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THE PROPERTIES OF REINFORCED LIGHTWEIGHT FLAT PRESSED WOOD PLASTIC COMPOSITES

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ABSTRACT

The properties of reinforced lightweight flat pressed wood plastic boards are examined in this study. The laboratory shredded low density polyethylene (rLDPE) particles, wood particles (WP) and expanded polystyrene (EPS) were used for making WPC boards. The fiberglass mesh and polypropylene fibers were used for reinforcing the lightweight WPC. The bending strength (MOR), modulus of elasticity (MOE), tensile strength perpendicular to the plane of the board (or internal bond - IB) and thickness swelling of reinforced lightweight WPC after immersions in water for 24 hours (TS) were evaluated. The results showed that the strength properties of WPC boards were improved with the addition of polypropylene fibers and fiberglass mesh. The fact that the values of MOR/MOE increased with adding the polypropylene fiber and fiberglass mesh by 11.6%/7.7% and 77.5%/51.3%, was found. The IB of lightweigth WPC reinforced with polypropylene fiber and fiberglass mesh increased up to 7.4% and 11.1% compared to unreinforced lightweight WPC. The TS was not affected by the addition of reinforcing materials. However, the obtained values of MOR, MOE, IB of the reinforced lightweight WPC meet the requirements of the standards EN 16368 and EN 312.

Key words: lightweight wood plastic composites, expanded polystyrene, fiberglass mesh, polypropylene fibers, reinforced materials.

INTRODUCTION

One of the problems of increasing the lightweight boards development is the shortage of raw material and the need to reduce costs in the wood-based composites industry. Also the fast-growing market of knockdown furniture, reduce material weight, customers' packaging and transportation demands leads to production of new products and production concepts which increase the resource efficiency without compromising the mechanical properties of the composites (BARBU and VAN RIET 2008).

The scientists have been working to develop the various methods (tendency) for reducing the density of wood composite materials, particularly those intended for the manufacture of furniture, such as particleboards and fibreboards. So, ultra-low density fiberboards with the density 55 kg/m^3 are produced without applying any pressing pressure (YONGQUN *et al.* 2011). But mechanical properties of ultra-low density fiberboards still remain low in comparison with medium density boards (MDF) due to their extremely low density.

Among the production techniques, extrusion is another way to manufacture of extruded low density particleboards (KOLLMANN *et al.* 1975). The density of such boards varies from 210 to 460 kg/m^3 according to "Sauerland-spanplatte" technical characteristic. But, the bending strength (MOR) of these boards is unsatisfactory. Also there were the researchers of using of different agricultural plants (hemp, sunflower, topinambur, maize and miscanthus) such as light particles for the production of lightweight particleboards. However the lightweight boards bending strength does not meet the requirement of EN 312 type P2 (BALDUCCI *et al.* 2008).

Different foamable polystyrene and already foamed polystyrene particles could be used for the production of lightweight flat pressed wood plastic composites (LYUTYY *et al.* 2018). But all investigated boards produced with different compositions do not comply with the requirements of EN 312. That's why the modification additives need to be added to the lightweight WPC for the manufacture of composites with more homogeneous properties.

Lightweight boards could be laminated by different materials such as high press laminate (HPL), MDF, high density fiberboard (HDF) and plywood for the improvement of their mechanical and physical properties (JIVKOV *et al*. 2012).

There have been different attempts to improve the physical and mechanical properties of flat pressed WPC boards namely using right size of raw material, optimum mixture and preparation of the elements in the WPC board or using reinforcement materials. Reinforcements for the composites can be fibers, fabrics particles or whiskers. The points to be noted in selecting the reinforcements include compatibility with matrix material, thermal stability, density, melting temperature etc. The efficiency of discontinuously reinforced composites is dependent on tensile strength and density of reinforcing phases (BLEDZKI *et al*. 2002). Flat pressed WPC boards were surface-reinforced by two different types of thermoplastic face layers [a commingled fabric made of glass and polypropylene filaments (TWINTEX) and a glass fabric reinforced polypropylene laminate (S-TEX)] to improve flexural properties (SCHMIDT *et al*. 2013). The reinforced WPC boards exhibited greatly improved flexural properties, with MOE/MOR values up to nearly 10000/90 N/mm^2). RIZVI and SEMERALUL (2008) added 5% glass fibers to WPC specimen with varying amounts of wood fiber content and found significant improvement in bonding strength and modulus of elasticity. Improvement of MOR and MOE up to 60% was achieved by applying the reinforcement on both surfaces of the WPC deck boards.

