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Investigating the Characteristics of Particleboards Produced from a Combination of Pine Tree Branches / Melamine Impregnated Paper Waste with Industrial Wood Particles in Different Amounts of Resin

Istraživanje obilježja iverice proizvedene od borovih grana i melaminom impregniranoga papirnog otpada u kombinaciji s industrijskim drvnim iverjem i različitim količinama ljepila

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ABSTRACT • The properties of particleboards manufactured from pine tree branches /melamine impregnated paper waste with industrial wood particles were investigated. This research aims to reduce the amount of industrial wood particles and resin content. The proportions of industrial wood particles to an equal mixture of pine branches and melamine impregnated paper waste were 100: 0, 90:10, 80:20, 70:30 and urea-formaldehyde resin was used at two levels – 8 % and 10 %. A factorial test was used to statistically assess the board properties. According to the results, with increasing resin content, the physical and mechanical properties of the boards improved. With increasing the mixing ratio of pine branches and melamine impregnated paper waste up to 20 percent, the mechanical properties of the boards improved compared to the control sample (the boards containing 100 % industrial wood particles). The boards containing 90 % industrial wood particles and 8 % resin (mixture W90R8) as well as the boards containing 70 % industrial wood particles and 10 % resin (mixture W70R10) are recommended for the Type P1 boards. For the Type P2 boards, the boards containing 90 % industrial wood particles and 10 % resin (mixture W90R10) are recommended.

KEYWORDS: industrial wood particles; urea-formaldehyde resin; pine branches; melamine impregnated paper waste

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SAŽETAK • U radu su istražena svojstva iverice proizvedene od smjese borovih grana i otpadnog papira impregniranoga melaminom u kombinaciji s industrijskim drvnim iverjem. Ciljevi ovog istraživanja bili su smanjenje količine industrijskoga drvnog iverja i udjela smole. Omjeri drvnog iverja i smjese jednakih udjela borovih grana i otpadnog papira impregniranoga melaminom bili su 100:0, 90:10, 80:20, 70:30, a udio urea-formaldehidne smole iznosio je 8 % i 10 %. Za statističku procjenu svojstava ploče primijenjen je faktorski test. Prema rezultatima istraživanja, s povećanjem udjela smole poboljšala su se fizička i mehanička svojstva ploča. S povećanjem udjela smjese borovih grana i otpadnog papira impregniranoga melaminom do udjela od 20 % mehanička svojstva ploča poboljšala su se u usporedbi s kontrolnim uzorkom (ploče sa 100 % drvnog iverja). Glede ploča tipa P1 preporučuje se proizvodnja onih koje sadržavaju 90 % drvnog iverja i 8 % smole (smjesa W90R8), kao i ploča s udjelom 70 % drvnog iverja i 10 % smole (smjesa W70R10). Za ploče tipa P2 preporučuje se proizvodnja onih koje sadržavaju 90 % drvnog iverja i 10 % smole (smjesa W90R10).

KLJUČNE RIJEČI: drveno iverje; urea-formaldehidna smola; borove grane; melaminom impregniran otpadni papir

