PROPERTIES OF WOVEN GLASS FIBER FABRIC REINFORCED POLYPROPYLENE BASED WOOD PLASTIC COMPOSITES

Sefa Durmaz, Yusuf Ziya Erdil, Erkan Avci
Mugla Sitki Kocman University, Turkey
e-mail: sefadurmaz@mu.edu.tr; erdil@mu.edu.tr; erkanavci@mu.edu.tr

ABSTRACT

Wood-plastic composites (WPCs) have excessively taken place in the construction industry in recent years. The high technological properties are crucial for WPCs when utilized as structural members. In this study, flat-pressed WPCs produced with polypropylene (PP) were reinforced with woven glass fiber fabric to enhance their properties. The effect of intensity of woven fabric (195 gr/m2 and 390 gr/m2) and wood flour content (40, 50, 60%) on WPCs' physical and mechanical properties were investigated. The addition of a coupling agent (CA) positively influenced WPCs' mechanical properties and restricted water absorption. However, water absorption increased with an increase in wood flour content. The increase in water exposure time from 1 day to 30 days increased water absorption up to 37%. In terms of water absorption, there was no significant difference between reinforced WPCs and controls. The reinforcement of WPCs improved mechanical properties significantly; i.e., flexural strength was increased up to 252%, while tensile strength reached up to 667%. As expected, the increase in wood flour content decreased mechanical properties. The incompatibility between wood flour and PP negatively influenced WPCs properties. It could be concluded that, if configured appropriately to the usage conditions, flat-pressed WPCs reinforced with woven glass fiber fabric have a potential for areas where high strength is required.

Key words: Wood-plastic composites, reinforcement, glass fiber, physical properties, mechanical properties.

INTRODUCTION

One way to evaluate woody materials efficiently is to combine them with different materials that also provide unique properties to a new material called "composite material." Wood-plastic composites (WPCs) had been introduced after the mid-20th century, in addition to other wood composites such as particleboard, MDF, etc. During the first years, WPCs were used in applications where high mechanical properties were not required, such as a deck, fence, etc. (Klyosov, 2007; Kim and Pal, 2010). The addition of wood fiber in the thermoplastics reduces the prices of the new materials and adds superior properties such as stiffness (Kaymakci et al., 2017; Kim and Pal, 2010; Kordkheili et al., 2013). However, wood has some disadvantages. Wood changes its dimensions depending on the relative humidity of air (Hon and Shiraishi, 2001), can be degraded under adverse conditions (Hill, 2007; Schmidt, 2006), and also affected by UV lights which results in color change (Fabiyi ve McDonald, 2010; Feist ve Hon, 1984; Ozgenc, 2014).

In recent years, WPCs have been desired to be utilized in applications where high mechanical properties are required, such as structural members in construction. For this purpose, WPCs are reinforced with synthetic fibers made of glass, carbon, and aramid. Among those, glass fiber is usually used in low-cost reinforcement applications due to its relatively low price, high strength, and high stiffness (Frederic, 1992; Zoghi, 2013).

Fu et al. (2000) determined an increase for tensile strength up to 50%; while, the enhancement reached up 111% for tensile strength (Gullu et al. 2006) with glass fiber reinforcement. Valente (2011) also reported that the mechanical properties of WPCs reinforced with glass fiber were improved; however, the increase in the wood flour content negatively affected the mechanical properties.

The infinite filaments have provided woven fabrics with high strength as compared to short fiber. Woven fabrics are well-known to be used in the application where thermosetting resins are used. However, in recent years, woven fabrics have been used to improve the mechanical properties of thermoplastic polymers, too (Boccardi et al. 2016; Kollerov et al., 2019; Russo et al. 2013; Simeoli et al. 2014; Sorrentino et al. 2015). Woven fabric reinforcement increased up to 500% for tensile strength (Russo et al. 2013). Although some research gives promising results, there is still limited study about WPCs reinforced with woven fabrics.

In this study, PP-based flat-pressed WPCs were reinforced with glass fiber woven fabric to improve some physical and mechanical properties. Water absorption properties were investigated. The mechanical properties, which are expected to be most improved, were also examined; namely, tensile strength, flexural strength, and modulus of elasticity were tested. The effects of wood flour content and coupling agent on the reinforcement were also evaluated.

MATERIALS AND METHODS

Pinewood flour (*Pinus sylvestris* L.), a coniferous wood species, 40 to 60 mesh, was used as lignocellulosic filler. The powder of polypropylene (Ucar Plastic, İzmir, Turkey) was used as a thermoplastic polymer. The density and melt flow index (MFI) of polypropylene are 0.905 g/cm^3 and 3–27 g/10 min (190ºC/2.16 kg). Glass fiber woven fabrics with two different densities (195 and 390 gr/m^2) (SPM Composites, Ankara, Turkey) were selected for reinforcement.