Nowadays, there is very little research on the the reinforcing of WPCs and no study has been reported concerning the reinforcing of lightweight WPCs. But lightweight WPCs still suffer from lack of strength and toughness, which can be improved by adding of reinforcement materials. Therefore, the objective of this study was to investigate the possibility of improvement of mechanical properties of lightweight flat pressed wood plastic composites by reinforcement materials using.

MATERIALS AND METHODS

The WPC boards were made using laboratory shredded recycled low density polyethylene (rLDPE) and wood particles (WP) with moisture content of 2-3 % and expanded polystyrene (EPS). The WP were commercially produced for particleboard mill. The rLDPE particles were used as the polymer matrix. The fraction analysis of rLDPE and WP particles is presented in Table 1. The properties of EPS granules were as follows: diameter – 2–4 mm; the bulk density – in the range from 6 to 10 kg/m^3. The fiberglass mesh A-125 (Fig. 1, a) and polypropylene fibers HLV-52 (Fig. 1,b) were used for reinforcing lightweight WPC. The density of the polypropylene fibers HLV-52 was 91 g/cm^3; melting temperature

– 160 °C; fibers length - 12 mm and fibers diametr – 18 microns. The density of fiberglass mesh A-125 was 0.125 kg/m^3; mesh thickness – 0.47 mm; cell size – 4×5 mm.

The ratio of WP to rLDPE was 60:40. The content of EPS was 2 % from the weight of the WP/rLDPE composition.

Tab. 1 Fraction analysis (by % weight).

Components	Screen hole size (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	–	–

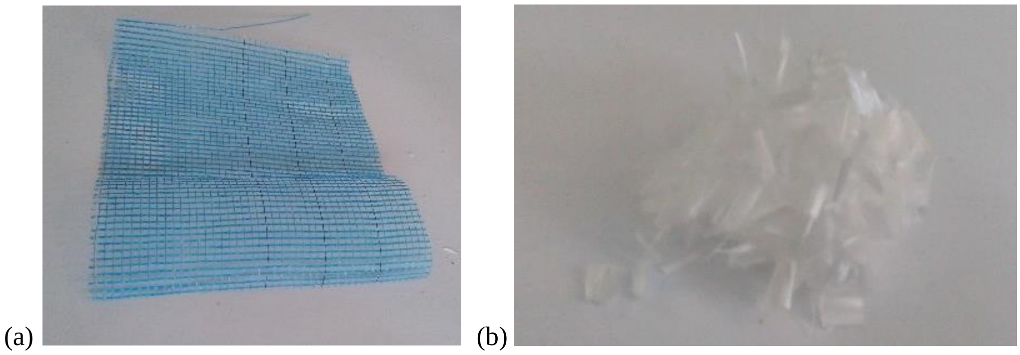


Fig. 1 Reinforcing materials: (a) – fiberglass mesh; (b) – polypropylene fibers.

The manufacture of lightweight WPC boards reinforced by polypropylene fibers. The content of polypropylene fibers was 7.5% from the weight of the WP/rLDPE composition. WP, rLDPE, EPS and polypropylene fibers (in the natural dry state) were mixed by hand during 10 minutes. The WPC composition was formed into the packet at the open form and thereafter the packet was transferred into hot press (Figure 2).

