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The influence of the structure of three-layer particle boards on the thickness and density of surface layer

Utjecaj strukture troslojne iverne ploče na gustoću i debljinu vanjskog sloja

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SUMMARY • *In this research the influence of the structure of surface layer on the density and thickness of surface layer of three-layer particleboard was examined. Four wood species (spruce, beech, oak and poplar) and their mixture were used to evaluate their influence. The structure of wood particles with regard to wood species was altered only in the surface layer, while its composition in the core layer remained unchanged. For particleboard manufacturing urea-formaldehyde resin was used. The thickness, length, slenderness ratio and specific surface of particle used were determined by using the image analysis and the absorption method. Vertical density distribution was determined by using device for vertical density distribution measurement. From the data obtained by this device, the thickness and density of surface layer was determined.*

Particle geometry is strongly influenced by density of wood species used. Spruce wood particles are the thinnest with the highest slenderness ratio and specific surface area. Among the wood of deciduous trees, poplar particles are the thinnest; those of oak are a bit thicker, and particles of beech are the thickest. Slenderness ratio and specific surface area are smaller when using thicker wood particles.

Wood species used in the surface layer strongly influence the thickness and density of surface

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layer. By increasing the share of spruce, oak and poplar particles the thickness of surface layer decreases while with increasing the share of beech particles the thickness increases. By decreasing the share of beech particles the density of surface layer increases, while with decreasing the share of spruce, oak and poplar the density of surface layer decreases.

Increasing of thickness of the surface layer leads to a decrease of thickness of the core layer. If the surface layer is thinner, its density is higher.

Key words: *particleboard, spruce, beech, oak, poplar, surface layer, core layer, particle geometry, vertical density distribution, layer thickness, layer density.*

SAŽETAK • *U istraživanju je proučavan utjecaj strukture površinskog sloja na gustoću i debljinu toga sloja kod troslojnih ploča iverica. Ispitan je utjecaj četiriju vrsta drva (smrekovina, bukovina, hrastovina i topolovina) i njihovih mješavina. Struktura drvnog iverja s obzirom na vrstu drva je mijenjana samo u površinskom sloju, dok je sastav iverja srednjeg sloja ostao isti. Za izradu (pokusnih) ploča je primijenjeno urea – formaldehidno ljepilo. Metode slikovne analize i apsorpcijske tehnike su uporabljene za određivanje debljine, dužine, specifične površine iverja i njegovog koeficijenta vitkosti.*

Geometrija iverja je jako uvjetovana gustoćom vrste drva. Smrekovo iverje je najtanje i ima najveći koeficijent vitkosti i specifičnu površinu. Među listačama je iverje topolovine najtanje, hrastovo je nešto deblje, a bukovo iverje je najdeblje. Koeficijent vitkosti i specifična površina su tim manji što je iverje deblje.

Izbor vrste drva za površinski sloj bitno utvrđuje njegovu debljinu i gustoću. Povećanjem udjela smrekovog, hrastovog i topolovog iverja u površinskom sloju raste i njegova gustoća, a smanjuje se debljina. Obrnuto vrijedi za učešće bukovog iverja.

Povećanje debljine površinskog sloja dovodi do smanjenja debljine srednjeg sloja. Što je površinski sloj tanji, to mu je veća gustoća.

Ključne riječi: *iverice, smrekovina, bukovina, hrastovina, topolovina, vanjski sloj, srednji sloj, geometrija ivera, debljinska razdioba gustoće, debljina sloja, gustoća sloja.*

1. INTRODUCTION
1. UVOD

The structure of surface layer with regard to the wood species used is a very important factor. The composition is important not only with regard to the mechanical and physical properties but also with regard to thickness and density of the entire board and of each individual layer. Particles from different wood species are characterized by different geometry and different compressibility. Thus, already Mainecke and Klauditz (1962), Neusser et al. (1969), Grigoriou (1981), May (1982, 1983a, 1983b, 1983c, 1983d), Niemz and Wenk (1989), Niemz & Fuchs (1990) and Plinke (1998) found that particles from wood species with lower density are thinner and have a higher slenderness ratio and specific surface area. Particles from wood species with a higher specific surface area are also more compressible, which results in thinner boards with greater density. When using wood species with a lower density, board density is higher. Core layer is also influenced by the structure of surface layer. Hänsel et al. (1988) consider that the increasing of the ratio between wood particles thickness in core and surface layers also leads to an increase in the counterforce in core layer, and this leads to a greater compression of the surface layer after the opening of the press and to an increase in core layer thickness and a decrease in thickness and increase in density of the surface layer.

