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Effects of Different Kinds of Coating Materials on Properties of Flat Pressed WPC Panels

Utjecaj različitih vrsta materijala za oblaganje na svojstva ravnih prešanih drvno-plastičnih kompozitnih ploča

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ABSTRACT • *The effects of different kinds of coating materials on the properties of flat pressed wood plastic composite (WPC) panels were studied in this work. Rotary-cut birch veneer, sliced oak veneer, phenolic impregnated paper, polyethylene (PE) film, and recycled polyethylene (rPE) layer were used as coating materials. One or two-side coating of WPC panels was carried out simultaneously with their flat pressing. No coupling agents were used for production of WPC. It was found that properties of flat pressed WPC panels improved by coating with all investigated coating materials. The highest values of modulus of rupture (MOR) were observed in WPC panels coated with rotary-cut birch veneer and MOR values were higher in along direction than in across direction of veneer fibers. The highest values of water resistance were observed in WPC coated with PE film or rPE layer. Coating of WPC with natural veneer leads to the decreasing of water resistance. Besides, water resistance of WPC coated with one side of natural veneer was higher in comparison with two side coated WPC panels with natural veneer. The two-side coating of WPC with phenolic impregnated paper, PE film or rPE layer leads to the decreasing of water absorption and thickness swelling.*

Key words: *coating materials, flat pressing, recycled polyethylene, veneer, wood plastic composites.*

SAŽETAK • *U radu su predstavljeni rezultati istraživanja utjecaja različitih vrsta materijala za oblaganje na svojstva ravnih prešanih drvno-plastičnih kompozitnih (WPC) ploča. Za oblaganje ploča primijenjeni su ljušteni brezov furnir, rezani hrastov furnir, fenolni impregnirani papir, polietilenska (PE) folija i reciklirani polietilen (RPE). Oblaganje WPC ploča s jedne ili s obje strane obavljeno je istodobno s prešanjem ploča. Za proizvodnju ploča nisu upotrebljavana sredstva za kondenzaciju. Utvrđeno je da su svojstva ravnih prešanih WPC ploča poboljšana oblaganjem bilo kojim navedenim ispitivanim materijalom. Najveće vrijednosti modula loma (MOR) zabilježene su za WPC ploče obložene ljuštenim brezovim furnirom. MOR vrijednosti bile su veće uzduž vlakanaca furnira nego okomito na njihov smjer . Najveća otpornost na vodu zabilježena je u ploča obloženih polietilenskom folijom i recikliranim polietilenskim slojem. Oblaganje WPC ploče prirodnim furnirom utječe na smanjenje otpornosti na vodu. Osim toga, otpornost na vodu WPC ploča obloženih s jedne strane prirodnim furnirom bila je veća nego WPC ploča obloženih prirodnim furnirom s obje strane. Dvostrano oblaganje WPC ploča fenolnim impregniranim papirom, polietilenskom folijom i recikliranim polietilenskim slojem pridonosi smanjenju apsorpcije vode i debljinskog bubrenja.*

Ključne riječi: *materijali za oblaganje, ravno prešanje, reciklirani polietilen, furnir, drvno-plastični kompoziti*

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1 INTRODUCTION
1. UVOD

Wood plastic composites (WPC) are universal materials with high modulus of rupture (MOR) and elasticity (MOE), internal bond strength, water resistance (Klyosov, 2007), biological resistance (Segerholm, 2012; Segerholm, 2007) and non toxicity (Lindfors and Salo, 2012). Therefore, WPC can be used in different sectors of economy and can be produced by different methods: extrusion, injection and compression molding, which depends on the configuration forms of the products and the field of their use (Klyosov, 2007). Extrusion is a predominant technology for manufacturing WPC in the USA and Europe. WPC panels can also be produced by flat-pressing in hot press (Ayrilmis *et al*., 2011; Ayrilmis and Jarusombuti, 2011; Ayrilmis *et al*., 2012; Benthien and Thoemen, 2012; Kargarfard and Jahan-Latibari, 2012). Herewith, the pressing parameters depend on the type of thermoplastic materials and surface configuration. In particular, particleboards, oriented strand boards (OSB), and medium density fiberboards (MDF) are manufactured in this way (Thoemen *et al*., 2010).

