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MECHANICAL PROPERTIES OF THREE-LAYERED PARTICLEBOARDS WITH FACE LAYERS OF BEECH AND OAK PARTICLES AND A CORE LAYER OF CONIFER AND SUNFLOWER STALKS PARTICLES

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ABSTRACT

The present study aims to establish the mechanical properties of three-layered particleboards with a face layer entirely from beech and oak particles. Three compositions of the panels were studied, with the corresponding content of the face layers as follows: 30%, 40% and 50%. To analyse the possibility of reducing the content of pinewood particles in the core layer, it is replaced with sunflower stalk particles with the participation of 30%, 40% and 50%. This research determined the effect of those factors on the main mechanical properties of particleboards.

As a result of the study, it was found that the increase in the percentage of the face layers leads to a significant increase in the mechanical properties of the panels. It was found that by using the hardwood in the face layers of the panels, the share of this raw material can be increased to 50%, and sunflower stalks are a suitable raw material as an alternative raw material for the core layer of the particleboards.

Key words: three-layered particleboards, hardwood face layers, sunflower stalks, the core layer content, mechanical properties.

INTRODUCTION

The primary raw material for producing particleboards is the small-sized and low-quality round wood obtained during logging. The second significant raw material is the wood waste obtained during round wood processing. From the early studies of particleboard production technology (Klauditz, W. 1955; Kollman, F. 1966), it was found that with a decrease in the density of the panels, their mechanical properties deteriorate, and the wood of coniferous and other softwood species is the most suitable for the production of this type of panels (Klauditz, W.; Stegmann, G.1957), (Istek, A.; Siradag, H. 2013). Among the mechanical properties of particleboards, bending strength (MOR) is one of the most important, being strongly affected by the properties of the face layers of three-layer panels (Suzuki, S., K. Takeda, 2000). According to Ghalehno (Ghalehno et al., 2010), the structure of the face layers is most strongly influenced by the size of the wood particles and the wood species used. As the particle size and thickness of the face layer decrease, its compression ratio increases (Medved and Resnik, 2007), resulting in increased density.

Previous studies aimed to change the structure of the core layer to increase its resistance to compression and densification of the face layers to improve the mechanical properties of lightweight panels reported positive results (Benthien et al., 2018). Increasing the particle size in the core layer leads to the increment of compression resistance. Combining the particle sizes of the face and core layers can improve the density profile of the panels. A study (Benthien and Ohlmeyer, 2017) related to the fabrication of lightweight particleboards with different ratios of face-to-core layers found that increasing the proportion of the face layers at the expense of the core layer leads to a minimal effect of reducing the properties of panels as their density decreases.

Increasing the compression resistance of the core layer can be achieved by adding lignocellulosic raw materials. The bulk density of the shredded lignocellulosic residues is lower than that of wood. When forming the mat for the core layer, it will have a greater thickness and, hence, a more significant resistance to compression. Several studies show that using some lignocellulosic residues improves particleboards' mechanical properties and economic indicators (Seng Hua Lee et al., 2022; Klímek, P. 2016). Research by Nikvashet et al. (2010) found that particleboard with a core layer of 50% bagasse particles and 50% hemp shives met the requirements of EN 312-2. The same study found that hemp shives can be used at 100%, and bagasse particles can be up to 35% in the core layer. Research by Guler (Guler, C., 2006) on three layered panels made from mixtures of sunflower stalks and pine particles showed that a combination of 50% Calabrian pine particles and 50% sunflower stalks particles gave the highest values in terms of mechanical properties of particleboard.

Using sunflower stalks in producing particleboards can be an alternative to reduce the amount of wood used (Bekhta, P. et a. 2023). In Bulgaria, the cultivation of sunflower as an oilseed crop is widespread, as our country is one of the largest producers in the European Union and the World (Agrostatistical reference book, 2018), and this is a prerequisite for the availability of a significant raw material base.

