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EFFECT OF WOOD FLOUR CONTENT ON THE PROPERTIES OF FLAT PRESSED WOOD PLASTIC COMPOSITES

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ABSTRACT

This study focused on the effect of wood flour content on some mechanical and physical properties of flat pressed wood plastic composites (WPC). The results revealed changes in the wood flour content affected the density of flat pressed WPC. Moreover, as exposure time increased, water absorption values were increased. The changes in the wood flour content considerably affected the mechanical properties of WPC. The decrease in the flexural strength reached up to 58%, while it was 61% for tensile strength. However, modulus of elasticity increased with increasing wood flour content. Meanwhile, the decrease was inevitable for screw withdrawal strength, where the increase in wood flour content resulted in a reduction of up to 50%. It was clearly determined that wood flour content above 60% evidently affects the physical and mechanical properties of flat pressed WPC, which should be considered in the utilization areas where high mechanical properties are critical.

KEYWORDS: Flexural strength, tensile strength, screw withdrawal strength, water absorption.

INTRODUCTION

In recent years, composite materials have gained considerable attention due to increasing environmental concerns. Composite materials offer superior properties compared to their individual components (Frącz and Janowski 2018). Moreover, they enable the raw materials to be used more efficiently. Wood plastic composites (WPC) have been in life for more than 50 years. The negative properties of lignocellulosic materials and thermoplastics have been limited or restricted by their combination as a result of the fabrication of composite. WPC initially appeared as decking materials, while they are used as fences, window and door frames, furniture, siding, timber, playground equipment (Kim and Pal 2010, Xu et al. 2017). WPC has also been used in construction such as in docks, bridges, and traverses (Smith and Wolcott 2006).

The advantages of being cost efficient, stiff, nonhazardous, sustainable, renewable, and environment friendly have defined the wood as a favorable lignocellulosic material (Nourbakhsh and Ashori 2010). The addition of wood flour to neat plastic decreases plastic consumption, positively contributing to plastic pollution threats to natural habitats. Moreover, the addition of wood flour also reduces the cost of composites (Kim and Pal 2010). Wood is also more attractive compared to other fillers, such as clay and synthetic fibers (glass, carbon, etc.), providing composites with lower density (Kordkheili et al. 2013). Meanwhile, WPC has a more natural appearance compared to polymers. However, the inconsistency in material properties between wood flour and plastics results in trouble in the service life of WPC. Wood is a hydrophilic substance that easily attaches water molecules via hydroxyl groups of its cell wall components (Ayrilmis et al. 2011a, Rydzkowski and Michalska-Pożoga 2016). Additionally, the difference between the surface energy of wood fiber (high) and plastic (low) complicates the bonding of the components. The high surface energy of wood fibers causes the agglomeration and restrains the dispersion (Ndiaye et al. 2013). The well provided load transfer between the components improves the mechanical properties of composites. However, the reducing adhesion due to the incompatibility of wood and plastics influences the load transfer (Arwinfar et al. 2016, Kaymakci et al., 2016). Therefore, the increasing wood content negatively affects the mechanical as well as physical properties of WPC (Kordkheili et al. 2013).

The polymer, the primary purpose of holding the lignocellulosic fiber together, is effective on the internal bonding (Chavooshi and Mahhoushi 2013). The decrease in the polymer content has resulted in weak bonding between the lignocellulosic fibers, which negatively influences mechanical and physical properties of the composites prepared. Lue et al. (2012) investigated the effect of wood flour content on mechanical properties. For flexural strength, the decrease was up to 29% as wood flour content increased from 30% to 60%. However, the modulus of elasticity (MOE) was increased 30%. Similarly, Tascioglu et al. (2016) highlighted that the decrease in flexural strength was inevitable as wood flour content increases. In another study, tensile strength decreased with increasing wood flour content while there was an increase of up to 40% flour content for flexural strength; after that, the decrease was inevitable (Kajaks et al. 2018). Bhaskar et al. (2021) also highlighted the efficiency of wood flour content, which increased the water absorption values with increasing exposure time.