Wood flour was dried under 2% moisture content. Wood flour and PP powder were mixed with a rotary drum blender (30–40 rev/min). Wood flour and PP ratio were adjusted to 40:60%, 50:50%, and 60:40% in weight. The coupling agent (maleic anhydride grafted polypropylene) at 3% was used. The 20% of the mixture was laid on the aluminium plate, and the woven fabric was placed. Then, 60% of the mixture was laid on the fabric, and the second fabric was placed. Finally, the rest of the mixture was laid on the fabric, and the draft was formed. The target density was 1 gr/cm^3. The press temperature and pressure were 170°C and 24–26 kp/cm^2 (CemilUsta SSP 125, Istanbul, Turkey), respectively. The pressing time was 15 minutes. The final dimensions of produced panels were 500x500x4mm. All panels were conditioned according to ASTM D618 (2000). Figure 1 shows profile of a sample WPC panel.

The water absorption property of specimens was determined according to ASTM D570. The specimens were thoroughly soaked in the water for one day, three days, seven days, 14 days, and 30 days. The measurements were taken from the clean and dry surface of the specimens. Twelve samples were tested for each group.

According to procedures outlined in ASTM D790, the three-point bending test was carried out to determine the flexural strength and modulus of elasticity. The tensile strength was determined according to ASTM D638. The mechanical tests were performed with a universal testing machine

(Marestek, Istanbul, Turkey). Twenty samples were tested for each group.

Figure 1: Profile of a reinforced WPC panel

RESULTS AND DISCUSSION

1. WATER ABSORPTION (WA)

The WA of reinforced WPCs was investigated as compared to control samples, as seen in Table 1. The WA rate of WPCs increased up to 37% with increasing exposure time. The WA rate of WPCs was significantly changed in the first seven days. However, there was no significant difference after 14 days. The highest WA was obtained in 30 days. The hydroxyl groups of wood interact with water molecules, resulting in water absorption or desorption depending on the environment (Ayrilmis et al., 2011). As expected, the increase in wood flour content increased WA rate of WPCs for all groups. The highest water absorption was obtained from 60% wood flour content. The coupling agent positively influenced WA rate. Incompatibility was reduced with the addition of a coupling agent, which improved the properties of WPCs (Mengeloglu and Kabakci, 2008). As can be seen that the effect of reinforcement on WA was not significant; i.e., WA rate of reinforced and control specimens was quite alike.

Table 1: The water absorption rate of WPC samples

	Wood/PP (%)	Coupling Agent	Water Absorption Rate (%)				
			1 day	3 day	7 day	14 day	30 day
Control	40/60	Not incl.	9.91	17.31	25.21	31.47	32.10
		Inc.	8.38	16.64	22.90	24.90	25.01
	50/50	Not incl.	13.08	21.19	26.80	30.44	32.90
		Inc.	10.76	19.90	26.58	28.76	30.39
	60/40	Not incl.	15.12	23.72	29.45	32.79	37.05
		Inc.	12.03	21.13	25.87	29.08	31.55
GF 195	40/60	Not incl.	9.49	15.68	20.14	22.53	23.57
		Inc.	8.27	13.78	18.80	21.65	23.50
	50/50	Not incl.	11.70	18.59	23.03	24.54	27.00
		Inc.	10.69	18.03	22.85	23.92	26.21
	60/40	Not incl.	13.53	23.68	28.20	28.91	32.67
		Inc.	12.50	20.90	25.41	28.14	32.41
GF 390	40/60	Not incl.	9.27	16.24	22.09	27.44	29.12
		Inc.	8.90	14.08	18.94	20.59	22.60
	50/50	Not incl.	13.58	19.95	23.61	26.02	29.15
		Inc.	10.49	15.50	19.70	21.74	24.86
	60/40	Not incl.	16.59	27.55	27.13	31.91	35.96
		Inc.	15.82	20.32	26.07	28.17	32.03

2. MECHANICAL PROPERTIES

Glass fiber is well-known to have high mechanical properties. The effect of reinforcement with glass fiber woven fabric on the mechanical properties of WPCs was investigated. Overall results are given in Table 2. Results showed that glass fiber fabric reinforcement yielded high mechanical properties. Considerable improvement was achieved with reinforcement with compared to unreinforced control specimens. The flexural strength was increased up to 123% with reinforcement; while, the increase passed over 250% with the addition of a coupling agent. Incompatibility between wood and polymer negatively affected mechanical properties. The effective load transfer in the matrix could be provided with a good linkage which the coupling agent could positively influence. The highest flexural strength was obtained from WPC containing 40% wood flour content reinforced with 390 gr/m^2 glass fiber fabric. The increase in the wood flour content decreased flexural strength. However, increase in wood flour content improved the modulus of elasticity. The highest modulus of elasticity was obtained from WPC containing the highest wood flour content (60%) reinforced with 390 gr/m^2 glass fiber woven fabric. Addition of the coupling agent also increased MOE.