In Bulgaria, there is a significant raw material potential for small-sized and lower-quality hardwood. This type of wood cannot be used to produce solid wood materials, and due to the resulting low compression ratio, it is also challenging to use in wood-based panels. However, due to the higher density of the face layers of particleboards, this wood raw material could find application there.

The present study aims to achieve densification of the structure of the face layer of three-layered particleboards, thereby increasing their mechanical properties. That could be achieved by using particles for the face layer of panels- hardwood species − beech and oak, and for the core layer to consist of sunflower particles. That is expected to be achieved using hardwood particles (beech and oak) from softwood and sunflower stalk particles for the face and core layers. The increase of the face layers percentage, composed of particles of oak and beech, is intended to establish the maximum amount of hardwood that can be used without deteriorating the mechanical properties of panels so they could meet the standard requirements.

MATERIALS AND METHODS

The particles for the face layer (beech and oak) were fabricated by crushing industrially produced chips in a hammer mill with a sieve size of 2.0 mm. The particles were then dried to 9.2% moisture content as determined by the weight method (EN 322). Separating particle size fractions was performed with a laboratory screening machine with a sieve size of 2.0 mm to 0.1 mm. The pine particles were obtained after chipping caps and grinding them into particles using a hammer mill. They were separated into fractions, and a 6.0-0.2 mm fraction was taken for the study. Sunflower stalks were supplied by a local farmer (Gorna Oryahovitsa municipality) in a dry state -9.5% water content, then crushed into particles using a hammer mill with sieve holes of 10 mm. Using a laboratory screening machine, the particles were screened and retained on a 1.0 mm sieve and passed through a 6.0 mm sieve.

The industrially produced urea-formaldehyde (UF) resin with the trade name − Sadekol-P410 of Henkel GmbH − Germany was used for the adhesive. Ammonium sulfate (NH_4SO_4) is used as a resin hardener in the core layer at 1.5% relative to the dry resin. In the adhesive system, the hardener is introduced as a solution with a concentration of 20%. The properties of the used UF resin are presented in Table 1.

Table 1: Properties of UF resin

Property	Value
Concentration, %	54±1
Density, kg.m^{-3}	1 220 ÷ 1 240
Dynamic viscosity Pa.s	0.5
Acid factor (pH)	7.5 ÷ 7.8
Gelling time at 100°C, s	50

A laboratory blender was used to mix particles and the UF resin. The pulverisation of the adhesive solution was carried out by spraying through a nozzle with a diameter of 1.5 mm. The content of UF resin in the face layers was 11% and in the core layer 9% relative to the dry particles. For the hot-pressing, a hydraulic laboratory press Manni-S.P.A − In Italy, the PMC ST 100 model was used. The hot-pressing temperature was 180°C and a press factor of 30 s.mm^{-1}. The laboratory panels had a length of 450 mm, a width of 450 mm and a set thickness of 16 mm. The set density was 650 kg.m^{-3}.

The composition of laboratory particleboards is presented in Table 2.

Table 2: Composition of laboratory particleboards

Panel Type	Relative share of face layers, %	Participation of different wood particles in the face layers, %		Relative share of core layer, %	Participation of different particles in the core layer, %		
		hardwood	softwood		softwood	sunflower stalks	hardwood
1	30	100	0	70	100	0	0
2	40	100	0	60	100	0	0
3	50	100	0	50	100	0	0
4	30	100	0	70	70	30	0
5	40	100	0	60	60	40	0
6	50	100	0	50	50	50	0
7 (REF)	30	35	65	70	65	0	35

The fabricated panels were kept for 48 hours in a room with a relative air humidity of 65±5% and a temperature of 20±2°C for air conditioning. Laboratory particleboards were cut into test samples according to the requirements of the EN 326 standard. The bending strength (MOR) and modulus of elasticity (MOE) were determined according to EN 310 standard. The internal bond (IB) strength was determined by the EN 319 standard. The screw withdrawal resistance was determined by EN 320 standard. The mechanical properties of particleboards were determined using 10 test samples. Experimental data were statistically analysed using standard Microsoft STATISTICA 12 software.