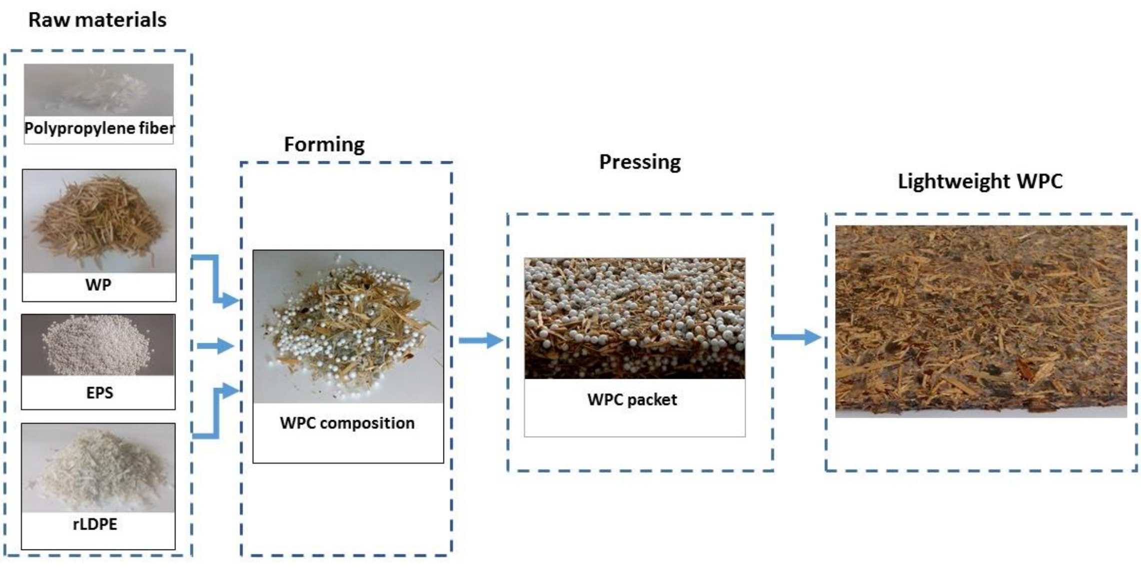


Fig. 2 Manufacturing process of lightweight WPC boards reinforced by polypropylene fibers.

The manufacture of lightweight WPC boards reinforced by fiberglass mesh. After mixing of WPC composition (WP/rLDPE/EPS), it was divided into three equal parts. Then first part was formed in the open press form and fiberglass mesh was putted above.

Whereupon was formed middle layer and above was formed fiberglass mesh and the last layer of WPC composition (Figure 3).

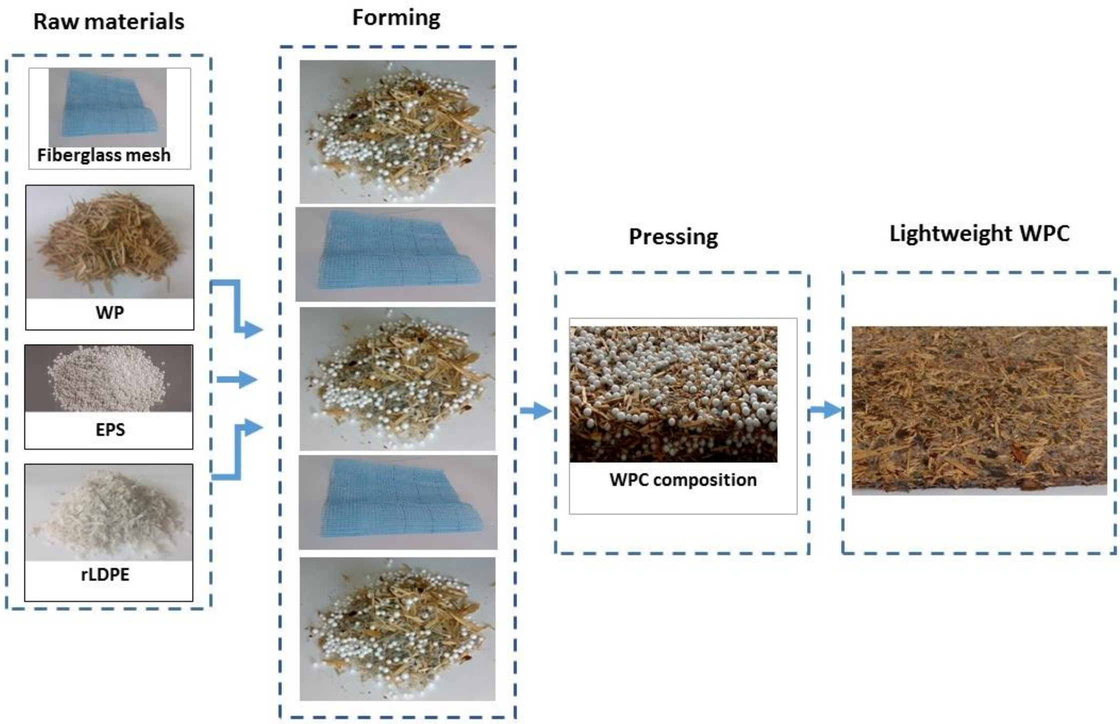


Fig. 3 Manufacturing process of lightweight WPC boards reinforced by fiberglass mesh.

