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Influence of the filler on the density profile of wood polymer composites

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Abstract: ***Influence of the filler on the density profile of wood polymer composites***. WPC panels with HDPE matrix composites made in two stages were tested: 1 - obtaining WPC granulate using the extrusion method, 2 - production of panels by flat pressing in the form. As a filler, sawdust was used with two degrees of fineness (about 10 - 35 mesh and below 35 mesh) and three levels of content (40, 50 and 60%). In total, 6 panel variants were created for which the density and density profile in the cross-section were determined. It was found that panels with a filler content of 40% are characterized by a uniform flat density profile. The increase in filler content (up to 50 - 60%) affects the density reduction in the core zone of the panel. The density and density profile of panels from WPC composites does not depend on the size of the filler particles.

Keywords: WPC composite, sawdust, HDPE, density profile

INTRODUCTION

The density profile is an important indicator of the structural construction of wood-based panels, which is decisive for their suitability for a particular application. In relation to traditional particleboards or dry-formed fiberboard, density profile is an elementary factor that determines their properties (Niemz 1993, Wong et al.1998, 1999, 2003, Treusch et al. 2004), wherein the symmetry of said distribution relative to the center of the panels it is very important. Materials with unsymmetrical distribution of density in the cross-section are generally easily deformed, have reduced mechanical parameters as well as functional features. The "typical" course of the density profile in cross-section for standard wood based materials is in the form of a U-shaped curve. Wong et al. (1999) determined that the type of density distribution (uniform - flat, or U-shape) is a clear correlation with the basic properties of the particleboard such as MOR, MOE, or IB. The course of the density profile is the result of pressing process, more precisely the rate of thickening of mattress, as well as the resistance of wood particles included in the pressed material (Drouet 1992). The rate of thickening mattress is dependent upon the parameters of the pressing process - primarily temperature and pressure, however, increase in these factors causes greater differences in density over the cross section (Mabiala 1992).

In relation to WPC composites, it is generally assumed that their density is evenly distributed over the cross-section (uniform - flat density profile). However this largely depends on the uniformity of the distribution of the filler particles in the polymer matrix and their size. Klyosov (2007) reports that the lignocellulosic particles (wood flour, sawdust) in WPC composites are compacted during extrusion and have a density of about 1300 - 1500 kg/m3. At the same time, he states that the density of WPC composites does not depend on the size of the filler particles. On the other hand, Chen et al. (2006) report that larger size of wood particles decreases the average density of composites. Geimer et al. (1993) and Zajchowski et al. (2005) report that the increase in the share of wood contributes to the increase in the overall density of WPC composites. In the current research, there are no references to the density distribution on the thickness of WPC composites, in particular those produced by pressing methods. As part of this work, density profiles of WPC composites filled with particles of shredded sawdust were determined.

MATERIALS AND METHODS

Six variants of WPC composite panels (Table 1) based on HDPE (Hostalen GD 7255) as a polymer matrix and coniferous sawdust obtained from a saw-mill as a filler were used for the research. Sawdust was prepared in two size variants:

1. Particles passing through a 2 mm sieve (about 10 mesh) and remaining on a 0.44 mm sieve (about 35 mesh);
2. Particles passing through a 0.44 mm sieve (above 35 mesh).

Table 1. Characteristics of individual panels variants.

Variant	Composition - weight shares	
	matrix: HDPE	filler: sawdust
I	60 %	40 % particles 10 – 35 mesh
II	60 %	40 % particles above 35 mesh
III	50 %	50 % particles 10 – 35 mesh
IV	50 %	50 % particles above 35 mesh
V	40 %	60 % particles 10 – 35 mesh
VI	40 %	60 % particles above 35 mesh

Composites have been prepared in two steps:

- In the first stage WPC granules with the appropriate formulation were prepared (table 1) - with the Leistritz Nürnberg extruder (temperatures in the individual extruder sections were 170°C - 180°C) a continuous composite web was obtained, which was then ground on a hammer mill;
- in the second stage, panels of nominal size 300x300x2.5 mm^3 were produced from the obtained granulate by flat pressing in a mold, using a single-plate press at 200°C and maximum specific pressing pressure p_{max} = 1.25 MPa (pressure during pressing together with plasticizing the material was gradually increased by 0 to p_{max}). The pressing time was 6 minutes. After pressing on hot panels, they were cooled in a mold under pressure for 6 minutes in a cold press.