Wood flour is usually used as the filler for the production of WPC (Winandy *et al*., 2004). Wood sawdust (Winandy *et al*., 2004), wood fiber (Benthien and Thoemen, 2012) and shavings (Segerholm, 2007) can be used, too. Moreover, except for wood particles, the agricultural residues, in particular wheat (Sardashti, 2009) and rice (Buzarovska *et al*., 2008; Yao, 2008) straw are often used as the filler for production of WPC. Wood flour is mainly used for the manufacture of WPC by extrusion (Winandy *et al*., 2004), while wood particles are used for the manufacture of WPC panels by flat-pressing (Ayrilmis *et al*., 2011; Ayrilmis and Jarusombuti, 2011; Ayrilmis *et al*., 2012; Benthien and Thoemen, 2012; Kargarfard and Jahan-Latibari, 2012).

Nearly 90 % of WPC are produced in the USA by using PE (Klyosov, 2007). In Europe, the use of PE is lower – about 70 %; polypropylene (PP) – 11 % and polyvinyl chloride – 9 % (Eder, 2010). The use of these thermoplastic polymers can be explained by their low melting temperatures (110-160 ºC). The thermal stability of wood becomes worse when higher temperatures (more than 200 ºC) are used (Klyosov, 2007). Further increasing of the temperature (over 200 ºC) causes the decomposition of wood macromolecules and negative changes of wood properties.

Maleic anhydride-grafted can be used as a coupling agent for the increase of bonds between the wood particles and polymeric material. Recycled PE in combination with UF resins were also used (Kargarfard and Jahan-Latibari, 2012). There are also various reactive groups in recycled polyesters. In particular, C=O, -C=C-, -CH=CH_2 reactive groups were found in recycled PE and PP (Moldovan *et al*., 2012). These groups can react with cellulose, lignin and other chemical components of wood. Therefore, no coupling agents are required for the production of WPC on the basis of recycled polyester.

However, the enhancing of mechanical properties of flat pressed WPC (in particular its outer layers) can be executed by strengthening their outer layers. For this purpose, the same coating materials, which are usually used for particleboard, can be applied, for example impregnated paper, natural veneers, laminates, paints, varnishes and other coating materials (Istek *et al*., 2010; Norvyda and Minelga, 2006). The possibilities of single-stage pressing of veneered particleboards were also investigated (Borysiuk *et al*., 2011). There were three variants of producing particleboards: variant I – single-layer particleboard; variant II – single layer veneered particleboard produced in two stages, first 14 mm board was pressed, and then finished by veneer; variant III – single layer veneered particleboard, manufactured in single operation. Two different types of thermoplastic reinforcement materials were also used as surface layers for coating of WPC (Schmidt *et al*., 2013). One of them was TWINTEX (reinforcement fabric of commingled thermoplastic and glass filaments), the second one was S-TEX (glass fabric reinforced polypropylene laminate with randomly oriented glass fibers).

However, only a few studies were carried out for surface coating of flat pressed WPC (Schmidt *et al*., 2013). Physical and mechanical properties of WPC can be improved by coating of their surface with different coating materials and this can expand the field of their applications. Therefore, the objective of this study was to investigate the effects of different kinds of coating materials on the properties of flat-pressed WPC panels.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

The particles of recycled polyethylene (rPE) and wood with moisture content of 2-3 % were used in this study for making WPC panels. The particles are shown in Figure 1 and their fraction analysis is presented in Table 1.

The ratio of wood particles to rPE was 60:40. Wood particles and rPE (in the natural dry state) were mixed by hand for 10 minutes. The coating was made from one or two surface sides of WPC panel. Two groups of coating materials were used: natural veneer – the rotary-cut birch veneer and sliced oak veneer; and synthetic materials - phenolic impregnated paper, PE film and rPE layer.

Process of one-side coating (Figure 2a). The rotary-cut birch veneer, sliced oak veneer, phenolic impregnated paper, PE film or rPE layer was put into open press-form. Then the mat was formed from the wood-polymer mixture in an open press-form and transferred to the hot press.

Process of two-side coating (Figure 2b). The lower layer of the rotary-cut birch veneer, sliced oak veneer, phenolic impregnated paper, PE film or rPE layer was put into open press-form. Then the mat was formed from the wood-polymer mixture into an open press-form. After that, the outer layer of the rotary-cut birch veneer, sliced oak veneer, phenolic impregnated paper, PE film or rPE layer was put on the prepared composition. Then this sandwich packet was transferred to the hot press.