The WPC packets were hot pressed under pressure 3.5 MPa at temperature 180 °C and duration 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 with the temperature 20 °C for the cooling to the temperature 30–40 °C. WPC boards with 8 mm thickness were trimmed to a final size of 250 × 230 mm. The target densities of lightweight WPC boards were 600 kg/m^3. WPC boards with the same target density but without reinforced materials were manufactured at the same pressing parameters.

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

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 24 hours (TS) of the lightweight WPC boards were evaluated according to EN 310, EN 317 and EN 319 standards respectively.

RESULTS AND DISCUSSION

Statistical analysis of variance (ANOVA) was conducted to determine whether there was a significant difference between mechanical and physical properties of reinforced lightweight WPC with type of reinforcing material (Table 2). It was found that the type of reinforcing material significantly influenced the mechanical properties but had no effect on the thickness swelling of WPC boards. The greatest effect on the MOR, MOE and IB values was observed for the fiberglass mesh.

Tab. 2 The test results of ANOVA for properties of reinforced lightweight WPC samples (α=0.05).

Source	Dependent variable	Sum of Squares	df	Mean Square	F	Sig.
Type of additive	MOR	206.647	2	103.323	208.649	.000
	MOE	702736.000	2	351368.000	150.738	.000
	IB	.004	2	.002	36.580	.000
	TS	19.043	2	9.521	1.352	.283

The highest values of MOR and MOE were observed in lightweight WPC boards with using fiberglass mesh (Figure 4). The fiberglass mesh create more structural construction of the composition. The use of polypropylene fibers did not allow to create homogeneous and completely correct placement of fibers in the composite. As a confirmation of this the E-glass fiber for two different fiber lengths (5 and 10 mm) were used (ASHRAFI *et al*. 2011). Fiber reinforcement did not have significant effect on the elastic modulus of WPC. However, the flexural strength of WPC reinforced with E-glass fibers is considerably lower than the unreinforced one. Again, the presence of fibers does not have significant effect on the elastic modulus, while even 5% addition of fibers results in significant reduction in the flexural strength of WPCs. Orientation of the fibers in the direction of the load is critical for enhancing the mechanical properties of composites (ASHRAFI *et al.* 2011).

However, it was difficult to form a packet where all the reinforced fibers will be directed perpendicular to the load action. That's why the values MOR and MOE were significantly higher in lightweigth composites with fiberglass mesh in composition. The MOR of WPC reinforced with fiberglass mesh is considerably higher than the unreinforced one. Any way, the using of fiberglass mesh and polypropylene fibers leads to increase of MOR and MOE. In particular, the values of MOR/MOE increased by 11.6%/7.7% and 77.5%/51.3%, recpectively with adding of polypropylene fiber and fiberglass mesh.

Figure 5(a) shows the effect of the type of reinforcing materials on the IB of lightweight WPC. It was found that the IB of lightweight WPC reinforced with fiberglass mesh significantly increases up to 11.1% and reinforced with polypropylene fiber increases up to 7.4 % in comparison with control.

Reinforcement with fiberglass mesh and polypropylene fibers did not have a significant effect on TS (Figure 5(b)). The values of TS for control and TS for reinforced composites are approximately on the same level.

