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INFLUENCE OF DENSITY ON THE WITHDRAWAL STAPLE STRENGTH FROM HEMP SHIVE PANELS

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Abstract: *Particleboards are the main material used in the production of furniture and furnishings. The shortage of wood raw material and the ever-increasing amount of particleboards produced suggest a search for alternative raw material sources for this panel type. On the other hand, significant quantities of agro-industrial lignocellulosic residues are available worldwide. Such a type of residue is hemp shives. Basic joints in furniture frames are stapled joints, as it should be said that density is the main characteristic of particleboards, and their other properties strongly correlate with it. The present research studies the influence of the density of panels from hemp shives on their staple withdrawal resistance. For this purpose, panels from hemp shives with melamine-formaldehyde (MF) resin as an adhesive and densities from 600 kg.m*$^{-3}$ *to 900 kg.m*$^{-3}$ *were produced in laboratory conditions. The density of the panels varied with a step of 100 kg.m*$^{-3}$*. As a result of the research, it was found that the staple withdrawal resistance of hemp shives particleboards from the edge and side of the panels increases almost twice with the increase of their density. It was also found that, unlike industrial particleboards, edge staple withdrawal resistance is higher in hemp shive panels than side staple withdrawal resistance. Laboratory-produced panels from hemp shives have a higher staple withdrawal resistance at similar densities than industrial particleboards. However, this is at the expense of using expensive MF resin and the significantly extended press factor. The main novelty of the research is the establishment of the effect of the density of hemp shive particleboards on their staple withdrawal resistance, as well as the demonstration of the possibility of producing panels from an alternative lignocellulosic raw material with a better staple withdrawal resistance than that of industrial particleboards manufactured from wood raw material.*

Key words: *furniture frame structures, stapler withdrawal resistance, hemp shive panels.*

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1. Introduction

Due to the shortage of wood raw material, the question of using agricultural waste as a raw material for panels with application as a material for furniture production is relevant. Such an auspicious raw material is hemp shives, and the panels fabricated from this type of agro-industrial residue have shown satisfactory physical and mechanical properties [2, 17, 23]. These types of panels have shown good machinability [1]. At a low density of the panels from hemp shives (possible to be achieved given the low bulk density of hemp shives), they have very good insulating properties with satisfactory mechanical ones [10]. It was established that by modifying the core layer of particleboards by including hemp shives in their composition, no significant deterioration in the mechanical properties of the panels was observed [15, 16]. That makes this agro-industrial residue interesting for research and promising for obtaining materials for furniture production [11].

In recent years, joints using smoothing and metal clamps (staples) have increasingly entered production practice. This is dictated by the higher productivity and less labor-intensive technological operations compared to other non-detachable joints used in the construction of upholstered furniture. That necessitates conducting many studies on their strength and deformation behavior. Several scientific publications have studied the tensile and shear strength of stapled joints. The effect of leg penetration on the strength of staple joints [18] and withdrawal resistance for materials from softwood [19, 20], hardwood [22], and plywood [9, 21] have been studied. Results from individual publications could hardly be compared since their authors used different methodologies and materials to evaluate the strength of the compounds. There are also specific differences in the type and location of the staples and construction details. Bearing in mind that particleboard is the most commonly used material for producing furniture box frames in the skeletons of upholstered furniture, it has been studied in sufficient detail. The results for determining the strength of joints by staples are not particularly satisfactory, which implies the search for new, alternative options for producing wood-based panels, such as hemp shive particleboards.

This research aims to determine the effect of the density of hemp shive panels on their staple withdrawal resistance, given their applicability in skeletons of upholstered furniture.

2. Materials and Methods

For the purpose of the study, one-layered particleboards from hemp shives were fabricated in laboratory conditions. The panels had dimensions as follows: width - 50 cm, length - 50 cm, and thickness 16 mm. Seven types of hemp shive particleboards were fabricated, with target densities as follows: 600, 650, 700, 750, 800, 850, and 900 $kg.m^{-3}$.

The hemp shives were preliminarily dry to a moisture content of 11%. The adhesive system for the panels consisted of melamine formaldehyde (MF) resin in a content of 10% relative to the dry shives. The melamine-formaldehyde resin was used because of the better properties it gives to the wood-based panels, in comparison with the urea-formaldehyde resin. Of course, the main disadvantage of this resin is its higher price [12]. The melamine formaldehyde resin had the following properties: molar ratio (M:F) 1.76; dry content 54%; dynamic viscosity 21±0.76 $MPa.s^{-1}$. A wax (paraffin) emulsion was used as a waterproof substance. The wax content relative to the dry shives was 0.5%, and the emulsion was introduced into the shives at a concentration of 50%. The MF resin and wax were produced by "Kronospan-Bulgaria".