1 INTRODUCTION

1. UVOD

In 2020, 96.01 million cubic meters of particleboards were produced worldwide (Lee *et al.*, 2022). The cost of wood has increased significantly in recent years. Many researchers investigated the use of various wastes, such as recycled wood, tea leaves, fruits, as raw materials for particleboard production (Mostafalo *et al.*, 2019; Baharlouei *et al.*, 2020; Ebrahimi *et al.*, 2021). They determined that these wastes may be utilized to make particleboards. To protect the environment, wood products can be made from industrial waste, such as sawdust, bark, wood pulp, wastepaper fibers, and waste from sawmills and veneering. During the veneering process, the melamine impregnated paper production line produces a significant amount of waste that is burned to produce energy. Wood product waste can be recycled and reused in the manufacturing process (Babazadeh Lehi *et al.*, 2018). Nemli *et al.* (2003) investigated the use of kiwifruit pruning in the particleboard production. Incorporating kiwifruit branches into the board center layer was shown to improve the boards resistance above the minimum set by the European standard. However, the physical properties of the boards increased. According to Thomas *et al.* (2011), the veneer production process generates a large amount of melamine resin-impregnated paper waste, which can be used instead of adhesive to produce particleboards. The results demonstrated that using melamine-coated paper improved the board strength properties and reduced the quantity of urea-formaldehyde adhesive utilized. Varga *et al.* (2004) studied the usage of melamine-coated paper waste in particleboard production. The results showed that adding melamine-coated paper improved the strength properties of the boards and decreased the usage of urea-formaldehyde adhesive. Melamine-coated paper powder was used by Alpar and Winkler (2006) as a filler and adhesive in the production of particleboards. The findings revealed no appreciable variation between the boards made with urea-formaldehyde adhesive and melamine-coated paper powder.

Silva *et al.* (2012) used variable amounts of 6 mm long melamine veneer waste as a synthetic resin in the central layer of the particleboard. The findings revealed that boards with melamine veneer waste of 4 % and 8 % met the minimum standard criteria, while those with 12 % had lower strengths than the standard. The particleboard properties manufactured from waste leather and wastepaper were studied by Kibet *et al.* (2022). The two materials listed above were found to be suitable wood replacements for the production of particleboards.

Babazadeh Lehi *et al.* (2018) studied the replacement of urea formaldehyde adhesives with melamine wastepaper in the center of particleboard. In this research, melamine wastepaper was used in the core layer at four concentrations: 0, 20, 40, and 60 % of the dry weight of the resin used. The research found that while the boards resistance declined with higher wastepaper powder concentration, as required by the Iranian National Standard 9044, the strength of the boards remained within acceptable limits up to 40 % of the melamine wastepaper powder. Additionally, the physical properties of the board improved as the melamine wastepaper powder content increased. According to the research, using melamine wastepaper in particleboard manufacturing lowers the usage of urea-formaldehyde resin.

Latibari *et al.* (2013) investigated the possibility of using pine and sycamore waste and grape pruning in comparison to a combination of hardwoods in the production of particleboards. According to the results, pine wood boards had the greatest bending strength and modulus of elasticity because of their lower bulk density, while mixed hardwood chips had the highest internal bonding.

Wronk and Kowaluk (2022) investigated the possibility of using pine branches as a replacement material in the particleboard. The study showed that increasing the proportion of pine branches improved the boards' internal bonding and water absorption but reduced their bending strength and modulus of elasticity.

Basboga *et al.* (2016) studied the use of different types of melamine-saturated paper waste in particleboard production. Because of its economic and envi-

ronmental benefits, the aforementioned material can be used as a resin replacement in the production of particleboards, and the result showed that 15 % melamine paper provides the most significant resistance.

Due to the importance of alternative raw materials and waste, and the reduction of industrial wood consumption in boards production, the objective of this research is to substitute pine branches and melamine paper waste with industrial wood particles to produce particleboards with desirable physical and mechanical properties at different amounts of resin.

2 MATERIALS AND METHODS

2. MATERIJALI I METODE

2.1 Raw materials

2.1. Sirovine

Melamine-impregnated paper waste was taken from the coating line of the Northern Wood Industry Company and then ground into powder in a hammer mill. Industrial wood particles with a thickness of 0.8-1.5 mm (10-20 mesh) were obtained from the Northern Wood Industry Company, and pine tree branches (*Pinus*

brutia) from Gonbad Kavous city, and processed into wood chips using chipper and mechanical grinding. These particles were dried to a moisture content of 4 %.

2.2 Adhesive

2.2. Ljepilo

Urea-formaldehyde (UF) resin was used at two levels – 8 and 10 %. Table 1 lists the properties of UF resin. The ammonium chloride was used as hardener at 2 % of the weight of the resin.