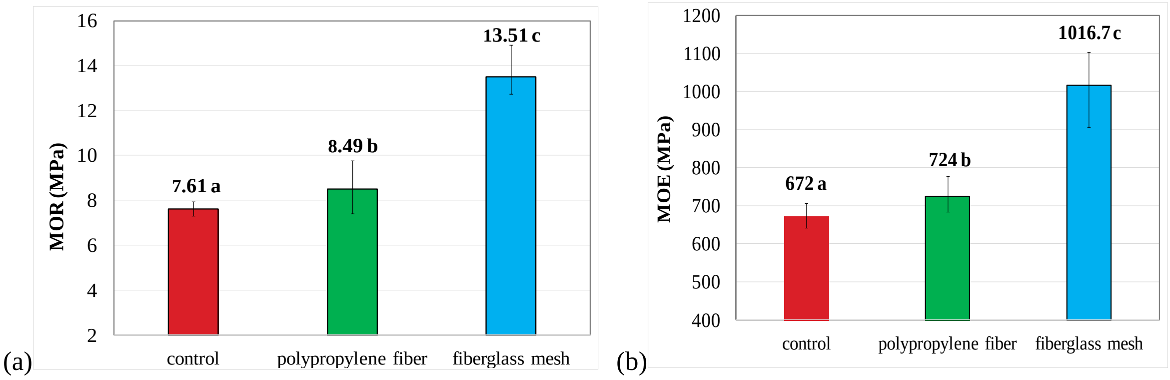
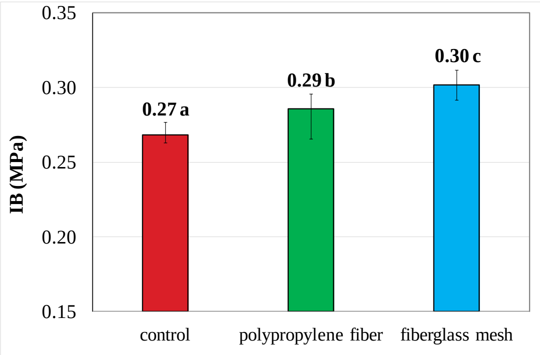
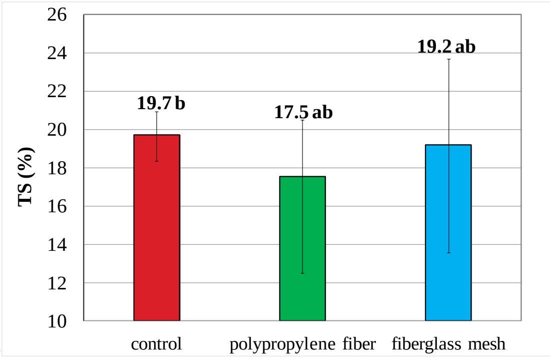


Fig. 4 The influence of the type of reinforcing material on the MOR (a) and MOE (b) of lightweight WPC boards. (Vertical bar: standard deviation; means followed by different letter denotes that they are statistically different according to the Duncan test at α=0.05).



(a)



(b)

Fig. 5 The influence of the type of reinforcing material on the IB (a) and TS (b) of lightweight WPC boards. (Vertical bar: standard deviation; means followed by different letter denotes that they are statistically different according to the Duncan test at α=0.05).

Lightweight WPC boards with polypropylene fibers could be classified as type LP1 (EN 16368), LD-1 and LD-2 (ANSI A208.1) (Table 3). However, boards with fiberglass mesh also meet the requirements LP2 (EN 16368) P1 (EN 312) and do not comply with the P2 (EN 312) norms regarding to the values of MOE. According to ANSI A208.1 the investigated WPC boards could be used as the door core.

Tab. 3 The requirements to the properties of lightweight and conventional particleboards according to EN standards and their comparison with the investigated reinforced lightweight WPC boards.

Board Type	MOR/MOE (MPa)	IB (MPa)	TS (%)
Reinforced lightweight WPC boards:			
Polypropylene fiber	8.49 / 724	0.29	17.5
Fiberglass mesh	13.51 / 1016.7	0.30	19.2
Control lightweight WPC boards	7.61 / 672	0.27	19.7
Lightweight particleboards (EN 16368):			
LP1	4.0 / 550	0.28	-
LP2	8.0 / 1000	0.40	-
Particleboards (EN 312):			
P1	10.5	0.28	-
P2	11.0 / 1800	0.40	-
P3	15.0 / 2050	0.45	17.0
Low density particleboards (ANSI A208.1)			
LD-1	2.8 / 500	0.10	-
LD-2	2.8 / 500	0.14	-

CONCLUSIONS

The using of polypropylene fibers and fiberglass mesh creates the possibility of producing reinforced lightweight WPC boards in the laboratory scale. The influence of the type of reinforcing material on the properties of lightweight WPC boards was studied. The values of MOR/MOE increased by 11.6%/7.7% and 77.5%/51.3%, recpectively with adding of polypropylene fiber and fiberglass mesh. It was found that the highest values of MOR and MOE were observed in lightweight WPC boards with using fiberglass mesh. The obtained values of TS of the reinforced composites and control lightweight WPC are not significantly different. Based on the obtained results, lightweight WPC boards with polypropylene fibers could be classified as type LP1 (EN 16368), LD-1 and LD-2 (ANSI A208.1). However, boards with fiberglass mesh also meet the requirements LP2 (EN 16368) P1 (EN 312). These positive results from the laboratory experiments give the base to plan experiments in industrial conditions.

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