After production, the panels were conditioned for 7 days under laboratory conditions, and then samples were obtained from them for further testing. The density profile was determined on 50x50 mm^2 samples (3 for each variant) using the GreCon Laboratory Density Analyzer DA-X. During the test, the measurement speed was 0.05 mm/s, and the density measurement was made every 0.02 mm. In order to visualize the samples, microscopic photos were taken at 40x magnification using Hand USB Digital Microscope TPL 1.3 Mpix.

RESULTS AND DISCUSSION

Table 2 presents results of average density test for individual sample variants. The average density of tested composites was in range of 1024 - 1076 kg/m^3, while density of pure HDPE is 955 kg/m^3. The addition of a wood filler and its appropriate homogenization with a polymer matrix in the extruder (concentration and elimination of voids in the structure of wood particles) have therefore increased the density of WPC composites in relation to pure polymer (Geimer et al. 1993, Zajchowski et al. 2005, Klyosov 2007). There was also no influence of wood particle size on the density of WPC composites, which is in line with the data presented by Klyosova (2007). The observed differences in the average density are statistically insignificant. It should be noted, that visually differentiation of particle size in produced composites was still noticeable (Fig. 1), in particular due to the use of colorless HDPE as a matrix.

Table 2. The results of the density measurement of tested variants of WPC composite panels.

Variant	Density [kg/m^3]			SD* [kg/m^3]	COV** [%]
	min.	max.	average		
I	993	1053	1025	16	1.6
II	987	1060	1024	27	2.6
III	1014	1088	1035	22	2.1
IV	987	1117	1038	42	4.0
V	990	1048	1025	20	1.9
VI	1047	1122	1076	25	2.3

*STD – standard deviatin; **COV – Coefficient of Variation.

