Pavlo Lyutyy, Pavlo Bekhta and Galyna Ortynska[1]

Lightweight Flat Pressed Wood Plastic Composites: Possibility of Manufacture and Properties

Lagane drvno-plastične kompozitne ploče: mogućnost proizvodnje i svojstva

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ABSTRACT • *Usually the conventional wood plastic composites (WPC) are produced with the densities of approximately 800-1000 kg/m^3. The possibility of manufacture and properties of the lightweight flat pressed WPC using expanded polystyrene was described in this study. The shredded recycled low density polyethylene (rLDPE), wood particles (WP) and expanded polystyrene (EPS) were used for making one-layer lightweight WPC boards (non-laminated and laminated). Bending strength (MOR), modulus of elasticity (MOE), tensile strength perpendicular to the plane of the board (IB) and thickness swelling after immersions in water for 2 hours (TS/2h) and 24 hours (TS/24h) of the lightweight WPC boards were evaluated. It was established that the EPS content and boards' density as well as the lamination process have a significant impact on the properties of lightweight WPC boards. Thus, it was found that the use of expanded polystyrene enables the production of lightweight WPC within a density range of 500-700 kg/m^3, which is almost twofold less than the density of the conventional WPC. The results of research have shown that the bending strength, modulus of elasticity and internal bond strength of non-laminated lightweight WPC boards meet the requirements (for lightweight particleboards) of EN 16368 (type LP1) and ANSI A208.1 (types LD-1 and LD-2) standards. The bending strength and modulus of elasticity of laminated lightweight WPC boards meet the requirements of ISO 13894-2.*

Keywords: *lightweight wood plastic composites, recycled low density polyethylene, expanded polystyrene, wood particles, lamination*

SAŽETAK • *Konvencionalni drvno-plastični kompoziti (WPC) obično se proizvode s gustoćom od približno 800 – 1000 kg/m^3. Tema ove studije jest mogućnost proizvodnje lakih WPC ploča proizvedenih dodatkom ekspandiranog polistirena i njihova svojstva. Za izradu jednoslojnih laganih WPC ploča (nelaminiranih i laminiranih) upotrijebljeni su: usitnjeni reciklirani polietilen niske gustoće (rLDPE), drvne čestice (WP) i ekspandirani polistiren (EPS). Istraživanjem su određena ova svojstva laganih WPC ploča: čvrstoća na savijanje (MOR), modul elastičnosti (MOE), vlačna čvrstoća okomito na ravninu ploče (IB) i debljinsko bubrenje nakon uranjanja ploča u vodu u trajanju 2 sata (TS/2 h) i 24 sata (TS/24 h). Utvrđeno je da udio EPS-a i gustoća ploča, kao i proces laminiranja imaju značajan utjecaj na svojstva laganih WPC ploča. Tako je utvrđeno da upotreba ekspandiranog polistirena omogućuje proizvodnju laganih WPC ploča u rasponu gustoće 500 – 700 kg/m^3, što je gotovo dvostruko manje od gustoće konvencionalnih WPC ploča. Rezultati istraživanja pokazali su da čvrstoća na savijanje, modul elastičnosti i čvrstoća unutarnje veze nelaminiranih laganih WPC ploča udovoljavaju zahtjevima (za lagane ploče*

[1] Authors are professors at Department of Wood-Based Composites, Ukrainian National Forestry University, Lviv, Ukraine.
[1] Autori su profesori Odjela za drvne kompozitne materijale, Ukrajinsko nacionalno šumarsko sveučilište, Lviv, Ukrajina.

iverice) standarda EN 16368 (tip LP1) i ANSI A208.1 (tip LD-1 i LD-2). Čvrstoća na savijanje i modul elastičnosti laminiranih laganih WPC ploča udovoljavaju zahtjevima norme ISO 13894-2.

Ključne riječi: *lagani drvno-plastični kompoziti, reciklirani polietilen niske gustoće, ekspandirani polistiren, drvne čestice, laminiranje*

1 INTRODUCTION
1. UVOD

Wood plastic composites (WPC) can be used in different sectors of economy and are produced by different methods: extrusion, injection and compression moulding, etc., which depends on the configuration forms of the products and the field of their use (Niska and Sain, 2008). They are characterized by good performance properties and could be considered as the "green composites" (Lyutyy *et al*., 2017). One of the disadvantages of the WPC is their high density in comparison with other conventional wood based composites, such as particleboards and medium density fibreboards (MDF). The density of the conventional flat pressed WPC is approximately about 800-1000 kg/m^3 (Lyutyy *et al*., 2014), the density of MDF and particleboards is approximately about 650-750 kg/m^3. It is well known that high density composite materials have some disadvantages: rapid tool wear, material and transportation costs, handwork, high weight of construction. In this regard, the high density WPC is difficult to compare with particleboards and MDF.