2. METHOD OF WORK
2. METODA RADA

For particleboard manufacturing particles of four wood species: spruce (*Picea abies Karst. L.*), beech (*Fagus silvatica L.*), oak (*Quercus robur L.*), and poplar (*Populus nigra L.*) and their mixtures (Table 1) were

Variant Varijanta	Surface layer Vanjski sloj			
	Spruce Smreka (Sp)	Beech Bukva (Be)	Oak Hrast (Oa)	Poplar Topola (Po)
	%	%	%	%
V_1	100	0	0	0
V_2	0	100	0	0
V_3	0	0	100	0
V_4	0	0	0	100
V_5	50	50	0	0
V_6	50	0	50	0
V_7	50	0	0	50
V_8	0	50	50	0
V_9	0	50	0	50
V_{10}	0	0	50	50
V_{11}	0	33	33	33
V_{12}	33	0	33	33
V_{13}	33	33	0	33
V_{14}	33	33	33	0
V_{15}	25	25	25	25

Table 1
Structure of the surface layers of test boards according to wood species used • Sastav vanjskih slojeva probnih ploča s obzirom na upotrijebljenu vrstu drva

used in the surface layer.

For the core layer we used wood particles with the following structure: 77% of wood particles of spruce, 1% of other coniferous trees, 7% of beech, 2% of oak and 13% of other deciduous trees.

For particleboard manufacture urea formaldehyde adhesive was used to which paraffin emulsion was added as hydrophobic agent. Gluing factor in surface layer was 11,5 and in core layer 7,5%. In core and surface layer 1% paraffin emulsion was added. Particle humidity after gluing was approximately 8,7% in core layer and 12,5% in surface layer. Pressing temperature was 180°C. Pressing time was 4 minutes.

Specific surface area of the particles used was determined by the image analysis and absorption method.

2.1. IMAGE ANALYSIS OF PARTICLES
2.1. SLIKOVNA ANALIZA IVERJA

Image analysing of particles was carried out by means of a microscope. Particle thickness and length were measured for each fraction separately. The share of individual fraction in the surface layer is shown in Figure 1.

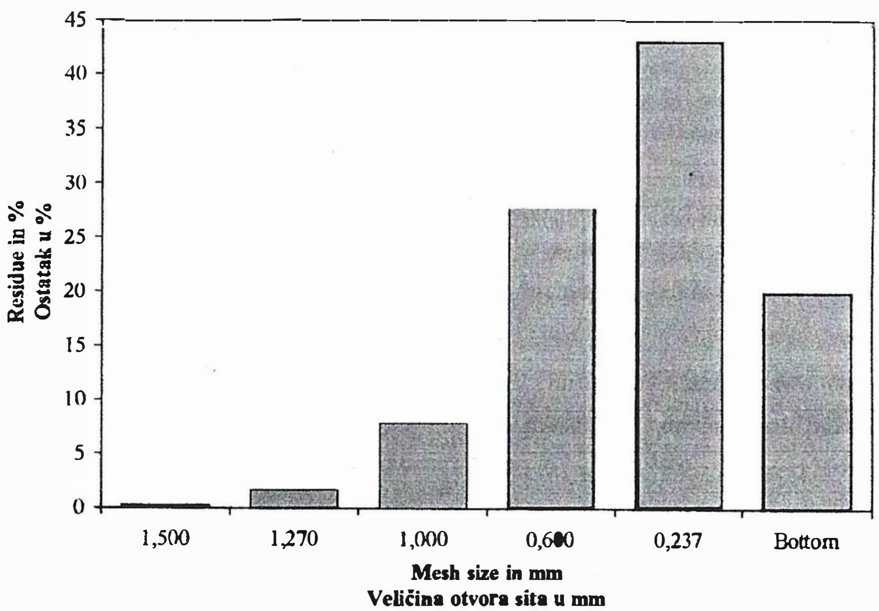


Figure 1
A share of individual fraction in the particle structure for surface layer • Udio pojedine frakcije u sastavu iverja za vanjski sloj

100 g of particles of individual fraction were divided by cross method into 4 parts. From each part five wood particles were randomly selected – giving a total of 20 particles for individual fraction (120 particles total for one wood species). The particles selected were then placed under a microscope. The images of particles projected on the eyepiece were used to measure the particle thickness and length.