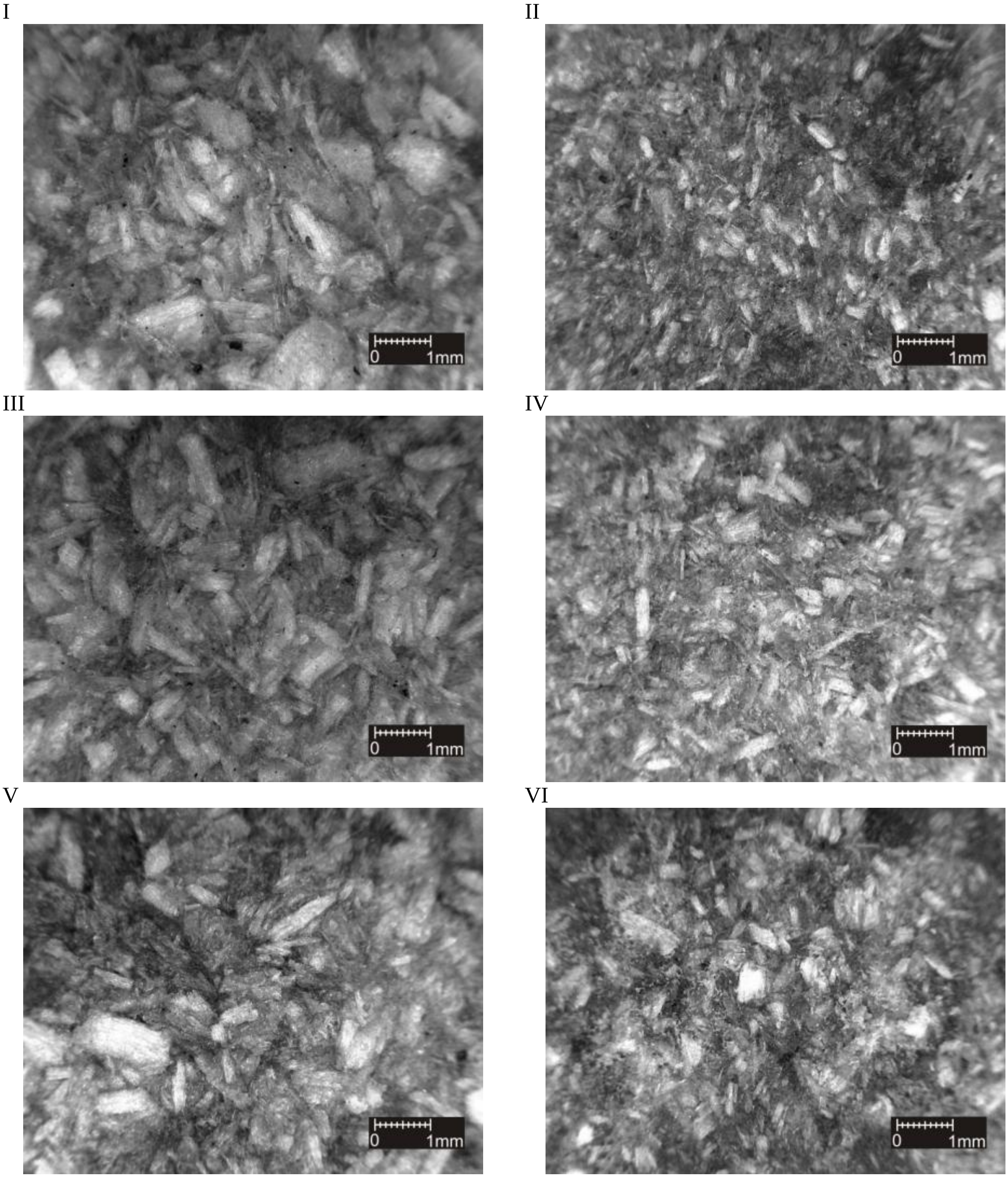
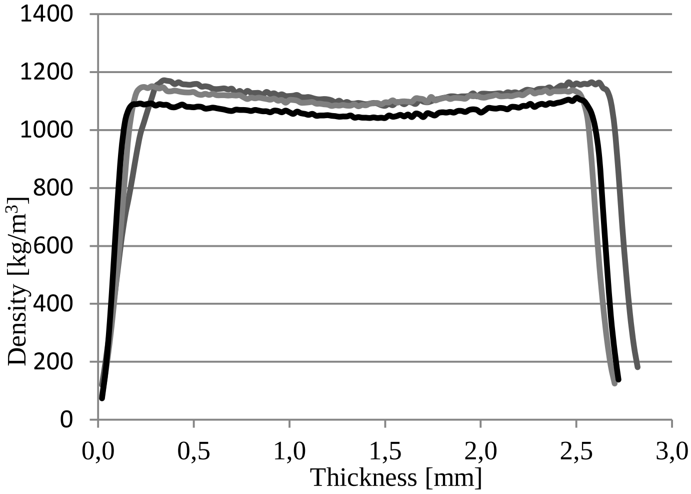


Figure 1. Images of the surface of samples of individual panel variants - visible wood particles in a colorless polymer matrix (magnification 40x).

Figures 2, 3, 4, 5, 6 and 7 present density profiles and cross-sections of tested variants. It can be concluded that the increase of lignocellulosic particles content changes density profile of panel. With a filler content of 40%, irrespective of the particle size (Figures 2 and 3), the panels are characterized by a uniform flat density profile. The variation in density of subsurface and core zones ranges from 2 to 88 kg/m^3.

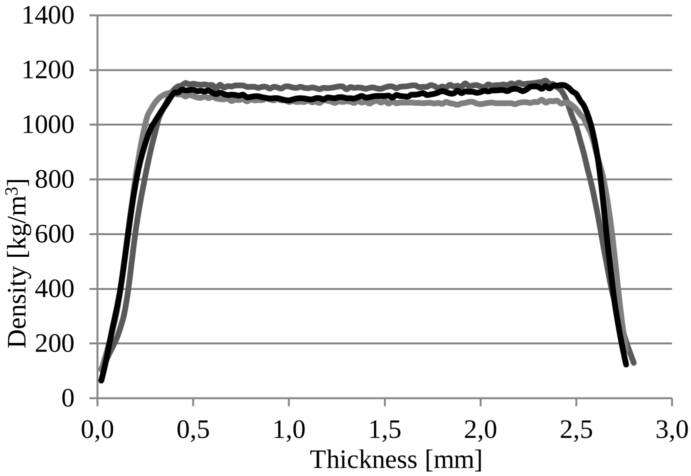
a)



b)