The development of lightweight boards has been dictated by the fast-growing market of knockdown furniture, the shortage of raw material and the need to reduce costs in the wood-based composites industry, customers' packaging and transportation demands (Barbu and Van Riet, 2008). As a matter of fact, these trends draw attention towards both the use of so far underutilized resources and the innovation of new products and production concepts which increase the resource efficiency (Eder *et al*., 2010). Nevertheless, during recent decades all strategies, which are used for the reduction of board density, can be segregated in three major groups: technology, materials and sandwich concept (Shalbafan, 2013).

Low matt-furnish compaction is one of the strategies to produce low or ultra-low density fibreboards with the density of about 55 kg/m^3 without applying any pressing pressure (Yongqun *et al.*, 2011). Mechanical properties of such boards still remain low in comparison with MDF due to their extremely low density. However, those boards can provide low thermal conductivity and thus could be considered as good building insulation materials (Yongqun *et al.*, 2011).

The tubular extrusion technology is another way to manufacture low density wood based boards (Kollmann *et al.,* 2013), but the bending strength (*MOR*) of those boards is unsatisfactory. Different foamable polystyrene and already foamed polystyrene particles could be used for the production of wood based boards with the density that varies from 200 to 600 g/m^3 (BASF, 2012).

Moreover, lightweight wood based boards (density of 400 kg/m^3) could be produced by using different raw materials, for example, by replacing wood particles and fibres by low weight agricultural particles: hemp, kenaf, sunflower, maize, rape, miscanthus, topinambur (Balducci *et al.,* 2008). Unfortunately, the bending strength of lightweight boards made from annual/perennial farm plants does not meet the requirement of EN 312 (2010) type P2 (Balducci *et al.,* 2008).

Another way to make low density composites is the use of different foam-type resins. The foam-type urea-formaldehyde (UF) resins were prepared by mixing three kinds of foaming agents with UF resin for the production of lightweight MDF with the density of 600 kg/m^3 (Wen *et al.,* 2014). Such MDF showed satisfactory mechanical properties and dimensional stability.

The largest strategy for the production of lightweight wood based composites is the sandwich concept. Different materials, such as honeycomb (Thoemen *et al.,* 2007), foam core (Shalbafan 2013), and profiled spacers (webs) (Nilsson *et al*., 2013), could be used for the middle layer of the sandwich boards. However, honeycomb sandwich boards are acceptable for the manufacture of the boards with thickness higher than 25 mm (Cremonini *et al*., 2008).

Some researchers make combinations of different strategies to reduce density of boards. The usage of expanded polystyrene and rape straw for the manufacture of lightweight particleboards was one of them (Dziurka *et al*., 2013; Dziurka *et al*., 2015). Those studies showed that lightweight wood chip-rape straw particleboards, substituted in the core layer with 10 % expanded polystyrene, meet the requirements of the relevant European standard (EN 312, 2010) for P2 boards, concerning their bending strength, modulus of elasticity and tensile strength perpendicular to their planes. Another advantage of that type of boards is their high-water resistance.

Unfortunately, most of the methods mentioned above cannot be used to produce lightweight flat pressed WPCs. The production of WPCs having a density similar to the one of particleboard or MDF could greatly expand their field of application. However, to the best of the author's knowledge, no study has been reported in literature concerning the manufacture and properties of lightweight WPCs. Therefore, the objective of this study was to investigate the possibility of the manufacture and properties of lightweight flat pressed wood plastic composites using expanded polystyrene.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

In this study, the particles of laboratory shredded recycled low density polyethylene (rLDPE) and wood particles (WP) with moisture content of 2-3 % commercially produced for particleboard mill, and expanded polystyrene (EPS) were used for making WPC boards. The rLDPE particles were used as the polymer

Table 1 Fraction analysis (by % weight)
Tablica 1. Granulometrijska analiza (udio frakcija izražen postotcima 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
WP	4.75	12.2	15.79	40.28	15.67	9.13	2.18
rLDPE	9.53	3.04	53.14	32.45	1.83	-	-