There is extensive research regarding the effect of wood flour content on WPC properties. However, the study is limited with regards to flat pressed WPC. Flat pressed method offers a high production rate, large size production and also used larger wood flours (Benthien et al. 2012, Mirski et al. 2019). Thus, the main objective of this study was to investigate the effect of the variance in wood flour content on the physical and mechanical properties of flat pressed WPC. The changes in the density, water absorption (WA), and thickness swelling (TS) with the changes of wood flour content were investigated. The effect of wood flour content on the mechanical properties was also examined. The flexural strength, the tensile strength, MOE, and the screw withdrawal strength (SWS) were determined for this purpose.

MATERIALS AND METHODS

Materials

Scotch pine wood flour (Marmara Wood Shaving, Istanbul, Turkey) with a particle of 40 to 60 mesh was used as a lignocellulosic material in the powder form of high density polyethylene (HDPE) (Ucar Plastic, Izmir, Turkey) provided by commercial suppliers. The polymer's density and melt flow index (MFI) were 0.965 $g \cdot cm^{-3}$ and 5.5 g/10 min (190°C/2.16 kg), resp. The maleated anhydride grafted polyethylene (MAPE) was used as a coupling agent. The density and MFI of MAPE were 0.92 $g \cdot cm^{-3}$ and 3 g/10 min (190 °C/ 2.16 kg), resp.

Preparation of wood plastic composites

The wood flour was dried to under 2% of moisture content. The wood flour and polymer were premixed with a mechanical blender (1200 $rev \cdot min^{-1}$). Then, the rotary drum blender (30 to 40 $rev \cdot min^{-1}$ for 5 min) was used to obtain a homogeneous mixture. The mixture was laid on the aluminum caul plate. The draft was hot pressed (CemilUsta SSP 125, Istanbul, Turkey) for 15 min with a pressure of 2.3 to 2.5 $N \cdot mm^{-2}$ at 170°C. Afterward, the panels were left in the turned off hot press for cooling. The panels were produced with dimensions of 500 × 500 × 4 mm. The target density of the panels was 0.96 $g \cdot cm^{-3}$. The panels were conditioned according to ASTM D618-21: 2021. The wax paper was used to prevent the sticking of the mixture to the plate. The wood flour, HDPE, and MAPE contents are given in Tab. 1.

Tab. 1: The content of wood flour, HDPE, and MAPE in the mixture.

Groups	Wood flour (%)	HDPE (%)	MAPE (%)
WPC0	0	98	2
WPC1	10	88	2
WPC3	30	68	2
WPC5	50	48	2
WPC7	70	28	2

Density

The density was calculated according to TS EN 323: 1999. The samples with dimensions of 50 × 50 × 4 mm were oven dried until constant weight. The density was calculated by proportioning of weight to volume. Ten replications were taken for each group.

Water absorption and thickness swelling

The WA and TS values of samples were determined according to ASTM D570-98: 2018. The specimens with dimensions of 50 × 50 × 4 mm were entirely soaked in the water at 20°C ± 1°C. The specimens' surfaces were then cleaned and dried and measurements were recorded at 24 h, 72 h, and 168 h. Ten replications were taken for each group.

Flexural strength and modulus of elasticity

Flexural strength and MOE were determined according to ASTM D790-17: 2017. The specimens with dimensions of 127 × 12.7 × 4 mm were tested. The tensile strength was also determined according to ASTM D638-14: 2014. The ten replications were used for each flexural and tensile strengths. Tests were conducted with a universal test machine (Marestek, Istanbul, Turkey).

Screw withdrawal strength

Screw withdrawal strength was determined according to ASTM D1037-12: 2020 standard using specimens with dimensions of 50 × 50 × 4 mm. The pilot hole diameter for each screw was 2.7 mm. The screw diameter of 4.2 mm and length of 38 mm was used in this study. The thread pitch of the screw was 1.4 mm. The screws were hand driven 15 ± 0.5 mm into the test samples. Ten samples were used for each group. The maximum holding strength was then divided by the panel thickness, and the results were recorded as $N \cdot mm^{-1}$.