Figure 2. Panel variant I: a) composite density profiles, b) cross section of the panel.

a)



b)

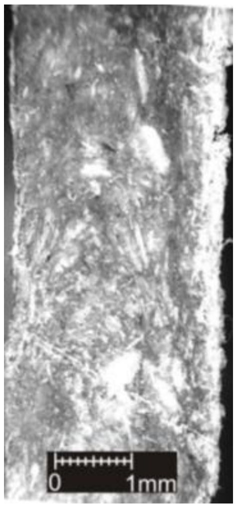


Figure 3. Panel variant II: a) composite density profiles, b) cross section of the panel.

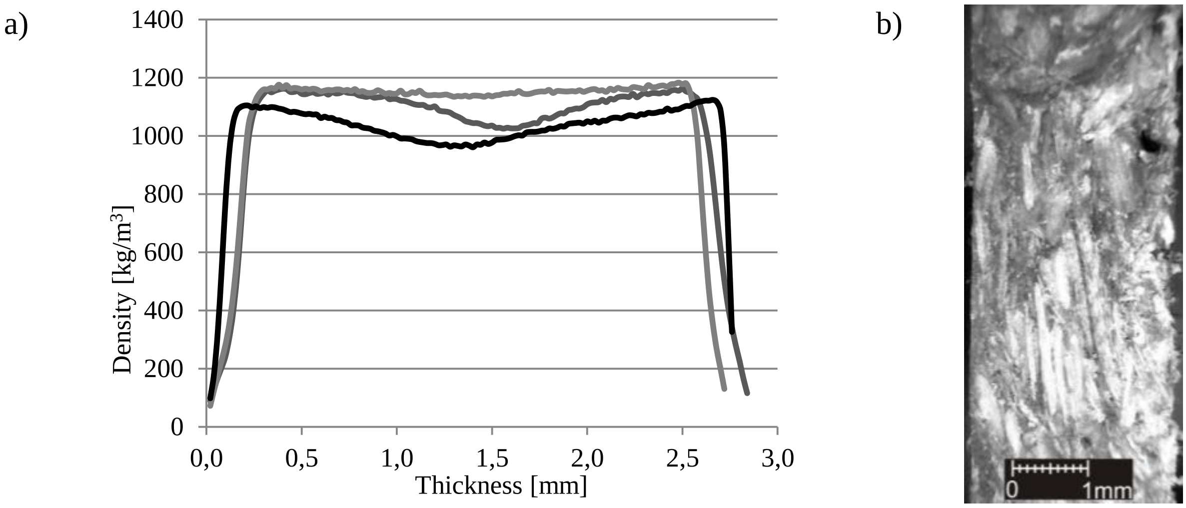


Figure 4. Panel variant III: a) composite density profiles, b) cross section of the panel.