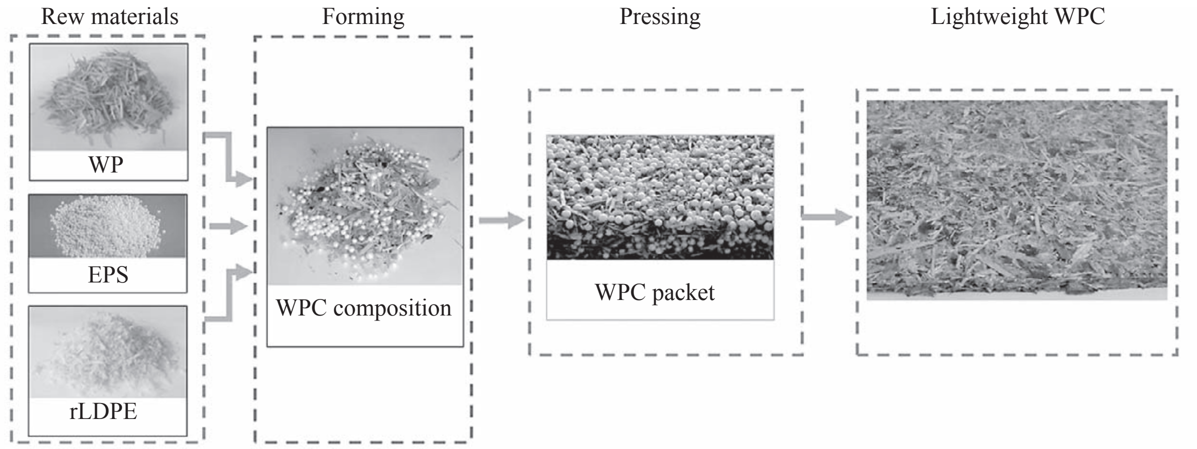


Figure 1 Manufacturing process of non-laminated one-layer lightweight WPC boards
Slika 1. Proces proizvodnje nelaminiranih jednoslojnih laganih WPC ploča

matrix. The melting point of LDPE is in a range of 105-115 °C (Tice, 2003). The rLDPE and WP particles fraction analysis is presented in Table 1. The diameter of EPS granules was 2-4 mm and the bulk density was in the range from 6 to 10 kg/m^3. High pressure laminate (HPL) with the thickness of 0.5 mm was used for the lamination of lightweight WPC boards.

Two types of one-layer lightweight WPC boards were manufactured: non-laminated and laminated. The ratio of WP to rLDPE was 60:40. The EPS content was about 1, 2 and 3 % of the weight of the WP/rLDPE composition. No adhesive was used due to the presence of 40 % polyethylene, which melts and acts as a bonding adhesive for the mat particles.

The manufacture of non-laminated lightweight WPC boards

WP, rLDPE and EPS (in the natural dry state) were mixed by hand for 10 minutes. The mat of WPC composition was formed into the open form and afterwards transferred to the hot press (Figure 1).

The manufacture of laminated lightweight WPC boards

The back sheet of HPL was put into open press-form. The mixing of WPC composition (wood parti-

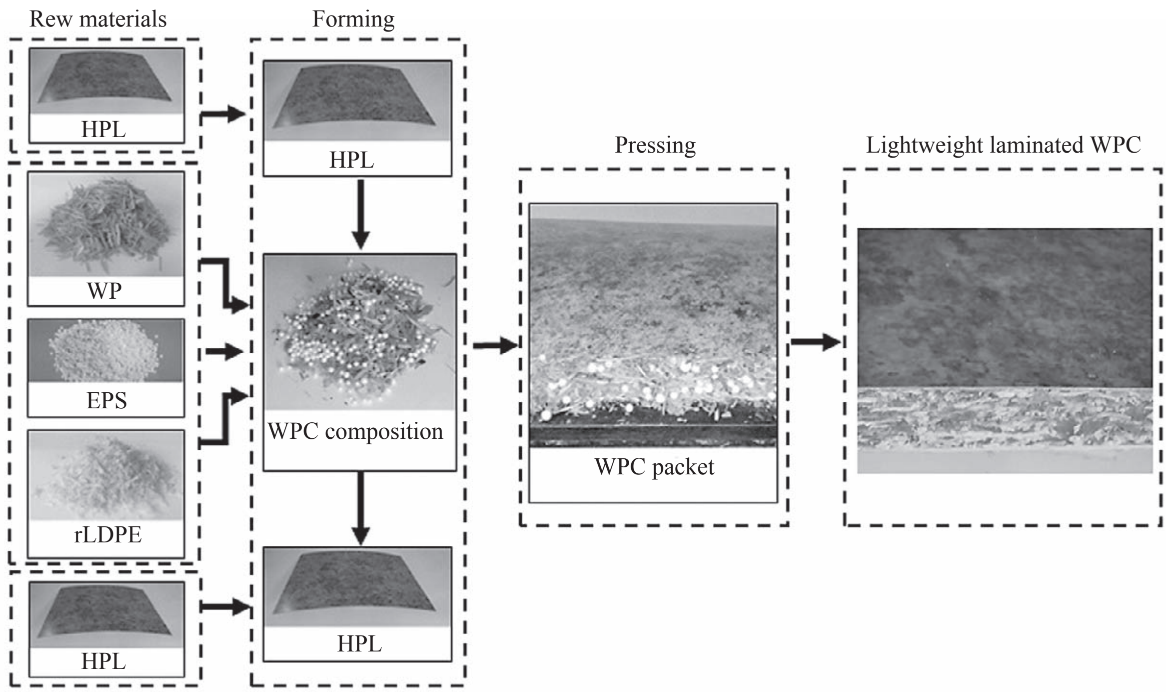


Figure 2 Manufacturing process of laminated one-layer lightweight WPC boards
Slika 2. Proces proizvodnje laminiranih jednoslojnih laganih WPC ploča