RESULTS AND DISCUSSION

For more clarity, the results from the study are presented in tabular and graphic form. Table 3 shows the main requirements for the mechanical properties of particleboards according to the EN 312 standard.

Table 3: Requirements for the minimum mechanical strength of particleboards according to EN 312

Property	Unit	Particleboard thickness >13 to 20 mm		
		Type P2	Type P3	Type P4
Bending strength (MOR) f_m	N.mm^{-2}	11.5	13	15
Modulus of elasticity (MOE) E_m	N.mm^{-2}	1600	2150	2400
Internal bond (IB) strength ft	N.mm^{-2}	0.35	0.35	0.45

The results for the MOR of the panels are presented graphically in Figure 1.

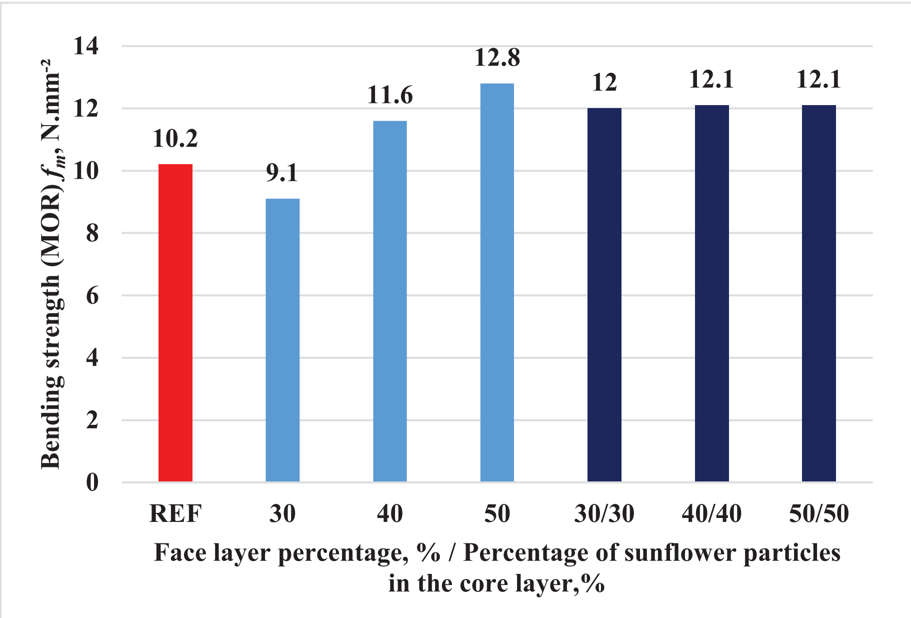


Figure 1: Bending strength (MOR) of the laboratory particleboards

The results presented show that increasing the face layer of oak and beech particles leads to an increase in bending strength. At 40% face layer participation, the MOR exceeds that of the control panel by 13.7%. At 50% face layer, it exceeds by 25.4%. The addition of sunflower stalk particles in the core in amounts of 30% and 40% leads to an increase in the bending strength of the panels, but at 50% participation, a slight decrease is observed. With all three participations of sunflower particles in the core layer, the panels have 20% higher bending strength than the one of the control particleboard.

The results for the modulus of elasticity (MOE) are given in Figure 2.