Statistical analysis

The test results were evaluated statistically according to the analysis of variance (ANOVA) (SPSS, IBM Corporation, Version 22, Armonk, NY, USA). The difference between the groups was also determined by the Duncan test ($p < 0.05$).

RESULTS AND DISCUSSION

Density

The effect of wood flour content changes on the density of flat pressed WPC is shown in Fig. 1. The density values of WPC varied between 0.931 to 0.959 $g \cdot cm^{-3}$. The increase in the wood flour content affected the density of samples. The target density value was nearly obtained from only the neat polymer. In contrast, as expected, the decrease in the polymer content in the matrix slightly reduced the density values of WPC samples. This result is because of the viscoelastic behavior of wood fiber. The gaps in the lumens of lignocellulosic materials are crushed/jammed under high pressure and temperature. However, the composites consisting of high wood content have exhibited much more viscoelastic behavior as the flat press method utilized in this study. In other words, the thickness of the board increased after pressing, which affects the density negatively (Benthien et al. 2012). It could be stated that the density is associated with wood flour content when flat pressed method is considered as production method.

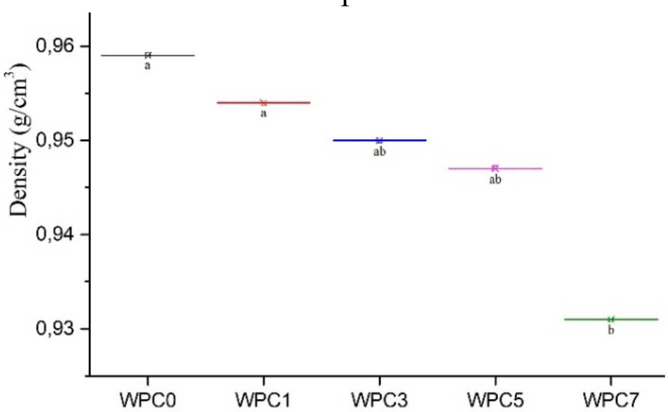

Fig. 1: The density of WPC (different letters indicate different homogeneity groups, $p \leq 0.05$).

Water absorption and thickness swelling

The effect of the wood flour content changes on the WA and TS was investigated throughout the 14 days test, as seen in Tab. 2. As is well known, wood is a hydrophilic material with hydroxyl groups (-OH) that interact with water molecules and easily bond each other. In contrast, the polymers are hydrophobic and are not influenced by water molecules, as seen that the WPC0 (neat HDPE) was almost unaffected in this study; compared to the increase in the wood flour content that increased the WA and TS values as the exposure time was increased. The highest WA and TS values were obtained from WPC7. Wood fibers encapsulate with the polymer under high pressure and temperature, restraining wood fibers from interacting with water molecules. However, the encapsulation could be incapable of inhibiting as the content of wood flour was increased. Moreover, the increased wood flour content also resulted in surface roughness, making it easy for water molecules to penetrate into the composites' center (Borysiuk et al. 2020). As a result, the WPC samples with the highest wood flour content caused an increase of 14% and 32% for WA and TS, respectively, while they were 4% and 3% for neat HDPE sample.

Tab. 2: The water absorption and thickness swelling values of WPC.

Groups	Water absorption (%)				Thickness swelling (%)			
	24 h	72 h	7 days	14 days	24 h	72 h	7 days	14 days
WPC0	0.026^{a}	0.053^{a}	0.100^{a}	0.133^{a}	0.073^{a}	0.233^{a}	0.277^{a}	0.330^{a}
WPC1	0.443^{a}	0.687^{a}	1.080^{a}	1.160^{a}	0.603^{a}	0.863^{a}	1.207^{a}	2.517^{a}
WPC3	2.730^{b}	4.393^{b}	7.427^{b}	9.540^{b}	3.046^{b}	4.373^{b}	5.983^{b}	7.587^{b}
WPC5	9.245^{c}	11.613^{c}	15.063^{c}	16.220^{c}	7.673^{c}	8.163^{c}	10.703^{c}	10.017^{c}
WPC7	43.924^{d}	45.447^{d}	49.080^{d}	50.237^{d}	14.130^{d}	15.217^{d}	17.483^{d}	18.720^{d}
Note: Different letters indicate different homogeneity groups, $p \leq 0.05$.								