cles/rLDPE/EPS) was made in the same way as for non-laminated one-layer lightweight WPC boards. Then WPC composition was formed on HPL sheet and laminated by face HPL sheet (Figure 2). The WPC packets were hot pressed under the pressure of 3.5 MPa at the temperature of 180 °C for 1 min/mm in a one-step process. At the end of the hot-pressing cycle, the WPC board was immediately moved from the hot press into the cold press at the temperature of 20 °C for cooling to the temperature of 30-40 °C. The WPC boards with 8 mm thickness were trimmed to a final size of 250 mm × 230 mm. The target densities of lightweight WPC boards were of 500, 600 and 700 kg/m^3. The WPC boards with the same target density but without EPS (control board) were manufactured with the same pressing parameters.

Finally, the manufactured WPC boards were conditioned in a climate room with the relative humidity of 65 ± 5 % and the temperature of 20 ± 2 °C before being cut into test specimens.

The bending strength (*MOR*), modulus of elasticity (*MOE*), tensile strength perpendicular to the plane of the board (or internal bond) (IB) and thickness swelling after immersions in water for 2 hours (TS/2h) and 24 hours (TS/24h) of the lightweight WPC boards were evaluated according to the standard EN 310 (1993), EN 319 (1993) and EN 317 (1993), respectively.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Statistical analysis of variance (ANOVA) was conducted to determine whether there was a significant difference between the mechanical and physical properties of lightweight WPC with EPS content and density of boards (Table 2 and 3). It was found that significant difference existed among all properties of the samples made with different EPS content and density of board. ANOVA showed that the content of EPS, board density and lamination of lightweight WPC significantly influenced the board properties.

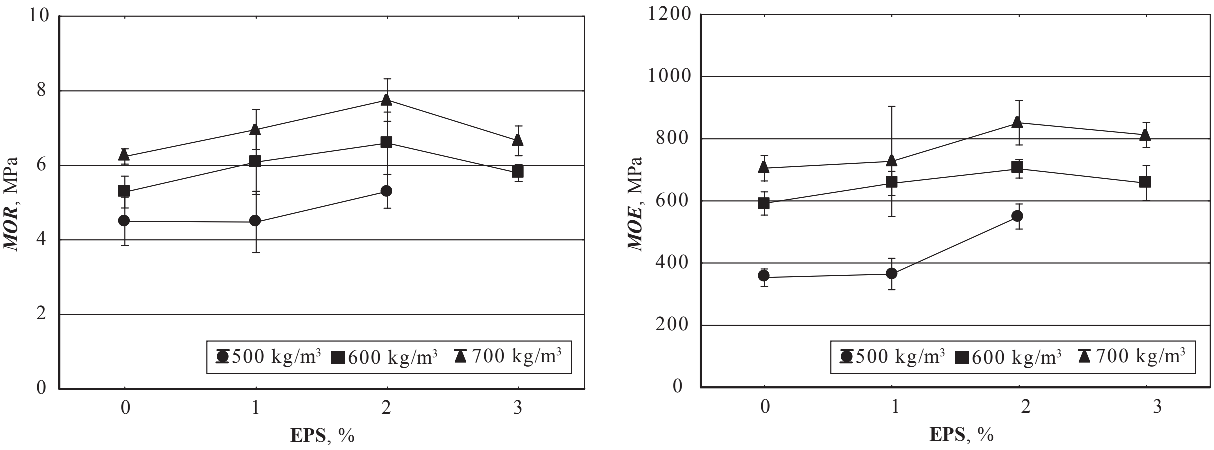
The highest values of *MOR* and *MOE* were observed in lightweight WPC boards with 2 % EPS content (Figure 3). The increase of EPS content leads to the increase of the volume and quantity of EPS granules in the WPC composition. The bulk density of EPS is very low and the EPS content is higher than 2 %. There were many weak bonds between the EPS granules in the board, and they had low adhesive strength. The proof of this could be the decrease of IB at the EPS content of

Table 2 Test results of Two-Way ANOVA for properties of non-laminated lightweight WPC samples (α=0.05)
Tablica 2. Rezultati dvosmjerne ANOVA analize svojstava nelaminiranih laganih WPC ploča (α = 0,05)