A laboratory blender with needle-shaped blades and a rotation frequency of 400 rpm was used for gluing. The adhesive system was applied by injection through a nozzle with a diameter of 1.5 mm at a pressure of 4.0 MPa. The total retention of particles in the blender was 3 min.

A laboratory hydraulic press, PMC ST 100, Italy, was used to fabricate the panels. Hot-pressing was carried out at a temperature of 160°C. The hot-pressing regime consisted of three stages: First stage – pressure 4.0 MPa and time of 1 min; Second stage – pressure 1.2 MPa and time of 1 min; Third Stage – pressure 0.6 MPa and time of 14 min. The press factor was 60 $s.mm^{-1}$. This regime of hot-pressing was determined based on previous studies to fabricate particleboards with a similar moisture content of the particles [7, 13, 14].

The physical and mechanical properties of the one layered laboratory particleboards from hemp shives were determined according to the requirements of the European Norms (EN): Density ρ - EN 323:2001 [8]; Thickness swelling [6]; Modulus of elasticity E_m and bending strength f_m – EN 310:1999 [4]; Internal bond (IB) strength f_t – EN 319:2002 [7]. The industrial particleboard type P2 with a thickness of 16 mm [5] from the company "Kronospan-Bulgaria" was used as a control in the conducted test. Staples series 100 type M1 (caliber 17) of the OMER company were used as connecting elements, with a cross-section of 1.3/1.45 mm, wire thickness of 1.367 mm, crown width of 10.4 mm, and leg length of 30 mm. The staples were made from wire steel AISI 1006 with density ρ = 7870 $kg.m^{-3}$. The linear, structural, physical, and mechanical properties of the staples are based on certificates provided by the manufacturers and control measurements of the linear parameters. The staple withdrawal resistance was determined on the test samples with dimensions 50 mm /50 mm /16 mm. The withdrawal strength *f* in the wide side and the edge of the particleboards of the connecting elements - clips $M_{1/30}$, was determined according to EN 13446:2003 [3].

The abbreviations of the series of test samples for determining the staple withdrawal resistance depending on the location of the applied force during testing are shown in Table 1.

Figure 1 shows the principle scheme of nailing the connecting element with a force *F*, with a depth of penetration of the stapler into a test body (1) guaranteed by a pawl (2), which limits the safety of a pneumatic pistol company "FASCO", model F44C (3), when nailing, with the nailing direction of the staple opposite to the direction of the applied tensile force *Ft*.

Table 1

Abbreviations of the series of test samples for determining the withdrawal resistance of $M_{1/30}$ type staples from the side and edge of hemp shive and P2 type wood particleboards with a thickness of 16 mm

No.	Series	Side/Edge	Raw material for particleboards	Target density, ρ [kg.m^{-3}]
1	HEMP_1_M1/30_600	side	hemp shives	600
2	HEM _1_M1/30_650	side	hemp shives	650
3	HEMP_1_M1/30_700	side	hemp shives	700
4	HEMP_1_M1/30_750	side	hemp shives	750
5	HEMP_1_M1/30_800	side	hemp shives	800
6	HEMP_1_M1/30_850	side	hemp shives	850
7	HEMP_1_M1/30_900	side	hemp shives	900
8	HEMP_2_M1/30_600	edge	hemp shives	600
9	HEMP_2_M1/30_650	edge	hemp shives	650
10	HEMP_2_M1/30_700	edge	hemp shives	700
11	HEMP_2_M1/30_750	edge	hemp shives	750
12	HEMP_2_M1/30_800	edge	hemp shives	800
13	HEMP_2_M1/30_850	edge	hemp shives	850
14	HEMP_2_M1/30_900	edge	hemp shives	900
15	PB_1_M1/30_640	side	wood particles	640
16	PB_2_M1/30_640	edge	wood particles	640