On the basis of the data so obtained, specific surface area and slenderness ratio of particles were calculated. This method enabled the calculation of only the external surface area of wood particles. Absorption method, on the other hand, enabled information concerning the total (external plus internal) wood particle surface area. Namely, at the pressure above 0.1 MPa nearly all pores are filled with absorption gas (nitrogen). The external surface area of wood particles $A_{s\text{-}ext}$ in $m^2/100$ g was calculated by using the following formula:

$$A_S = \frac{0,2}{t \cdot \rho_0}$$

Where:

t - wood particle thickness in mm

ρ_0 - density of absolutely dry wood particles in g/cm^3

If in addition to thickness, wood particle length is also measured, slenderness ratio of particles can also be calculated. Slenderness ratio in mm/mm is calculated by using the formula:

$$\lambda = \frac{b_l}{t}$$

Where:

b_l - wood particle length in mm

t - wood particle thickness in mm

On the basis of the share of individual fraction in the structure of particles used for surface layer average thickness, length, slenderness ratio and their specific surface area of them were calculated according to the following formula:

$$X_i = \sum \omega_j \cdot x_j$$

Where:

X_i - characteristic of particles of a particular wood species, with i standing for spruce, beech, oak or poplar

3_j - share of each individual fraction in the composition of wood particles used for surface layer

x_j - characteristic of wood particles (t, b_l, , A_s)

j - mesh size

2.2. ABSORPTION METHOD FOR DETERMINATION OF PARTICLE SURFACE AREA
2.2. ABSORPCIJSKA METODA ODREĐIVANJA SPECIFIČNE POVRŠINE IVERJA

The determination of particle surface area by the absorption method was carried out on GEMINI 2360 device in the Austrian company SY-LAB. The absorption method is based on the absorption of a gas (nitrogen was used) into the surface and into pores of particles, that is, not only into the external surface as seen with the eyes but also into internal surface. Before carrying out the measurement of specific surface area of particles, samples were dried for 4 hours at the temperature of 90°C. The apparatus for surface area measurement (GEMINI 2360) consists of two systems. One system is the so–called sample system and the other is the so--called equalising system. The systems are connected, as shown in Figure 2, and also connected to a gas accelerator, which is used for the analysis. Gas flow rate is controlled on the basis of the gas quantity absorbed by the sample.

The equalising system and the sample system are exposed to the identical conditions, which are ensured by a system of equalising valves. In a chamber with constant temperature there are two reservoirs (A), one for the equalising and one for system with a sample, and each is filled with an identical volume of gas for the sample analysis. The equalising of gas volume and pressure in the reservoirs is achieved with volume transducer (F) located between the two reservoirs. From the tanks, gas flows through the equalising tube and the test tube containing the sample. The required pressure in the test tube with the sample is controlled through a pressure transducer (B). The absorption of gas by the sample leads to a pressure drop in the tube. The pressure in the tube is controlled by the equalising valve C and in the equalising tube by the equalising valve E. The pressure difference in the tubes is equalised by means of an equalising pressure transducer D (GEMINI - Analysis technique...1998).

Specific surface area of particles is calculated by using the multipoint BET gas absorption method (as reported by BRUNAUER, EMMETT & TELLER; GEMINI - Analysis technique...1998).