Source *Izvor varijacije*	**Dependent variable** *Zavisna varijabla*	**Sum of Squares** *Zbroj kvadrata*	***df*** *Stupanj slobode*	**Mean Square** *Srednja vrijednost kvadrata*	***F***	**Sig.**
EPS *ekspandirani polistiren*	*MOR*	13.027	3	4.342	19.437	.000
	MOE	212455.562	3	70818.521	34.469	.000
	IB	.070	3	.023	7.737	.000
	TS/2h	136.068	3	45.356	31.137	.000
	TS/24h	383.207	3	127.736	31.181	.000
Density *gustoća*	*MOR*	43.990	2	21.995	98.458	.000
	MOE	980173.873	2	490086.937	238.538	.000
	IB	.118	2	.059	19.564	.000
	TS/2h	154.526	2	77.263	53.041	.000
	TS/24h	106.047	2	53.024	12.943	.000
EPS × Density *ekspandirani polistiren × gustoća*	*MOR*	1.299	5	.260	1.163	.341
	MOE	31220.242	5	6244.048	3.039	.018
	IB	.015	5	.003	.968	.443
	TS/2h	28.019	5	5.604	3.847	.005
	TS/24h	8.455	5	1.691	.413	.838

Table 3 Test results of Two-Way ANOVA for properties of laminated lightweight WPC samples (α=0.05)
Tablica 3. Rezultati dvosmjerne ANOVA analize svojstava laminiranih laganih WPC ploča (α = 0,05)

Source *Izvor varijacije*	**Dependent variable** *Zavisna varijabla*	**Sum of Squares** *Zbroj kvadrata*	***df*** *Stupanj slobode*	**Mean Square** *Srednja vrijednost kvadrata*	***F***	**Sig.**
EPS *ekspandirani polistiren*	*MOR*	174.546	2	87.273	36.129	0.000
	MOE	1127864.486	2	563932.243	13.752	0.000
	TS/24h	58.386	2	29.193	19.205	0.000
Density *gustoća*	*MOR*	561.082	2	280.541	116.136	0.000
	MOE	2806866.400	2	1403433.200	34.224	0.000
	TS/24h	41.623	2	20.812	13.692	0.000
EPS × Density *ekspandirani polistiren × gustoća*	*MOR*	11.665	4	2.916	1.207	0.332
	MOE	1038309.607	4	259577.402	6.330	0.002
	TS/24h	4.144	4	1.036	0.682	0.611



a) b)

Figure 3 The influence of EPS content and density of board on *MOR* (a) and *MOE* (b) of non-laminated lightweight WPC boards
Slika 3. Utjecaj sadržaja ekspandiranog polistirena i gustoće nelaminiranih laganih WPC ploča na (a) *MOR* i (b) *MOE*

more than 2 % (Figure 4). The values of *MOR* and *MOE* were also reduced when the EPS content was less than 2 %. It can be explained by the low content of the EPS and the existence of some voids in WPC, which lead to the decrease of *MOR* and *MOE* values.

The increase of board density from 500 to 700 kg/m^3 leads to a significant increase of *MOR*/*MOE* of 1.44/1.81 times, as well as the increase of *IB* values of 1.5 times. Another important moment is that the mean deviation from *IB* average values increased with the increase of EPS content. The EPS granules statically attracted each other during the formation and mixing of WPC composition. That is why, the increasing of EPS content leads to generate a zone with a high content of EPS, which has different *IB* values. It is, therefore, necessary to add antistatic agent to the composition (BASF, 2012).

However, it should be mentioned that the values of *MOR*, *MOE* and *IB* of the investigated WPC boards were a little bit lower when compared to the values in other lightweight wood based boards (at the same density). For example, the *MOR*/*MOE* values of the wood chip-expanded polystyrene particleboards at the target density of 500 kg/m^3 were 10.1/2080 MPa (Dziurka *et al*., 2015). However, in that work, the particleboards were manufactured with melamine-urea-formaldehyde resin, which is intended for the manufacture of waterproof wood-based materials. Similar results concerning the values of *MOR* and *MOE* were also observed in the work (Shalbafan *et al*., 2016). The *MOR* values of the boards (with density of 500 kg/m^3) were almost identical but the *MOE* values were a little bit higher. This can be explained by the fact that Shalbafan *et al*., (2016) used UF resins and three-layered structure of particleboards. Moreover, the EPS granules were only used in the core layer (not in the face layers), and, therefore, the face layers have higher density than the core layer. It is well known that the face layers are most loaded during bending test. Also, the rLDPE particles are not able to provide the same rigidity and adhesive strength with wood particles as with UF resins. That is why the values of *MOE* could be a little bit lower for the investigated lightweight WPC boards when compared to UF particleboards.