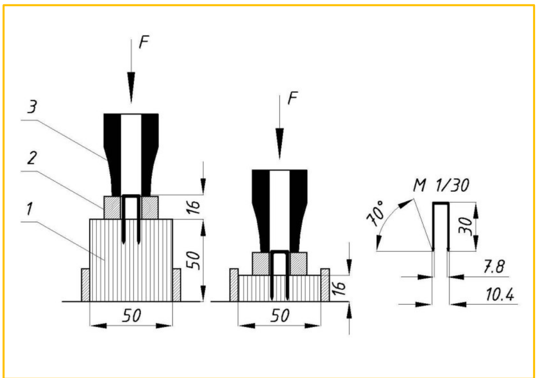

Fig. 1. *Schematic diagram of nailing the connecting element in the test sample*

The samples were conditioned to a constant weight at a temperature of 20±2°C and a relative air humidity of 65±5%. The depth of penetration of the stapler into the particleboard was calculated according to the part of the stapler that remained outside the test sample, measured using a digital caliber of the INSIZE company, model 1103-300, with an accuracy of 0.01 mm and a tolerance of ±0.1 mm.

The tests were carried out on a universal testing machine, WDW – 50E, manufactured by the HST company, China, 2022, by measuring the force required to remove the stapler from the test sample. The load was applied at a constant rate. The loading rate was adjusted to reach the maximum in a time of (60±30) s. The withdrawal resistance *f* in $N.mm^{-2}$ was determined according to Equation (1):

$$f = \frac{F_{max}}{d \cdot 2 \cdot l_p} \qquad (1)$$

where:

d is the smallest cross-sectional size of the staple [mm];

F_{max} – the maximal (withdrawal) force [N];

f – the withdrawal resistance [N/mm];

l_p – the penetration depth of the connecting element [mm].

The laboratory experiment results were processed statistically using the least squares method. The following statistics are defined: the average (mean) value ($\overline{x}$), the maximum value (*max*), the minimum value (*min*), the median (*med*), the standard deviation (*s*), the coefficient of variation (*v*), and the probability in percents (*p*) for the corresponding property.

3. Results

The properties of the laboratory-fabricated hemp shive panels are presented in Table 2.

As a result of the research, the mean values of the withdrawal resistance of stapler type $M_{1/30}$ from the side and edge of the particleboards from hemp shives with a thickness of 16 mm were determined. The values are presented in Table 3 and Table 4, as the probability *p* in all series was below 5 %.

Properties of the laboratory fabricated hemp shive panels Table 2

No.	Series	Raw material for particleboards	Density, ρ [$kg.m^{-3}$]	Modulus of elasticity (MOE), E_m [$N.mm^{-2}$]	Bending strength (MOR), f_m [$N.mm^{-2}$]	Internal bond (IB) strength, f_t [$N.mm^{-2}$]
1	HEMP_1_M1/30_600	hemp shives	600±15	2067±272	16.83±1.32	0.62±0.05
2	HEM _1_M1/30_650	hemp shives	650±16	2479±179	19.35±1.5	0.71±0.08
3	HEMP_1_M1/30_700	hemp shives	700±17	2738±104	20.07±1.12	0.86±0.10
4	HEMP_1_M1/30_750	hemp shives	750±19	2970±259	24.38±1.25	0.98±0.11
5	HEMP_1_M1/30_800	hemp shives	800±20	3805±89	31.20±1.11	1.19±0.04
6	HEMP_1_M1/30_850	hemp shives	850±21	3879±89	32.17±1.05	1.23±0.03
7	HEMP_1_M1/30_900	hemp shives	900±23	3955±142	32.89±1.37	1.30±0.05
8	HEMP_2_M1/30_600	hemp shives	600±15	2067±272	16.83±1.32	0.62±0.05
9	HEMP_2_M1/30_650	hemp shives	650±16	2479±179	19.35±1.5	0.71±0.08
10	HEMP_2_M1/30_700	hemp shives	700±17	2738±104	20.07±1.12	0.86±0.10
11	HEMP_2_M1/30_750	hemp shives	750±19	2970	24.38±1.25	0.98±0.11
12	HEMP_2_M1/30_800	hemp shives	800±20	3805	31.20±1.11	1.19±0.04
13	HEMP_2_M1/30_850	hemp shives	850±21	3879	32.17±1.05	1.23±0.03
14	HEMP_2_M1/30_900	hemp shives	900±23	3955±142	32.89±1.37	1.30±0.05
15	PB_1_M1/30_640	wood particles	640±16	1600±106	11±0.36	0.38±0.03
16	PB_2_M1/30_640	wood particles	640±16	1600±106	11±0.36	0.38±0.03