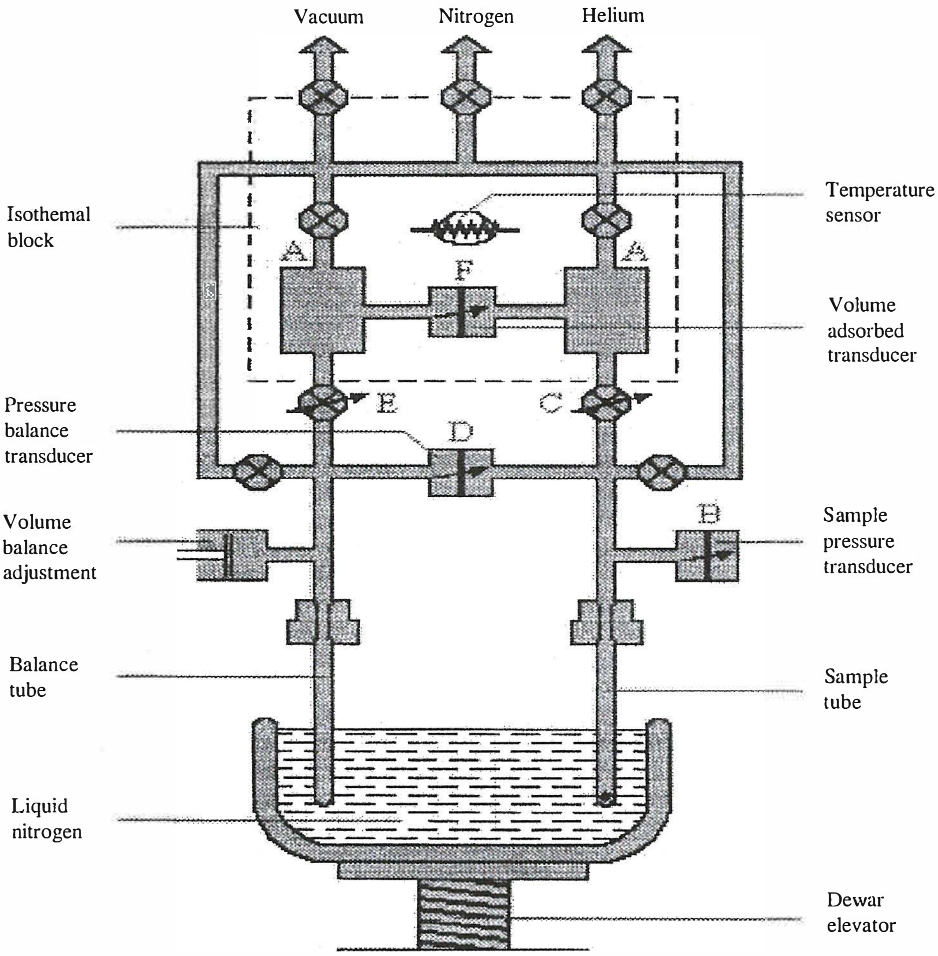


Figure 2
Schematic diagram of the device for the determination of specific surface area - GEMINI 2360 • Shematski prikaz uređaja za određivanje specifične površine (GEMINI - Analysis technique...1998)

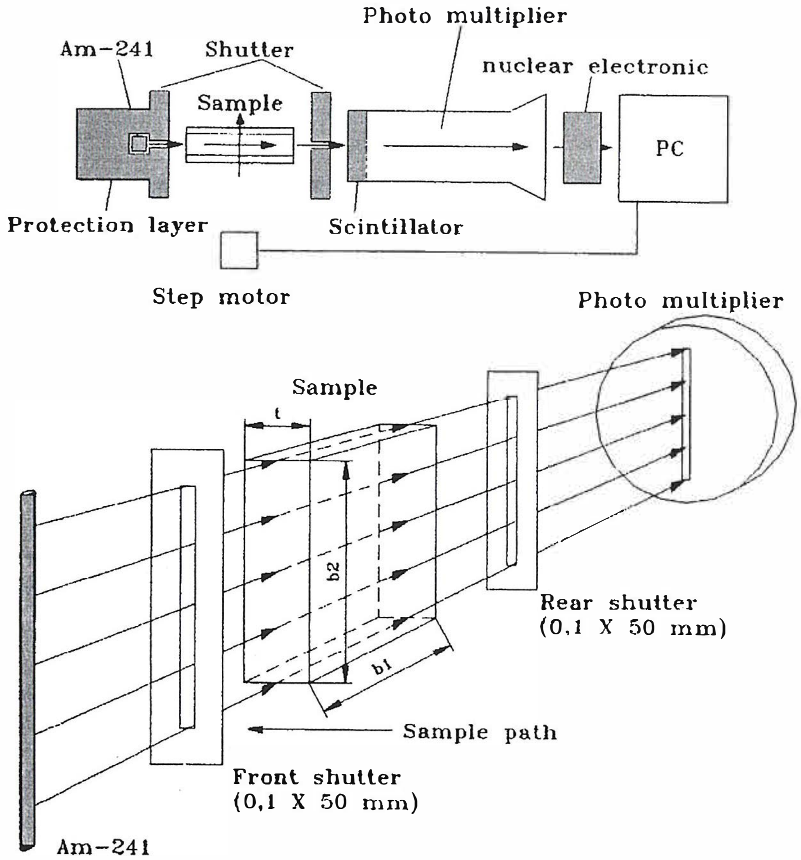
2.3. DETERMINATION OF VERTICAL DISTRIBUTION OF DENSITY
2.3. ODREĐIVANJE DEBLJINSKE RAZDIOBE GUSTOĆE PLOČA

To determine the thickness and density of external layer, we used a vertical density distribution (hereinafter: VDD) determination device, which is based on the measurement of a change in the intensity of gamma rays passing through a particleboard sample. The measuring apparatus is the result of the co–operation between the Department of Wood Science and Technology, AMES, and JOŽEF STEFAN INSTITUTE in the research project »Development of density profiles measuring apparatus«. As a radiating source, the radioactive isotope of Am-241 with gamma ray power 60 keV and activity 3.7 GBq is used. The apparatus can hold 12 samples with the total thickness of up to 300 mm. Sample height may not be less that 50 mm and not more than 60 mm, while the sample width may vary between 0.1 and 60 mm. The table travels at the speed of 0.1 mm/sec (in one second, the intensity of the rays passing through the sample is measured in a band of b_1 in length, b_2 in width and 0.1 mm thick).