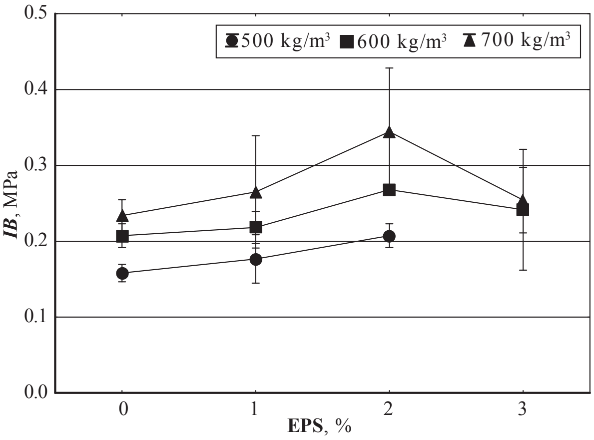


Figure 4 The influence of EPS content and density of board on IB of non-laminated lightweight WPC boards
Slika 4. Utjecaj sadržaja ekspandiranog polistirena i gustoće nelaminiranih laganih WPC ploča na čvrstoću unutarnje veze

The values of TS/2h and TS/24h of the lightweight WPC boards are improved with the increasing of EPS content and board density (Figure 5). The EPS is an inert material to the impact of water and does not swell too much during the immersion in water. In our case, only one component (wood particles) of the WPC composition had significant effect on the TS/2h and TS/24h. The increase of EPS granules content accordingly leads to the reduction of wood particles content and gives higher water resistance to the lightweight WPC boards (low values of thickness swelling).

The increase of board density, as well as the EPS, leads to a closer contact between the wood particles and thermoplastic polymer. The increase of density also leads to the creation of a thermoplastic film on the surface of wood particles and prevents the interaction between the molecules of water and wood components that reduces thickness swelling (Lyutyy *et al*., 2014). The values of TS/24h of the investigated boards were

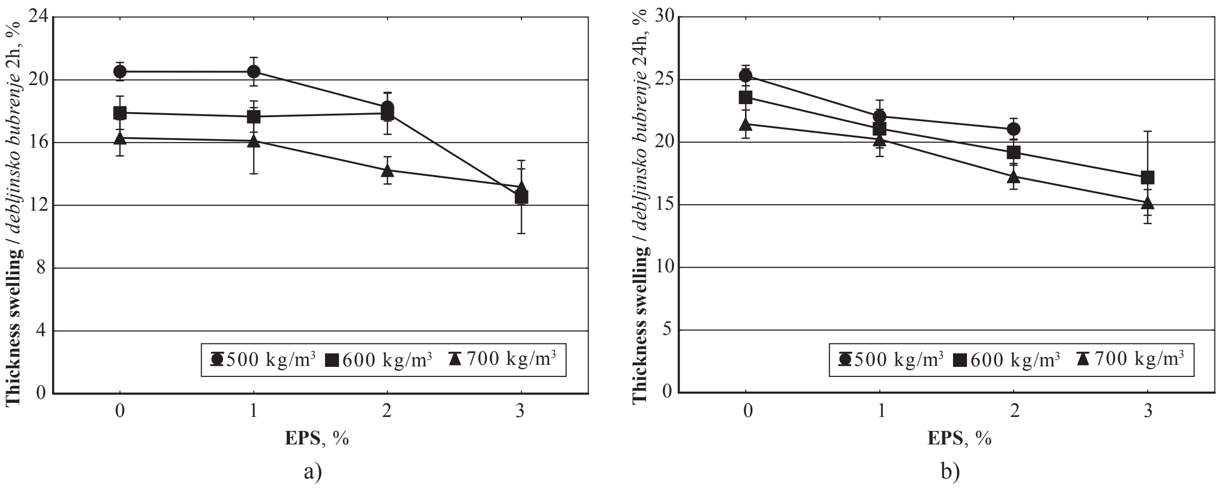


Figure 5 The influence of EPS content and board density on TS/2h (a) and TS/24 (b) of non-laminated lightweight WPC boards
Slika 5. Utjecaj sadržaja ekspandiranog polistirena i gustoće nelaminiranih laganih WPC ploča na (a) TS/2 h i (b) TS/24 h

lower in comparison with the values for wood chip-expanded polystyrene board and wood chip-rape straw-expanded polystyrene board (Dziurka *et al*., 2015). In contrast, the values of TS/2h and TS/24h of the investigated WPC boards were much higher than the values of the WPC boards made of milled foam core (Shalbafan *et al*., 2016). This can be explained by the higher (1.4-2.0 times) target density (1000 kg/m^3) of those boards when compared to the density of the investigated lightweight WPC boards.