Stapler withdrawal resistance from the edge of the panels Table 3

No.	Series	Stapler withdrawal resistance from the edge of the panels, f [N.mm^{-1}]						
		Average (mean value) $\overline{\chi}$, [N.mm^{-1}]	Max. value, f_{max} [N.mm^{-1}]	Min. value, f_{min} [N.mm^{-1}]	Median [N.mm^{-1}]	Standard deviation, S [N.mm^{-1}]	Coeff. of variation, V [%]	Probability, P [%]
1	HAMP_1_M1/30_600	13.09	20.05	10.94	12.74	2.07	15.79	0.99
2	HAMP_1_M1/30_650	15.50	18.50	12.73	15.09	1.68	10.82	0.68
3	HAMP_1_M1/30_700	18.38	23.42	12.25	18.64	2.32	12.61	0.53
4	HAMP_1_M1/30_750	21.04	22.76	19.25	20.85	1.20	5.69	0.57
5	HAMP_1_M1/30_800	23.22	27.82	19.54	23.10	2.17	9.35	0.39
6	HAMP_1_M1/30_850	25.90	28.97	23.75	26.04	1.94	7.48	0.75
7	HAMP_1_M1/30_900	29.06	34.57	26.12	28.47	2.85	9.81	0.82
8	PB_1_M1/30_640	7.73	9.68	6.19	7.54	1.06	13.71	1.37

Stapler withdrawal resistance from the side of the panels Table 4

No.	Series	Stapler withdrawal resistance from the side of the panels, f [N.mm^{-1}]						
		Average (mean value) $\overline{\chi}$, [N.mm^{-1}]	Max. value, f_{max} [N.mm^{-1}]	Min. value f_{min} [N.mm^{-1}]	Median [N.mm^{-1}]	Standard deviation, S [N.mm^{-1}]	Coeff. of variation, V [%]	Probability, P [%]
1	HAMP_2_M1/30_600	10.38	13.50	8.67	10.30	1.35	13.00	0.72
2	HAMP_2_M1/30_650	12.62	15.45	11.08	12.59	1.15	9.14	0.51
3	HAMP_2_M1/30_700	14.97	21.04	11.26	14.95	2.56	17.12	0.71
4	HAMP_2_M1/30_750	16.41	19.15	11.60	16.97	2.71	16.53	1.65
5	HAMP_2_M1/30_800	17.63	23.03	11.14	17.57	3.29	18.64	0.78
6	HAMP_2_M1/30_850	19.38	21.45	17.15	19.55	1.93	9.95	1.66
7	HAMP_2_M1/30_900	21.47	23.32	20.03	21.06	1.50	7.00	1.17
8	PB_2_M1/30_640	8.40	9.40	13.12	8.67	0.82	9.82	0.98

4. Discussion

As the density of the hemp shive particleboards glued with the melamine-formaldehyde resin increased from 600 to 750 kg.m^{-3}, the staple withdrawal resistance from the edge of the panels increased from 15.55 to 15.67%. The increasing trend is constant, and at densities between 750 and 900 kg.m^{-3}, it increased from 9.39% to 10.87%. In the studied density range, the withdrawal resistance values of the hemp shive particleboards increased by 54.96%. From the values for the withdrawal resistance from the side of the panels, it was found to be from 15.69 to 17.74% when density increased from 600 to 700 kg.m^{-3} and from 6.92 to 9.73% when density increased from 700 to 800 kg.m^{-3}. The values of staple withdrawal resistance from the side of the panels increased by 51.56% over the investigated density range of the hemp shive particleboards. Notably, the percentage differences for a series of test samples with a density of 600 to 700 kg.m^{-3} in both tests are more significant than the percentage differences between the series values with a density above 700 kg.m^{-3}. Laboratory-produced hemp shive particleboards with a density of 700 to 900 kg.m^{-3} are classified as heavy panels, meeting the requirements for composite materials for load-bearing structures for particleboards type P7 (heavy-duty load-bearing boards).

Higher staple withdrawal resistance values were found from the edge of the panels compared to the side. For groups of specimen series with a density of 600 to 700 kg.m^{-3}, the calculated difference was from 13.93 to 20.70%; for a density between 750 and 800 kg.m^{-3}, it was from 22 to 24.07%, and for a series of specimens with ρ = 850-900 kg.m^{-3} it was from 25.17 to 26.26%.

The correlation between the density of the particleboards from hemp shives and the staple withdrawal resistance from the edge and the side of the panels is linear. That relationship is graphically shown in Figures 2 and 3.