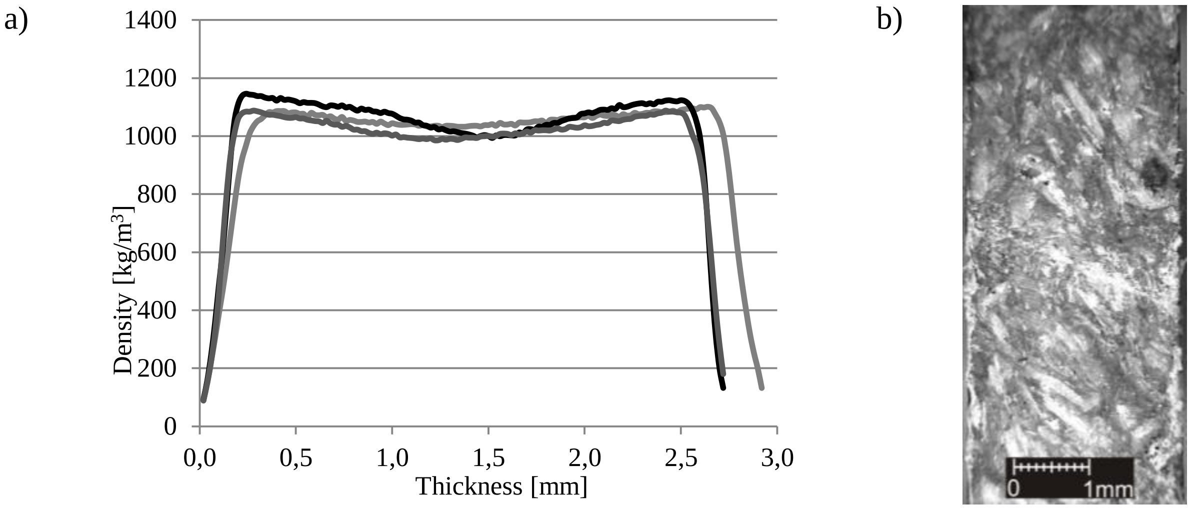


Figure 5. Panel variant IV: a) composite density profiles, b) cross section of the panel.

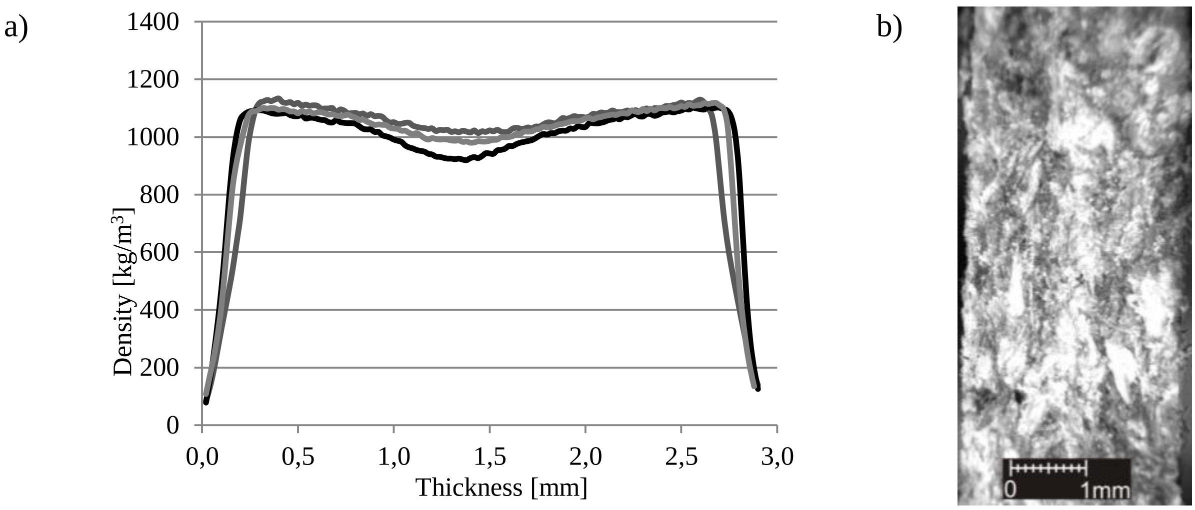


Figure 6. Panel variant V: a) composite density profiles, b) cross section of the panel.