Table 1 Fraction analysis (by % weight)
Tablica 1. Analiza frakcija (% mase)

Components *Sastavnice*	**Screen hole size, mm** / *Veličina otvora sita, mm*						
	-/5	5/4	4/2	2/1	1/0.63	0.63/0.315	0.315/0
Wood particles / *drvno iverje*	4.75	12.2	15.79	40.28	15.67	9.13	2.18
rPE / *reciklirani polietilen*	9.53	3.04	53.14	32.45	1.83	-	-

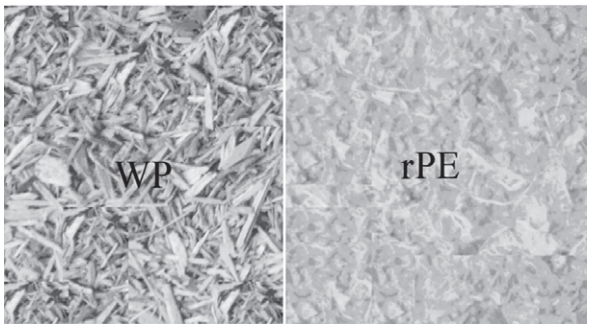

Figure 1 Wood particles (WP) and recycled polyethylene (rPE)
Slika 1. Drvno iverje (WP) i reciklirani polietilen (rPE)

The size of all manufactured WPC test panels was 250 mm in length and 230 mm in width, and 8.0 mm in thickness. All manufactured WPC panels were made in the laboratory press. The hot press was operated in plate position control mode, with the pressure limited to a maximum of 3.5 MPa. The pressing temperature was 180 ºC and pressing time was 8.0 min. At the end of the press cycle, the WPC panels were removed from the press for cooling to the temperature of 30-40 ºC. The density of non-coated WPC panels was 800 kg/m^3. Non-coated WPC panels were manufactured at the same pressing parameters (Lyutyy *et al*., 2014).

Modulus of rupture (MOR) and water resistance (thickness swelling (TS) and water absorption (WA)) of the panels were evaluated according to EN 310 and EN 317, respectively.

The analysis of variance (ANOVA) was conducted to study the effect of different kinds of coating materials (rotary-cut birch veneer, sliced oak veneer, phenolic impregnated paper, PE film and rPE layer) and the type of coating (one or two-side) on the modulus of rupture, thickness swelling and water absorption of coated WPC panels at a 0.05 significance level. Duncan's multiple range tests were conducted for multiple comparisons between the means of the measured properties for different kinds of coating materials and different types of coating.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

ANOVA showed that the kind of coating materials and the type of coating significantly influenced MOR, TS and WA. All investigated coating materials lead to the increase of the MOR of coated WPC panels (Table 2 and 3). The highest values of MOR were observed in WPC panels coated with rotary-cut birch veneer. In particular, the MOR of one-side coated WPC panels with rotary-cut birch veneer increased in 4.9-6.0 times in along veneer fibers and in 1.6-1.7 times in across veneer fibers depending on the coating location (up or down) during the test. Slightly lower values of MOR (in 4.3-5.3 times in along veneer fibers and in 1.5 times in across veneer fibers) were observed in one-side coated WPC panels with sliced oak veneer. The higher values of MOR in one-side coated WPC panels with sliced veneer were obtained in the work (Norvyda and Minelga, 2006). This can be explained by higher initial MOR of non-coated WPC panels and the use of five layers of veneer for coating of WPC panels except for one layer as in our case.

MOR of WPC panels coated with phenolic impregnated paper was increased in 1.7 times and for WPC panels coated with PE film and rPE layer in 2.0-2.2 and about 1.8 times, respectively.