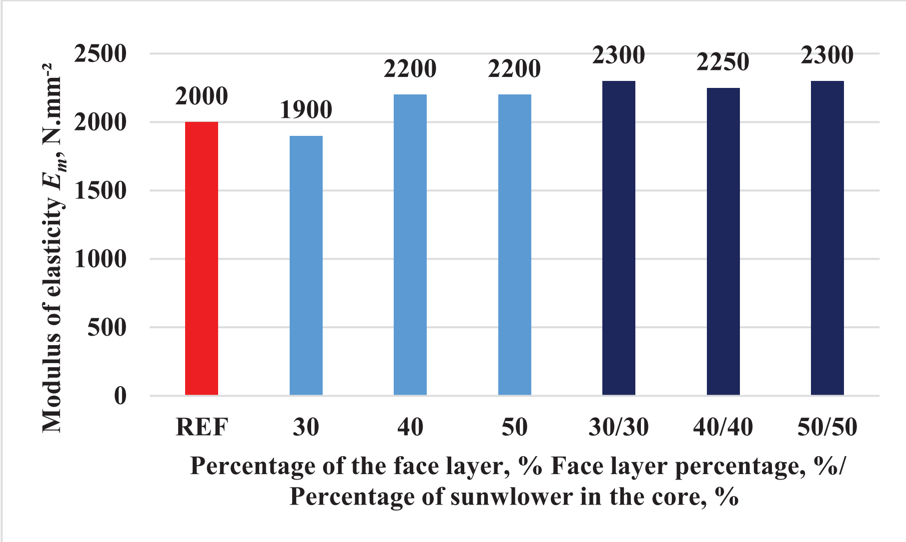


Figure 2: Modulus of elasticity (MOE) of the laboratory particleboards

From the figure presented, it can be seen that the production of a face layer only from hardwood particles leads to an increase in the MOE of the panels, with values corresponding to type P3 particleboards being achieved. In the panels with 40% and 50% participation of the face layer, the identical MOE of 2200 N.mm^{-2} was achieved, and it is 10% more than the standard industrial particleboards. The addition of sunflower particles in the core layer in the amount of 30, 40 and 50% leads to an increase in the modulus of elasticity by 4.5%, compared to the panels with a core layer of softwood particles. The increase in the participation of sunflower particles in the core layer combined with the rise in the share of the face layer of hardwood particles leads to achieving the identical MOE for all three percentage participations.

The results of the conducted research on the IB strength are presented in Figure 3.

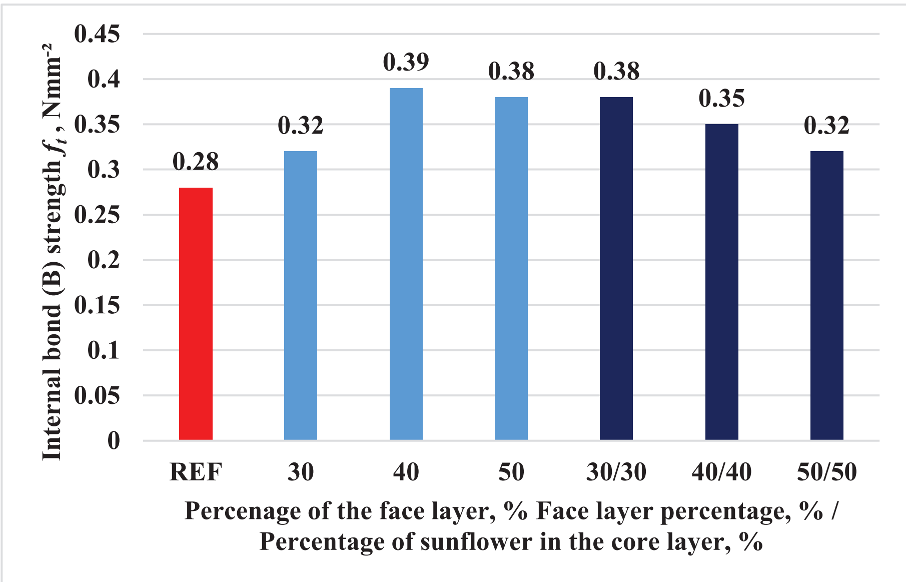


Figure 3: Internal bond (IB) strength of the laboratory particleboards

As the face layer composed of hardwood particles increases from 30 to 50%, the IB strength remains high, approximately 0.39 N.mm^{-2}, thus meeting the requirements for particleboard type P2. The addition of sunflower particles in the core layer degrades the IB strength. The low bulk density of the sunflower particles results in a large volume of particles to which adhesive must be applied, and this leads to a reduction in the adhesive bonds between the particles and, hence, reduced IB strength. Only with a 30% participation of sunflower particles is the requirement of the standard for using the particleboard in furniture production achieved.

In graphic form, the results for screw withdrawal resistance on the edge of the panels are given in Figure 4.

