Sergej Medved[1], Alan Antonović[2], Vladimir Jambreković[2]

Impact of Resin Content on Swelling Pressure of Three Layer Particleboard Bonded with Urea-Formaldehyde Adhesive

Utjecaj sadržaja smole na tlak bubrenja troslojne ploče iverice vezane urea-formaldehidnim ljepilom

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 27. 7. 2010.
Accepted – prihvaćeno: 25. 2. 2011.
*UDK: 630*863.21*
doi:10.5552/drind.2011.1025

ABSTRACT • *When particleboards are exposed to water or moist environment, they tend to swell and expand in all directions. The degree of swelling or expansion depends on the type of adhesive used, its share, and the time of exposure and pressure used at hot pressing. The expansion of particleboard, exposed to water or high moisture content, is accompanied by swelling and/or expansion pressure. The purpose of this paper is to present the impact of adhesive share on thickness swelling and swelling pressure of three layer particleboard bonded with urea-formaldehyde adhesive. The resin content was altered in both layers; in core layer it was between 6 and 9 %, and in surface layer between 11 and 13 %. Thickness swelling and swelling pressure were determined with 24-hour immersion test. For the swelling pressure measurement, special force gauge device was used. The biggest changes in swelling and pressure were observed when the resin content was changed in core layer. The fastest change in swelling and swelling pressure was observed in the first few hours after immersion in water.*

Keywords: *particleboards, resin content, swelling, swelling pressure*

SAŽETAK • *Ploče iverice teže bubrenju i povećanju dimenzija u svim smjerovima kada su izložene vodi ili vlažnom okruženju. Stupanj bubrenja ili povećanja ovisi o vrsti korištenog ljepila, njegovu udjelu te vremenu izlaganja i korištenom tlaku pri vrućem prešanju. Uz povećanje dimenzija ploča iverica izloženih vodi ili visokom sadržaju vlage javlja se i bubrenje i/ili povećanje tlaka. Svrha ovog rada jest prikazati utjecaj udjela ljepila na bubrenje u debljinu i tlak bubrenja troslojnih ploča iverica vezanih urea-formaldehidnom smolom. Sadržaj UF smole u oba je sloja promijenjen; u srednjem sloju bio je 6-9 %, a u vanjskom sloju 11-13 %. Bubrenje u debljinu i tlak bubrenja određeni su testom uranjanja tijekom 24 sata. Za mjerenje tlaka bubrenja upotrijebljen je uređaj za određivanje specifične sile. Najveće promjene u bubrenju i tlaku zabilježene su pri promjeni sadržaja smole u vanjskom sloju ploča iverica. Nadalje, najveće promjene pri bubrenju i tlaku bubrenja zabilježene su tijekom prvih nekoliko sati nakon uranjanja u vodu.*

Ključne riječi: *ploča iverica, sadržaj smole, bubrenje, tlak bubrenja*

[1] The author is assistant professor at Department of Wood Science and Technology, Biotechnical Faculty, University of Ljubljana, Slovenia. [2] The authors are assistant professor and associate professor at Department of Wood Technology, Faculty of Forestry, University of Zagreb, Croatia.

[1] Autor je docent Biotehničkog fakulteta Sveučilišta u Ljubljani, Slovenija. [2] Autori su, redom, docent i izvanredni profesor Šumarskog fakulteta Sveučilišta u Zagrebu, Hrvatska.

1 INTRODUCTION
1. UVOD

Particleboards are an important segment of the wood-based industry, especially in furniture industry. Their production and consumption increases from year to year. However, the use of particleboards in a humid environment, especially those bonded with urea-formaldehyde (UF) adhesive, is often limited, because of it hygroscopic nature, caused by wood (reversible swelling), pressing conditions (irreversible swelling) and also by adhesive used. This undesirable phenomenon is estimated by means of factors such as thickness swelling and water absorption. These factors are not the only changes that occur due to wood–water interaction. The interaction between water (moisture) and particleboard wood leads to the development of swelling stresses that cause the "separation" of the particles within the panel and hence the failure of the resin bond between particles.

According to Klauditz (1956) the thickness swelling is caused by pressed particles (wood) that tend to return to their position prior to pressing.

