the same time, the production costs decreases through the core layer of particles. Another advantage of the produced panels is the substitution of wood by vine particles with which the significant raw material potential of waste vine sticks from viticulture can be utilized. Thus again reducing production costs and mainly saves deficient wood raw material.

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UNIVERSITY OF FORESTRY

FACULTY OF FOREST INDUSTRY

INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN

1/2020

INNO vol. IX Sofia

ISSN 1314-6149
e-ISSN 2367-6663

Indexed with and included in CABI

INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN

Science Journal
Vol. 09/p. 1–78
Sofia 1/2020

ISSN 1314-6149
e-ISSN 2367-6663

Edition of
FACULTY OF FOREST INDUSTRY – UNIVERSITY OF FORESTRY – SOFIA

The Scientific Journal is indexed with and included in CABI.

Cover Design: DESISLAVA ANGELOVA

Printed by: INTEL ENTRANCE
Publisher address: UNIVERSITY OF FORESTRY – FACULTY OF FOREST INDUSTRY
Kliment Ohridski Bul., 10, Sofia, 1797, BULGARIA
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