Mechanical properties

The effect of changes in the wood flour content on the flexural strength, MOE, tensile strength, and SWS values of flat pressed WPC was investigated. The results are given in Tab. 3. The incompatibility between wood fiber and polymer materials influenced the mechanical properties. The low cost, natural abundancy, and biodegradability compared to the synthetic polymer are the reason for the preferred use of wood flour as a filling material. However, the incompatibility results in difficulties, such as significant reductions in mechanical properties, as seen in Tab. 3.

The flexural strength of samples varied between 18.88 MPa to 44.34 MPa. The increase in the wood flour content decreased the flexural strength (Chaharmahali et al. 2008, Ayrilmis and Jarusombuti 2011). The decrease was prominent after 50% of wood flour content. The increase in the wood flour content caused a decrease of up to 58%, limiting the usability of WPC where high mechanical properties are crucial. In contrast, the MOE of the WPC increased with increasing wood flour content. The highest increase in the MOE was obtained from WPC5 with 78%. Natural fibers have higher MOE than thermoplastic polymers, which clarifies the reason why MOE values are high (Chaharmahali et al. 2008). However, the increase gave way to a decrease after 50% of wood flour content. The decrease in the polymer content, which primarily acts as the adhesive in the matrix, negatively influenced the stress/load transfer.

Therefore, the load transfer is not well achieved, resulting in an inevitable decrease for higher wood flour content. Moreover, Ayrilmis et al. (2011b) also stated that the dispersion problem could also be the reason for such a decrease.

Tab. 3: The mechanical properties of WPC.

Groups	Flexural strength (MPa)	Modulus of elasticity (MPa)	Tensile strength (MPa)	Screw withdrawal strength ($N \cdot mm^{-1}$)
WPC0	44.34^{a} (2.07)	1544^{a} (142)	23.86^{a} (1.12)	191^{a} (11.49)
WPC1	35.05^{b} (0.88)	1757^{b} (117)	15.07^{b} (0.66)	185^{a} (9.44)
WPC3	32.36^{c} (1.60)	2389^{c} (183)	14.74^{bc} (1.40)	177^{b} (4.24)
WPC5	25.83^{d} (1.05)	2753^{d} (107)	13.22^{c} (1.06)	118^{c} (3.03)
WPC7	18.88^{e} (1.49)	2234^{e} (168)	9.33^{d} (0.87)	95^{d} (4.39)
Note: Values in the parentheses are standard deviations and letters indicate homogeneity groups. Different letters indicate different homogeneity groups, $p \leq 0.05$.				

The tensile strength of specimens varied between 9.33 MPa to 23.86 MPa. The highest tensile strength was obtained from WPC0, while WPC7 indicated the lowest strength. The increasing wood content decreased the tensile strength (Kajaks et al. 2017). The decrease reached up to 61% with increasing wood flour content. The reduction of polymer weakens the stress transfer from polymer to fiber, which results in a decrease in tensile strength (Arwinfar et al. 2016). The tensile strength values were close for WPC1, WPC3, and WPC5 samples. However, WPC7 exhibited noticeably low strength compared to the others. The incompatibility between wood and polymer materials shows itself clearly, although coupling agents improved the consistency between the components (Çavuş and Mengeloğlu 2020). The agglomeration of wood fiber with higher wood flour content also resulted in a severe reduction in mechanical properties (Dányádi et al. 2007).