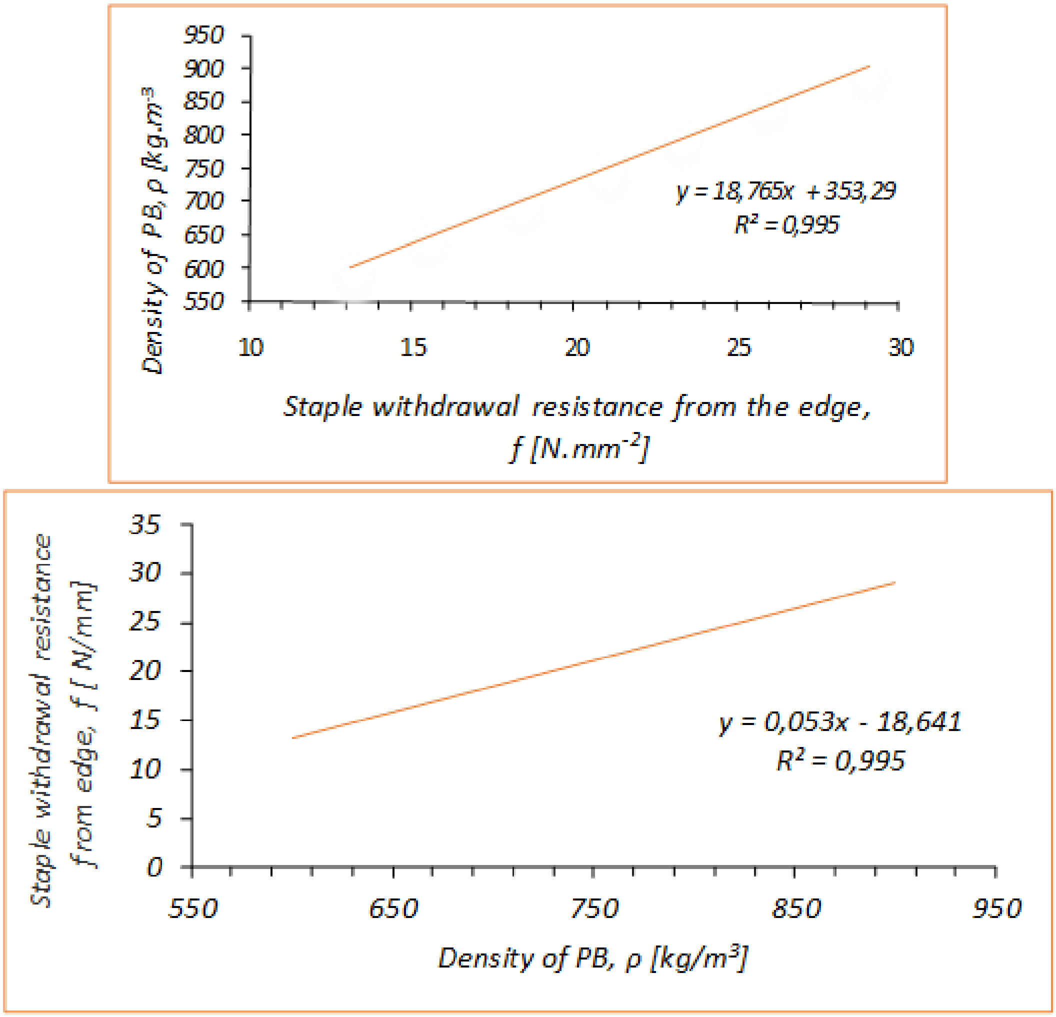

Fig. 2. *Correlation between staple withdrawal resistance from the edge and density of particleboards (PB) from hemp shives*