2.3 Manufacture of particleboards

2.3. Proizvodnja iverice

The mixed proportion of industrial wood particles, melamine impregnated paper waste, and pine tree branches was selected at four levels: (100 %: 0 %: 0 %), (90 %: 5 %: 5 %), (80 %: 10 %: 10 %), and (70 %: 15 %: 15 %), respectively. UF resin was used at two levels – 8 % and 10 % of the dry weight of the raw materials.

2.4 Evaluation of board properties

2.4. Analiza svojstava ploče

The boards were cut according to EN 326-1:1994 after two weeks. Thickness swelling of boards was

Table 1 Properties of urea-formaldehyde resin

Tablica 1. Svojstva urea-formaldehidne smole

Density, kg/m ³ Gustoća, kg/m ³	Manufacturer Proizvođač	Viscosity, cP Viskoznost, cP	Gel time, s Vrijeme želiranja, s	pH	Solids, % Suha tvar, %
1270	Samed Mashhad	320	56	7	61

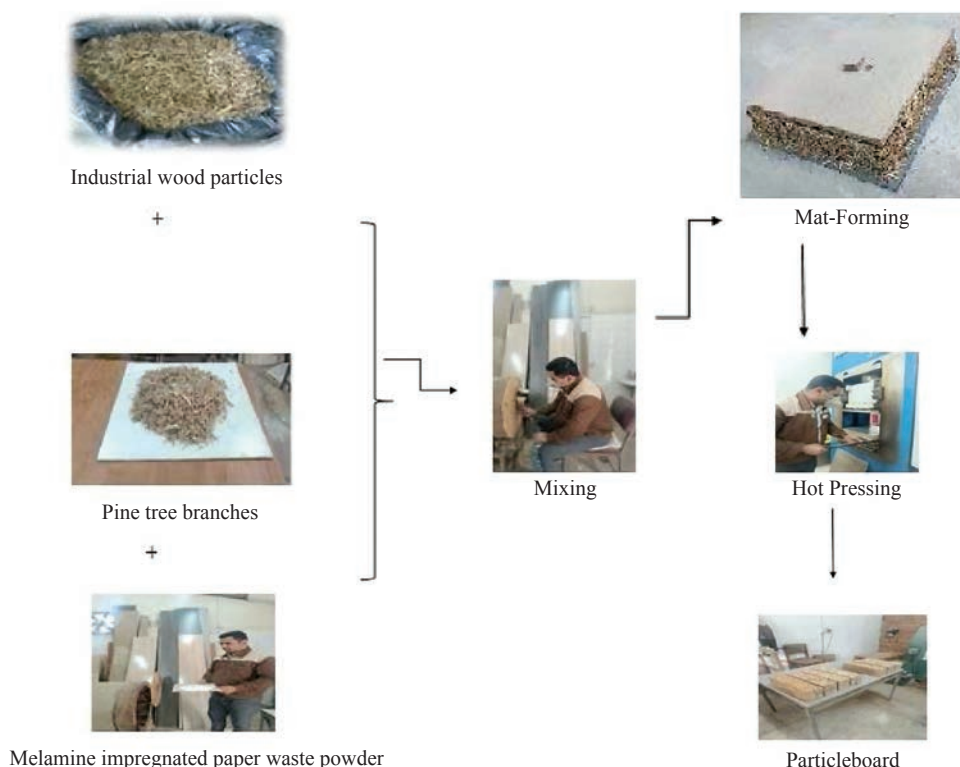


Figure 1 Production stages of particleboard

Slika 1. Faze proizvodnje iverice

Table 2 Combination of test samples**Tablica 2.** Kombinacije ispitnih uzoraka

Treatment code <i>Oznaka uzorka</i>	Particles for producing particleboard, % <i>Sirovina za proizvodnju iverice, %</i>			UF resin / UF smola	
	Industrial wood particles (W) <i>Drvno iverje (W)</i>	Pine tree branches <i>Borove grane</i>	Melamine-impregnated paper waste <i>Melaminom impregniran otpadni papir</i>	8 % (R8)	10 % (R10)
W100R8	100	0	0	8	-
W100R10	100	0	0	-	10
W90R8	90	5	5	8	-
W90R10	90	5	5	-	10
W80R8	80	10	10	8	-
W80R10	80	10	10	-	10
W70R8	70	15	15	8	-
W70R10	70	15	15	-	10