Radiating source is enclosed in lead sheathing which is in the direction towards the sample and the photo multiplier provided with slots 0.1 mm wide and 50 mm high. In front of the slot there is a shutter that makes it impossible for radiation to escape into the environment whenever measurements are not carried out. The layout of individual components of the measuring apparatus is shown schematically in Figure 3. At the start of the measurements, the shutter opens. Rays pass through the sample and then through the photo multiplier with the scintillator. The photo multiplier is connected to the scintillator in which photons (gamma rays) trigger light flashes (scintillations). A photo cathode located in the photo multiplier in which they are multiplied so as to form an electron avalanche detects the resulting scintillations. The signals from the photo multiplier are processed by means of nuclear electronic equipment and stored in PC for further use.

On the basis of the number of pulses per unit of time (intensity of passage through air) and the number of pulses recorded after the absorption of gamma rays (intensity of passage through the sample), it is possible to calculate density in 0.1 mm thick sample section $\rho_{section}$ in g/cm^3 according to the formula:

Figure 3
Schematic diagram of MGP-201 density profile measuring device • Shematski prikaz uređaja za određivanje profila gustoće MGP–201



$$\rho_{section} = \frac{\ln\left(\frac{I - I_B}{I_0 - I_B}\right)}{\mu \cdot t_{section}}$$

Where:

I - radiation intensity after the passage through the sample

I_0 - radiation intensity after the passage through air

I_B - radiation intensity after the passage through metal (background)

μ - mass attenuation coefficient (cm^2/g) for the variant selected

$t_{section}$ - section thickness in cm (0.01 cm)

The entire VDD* for the samples is obtained by a sequence of measurements at individual sections $t_{section}$. To determine the thickness, density and thickness swelling of individual layers, samples of the size 50'50 mm were used.

2.4. DETERMINATION OF THICKNESS OF EXTERNAL LAYER
2.4. ODREĐIVANJE DEBLJINE VANJSKOG SLOJA

Manufactured particleboards consisted of three layers – two surface layers and a core layer. The Core layer presents 60% and the surface layers 40% of the weight of wood particles. With the device for measuring VDD* we obtained information about the VDD of samples. On the basis of dimensions and density values of each individual section, the weight of each section was calculated. Individual section was 0.1 mm thick, while the section width and length were assumed to be the same as the sample width and length. Section weight $m_{section}$. in grams was calculated by using the formula:

Where:

$\rho_{section}$ - section density in g/cm^3

$t_{section}$ - section thickness in mm ($t_{section}$ = 0.1 mm)

b_1 - width of section or sample

b_2 - length of section or sample

$$m_{section} = \rho_{section} \cdot t_{section} \cdot b_1 \cdot b_2$$

Just as after the gluing of particles, the ratio between surface and core layers remained approximately the same, it was for the purpose of calculating the weight of surface layer assumed that it comprised 20% of the sample weight. The weight of one surface layer m_{SL} in grams was calculated by means of the formula:

$$m_{SL} = m \cdot 20\%$$

Where:

m - sample weight in grams

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* Vertical density distribution

By adding together the weights of individual sections, the weight of the surface layer was obtained. The number of sections necessary to reach the desired weight represented the thickness of the surface layer.

3. RESULTS AND DISCUSSION
3. REZULTATI I DISKUSIJA

Thickness of particles and characteristics relating thereto (specific surface area, slenderness ratio) strongly depend on the density of wood species used. Increasing the density decreases the thickness, the slenderness ratio and the specific surface area (see Table 2 and Figure 4).

No differences were found between thickness and density values of boards, at least if comparing the values for the entire board (Table 3). Differences regarding the thickness and density of surface layer, however, are higher.

As boards are not of identical structure in the surface layer (core layer is identical for all variants), we can see that differences in thickness and density of individual layer are due to the influence of surface layer and to the wood particles used in the surface layer (Figure 4).

Great differences can be seen in the area of surface layer. When using beech wood particles, the density of surface layer is low, while that of core layer is slightly higher than in the other variants (see also Table 3).