Tarkov and Turner (1958) determined that swelling stresses occur when water vapour diffuses into cell walls and micro. They determined that when compressed wood, conditioned to 30% relative humidity, is exposed to a saturated environment (room temperature), the swelling pressure increases with the increasing densification of the wood.

Perkitny and Helinska (1963) investigated the development and relaxation of stresses in wood. They determined that swelling was almost 40% greater when wood was exposed to water vapour compared to the results achieved when wood was immersed in water.

Stegmann and Kratz (1967) research the impact of density and resin content on thickness swelling of UF bonded particleboard. They determined that thickness swelling increased with increasing density, while it decreases with increasing resin content. They also determined that changes in density influences thickness swelling more than changes in resin content.

When solid wood or wood–based panels are exposed to water, moisture gain can occur, primarily, by two mechanisms. The first mechanism is liquid water transport, which is generally described by Darcy's law directly or indirectly. The second mechanism is diffusion (Fick's law). Diffusion normally occurs where the void spaces are small. When water vapour diffuses into cell wall and micro voids, it causes the movement or dislocation of tissue–fibre, which causes the development of swelling pressure (Skaar, 1988).

Niemz and Steinmetzler (1992) researched the impact of density and thickness swelling on swelling stress. They determined that swelling stress increased with increasing thickness swelling, which was more evident with boards with higher density.

Schneider *et al* (1996) researched the relationship between swelling and the type of resin used and resin content. They determined that thickness swelling and water absorption decreased with increasing resin content.

Swelling stresses depend upon the swelling itself, and upon the density of the material. Increase in swelling stresses with increasing swelling is more evident when dense materials are used (Niemz and Steinmetzler, 1992).

The influencing factors were also discussed by Jambreković (1996) and Jambreković et al. (1998). It was determined that increased share of wax emulsion decreases thickness swelling.

In the case of wood–based panels exposed to liquid water and/or water vapour, failure of the resin bond occurs mainly due to the development of swelling stresses (Rice and Wang, 2002). These authors researched the development of swelling stresses using a non-destructive method (measurements of acoustic emission). They found that the failure of the resin bond and the dislocation of fibres are accompanied by acoustic emission. The number of acoustic emission events depended on the resin content and the amount of wax emulsion. In the case of particleboard, the authors discovered that the number of acoustic emission events is higher in the case of higher resin content, whereas in the case of MDF they noticed a higher number of acoustic emission events in the case of lower resin content. Such results are, according to the authors, the effect of different quantities of micro voids where moisture could penetrate and cause swelling and the development of swelling stresses. The authors also determined that the number of acoustic emission events decreases with an increasing amount of wax emulsion in the board.

According to the literature, thickness swelling and swelling stresses depend on the type of adhesive used, its content and the time of immersion in water or exposure to moisture. This paper presents the impact of the change in resin content in different layers on the swelling stress and thickness swelling with three layer particleboard exposed to liquid water.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

For the purpose of investigation, particleboards were made in laboratory conditions. Particles were obtained from industry, and they were made from 75% of softwood and 25% of hardwood. Screen analysis of particles is presented in Table 1.

For board preparation, 1028 g of particles (H=0%) for two surface layer and 1543 g for core layer were used. Particles were blended with urea-formaldehyde adhesive. The resin content of individual layer is presented in Table 2.

Wax emulsion[1] (2% in both layers) and hardener[2] (3% in core layer) were also added to the resin. As hardener ammonia sulphate with 20% solid content was used, while solid content of wax emulsion was 60%. Blended particles were pressed into 500×500 mm board. Particle mat was pressed at 180° C, 3 N/mm^2 for

[1] Solids based on dry wood / *Krute tvari na temelju suhog drva.*

[2] Solids based on solids of resin / *Krute tvari na temelju krute tvari smole.*