measured according to EN 317:1993, and the mechanical properties of boards according to EN 310:1993 and EN 319:1993. The results were compared with Type P1 board and Type P2 board according to EN 312:2010.

2.5 Data analysis

2.5. Analiza podataka

Factorial test was used for data analysis. Duncan's test at a 95 % confidence level was used to compare the means.

3 RESULTS AND DISCUSSION

3. REZULTATI I RASPRAVA

3.1 Bending strength and modulus of elasticity

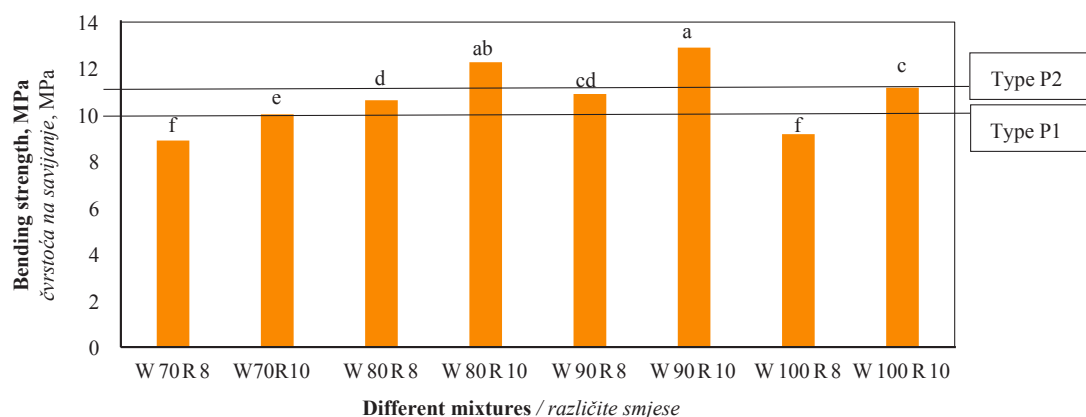
3.1. Čvrstoća na savijanje i modul elastičnosti

The results showed that different factors had a significant effect on the above mechanical properties at a 95 % confidence level (Table 3).

Table 3 Results of data analysis**Tablica 3.** Rezultati analize podataka

Parameter <i>Parametar</i>	Source of variance <i>Izvor varijance</i>	Degrees of freedom <i>Stupnjevi slobode</i>	Mean square <i>Srednji kvadrat</i>	F value	P Sig.
Bending strength <i>čvrstoća na savijanje</i>	Mixture / <i>smjesa</i>	3	7.599	4.368	0.020*
	Resin / <i>smola</i>	1	17.170	9.870	0.006**
	Mixture × Resin / <i>smjesa × smola</i>	3	0.253	0.145	0.031*
	Error / <i>pogreška</i>	16	1.740		
	Total / <i>ukupno</i>	23			
Modulus of elasticity <i>modul elastičnosti</i>	Mixture / <i>smjesa</i>	3	468252.642	7.139	0.003**
	Resin / <i>smola</i>	1	831904.370	12.684	0.003**
	Mixture × Resin / <i>smjesa × smola</i>	3	11772.305	0.179	0.039*
	Error / <i>pogreška</i>	16	65589.122		
	Total / <i>ukupno</i>	23			

*Significance at the level of 95 %, ** significance at the level of 99 % / *Značajno na razini od 95 %, **značajno na razini od 99 %