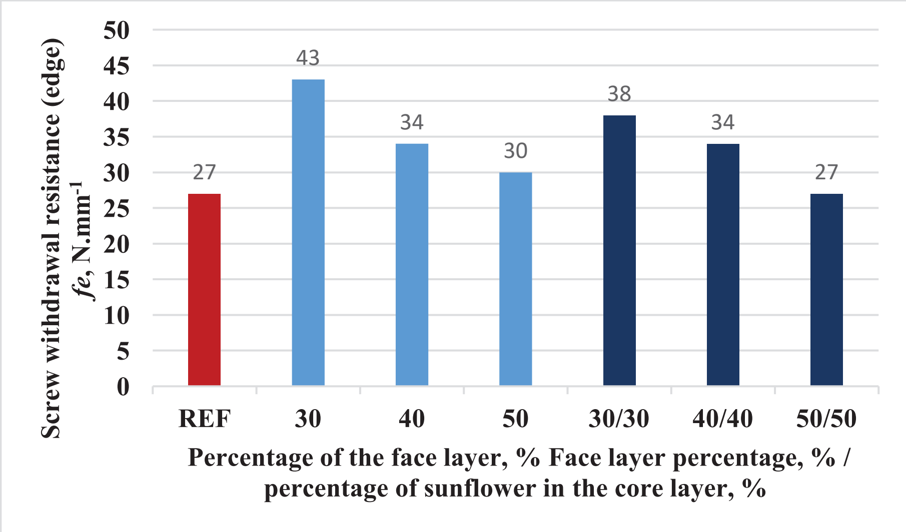


Figure 4: Screw withdrawal resistance (edge) of the laboratory particleboards

The presented results show that with the decrease in the percentage of the core layer, the screw withdrawal resistance in the edging decreases. Whether the core layer consists of softwood particles or a mixture of softwood particles and sunflower ones, the nature of the reduction in screw withdrawal resistance is the same. As the core layer participation decreases from 70% to 50%, its thickness decreases, respectively, fewer particles resist the helix line and fewer adhesive bonds need to be destroyed.

In graphic form, the results for screw withdrawal resistance on the face of the panels are given in Figure 5.

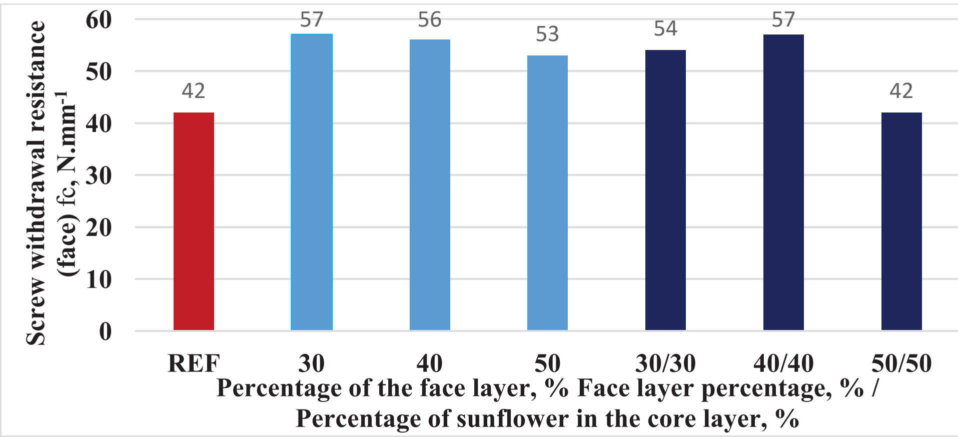
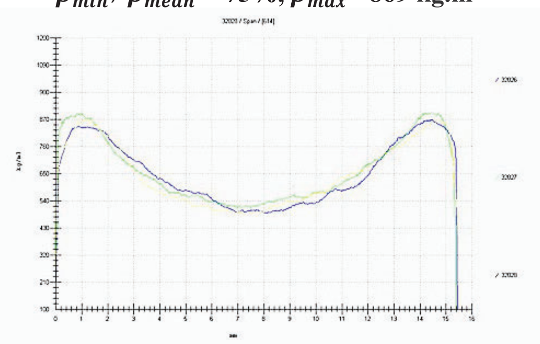