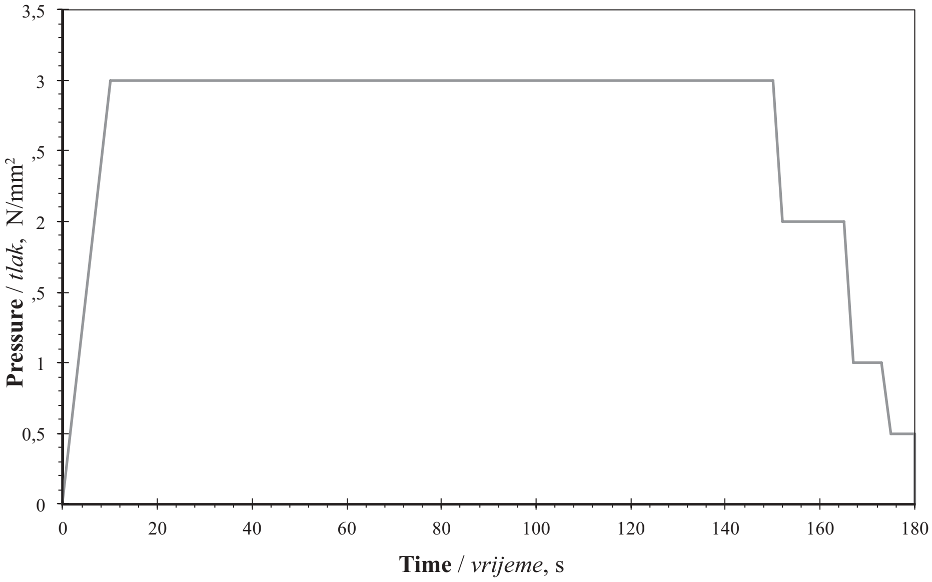

Figure 1 Press schedule
Slika 1. Dijagram prešanja

Table 1 Screen analysis* of particles with regard to the layer
Tablica 1. Granulometrijska analiza iverja s obzirom na sloj

Mesh size opening in mm *Veličina otvora sita u mm*	**Surface layer** *Vanjski sloj* %	**Core layer** *Srednji sloj* %
< 0.237	19.19	1.00
0.237 - 0.600	43.03	2.96
0.600 - 1.000	27.60	3.17
1.000 - 1.270	7.69	3.99
1.270 - 1.500	1.57	8.49
1.500 - 2.000	0.20	15.72
2.000 - 4.000	/	25.67
4.000 - 6.140	/	24.54
> 6.140	/	14.46

* Each mean is the result of three measurements of 100 g of particles for 10 minutes. / *Svaki je rezultat srednja vrijednost tri mjerenja na uzorku od 100 g u vremenu od 10 minuta.*

Table 2 Resin content of individual layer with regard to the layer
Tablica 2. Sadržaj smole u pojedinom sloju

Type *Tip*	**Resin content** / *Sadržaj smole*	
	Surface layer *Vanjski sloj* %	Core layer *Srednji sloj* %
A	10.0	7.5
B	11.5	6.0
C	11.5	7.5
D	11.5	9.0
E	13.0	7.5

3 minutes. Press schedule is shown in Figure 1. For each type (variation) two boards were made. Nominal thickness of boards was 16 mm, with nominal density 0,65 g/cm^3 (dry state).

2.1 Measurement of swelling force
2.1. Mjerenje sile bubrenja

Measurements of swelling force were conducted on 8 samples/board (16 samples/type) with the force gauge Wagner FDIX Force One, capable of measuring tensile and compression forces up to 1000 N at peak sampling rate up to 1000/sec.

For measuring the swelling force, 8 test samples 50×50 mm per board were used (16 test samples/type). The sample size was the same as for the determination of thickness swelling (according to EN 317). The samples were placed on a perforated stand, and a load (measuring) cell was brought near to the sample so that it just touched it, enabling the measurement of swelling pressure. The general arrangement of the test is shown in Figure 2.

After the load cell was placed in contact with the sample, 800 ml of distilled water with the pH value of 7 and the temperature of 20° C was poured into the bath and over the sample. The water level was kept at 25 mm above the sample, in order to minimize the effect of water pressure on the sample. Water could penetrate into the sample from all sides. The only closed surface was the surface that was in contact with the load cell (the surface of 133 mm^2). The time of measurement was 24 h, the same as for thickness swelling.

Beside the swelling force, the thickness swelling of samples was also determined after the measurement finished (after 24 h).