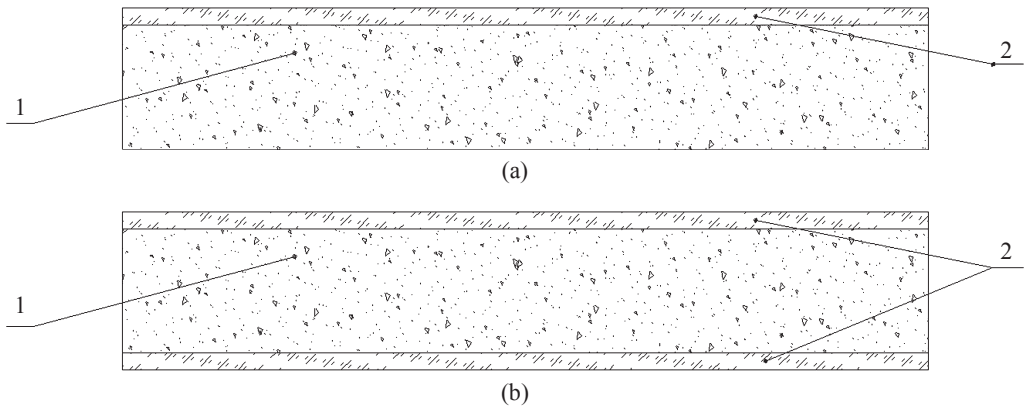

Figure 2 Coated flat pressed WPC: (a) – one-side coated; (b) – two-side coated: 1 – WPC composition; 2 – coating material (rotary-cut birch veneer, sliced oak veneer, phenolic impregnated paper, PE film or rPE layer)
Slika 2. Obložena WPC ploča: a) jednostrano obložena, b) dvostrano obložena, 1 – WPC kompozit, 2 – materijal za oblaganje (ljušteni brezov furnir, rezani hrastov furnir, fenolni impregnirani papir, polietilenska folija, reciklirani polietilenski sloj)

Table 2 Properties of one and two-side coated WPC panels with rotary-cut birch and sliced oak veneers
Tablica 2. Svojstva jednostrano i dvostrano obložene WPC ploče ljuštenim brezovim furnirom i rezanim hrastovim furnirom

Property *Svojstvo*	**Control** *Kontrolni uzorak*	**One-side** / *Jednostrano*				**Two-side** / *Dvostrano*	
		Rotary-cut birch veneer *Ljušteni brezov furnir*		**Sliced oak veneer** *Rezani hrastov furnir*		**Rotary-cut birch veneer** *Ljušteni brezov furnir*	**Sliced oak veneer** *Rezani hrastov furnir*
		Veneer up *furnir je s gornje strane*	Veneer down *furnir je s donje strane*	Veneer up *furnir je s gornje strane*	Veneer down *furnir je s donje strane*		
MOR, MPa	5.6 (0.43) *a*	27.4 (0.62) *c* 9.5 (0.38) *d*	33.6 (0.56) *f* 9.2 (0.51) *cd*	24.2 (0.29) *b* 8.6 (0.16) *b*	29.5 (0.32) *d* 8.7 (0.17) *bc*	48.2 (1.61) *g* 12.7 (0.55) *e*	31.1 (0.88) *e* 9.1 (0.88) *bcd*
WA, %	23.5 (1.30) *a*	35.7 (1.9) *c*		31.1 (1.3) *b*		37.0 (1.75) *cd*	38.6 (3.73) *d*
TS, %	10.1 (0.69) *a*	18.7 (2.2) *c*		15.4 (1.5) *b*		19.2 (2.30) *c*	21.8 (2.60) *d*

Key / *Legenda*: MOR – modulus of rupture / *modul loma* (MPa); WA – water adsorption / *upijanje vode* (%); TS – thickness swelling / *debljinsko bubrenje* (%)
*Values in parenthesis are standard deviations based on twelve samples. / *Vrijednosti u zagradama standardne su devijacije na temelju 12 uzoraka.***Different letters denote a significant difference. / *Različita slova označuju značajnu razliku*.***The numerator shows the value of MOR along veneer fibers, and the denominator - across veneer fibers. / *Brojnik pokazuje vrijednost modula loma uzduž vlakanaca furnira, a nazivnik okomito na njih*.

The similar results were found in the work (Borysiuk *et al*., 2011); for example, the coated particleboards showed variable MOR and MOE parameters depending on testing direction (along or across the outer layer veneers). Application of veneers to outer layers strengthened the boards in major axis (MOR and MOE gained around 65 ÷ 72 %) with simultaneous drop in minor axis (by around 23 ÷ 30 %).

The same results were observed in the work (Schmidt *et al*., 2013). The reinforcement of WPC panels with TWINTEX in a single step process leads to 2.4 (4.0) times higher MOE (MOR) in comparison with the unreinforced reference panel. Surface reinforced panels by use of S-TEX show 3.4 (5.6) times higher MOE (MOR). Moreover, the value of MOR of WPC panels coated with TWINTEX was 62.2 MPa and when coated with S-TEX the value of MOR was 89.7 MPa. Such higher values of MOR can be explained by the higher strength of TWINTEX and S-TEX core materials. In particular, the MOR of TWINTEX (in transverse direction) and S-TEX (in longitudinal direction) is 50 and 125 MPa, respectively. S-TEX reinforced material has higher flexural properties than TWINTEX reinforced material because of higher nominal weight and glass content.