Figure 5: Screw withdrawal resistance (face) of the laboratory particleboards

From the figure, it is clear that when the face layers are composed of beech and oak particles, screw withdrawal resistance in the face increases by 35% compared to the reference panel. But as the face layers increase to 50%, the r screw withdrawal resistance shows a slight drop of 4 $N.mm^{-1}$, possibly dictated by the decreasing core layer, which is also involved in the screw withdrawal resistance. The addition of sunflower particles in the core layer up to 30 and 40% shows that the screw withdrawal resistance is similar to that when there are only pine particles in the core layer. But at 50% sunflower stalk particles participation, there was a drop in screw withdrawal resistance compared to the control panel. That can be explained by the fact that sunflower particles have a lower mechanical strength than pine particles and are torn by the screw when it is removed.

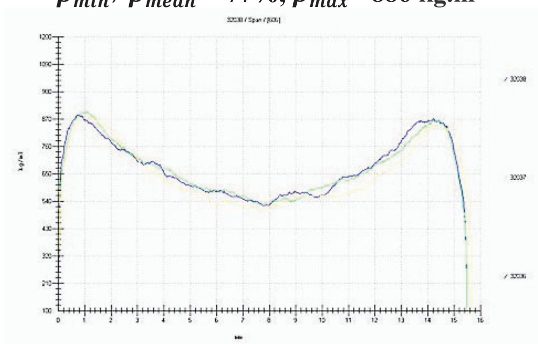
The results of the determined density profile of fabricated particleboards are presented in Figure 6.

ρ_{min} / ρ_{mean} = 75%, ρ_{max}= 869 $kg.m^{-3}$



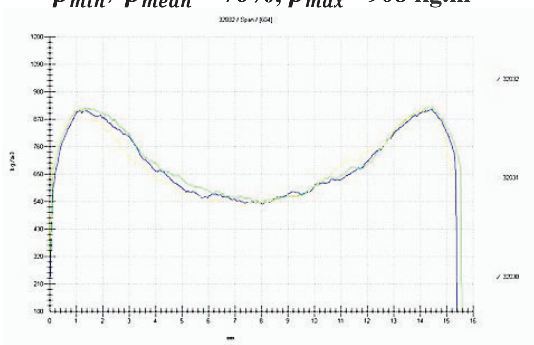
30% face layer from beech and oak particles/core layer from 100% pine particles

ρ_{min} / ρ_{mean} = 77%, ρ_{max}= 886 $kg.m^{-3}$



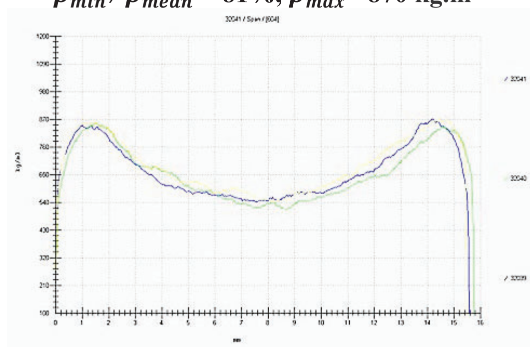
30% face layer from beech and oak /30% sunflower stalks particles in the core layer

ρ_{min} / ρ_{mean} = 76%, ρ_{max}= 908 $kg.m^{-3}$



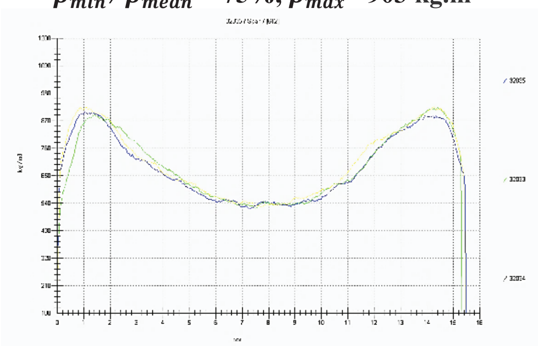
40% face layer from beech and oak particles/core layer from 100% pine particles