**Figure 2** The effect of different mixtures on boards bending strength**Slika 2.** Utjecaj različitih smjesa na čvrstoću ploča na savijanje

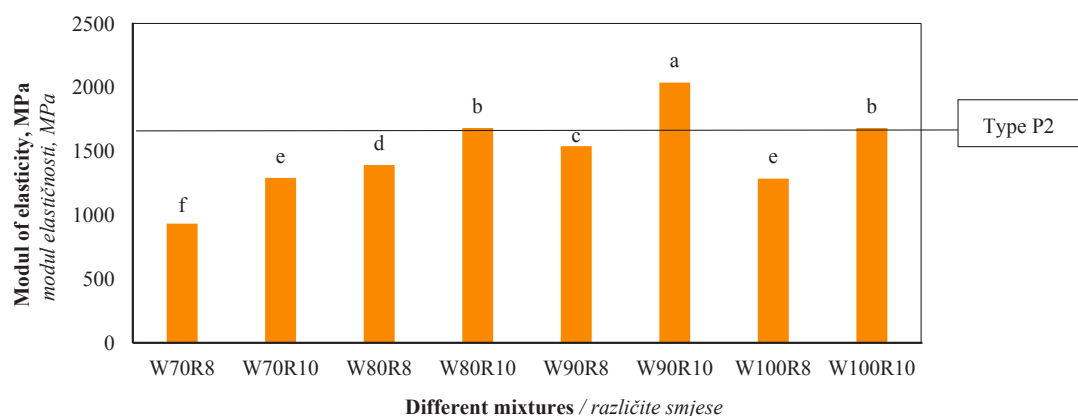


Figure 3 The effect of different mixtures on boards modulus of elasticity

Slika 3. Utjecaj različitih smjesa na modul elastičnosti ploča

Figures 2 and 3 show the effect of different mixtures on the bending strength and the modulus of elasticity of particleboards. The bending strength and the modulus of elasticity improved with increasing the amounts of UF resin and the mixture up to 80 %. As the density of pine wood is lower than that of industrial wood particles, which increases the compression coefficient, the bending strength and modulus of elasticity increase. At low content (up to 10 %), melamine impregnated paper waste acts as a filler, fills the inter-fiber voids, leading to improved strength (Bashoga *et al.* 2016). However, at higher contents (15 %), these wastes induce stress concentration, ultimately leading to a reduction in strengths. The maximum modulus of elasticity and bending strength values were achieved from a mixture of 90 % industrial wood particles and 10 % UF resin (mixture W90R10). The minimum bending strength and modulus of elasticity values were achieved in a mixture of 70 % industrial wood particles and 8 % UF resin (mixture W70R8). Figures 2 and 3 show that the mixtures of W100R10, W90R10, and W80R10 were comparable to the values required for Type P2 boards according to EN 312 (EN 2010). The

mixture of W90R8, W80R8, and W70R10 accomplished the requirements of EN 312 (EN 2010) for Type P1 boards.

3.2 Internal bonding strength

3.2. Čvrstoća na raslojavanje

The results showed that different factors had a significant effect on the internal bonding of the boards at a 95 % confidence level (Table 4).

Internal bonding value increased as resin content was increased from 8 wt% to 10 wt% (Figure 4). The maximum internal bonding values were achieved from a mixture of 90 % industrial wood particles and 10 % UF resin (mixture W90R10). Melamine paper waste functions as a filler in low amounts, while in greater amounts it has a high specific surface area. When the resin is applied in uniform amounts, it causes a decrease in the board internal adhesion. Figure 5 shows that mixtures of W100R10, W90R10 accomplished the requirements of EN 312 (EN 2010) for Type P2 (0.35 MPa), while mixtures of W80R10, W90R8, and W70R10 accomplished the requirements of EN 312 (EN 2010) for Type P1 boards (0.24 MPa).