When comparing the data of thickness of particles used and the surface layer thickness and density, we found that the surface layer thickness increases with increasing par-

Table 2
Thickness, length, slenderness ratio and specific surface area of particles with regard to wood species used • Debljina, duljina, koeficijenat vitkosti i specifična površina iverja s obzirom na upotrijebljenu vrstu drva

Properties Svojstva	Spruce Smreka	Beech Bukva	Oak Hrast	Poplar Topola
particle thickness in mm **debljina iveri in mm**	0'35	0'44	0'40	0'36
particle length in mm **duljina in mm**	2'02	1'91	1'99	2'00
exterior specific surface area in m²/100 g⁺ **vanjska specifička površina u m²/100 g**	3'49	2'46	2'48	2'65
total specific surface area in m²/100 g⁺⁺ **ukupna specifička površina u m²/100 g**	65'00	51'00	57'00	68'00
slenderness ratio in mm/mm **koeficijent vitkosti u mm/mm**	6'64	4'81	5'30	6'15

+ Data obnained by using image analysis
++ Data obnained by using absorption method

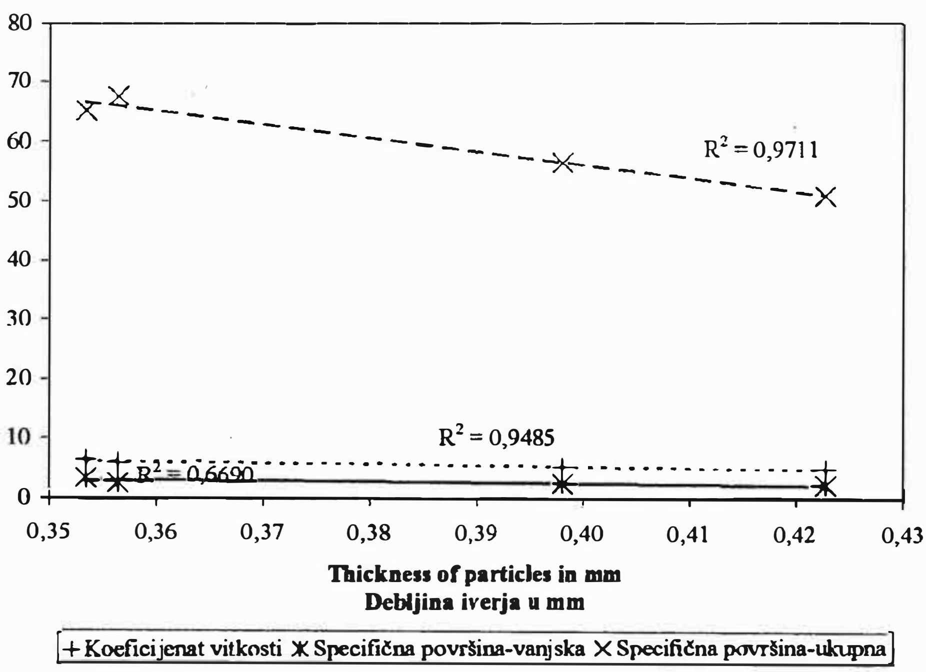


Figure 4
Dependence of slenderness ratio (mm/mm), external specific surface area (m^2/100 g) and total specific surface area (m^2/100 g) on wood particle thickness • Ovisnost koeficijenta vitkosti (mm/mm), vanjske specifične površine (m^2/100 g) i ukupne specifične površine (m^2/100 g) o debljini iverja

Table 3
Density and thickness values of experimental boards • Podaci o gustoći i debeljini slojeva pokusnih ploča

Structure of surface layer Struktura vanjskog sloja	Total Ukupno		Surface layer Vanjski sloj		Core layer Srednji sloj	
	Thickness Debljina	Density Gustoća	Thickness Debljina	Density Gustoća	Thickness Debljina	Density Gustoća
	mm	g/cm³	mm	g/cm³	mm	g/cm³
Sp *	16,24	0,661	5,25	0,915	11,00	0,655
Be**	16,24	0,671	5,68	0,829	10,56	0,677
Oa ***	16,10	0,668	5,33	0,900	10,77	0,654
Po****	16,19	0,666	5,26	0,900	10,93	0,648
Sp, Be	16,26	0,671	5,56	0,863	10,71	0,660
Sp, Oa	16,22	0,667	5,34	0,891	10,88	0,648
Sp, Po	16,28	0,671	5,26	0,917	11,02	0,646
Be, Oa	16,18	0,664	5,56	0,858	10,62	0,667
Be, Po	16,23	0,657	5,48	0,879	10,75	0,667
Oa, Po	16,20	0,660	5,37	0,905	10,84	0,662
Be, Oa, Po	16,17	0,665	5,42	0,870	10,75	0,648
Sp, Oa, Po	16,19	0,680	5,30	0,903	10,90	0,655
Sp, Be, Po	16,24	0,666	5,38	0,869	10,86	0,643
Sp, Be, Oa	16,23	0,667	5,41	0,891	10,82	0,660
Sp, Be, Oa, Po	16,27	0,660	5,39	0,885	10,88	0,655