The lightweight non-laminated WPC boards with 2 % EPS content could be classified as type LP1 (EN 16368, 2011), LD-1 and LD-2 (ANSI A208.1, 2009) (Table 4). The boards with 3 % EPS content do not comply with the EN and American norms regarding the values of *MOE*. According to ANSI A208.1 (2009), the investigated non-laminated boards could be used for door core. However, non-laminated WPC boards do not comply with the requirements of EN 312 (2010) conventional particleboards regarding mechanical (*MOE*, *MOR* and IB) and physical (TS/24h) properties. As a result, non-laminated lightweight WPC boards could be laminated by different materials such as HPL, MDF, HDF, and plywood for the improvement of their mechanical and physical properties (Jivkov *et al*., 2012).

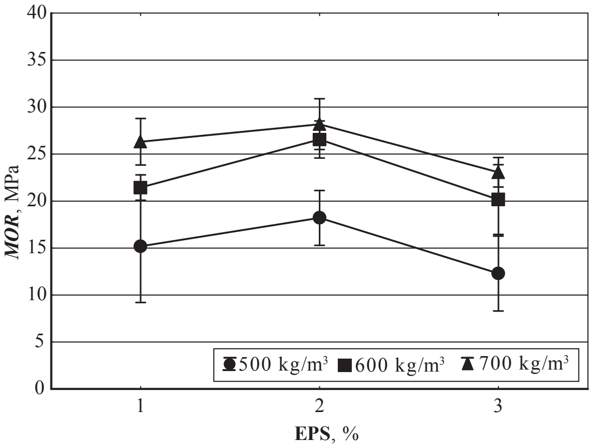
It was found that the lamination of lightweight WPC boards had a significant effect (Table 3) on *MOE* and *MOR* values. The influence of density and EPS content on *MOR* and *MOE* is shown in Figure 6. The highest values of *MOR* and *MOE* were observed for 2 % EPS content and board density of 700 kg/m^3.

Higher values of *MOR* and *MOE* were observed for the investigated laminated WPC boards in comparison with other lightweight particleboards (Shalbafan *et al*., 2016; Jivkov *et al*., 2012). Separately, the lowest *MOE* values of the investigated laminated boards (density of 500 kg/m^3 and EPS content of 3%) were 2.7 times higher than the values of the honeycomb panel commercially manufactured by Egger; and 3.86 times higher than the values of the five-layer board from

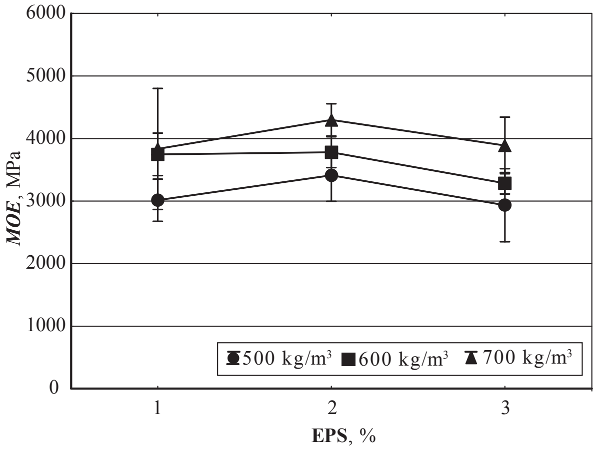
Table 4 Requirements for properties of lightweight particleboards and conventional particleboards according to EN standards
Tablica 4. Zahtjevi EN standarda za svojstva laganih ploča iverica i konvencionalnih ploča iverica

Board type / *Vrsta ploče*	***MOR* (*MOE*), MPa**	***IB*, MPa**	***TS/24h*, %**
Investigated non-laminated lightweight WPC boards *istraživane nelaminirane lagane WPC ploče*	4.3-7.7 (350-850)	0.16-0.34	15.51-25.51
Lightweight particleboards / *lagane ploče iverice* (EN 16368, 2011):			
LP1	4.0 (550)	0.28	-
LP2	8.0 (1000)	0.40	-
Particleboards / *ploče iverice* (EN 312, 2010):			
P1	10.5	0.28	-
P2	11.0 (1800)	0.4	-
P3	15.0 (2050)	0.45	17.0
Low density particleboards / *ploče iverice male gustoće* (ANSI A208.1, 2009)			
LD-1	2.8 (500)*	0.10**	-
LD-2	2.8 (500)*	0.14**	-

*According to test requirements, the width of specimens shall be 76 mm (instead of 50 mm in accordance with European standard) if the nominal thickness is greater than 6 mm; the length of span calculates with the same formula as in European and American standards. **The method of internal bond (IB) measurement in American standard complies with the relevant European standard.
** Ako je nominalna debljina ploča veća od 6 mm, prema zahtjevima ispitivanja, širina uzoraka mora biti 76 mm (umjesto 50 mm, prema Europskoj normi); duljina raspona izračunava se prema istoj formuli kao u europskim i američkim standardima. **Metoda mjerenja čvrstoće unutarnje veze (IB) u američkom standardu u skladu je s odgovarajućim europskim standardom.*



a)



b)