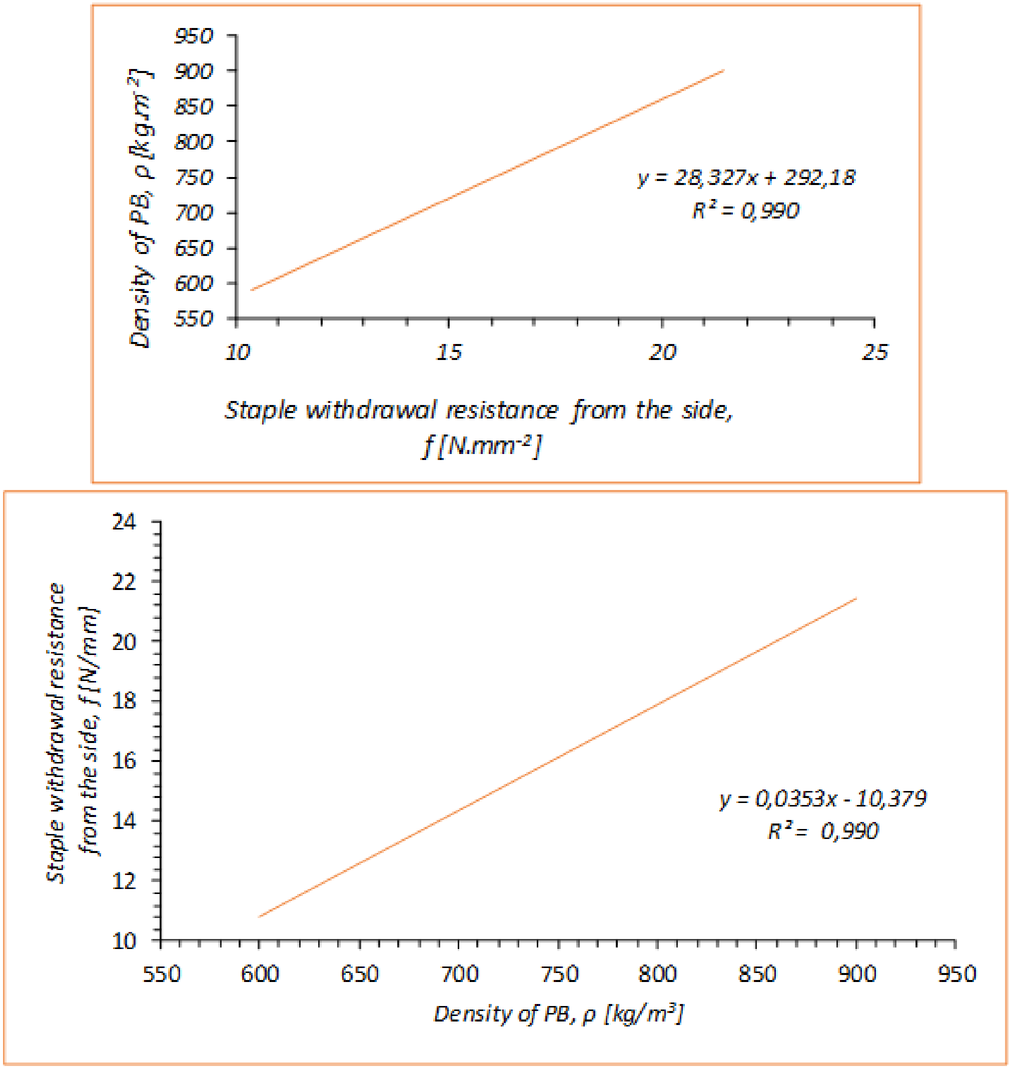

Fig. 3. *Correlation between staple withdrawal resistance from the side and density of particleboards (PB) from hemp shives*

5. Conclusions

As a result of the research, the values of the withdrawal resistance of $M_{1/30}$ staples from the edge and side of hemp shive particleboards with a density from 600 to 900 $kg.m^{-3}$ fabricated in laboratory conditions have been established. The obtained dependence between the density of the laboratory-fabricated plates of hemp shives and their staple withdrawal resistance is linear. As the density of the panels increases from 600 to 900 $kg.m^{-3}$, their edge staple withdrawal resistance rises by 2.1 times and the side staple withdrawal resistance by 2.2 times. A withdrawal resistance 1.2 to 1.4 times greater was found when removing an $M_{1/30}$ staple from the edge compared to one from the side of the panels.

The staple withdrawal resistance for laboratory-produced particleboards from hemp shives, with a density of 600 kg.m-3, is 1.2 times greater at the edge and 1.7 times greater at the side of the panels, compared to industrial particleboards from wood raw material. This makes hemp shive panels suitable and preferable to conventional particleboards from wood raw material for use in frame furniture constructions of joints by staples. However, it should be emphasised that the panels from hemp shives fabricated in this study are with melamine-formaldehyde resin. At the same time, industrial particleboards are mainly produced with urea-formaldehyde resin. For the laboratory-fabricated panels, a press factor several times higher than that of the industrial particleboards was used.

The main result of the research is the demonstration that panels with staple withdrawal resistance better than that of the industrial particleboards for furniture production can be fabricated from agros-industrial residue (hemp shives). That is possible to implement when using a more expensive resin (MF resin) and at the expense of an increased press factor.

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