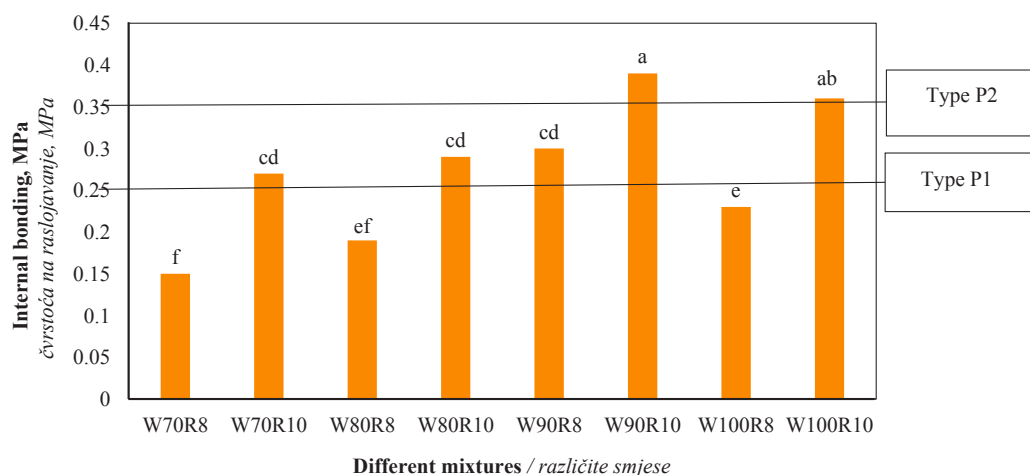


Figure 4 The effect of different mixtures on internal bonding

Slika 4. Utjecaj različitih smjesa na čvrstoću na raslojavanje

Table 4 Results of data analysis for board internal bonding strength**Tablica 4.** Rezultati analize podataka za čvrstoću ploča na raslojavanje

Parameter Parametar	Source of variance Izvor varijance	Degrees of freedom Stupnjevi slobode	Mean square Srednji kvadrat	F value	P Sig.
Internal bonding čvrstoća na raslojavanje	Mixture / smjesa	3	0.019	13.726	0.000**
	Resin / smola	1	0.070	50.298	0.000**
	Mixture × Resin / smjesa × smola	3	0.001	0.361	0.022*
	Error / pogreška	16	0.001		
	Total / ukupno	23			

*Significance at the level of 95 %, ** significance at the level of 99 % / *Značajno na razini od 95 %, **značajno na razini od 99 %

3.3 Water absorption and thickness swelling

3.3. Upijanje vode i debljinsko bubrenje

The results showed that different factors had a significant effect on water absorption (WA) and thickness swelling (TS) after 24 hours of immersion in water at a 95 % confidence level (Table 5).

The TS and WA values of boards decreased with increasing resin content and proportion of mixture (Figure 5), because the melamine impregnated paper waste is waterproof (Babazadeh Lehi *et al.*, 2018). The density of the boards was constant, which indicates that the amount of particles in the boards decreased when the

amount of the melamine paper waste was increased. Also, by increasing the amount of melamine paper waste, the amount of hydrophilic wood material decreased (Silva *et al.*, 2012). The minimum TS and WA values were obtained in a mixture of 70 % industrial wood particles and 10 % UF resin (mixture W70R10).