MOR of two-side coated WPC panels increased significantly in comparison with one-side coated panels. The values of MOR in two-side coated WPC panels with rotary-cut birch veneer were increased in 8.4 times in along veneer fibers and in 2.3 times in across veneer fibers. Coating of WPC panels with sliced oak veneer also resulted in higher values of MOR; for example, MOR was increased in 5.5 times in along veneer fibers and 1.6 in across veneer fibers. The MOR of WPC panels coated with phenolic impregnated paper and PE film or rPE layer was increased by 79 % and 135 %, respectively.

It should also be noted that WPC panels coated with natural veneers (rotary-cut birch veneer or sliced oak veneer) had higher values of strength properties in

Table 3 Properties of one and two-side coated WPC panels with phenolic impregnated paper, PE film or rPE layer
Tablica 3. Svojstva jednostrano i dvostrano obložene WPC ploče fenolnim impregniranim papirom, polietilenskom folijom i recikliranim polietilenskim slojem

Property *Svojstvo*	**Control** *Kontrolni uzorak*	**One-side** / *Jednostrano*						**Two-side** / *Dvostrano*		
		Phenolic impregnated paper *Fenolni impregnirani papir*		**PE film** *Polietilenska folija*		**rPE layer** *Reciklirani polietilenski sloj*		**Phenolic impregnated paper** *Fenolni impregnirani papir*	**PE film** *Polietilenska folija*	**rPE layer** *Reciklirani polietilenski sloj*
		Paper up *papir je s gornje strane*	Paper down *papir je s donje strane*	Film up *folija je s gornje strane*	Film down *folija je s donje strane*	Layer up *sloj je s gornje strane*	Layer down *sloj je s donje strane*			
MOR, MPa	5.6 (0.43) *a*	9.1 (0.72) *b*	9.5 (0.56) *bc*	11.5 (0.49) *e*	12.3 (0.20) *f*	10.3 (0.53) *d*	10.0 (0.58) *cd*	10.0 (0.64) *cd*	13.4 (0.84) *g*	13.2 (0.61) *g*
WA, %	23.5 (1.30) *e*	25.5 (1.7) *f*		17.5 (1.9) *c*		19.6 (1.35) *d*		23.3 (1.65) *e*	12.9 (1.32) *b*	6.9 (0.97) *a*
TS, %	10.1 (0.69) *c*	14.2 (1.8) *e*		10.0 (1.2) *c*		13.0 (1.7) *d*		8.6 (0.98) *b*	9.2 (0.93) *bc*	5.8 (0.80) *a*

Key / *Legenda*: MOR – modulus of rupture / *modul loma* (MPa); WA – water adsorption / *upijanje vode* (%); TS – thickness swelling / *debljinsko bubrenje* (%)
*Values in parenthesis are standard deviations based on twelve samples. / *Vrijednosti u zagradama standardne su devijacije na temelju 12 uzoraka.***Different letters denote a significant difference. / *Različita slova označuju značajnu razliku*.

Table 4 Duncan's test results for main effects
Tablica 4. Rezultati Duncanova testa

Main factors *Utjecajni činitelji*	**MOR (along fibers), MPa** *MOR (uzduž vlakanaca), MPa*		**MOR (across fibers), MPa** *MOR (poprečno na vlakanca), MPa*		**WA, %**		**TS, %**	
	Mean	SG	Mean	SG	Mean	SG	Mean	SG
Material / *Materijal*								
control (non-coated) / *kontrolni uzorak (neobloženi)*	5.56	a	5.56	a	23.47	b	10.11	b
rotary-cut birch veneer / *ljušteni brezov furnir*	36.21	f	10.49	d	36.36	d	18.99	d
sliced oak veneer / *rezani hrastov furnir*	28.24	e	8.78	b	34.81	c	17.98	d
phenolic impregnated paper / *fenolni impregnirani papir*	9.65	b	9.65	c	24.36	b	11.66	c
PE film / *polietilenska folija*	12.70	d	12.70	f	15.20	a	9.70	ab
rPE layer / *reciklirani polietilenski sloj*	11.66	c	11.66	e	14.50	a	8.98	a
Type of coating / *vrsta oblaganja*								
control (non-coated) / *kontrolni uzorak (neobloženi)*	5.56	a	5.56	a	23.47	a	10.11	a
one-side coating / *jednostrano oblaganje*	17.68	b	9.85	b	25.85	b	14.20	c
two-side coating / *dvostrano oblaganje*	18.55	c	11.84	c	24.93	b	12.90	b