Screw withdrawal strength varied between 95 to 191 $N \cdot mm^{-1}$. As wood flour content increased, the SWS of specimens were decreased. Madhoushi et al. (2009) also stated that a higher content of lignocellulosic material results in a lower fastener strength. The differences between the WPC groups were also analyzed statistically. The highest SWS was obtained from WPC0, while the lowest was with WPC7. The reduction in SWS value reached up to 50% with the increase of wood flour content. The low stiffness of cellulosic fibers and the weak bonds could be the reason for low fastener strength values (Ghanbari et al. 2014). Dányádi et al. (2007) also highlighted that the increased wood content caused agglomeration of wood fiber, thus restraining the stress transfer and reduction in the strength values.

CONCLUSIONS

In this study, the effect of wood flour content changes on some physical and mechanical properties of flat pressed WPC was investigated. The incompatibility between the wood fiber and polymer was clearly realized in this study, especially when the wood flour content is high. The decrease of polymer content, which helps isolate wood fiber against water, increased the effectiveness of water on wood fibers. The WA and TS values increased up to 14% and 32%, respectively. The increase was significant in the first 7 days, after that it was moderate.

The mechanical properties were adversely affected by increasing wood flour content. The bonding between polar wood and nonpolar polymer molecules weakened as wood flour content was increased. Therefore, the stress transfer was not well provided from polymer to wood fiber. As a result, the flexural strength decreased up to 58%, while the tensile strength decreased at 61%. However, up to some point, MOE was increased with increasing wood flour content at 78%. The reduction in the polymer content also influenced SWS, which decreased up to 50%. The increase of wood content provides more environment friendly composites. However, the decrease in the properties of flat pressed WPC was inevitable. According to the results obtained, flat pressed WPC containing high wood flour content should be evaluated in areas where high mechanical properties and water contact are not a concern.

REFERENCES

1. Arwinfar, F., Hosseinihashemi, S.K., Latibari, A.J., Lashgari, A., Ayrilmis, N., 2016: Mechanical properties and morphology of wood plastic composites produced with thermally treated beech wood. BioResources 11(1): 1494-1504.
2. ASTM D570-98, 2018: Standard test methods for water absorption of plastics.
3. ASTM D618-21, 2021: Standard practice for conditioning plastics.
4. ASTM D638-14, 2014: Standard test methods for tensile properties of plastics.
5. ASTM D790-17, 2017: Standard test methods for flexural properties of unreinforced and reinforced plastics and electrical insulating materials.
6. ASTM D1037-12, 2020: Standard test methods for evaluating properties of wood-based fiber and particle panel materials.
7. Ayrilmis, N., Jarusombuti, S., 2011: Flat-pressed wood plastic composite as an alternative to conventional wood-based panels. Journal of Composite Materials 45(1): 103-112.
8. Ayrilmis, N., Benthien, J.T., Thoemen, H., White, R.H., 2011a: Properties of flat-pressed wood plastic composites containing fire retardants. Journal of Applied Polymer Science 122(5): 3201-3210.
9. Ayrilmis, N., Jarusombuti, S., Fueangvivat, V., Bauchongkol, P., White, R.H., 2011b: Coir fiber reinforced polypropylene composite panel for automotive interior applications. Fibers and Polymers12(7): 919-926.
10. Benthien, J.T., Thoemen, H., Maikowski, S., Lenz, M.T., 2012: Resistance of flat-pressed wood-plastic composites to fungal decay: Effects of wood flour content, density, and manufacturing technology. Wood and Fiber Science 44(4): 422-429.
11. Bhaskar, K., Jayabalakrishnan, D., Kumar, M. V., Sendilvelan, S., Prabhahar, M., 2021: Analysis on mechanical properties of wood plastic composite. Materials Today: Proceedings 45(7): 5886-5891.
12. Borysiuk, P., Wilkowski, J., Krajewski, K., Auriga, R., Skomorucha, A., Auriga, A., 2020: Selected properties of flat-pressed wood-polymer composites for high humidity conditions. BioResources 15(3): 5141-5155.
13. Çavuş, V., Mengeloğlu, F., 2020: Effect of wood particle size on selected properties of neat and recycled wood polypropylene composites. BioResources 15(2): 3427-3442.