4 CONCLUSIONS

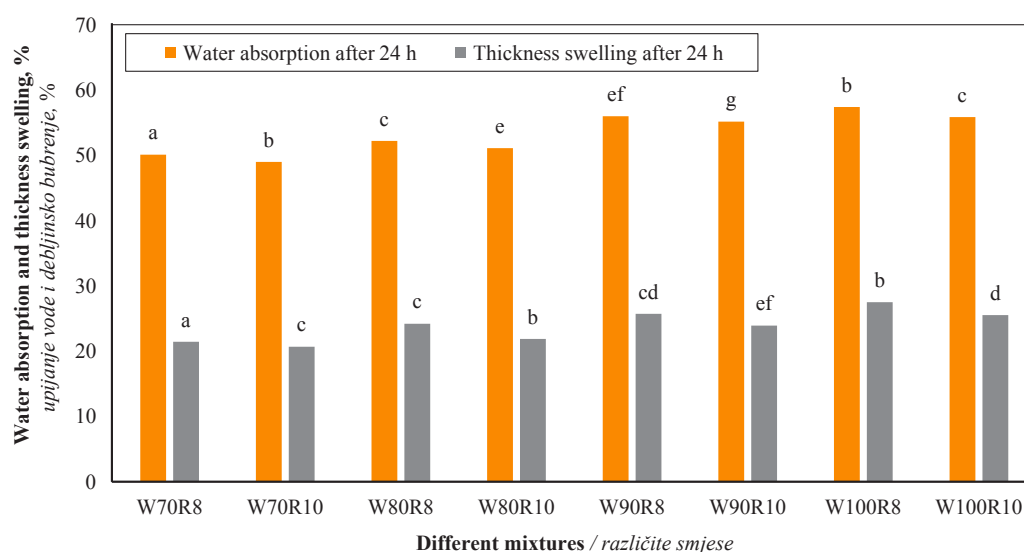
4. ZAKLJUČAK

The results showed that with increasing the resin content, the mechanical properties of the boards in-

Table 5 Results of variance analysis**Tablica 5.** Rezultati analize varijance

Parameter Parametar	Source of variance Izvor varijance	Degrees of freedom Stupnjevi slobode	Mean square Srednji kvadrat	F value	P Sig.
Water absorption after 24 h upijanje vode nakon 24 h	Mixture / smjesa	3	1461.200	13.537	0.000**
	Resin / smola	1	36.866	1.628	0.020*
	Mixture × Resin / smjesa × smola	3	162.156	0.028	0.023*
	Error / pogreška	16	1.297		
	Total / ukupno	23			
Thickness swelling after 24 h debljinsko bubrenje nakon 24 h	Mixture / smjesa	3	32.952	230.104	0.000**
	Resin / smola	1	17.665	123.352	0.000**
	Mixture × Resin / smjesa × smola	3	0.701	4.894	0.013*
	Error / pogreška	16	0.143		
	Total / ukupno	23			

*Significance at the level of 95 %, ** significance at the level of 99 % / *Značajno na razini od 95 %, **značajno na razini od 99 %

**Figure 5** The effect of different mixtures on board water absorption and thickness swelling**Slika 5.** Utjecaj različitih smjesa sirovine na upijanje vode i debljinsko bubrenje ploča

creased. Up to the level of 10 %, melamine-impregnated paper can act as a filler and improve the mechanical properties of boards; however, at higher contents (15 %), stress concentration results in a reduction in strength (Basboga *et al.*, 2016). With increasing the resin content and reducing the proportion of industrial wood particles, the physical properties of the boards decreased, as increasing the resin caused more fiber bonding and decreased water absorption. The amount of water absorption and thickness swelling of the boards decreased with reducing the proportion of industrial wood particles and increasing the amounts of pine wood, due to lower density and increased compression coefficient, and waterproofness of melamine paper waste.

According to the results obtained, boards containing 90 % industrial wood particles and 8 % resin (mixture W90R8) and boards containing 70 % and 80 % industrial wood particles and 10 % resin (mixture W70R10 and W80R10) can be used for general use (Type P1). In 10 % resin, the control sample (mixture W100R10) and 90 % industrial wood particles (mixture W90R10) can be used for interior fitments (Type P2). Considering that the aim is to reduce the amount of industrial wood particles and resin, boards containing 90 % industrial wood particles and 8 % resin (mixture W90R8) and boards containing 70 % industrial wood particles and 10 % resin (mixture W70R10) are recommended for Type P1 boards.

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