*Spruce **Beech ***Oak ****Poplar

Figure 5
Vertical density distribution with regard to the wood species used in surface layer • Debljinska razdioba gustoće ploča s obzirom na upotrijebljenu vrstu drva u vanjskom sloju

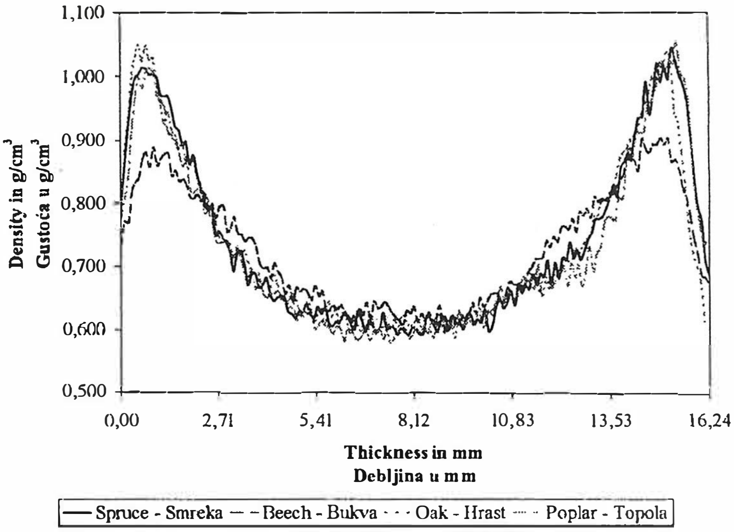
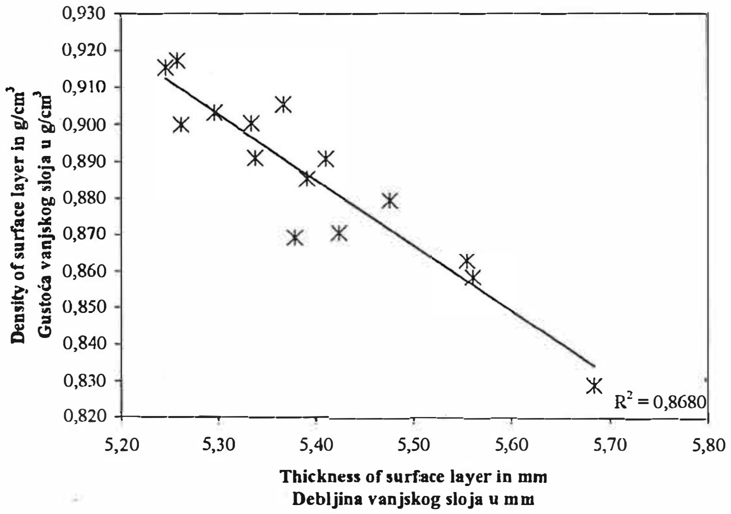


Figure 6
Dependence of surface layer density on surface layer thickness • Ovisnost gustoće vanjskoga sloja o njegovoj debljini



ticle thickness and that surface layer density decreases. The influence of wood species used in surface layer on core layer thickness is obvious. When using thinner wood particles for surface layer, the ratio between thickness of particles for core and surface layer is higher. At identical weight, thinner particles take less space, which is why thickness of surface layer is smaller. As thinner particles are more compressible than the thicker particles, the density of surface layer is higher when using thinner particles. Thus, the density of surface layer increases with decreasing thickness of surface layer (Figure 6). When using thinner particles, the possibility of development of cavities is smaller than when using thicker wood particles.

Thinner and more compressible particles were obtained from wood species with lower density, which is why in studying the influence on thickness and density one should not forget to take into consideration wood species. Figures 7 and 8 show the data about thickness and density of layers with regard to the structure of external layer.

Because of greater compressibility of particles in the surface layer, a smaller compression was observed in core layer when thinner wood particles were used. As already mentioned, the influence of wood species used in surface layer on the thickness and density of core layer is obvious. The increasing of thickness of surface layer the thickness of core layer decreases and the density increases. When using thinner particles for surface layer, the ratio between the thickness of particles for core and external layers is higher. With a higher ratio, there is also a higher counterforce in the core layer, and when the press is opened, this leads to a higher compression of both surface layers, and this increases the thickness of core layer