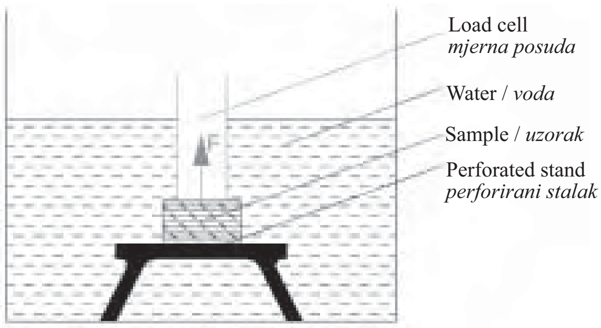

Figure 2 General arrangement of the test for measuring swelling pressure
Slika 2. Opći postupak testa za određivanje tlaka bubrenja

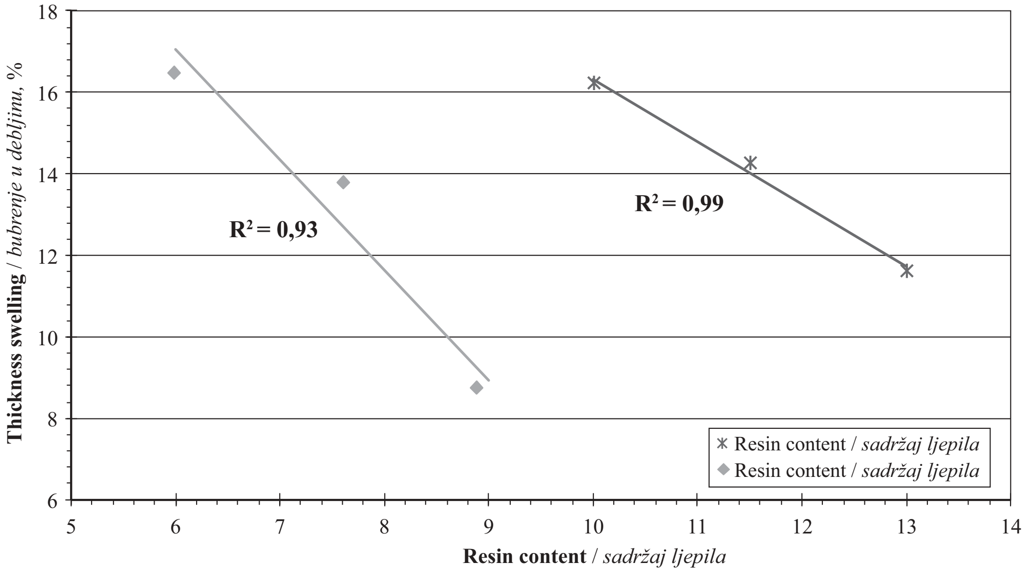

Figure 3 Thickness swelling with regard to the layer resin content**
Slika 3. Bubrenje u debljinu ovisno o sadržaju smole u pojedinom sloju

** For surface layer only values for board type A, C and E and for core layer only values for board type B, C and D are presented. Chosen values are presented because at board type A, C and E the resin content in core layer was held constant (7.5%), and at board type B, C and D the surface layer resin content was constant (11.5%). / *Za vanjski sloj predstavljeni su rezultati za tipove ploča A, C i D, a za srednji sloj tipovi ploča B, C i D. Predstavljene su izabrane vrijednosti zbog toga jer je kod tipova ploča A, C i E sadržaj smole u srednjom sloju jednak (7.5%), a kod tipova ploča B, C i D je sadržaj smole u vanjskom sloju jednak (11.5%).*

3 RESULTS AND DISCUSSION
3. REZULTATI I DISKUSIJA

The density of laboratory made boards is shown in Table 3.

It can be seen that there is a minimum density variation between the board types, and hence it can be said that this variation had no influence on the results of thickness swelling and swelling force. The thickness swelling was influenced by the resin content, as shown in Table 4.

As shown in Table 3, there are differences in thickness swelling, with regard to the resin content in individual layers. Thickness swelling decreases with increasing resin content. The greatest change was achieved when the resin content was changed in the core layer (Figure 3).

Similar correlation with regard to resin content, as shown in Table 4 and Figure 3, was also observed with values for swelling forces (Table 5).