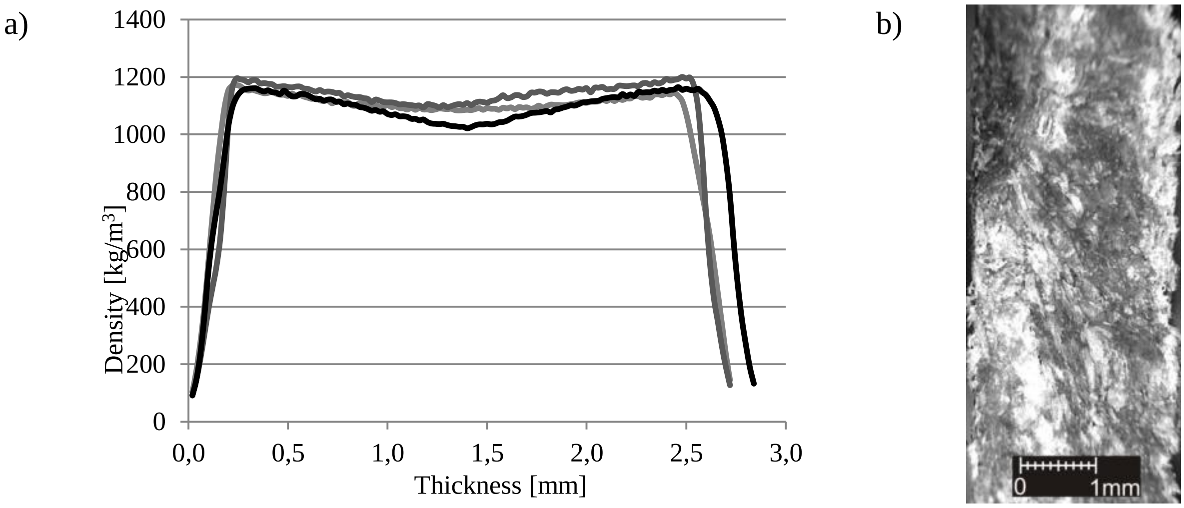


Figure 7. Panel variant VI: a) composite density profiles, b) cross section of the panel.

The increase in the filler content to 50% and 60% causes considerable variation in the course of the density profile - decrease of density in the core zone of the panel (Fig. 4, 5, 6, 7). In the case of filler content, 50% variation in density of subsurface and core zones ranges from 2 to 157 kg/m^3, similarly for the filler content of 60%, it ranges from 43 to 231 kg/m^3. The increase in density differentiation in the cross-section along with the increase in lignocellulosic filler content (sawdust particles) may result from differences in thermal conductivity coefficients for HDPE, respectively - about 0.5 W/m*K and pine wood (taking into account possible compaction) - approx. 0.25 W/m*K (Niemz 1993, Saechtling 1999). This affects the change of the material overheating conditions during flat pressing. The increase in the proportion of wood particles makes the overheating process more difficult, resulting in weaker plasticity and compaction (closer together) of the lignocellulosic filler particles in the center zone of the panel. A better fit of the lignocellulosic filler particles in zones of the core panels can lead to partial migration of the polymer matrix to the interior of the panel and thereby lowering the average density. At the same time, it should be emphasized that in none of the tested variants, the visible internal porosity zones of the internal structure were recorded in cross-section (Figures 2, 3, 4, 5, 6 and 7), which could affect the density decrease in the middle zone of the panels.

CONCLUSION

Based on the research of WPC composites with 40-60% lignocellulosic filler content, produced by the flat pressing method, following conclusions can be drawn:

- WPC composite panels with a filler content of 40% are characterized by a uniform flat density profile.
- An increase in lignocellulosic filler content (50 - 60%) affects the density reduction in the center zone of the panel.
- The density and density profile of WPC composite panels does not depend on the size of the filler particles.

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Streszczenie: *Wpływ napełniacza na profil gęstości kompozytów drzewno polimerowych*. Przeprowadzono badania płyt z kompozytów WPC o matrycy HDPE wytworzonych dwuetapowo: 1 – pozyskanie granulatu WPC metodą extruzji, 2 – wytworzenie płyt metodą prasowania płaskiego w formie. Jako napełniacz zastosowano trociny o dwóch stopniach rozdrobnienia (ok. 10 – 35 mesh i poniżej 35 mesh) i 3 poziomach zawartości (40, 50 i 60%). Łącznie wytworzono 6 wariantów płyt dla których określono gęstość i profil gęstości na przekroju poprzecznym. Ustalono, że płyt o zawartości napełniacza na poziomie 40% charakteryzują się jednolitym płaskim profilem gęstości. Wzrost zawartości napełniacza (do 50 – 60%) wpływa na obniżenie gęstości w strefie środkowej płyty. Gęstość i profil gęstości płyt z kompozytów WPC nie zależy od wielkości cząstek napełniacza.

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