*SG – statistical group / *statistička skupina*; **Different letters denote a significant difference. / *Različita slova označuju značajnu razliku*.

comparison with the using of synthetic materials (phenolic impregnated paper, PE film or rPE layer). In particular, the MOR values of two-side coated WPC panels were in 4.7 times higher using rotary-cut birch veneer (in along veneer fibers) in comparison with the using of phenolic impregnated paper and in 3.6 times higher in comparison with the using of PE film or rPE layer. Such dependencies could be explained by the properties of coating materials. The strength values of coating materials are quite different. In particular, for birch and oak wood with moisture content of 12 %, the MOR is in the range of 56-117 MPa and 75-125 MPa, respectively, and it should also be taken into account that these values depend on the conditions of tree growth (Green *et al*., 1999). Moreover, the thickness of the coating material should be considered; the rotary-cut birch veneer with the thickness of 1.5 mm, sliced oak veneer with the thickness of 0.5 mm, and PE film with the thickness of 0.1 mm and impregnated phenolic paper with gramature only 80 g/m^2 were used in this study.

The highest water resistance was observed in WPC panels coated with rPE layer. The coating of WPC with natural veneers also resulted in the increasing of TS and WA in comparison with non-coated WPC panels. It was found that coating with rotary-cut birch veneer and sliced oak veneer caused the increasing of TS (WA) on 57 (90) % and 64 (115) %, respectively, in comparison with non-coated WPC panels. It should also be noted that water resistance of one-side coating with natural veneer was higher than two-side coating with natural veneer. The values of water resistance of WPC panels coated with natural veneer were lower in comparison with synthetic materials, which could be explained by higher water absorption of wood veneer. The similar results were observed in the work (Istek *et al*., 2010). The minimum values of WA and TS at 2 and 96 hours were obtained as 56.7 % and 81.4 % in white oak-UF, 11.1 % in common maple-UF, and 14.8 % in white oak-UF (Istek *et al*., 2010) The higher TS and WA values of 21.8 % and 38.6 %, respectively, were reported in another work (Borysiuk *et al*., 2011).

It was found that one-side coating of WPC with phenolic impregnated paper leads to the increasing of TS and WA. In contrast, two-side coating of WPC with phenolic impregnated paper, PE film or rPE layer leads to the decreasing of WA and TS. In particular, the TS (WA) was decreased by 13 (1) % with using phenolic impregnated paper; by 10 (45) % with using PE film and by 46 (68) % with using rPE layer in comparison with non-coated WPC. The polyethylene has high water resistance; its water absorption for 24 hours is 0.10 %. The polyethylene formed water resistance layer (film) on the surface of WPC. This layer does not allow WPC to absorb water and swell. Rotary-cut birch and sliced oak veneers are natural materials in contrast with polyethylene. They can absorb a lot of water, which leads to the increasing of TS and WA of WPC.

The results of Duncan's tests conducted to determine the significance of the relationships between the kind of coating materials, the type of coating and MOR, thickness swelling and water absorption are given in Table 4.

As shown in Table 4, differences in the MOR, TS and WA between all the investigated coating materials and types of coating were statistically significant.

4 CONCLUSIONS
4. ZAKLJUČAK

The values of MOR were increased in WPC panels coated with all investigated coating materials. The highest values of MOR were observed in WPC coated with rotary-cut birch and sliced oak natural veneer. It should be noted that the highest MOR was observed in WPC coated with natural veneer along the grain. WPC panels coated with phenolic impregnated paper, PE film or rPE layer had lower values of MOR in com-

parison with WPC panels coated with natural veneer. Besides, the MOR was higher in two-side coated WPC panels with all investigated coating materials. The highest water resistance was observed in WPC panels coated with PE film or rPE layer. The coating with natural veneer leads to the decreasing of water resistance of WPC. Moreover, water resistance of one-side coated WPC panels with natural veneer was higher in comparison with two-sided coated WPC panels with natural veneer. The two-side coating of WPC panels with phenolic impregnated paper, PE film or rPE layer leads to the decreasing of WA and TS. As follows, coating materials that are widely used for coating of plywood, particleboards and fiberboards can be successfully used for coating of flat pressed WPC panels. Therefore, the results obtained in this study make it possible to expand the application of WPC panels and also provide important information for future research and use of such flat pressed coated WPC.

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