Table 3 Density of laboratory made boards with regard to the resin content
Tablica 3. Gustoća laboratorijski izrađenih ploča ovisno o sadržaju smole

Type *Tip*	**Resin content** *Sadržaj smole* **Surface layer** *Vanjski sloj* %	**Core layer** *Srednji sloj* %	**Density** *Gustoća* g/cm³	**Thickness** *Debljina* mm
A	10.0	7.5	0.703	16.25
B	11.5	6.0	0.704	16.23
C	11.5	7.5	0.703	16.30
D	11.5	9.0	0.702	16.27
E	13.0	7.5	0.703	16.28

Table 4 Thickness swelling, with regard to the resin content
Tablica 4. Bubrenje u debljinu ovisno o sadržaju smole

Type *Tip*	**Resin content** / *Sadržaj smole* **Surface layer** *Vanjski sloj* %	**Core layer** *Srednji sloj* %	**Thickness swelling***** *Bubrenje u debljinu* %
A	10.0	7.5	16,12 (1,120)
B	11.5	6.0	16,43 (1,757)
C	11.5	7.5	14,24 (1,957)
D	11.5	9.0	8,31 (1,070)
E	13.0	7.5	11,62 (1,455)

*** Values presented are average values for 16 samples. Values in brackets are the values of standard deviation. / *Prikazani rezultati su srednje vrijednosti za 16 uzoraka. Vrijednosti u zagradama su vrijednosti standardne deviacije.*

The lowest swelling force was observed on board D (SL[3] resin content 11.5% and CL[4] 9.0%), while the highest on board B (SL resin content 11.5 and CL 6.0%). A correlation was also observed between thickness swelling and swelling force (Figure 4).

With increasing swelling there is also the increase in swelling force. When manufacturing particleboards, the pressure and temperature during the pressing process are high, and they cause severe compression of wood cells. After coming into contact with water, the first stage of swelling occurs, due to wood swelling (reversible swelling). Due to the presence of water, the

[3] Surface layer / *Vanjski sloj*
[4] Core layer / *Srednji sloj*

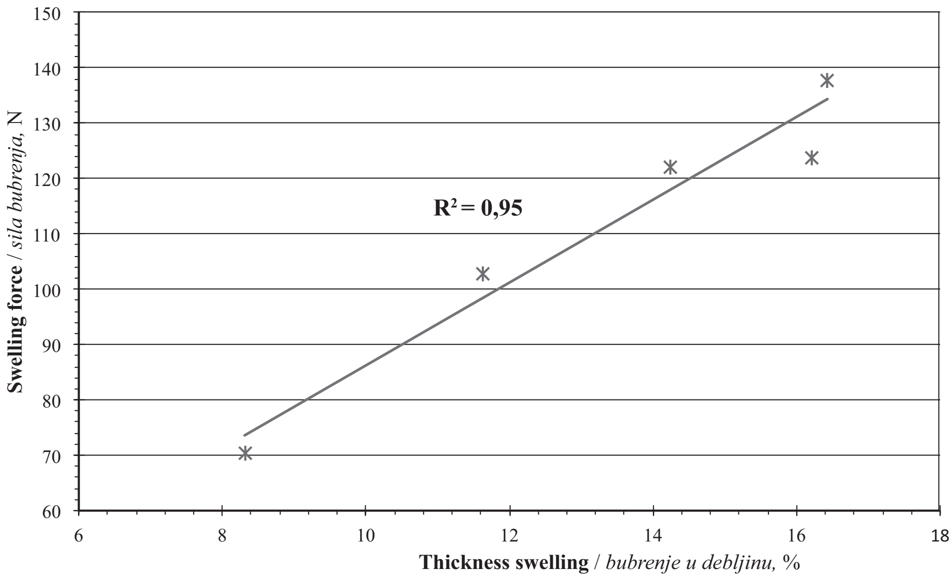

Figure 4 Correlation between thickness swelling and swelling force
Slika 4. Korelacija između bubrenja u debljinu i sile bubrenja

Table 5 Swelling force with regard to the resin content
Tablica 5. Sila bubrenja ovisno o sadržaju smole