14. Chaharmahali, M., Tajvidi, M., Najafi, S.K., 2008: Mechanical properties of wood plastic composite panels made from waste fiberboard and particleboard. Polymer Composites 29(6): 606-610.
15. Chavooshi, A., Madhoushi, M., 2013: Mechanical and physical properties of aluminum powder/MDF dust/polypropylene composites. Construction and Building Materials 44: 214-220.
16. Dányádi, L., Janecska, T., Szabo, Z., Nagy, G., Moczo, J., Pukánszky, B., 2007: Wood flour filled PP composites: Compatibilization and adhesion. Composites Science and Technology 67(13): 2838-2846.
17. Frącz, W., Janowski, G., 2018: Determination of viscosity curve and PVT properties for wood-polymer composite. Wood Research 63(2): 321-334.
18. Ghanbari, A., Madhoushi, M., Ashori, A., 2014: Wood plastic composite panels: Influence of the species, formulation variables and blending process on the density and withdrawal strength of fasteners. Journal of Polymers and the Environment 22(2): 260-266.
19. Kajaks, J., Kalnins, K., Naburgs, R., 2018: Wood plastic composites (WPC) based on high-density polyethylene and birch wood plywood production residues. International Wood Products Journal 9(1): 15-21.
20. Kaymakci, A., Ayrilmis, N., Akkilic, H., 2016: Utilization of tinder fungus as filler in production of hdpe/wood composite. Wood Research 61(6): 885-894.
21. Kim, J.K., Pal, K., 2010: Recent advances in the processing of wood-plastic composites. Springer-Verlag, Berlin, Heidelberg, Germany, 184 pp.
22. Kordkheili, H.Y., Farsi, M., Rezazadeh, Z., 2013: Physical, mechanical and morphological properties of polymer composites manufactured from carbon nanotubes and wood flour. Composites Part B: Engineering 44(1): 750-755.
23. Madhoushi, M., Nadalizadeh, H., Ansell, M.P., 2009: Withdrawal strength of fasteners in rice straw fibre-thermoplastic composites under dry and wet conditions. Polymer Testing 28(3): 301-306.
24. Mirski, R., Dziurka, D., Banaszak, A., 2019: Effects of manufacture conditions on physical and mechanical properties of rape-polymer boards. Wood Research 64(4): 659-666.
25. Ndiaye, D., Gueye, M., Diop, B., 2013: Characterization, physical and mechanical properties of polypropylene/wood-flour composites. Arabian Journal for Science and Engineering 38(1): 59-68.
26. Nourbakhsh, A., Ashori, A., 2010: Wood plastic composites from agro-waste materials: Analysis of mechanical properties. Bioresource Technology 101(7): 2525-2528.
27. Rydzkowski, T., Michalska-Pożoga, I., 2016: Analysis of intensity of changes in the moisture content of wood chips in the production of wood polymer composites during drying and storage processes. Wood Research 61(3): 457-464.
28. Smith, P.M., Wolcott, M.P., 2006: Opportunities for wood/natural fiber-plastic composites in residential and industrial applications. Forest Products Journal 56(3): 4-11.
29. Tascioglu, C., Tufan, M., Yalcin, M., Sen, S., 2016: Determination of biological performance, dimensional stability, mechanical and thermal properties of wood–plastic

composites produced from recycled chromated copper arsenate-treated wood. Journal of Thermoplastic Composite Materials 29(11): 1461-1479.
30. TS EN 323, 1999: Wood-based panels. Determination of density.
31. Xu, K., Kang, K., Liu, C., Huang, Y., Zhu, G., Zheng, Z., China, K.P., 2017: The Effects of Expoxidized Soybean Oil on The Mechanical, Water Absorption Thermal Stability and Melting Processing Properties of Wood Plastic Composites. Wood Research 62(5): 795-806.

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