Figure 6 The influence of EPS content and board density on *MOR* (a) and *MOE* (b) of laminated lightweight WPC boards
Slika 6. Utjecaj sadržaja ekspandiranog polistirena i gustoće laminiranih laganih WPC ploča na (a) *MOR* i (b) *MOE*

EPS, MDF with thickness of 8 mm and HPL; 11.9 times higher than the values of the multi-layer board from MDF, five-layer corrugated cardboard and face layer from HPL; 1.3 times higher than the values of the multi-layer board from plywood and cardboard; 2.7 times higher than the values of the five-layer board from EPS, MDF with 4 mm thickness and face layer from HPL; 3.0 times higher in comparison with multi-layer board from three-layer corrugated cardboard and face layer from HPL (Jivkov *et al*., 2012). The same trend was observed for *MOR* values.

The TS/24h values of the laminated lightweight WPC boards (Figure 7) were reduced by 1.06-1.13 times compared to the values of non-laminated boards. The HPL has high water resistance and prevents water absorption by surface layers of WPC boards. Accordingly, it leads to the decrease of the thickness swelling of boards. However, it is well known that wood composites absorb liquid water to a much greater degree through the swollen edge than through the surface of boards. That is why the lamination of boards has not such significant effect on water resistance when compared to mechanical properties.

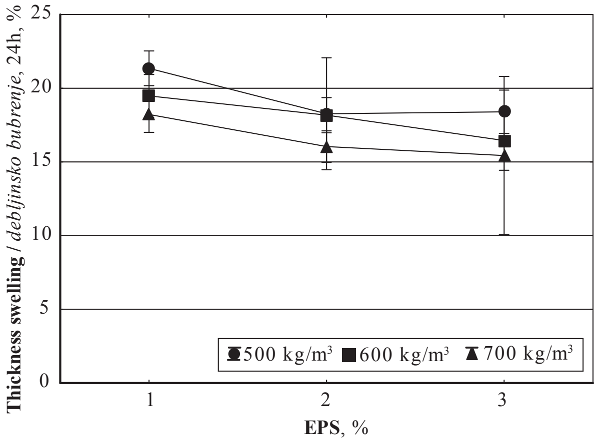


Figure 7 The influence of EPS content and board density on TS/24h of laminated lightweight WPC boards
Slika 7. Utjecaj sadržaja ekspandiranog polistirena i gustoće laminiranih laganih WPC ploča na debljinsko bubrenje nakon 24 h

It should be noted that *MOR* and *MOE* values of the investigated laminated WPC boards with 2 % content of EPS practically meet the requirements of ISO EN 13894-2 (2005). However, TS/24h values of the boards with the same EPS content do not comply with the requirements of this standard, being higher than 15 %. Laminated lightweight WPC boards meet TS/24h requirements according to this standard only for 3 % EPS content and board density of 700 kg/m³. According to ISO EN 13894-2 (2005), particleboards should be laminated by HPL with the thickness of 0.7 mm and bonded by UF resins. The thickness of HPL and type of resin have significant effect on the properties of boards. Moreover, the use of UF resins leads to the increase of formaldehyde emission, whereas the investigated lightweight WPC boards could be classified as E1 class according to EN 13986 (2015) without any testing. Therefore, the lightweight WPC boards made in the experiment are intended to substitute the traditional wood-based composites used in the furniture industry and door production.

4 CONCLUSIONS
4. ZAKLJUČAK

The outcome of this research demonstrates the possibility to manufacture lightweight wood plastic composites within the density range of 500-700 kg/m³ by flat pressing using expanded polystyrene. The EPS content, board density and lamination of lightweight WPC significantly influenced the board properties. The results of research have shown that the bending strength, modulus of elasticity and internal bond strength of non-laminated lightweight WPC boards meets the requirements (for lightweight particleboards) of EN 16368 (type LP1) and ANSI A208.1 (types LD-1 and LD-2). The values of bending strength and modulus of elasticity of the laminated lightweight WPC boards with 2 % content of EPS practically meet the requirements of ISO 13894-2. Moreover, the lightweight WPC boards made in the experiment could also be classified as E1 class according to EN 13986. Therefore, these lightweight WPC boards are intended as a possible substitute for traditional wood-based composites used in the furniture industry and door production. To increase the applications of lightweight WPC, future work is highly recommended to investigate the face and edge screw withdrawal resistance and the impact of various materials and processing factors on WPC performance.

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Corresponding address:

Prof. Ing. PAVLO BEKHTA, Dr.Sc.

Department of Wood-Based Composites, Cellulose and Paper umjesto Department of Wood-Based Composites
Ukrainian National Forestry University
Gen. Chuprynky 103
79057 Lviv, UKRAINE
e-mail: bekhta@ukr.net