Type *Tip*	Resin content / *Sadržaj smole*		Swelling force**** *Sila bubrenja*
	Surface layer *Vanjski sloj* %	**Core layer** *Srednji sloj* %	N
A	10.0	7.5	124 (9,989)
B	11.5	6.0	138 (11,540)
C	11.5	7.5	122 (10,212)
D	11.5	9.0	70 (7,312)
E	13.0	7.5	103 (7,359)

**** Values presented are average values for 16 samples. Values in brackets are the values of standard deviation. / *Prikazani rezultati su srednje vrijednosti za 16 uzoraka. Vrijednosti u zagradama su vrijednosti standardne deviacije.*

second stage of swelling occurs by regaining the original shape of particles (irreversible swelling). This irreversible swelling is caused by high pressure and temperature during the pressing process, and the compression and crushing of wood cells. Since the mass of wood in the board is almost the same for all board types, the higher or lower thickness swelling and swelling force is more related to the resin content and relaxation of stresses (irreversible swelling).

As shown in Figure 3, the greatest decrease in swelling force was determined when the resin content was changed in the core layer. Since the correlation was established between thickness swelling and swelling force (Figure 4), similar correlation can be expected between resin content and swelling force (Figure 5).

Again, it can be seen that changes in resin content in the core layer cause bigger change in swelling force than in resin content in the surface layer.

Thickness swelling, water absorption and swelling stress are also related to the porosity of the board especially in the core layer. Higher porosity, more free space between particles, enables faster penetration of water between particles. Since the resin does not cover the entire particle surface and its penetration is small, water can easily penetrate into the particles. Easy penetration of water into micro voids and micro fractures results in greater thickness swelling and a higher swelling stress.

Higher thickness swelling and swelling force, when the resin content in CL is 6% (resin content in SL 11.5%) is not only related to wood particles but also to the resin. As mentioned above, the resin does not entirely cover the particles (also determined by Medved et al., 2004 and Medved et al. 2010), and hence water can easily penetrate into wood particles. Due to the presence of water, particles tend to regain the position prior to pressing. They tend to flatten out, while in the board they are in a sort of curved shape. The adhesive is a “barrier” that helps to minimize the impact of water or moisture and it has to create a bond between particles. However, the bond created between particles does not guarantee low thickness swelling and hence lower swelling stresses. To withstand the stresses released due to the water, the bond between particles has to be strong. It has to withstand high tensile and shear forces that are created by the displacement of wood. The displacement of wood is caused by penetration of water. The stronger the bond between particles, less thickness swelling can be expected.

4 CONCLUSIONS
4. ZAKLJUČCI

It was determined in the research presented in this paper that there is a correlation between thickness swelling, swelling force and resin content in individual layer.

It was determined that with increasing thickness swelling, the increase in swelling force is also to be expected.

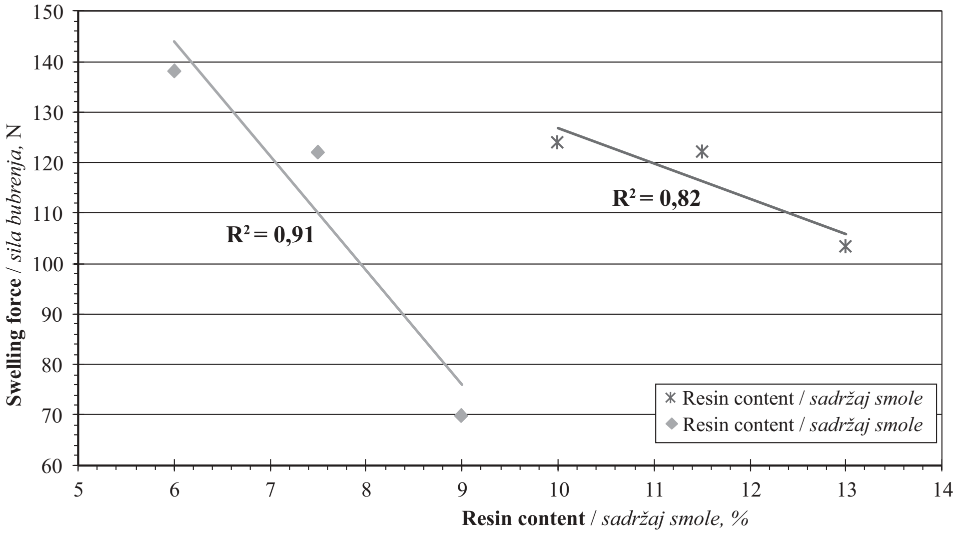

Figure 5 Swelling force with regard to the layer resin content**
Slika 5. Sila bubrenja ovisno o sadržaju smole u pojedinom sloju