ρ_{min} / ρ_{mean} = 81%, ρ_{max}= 870 $kg.m^{-3}$



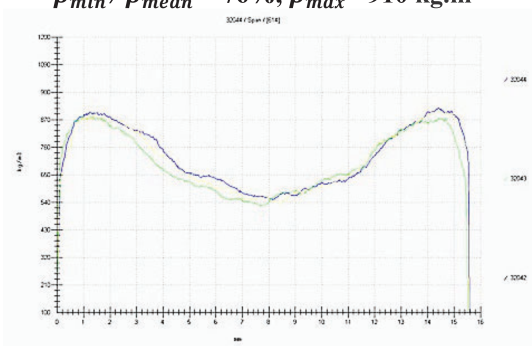
40% face layer from beech and oak /40% sunflower stalks particles in the core layer

ρ_{min} / ρ_{mean} = 75%, ρ_{max}= 903 $kg.m^{-3}$



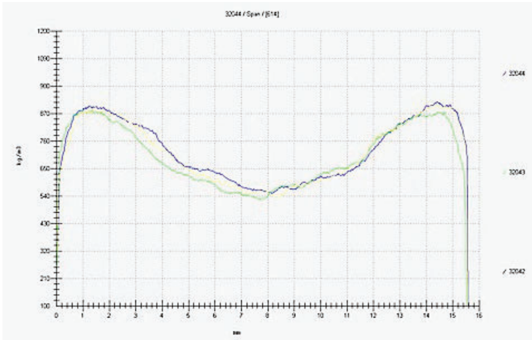
50% face layer from beech and oak particles/core layer from 100% pine particles

ρ_{min} / ρ_{mean} = 76%, ρ_{max}= 910 $kg.m^{-3}$



50% face layer from beech and oak /50% sunflower stalks particles in the core layer

ρ_{min} / ρ_{mean} = 76%, ρ_{max}= 996 $kg.m^{-3}$



Control particleboard

Figure 6: Density profile of the laboratory particleboards

For all panels, the ratio – ρ_{min}/ρ_{mean} is in the 76% range. On all particleboards, the minimum density – ρ_{min} in the core layer is about 540 kg.m^{-3}. This density corresponds to the density of pine wood, which is a prerequisite for the particles to transfer their mechanical strength to the panels to the maximum extent. Densities of 869 to 910 kg.m^{-3} were achieved in the face layers. That leads to the densification of the face layer of beech and oak particles to densities equal to and greater than the density of the wood from which the particles are made, and the oak and beech particles transfer their high mechanical strength to the face layer of the three-layer particleboards, which is evident from the presented results for the mechanical strength of the laboratory panels.

CONCLUSIONS

The research proves that producing three-layer particleboards with face layers made from beech and oak particles increases their mechanical properties.

It was found that increasing the participation of face layers from 30% to 50% leads to a significant increase in the mechanical strength of particleboards. That enables the face layer to be compressed to a density exceeding that of beech and oak wood. On the other hand, the core layer consisted only of pine wood particles, which are also compacted to a density close to or exceeding that of the wood from which they were made. The decrease in the percentage of the core layer (respectively, its thickness) reduces the screw withdrawal resistance of the edge. That could be compensated by changing the shape and size of the particles of which it is composed. The introduction of sunflower particles in the core layer in an amount of up to 50% can replace softwood without reducing the bending strength and modulus of elasticity of the panels. Sunflower particles have a negative effect on the IB strength of the panels when their amount starts to exceed 40% of the core layer.

The study shows that it is possible to achieve an increase in the amount of hardwood (beech and oak) in medium-weight particleboards (ρ = 650 kg.m^{-3}) up to 50% and also to achieve a reduction in the amount of use of softwood up to 30% of the total amount, by introducing sunflower particles.

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