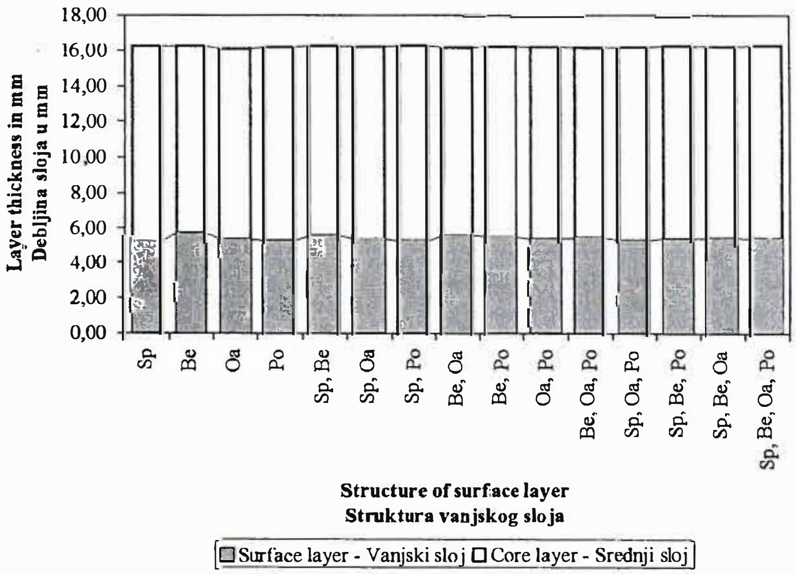


Figure 7
Thickness of layers with regard to the structure of surface layer • Debljina sloja s obzirom na sastav vanjskog sloja

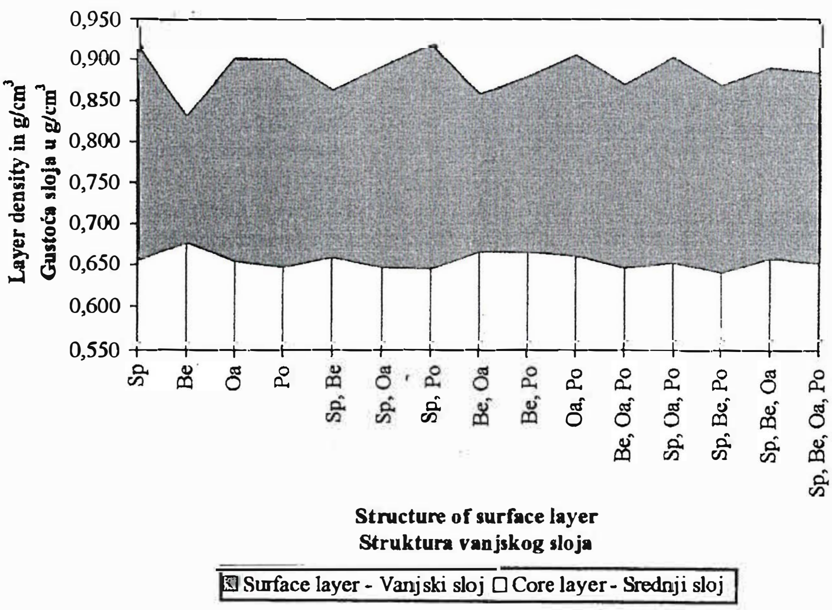


Figure 8
Density of layers with regard to the structure of surface layer • Gustoća slojeva s obzirom na strukturu vanjskog sloja

and decreases the thickness and increases the density of surface layer.

Although there is a close correlation between compressibility and geometry of particles, in addition to these two factors the other factors such as wood anatomy should also be taken into consideration. The influence of wood anatomy here refers primarily to the cell wall thickness and lumen size. The thinner the wall and the greater the lumens are, the easier it will be to compress wood (particles), and this will lead to a greater density and a smaller thickness of the layer (spruce, poplar).

4. CONCLUSION
4. ZAKLJUČAK

It was found that the wood species used in the surface layer has an influence both on the thickness and density of the surface layer. When using particles from wood species with lower density, the thickness of the surface layer will decrease and the density will increase.

Increasing the share of spruce particles will decrease the surface layer thickness and increase the density of it. When only spruce particles were used, the thinnest surface layers and the highest density of it were obtained.

Increasing the share of beech particles leads to increases of the surface layer thickness and to decreases of density of the surface layer. When only beech particles were used, thicker surface layer and lowest density of it were obtained.

With increasing a share of oak and poplar particles the surface layer thickness decreases and the density of it increases. The influence of poplar is higher than that of oak.

Wood species used in surface layer also influences core layer thickness and density. The use of wood species with a lower density (spruce, poplar) results in a thicker less dense core layer than when using wood particles of wood species with a high density (oak, beech).

5. LITERATURE
5. LITERATURA

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