** For surface layer only values for board type A, C and E and for core layer only values for board type B, C and D are presented. Chosen values are presented because at board type A, C and E the resin content in core layer was held constant (7.5%), and at board type B, C and D the surface layer resin content was constant (11.5%). / *Za vanjski sloj predstavljeni su rezultati za tipove ploča A, C i D, a za srednji sloj tipovi ploča B, C i D. Predstavljene su izabrane vrijednosti zbog toga jer je kod tipova ploča A, C i E sadržaj smole u srednjom sloju jednak (7.5%), a kod tipova ploča B, C i D je sadržaj smole u vanjskom sloju jednak (11.5%).*

Higher thickness swelling and swelling force was observed on the board with low resin content in the core layer. It can be concluded that the condition of the core layer (resin content) has higher impact on thickness swelling than changes of resin content in the surface layer.

5 REFERENCES
5. LITERATURA

1. Haligan, A. F., 1970: A review of Thickness Swelling in Particleboard. Wood Science and Tehnology, 4 (4): 301 – 312. doi:10.1007/BF00386406
2. Haligan, A. F.; Schniewind, A. P., 1972: Effect of moisture on physical and creep properties of particleboard. Forest Product Journal, 22 (4): 41 – 48.
3. Jambreković, V. 1996: Utjecaj međudjelovanja karbamid-formaldehidne smole i parafinske emulzije na kakvoću ploča iverica. Drvna industrija, 47 (4): 131-141.
4. Jambreković, V.; Brezović, M.; Bruči, V. 1998: Međuovisnost fizikalnih svojstava ploča iverica tipa V20 izrađenih s različitim vrstama i količinama hidrofobnih sredstava. Drvna industrija, 49 (1): 21-30.
5. May, H. A., 1978: Zur Optimierung der Herstellungsbedingungen phenolharzverleimter Spanplatten. Teil 1: Untersuchung einiger, die Beleimungsgűte beeinflussender Faktoren. Holz Roh – Werkstoff, 36: 441 – 449. doi:10.1007/BF02607687
6. Medved, S.; Resnik, J., 2004: Influence of particle size on the surface covered with adhesive at particles from beech wood. Wood research, 49 (1): 33 – 40.
7. Medved, S.; Resnik, J. 2010: Determination of share of adhesive on particles with FT-IR spectroscopy. Wood research, 55 (1): 101-109.
8. Medved, S.; Šernek, M.; Šega, B., 2006: Thickness swelling and swelling pressure of wood-based panels. Cost Action E44-E49 Conference in Valencia on Wood resourses and panel properties.
9. Rice, R. W.; Wang, C. ,2002: Assessing the effect of swelling pressures in particleboard and acoustic emission technology. Wood and Fiber Science, 34 (4): 577 – 586.
10. Scheider, M. H.; Chui, Y. C.; Ganev, S. B., 1992: Properties of particleboard made with polyfurfuryl – alcohol/urea – formaldehyde adhesive. Forest Products Journal, 46(9): 79 – 83.
11. Suchsland, O.; Danping, X. 1992: Determination of swelling stresses in wood – based materials. Forest Products Journal, 42(5): 25 – 27.
12. Tarkov, H.; Turner, H. D., 1958: The swelling pressure of wood. Forest Products Journal, 8(7): 193 – 197.
13. *** EN 317. Particleboard and fiberboards – Determination of swelling in thickness after immersion in water. 1993: 5 p.

Corresponding address:

Assist. Prof. SERGEJ MEDVED, Ph.D.

University of Ljubljana, Biotechnical Faculty
Department of Wood Science and Technology
Rožna dolina, C. VIII/34
SI-1000 Ljubljana, Slovenia
e-mail: sergej.medved@bf.uni-lj.si