Synthetic fibers such as glass fiber have high tensile strength. As seen in Table 2, the increase in the tensile strength was up to 639% with reinforcement. The increase reached up 667% with the addition of coupling agent. Likewise, flexural strength, increase in the wood flour content negatively affected tensile strength. The highest increase in the tensile strength was achieved with WPC samples containing 40% wood flour content reinforced with 390gr/m^2 glass fiber. The filament in the fabric increase with increasing fabric density which could carry more load. Therefore, the tensile strength increased with the increasing density of the woven fabric.

Table 2: Mechanical properties of WPCs

	Wood/PP (%)	Coupling Agent	Flexural Strength (Mpa)	Modulus of Elasticity (Mpa)	Tensile Strength (Mpa)
Control	40/60	Not incl.	14.63 (0.89)	2576 (153)	6.79 (0.55)
		Inc.	23.06 (2.12)	2884 (270)	7.05 (0.64)
	50/50	Not incl.	14.31 (0.86)	2671 (155)	6.72 (0.62)
		Inc.	22.52 (2.32)	3222 (180)	6.98 (0.77)
	60/40	Not incl.	13.70 (0.70)	2787 (176)	6.17 (0.57)
		Inc.	22.51 (1.91)	3359 (151)	6.92 (0.58)
GF 195	40/60	Not incl.	39.93 (2.48)	3021 (159)	24.45 (2.15)
		Inc.	40.85 (3.20)	4089 (314)	24.50 (1.95)
	50/50	Not incl.	37.84 (3.47)	3731 (128)	21.28 (3.91)
		Inc.	40.80 (3.60)	4420 (222)	21.98 (2.35)
	60/40	Not incl.	36.63 (2.40)	4027 (251)	16.95 (1.08)
		Inc.	39.28 (2.98)	4730 (198)	19.61 (2.03)
GF 390	40/60	Not incl.	44.02 (2.50)	4137 (425)	51.27 (5.95)
		Inc.	51.46 (4.86)	5001 (429)	52.12 (6.19)
	50/50	Not incl.	42.54 (3.24)	4279 (303)	51.19 (3.11)
		Inc.	49.57 (4.33)	5041 (418)	51.25 (6.84)
	60/40	Not incl.	39.56 (3.23)	4297 (215)	47.12 (3.15)
		Inc.	49.22 (2.21)	5180 (275)	48.81 (4.12)

**Values in parentheses are standard deviations*

CONCLUSIONS

In this study, PP-based flat-pressed WPCs were reinforced with glass fiber woven fabric. The physical and mechanical properties were investigated to determine the effect of reinforcement. There was no significant effect of reinforcement on the water absorption. Yet, as the density increased for woven fabric, a slight increase in water absorption has been observed. It is thought that the water molecules in the gaps of the woven fabric could be responsible for the increase in the WA. However, the increase in the wood flour content negatively influenced WA. The reinforcement with glass fiber woven fabric significantly increased mechanical properties. The increase in the flexural strength reached up 252% with the effect of reinforcement and coupling agent. The MOE of WPCs was also increased up to 86%. The effect of the coupling agent on the improvement of mechanical properties is significant. The interaction between wood/polymer/woven fabrics was improved with the addition of coupling agent. The tensile strength was also improved with reinforcement. The improvement reached 667% with the effect of reinforcement and coupling agent. This study showed that the reinforcement has allowed WPCs to be evaluated in the areas where high mechanical properties are desired.

ACKNOWLEDGEMENT

This study was supported by TUBITAK (Project No: 118O756). This study was presented at Tenth International Scientific and Technical Conference "Innovations in Forest Industry and Engineering Design" (INNO 2020) on 1–3 OCTOBER 2020.

REFERENCES

Ayrilmis N., Benthien J. T., Thoemen H., White R. H. 2011. Properties of flat-pressed wood plastic composites containing fire retardants. Journal of Applied Polymer Science, 122, 5: 3201–3210.

ASTM D 570–98 "Standard test methods for water absorption of plastics", Annual Book of ASTM Standards, West Conshohocken, PA, USA, Vol. 08, 01.

ASTM D 618–00 Practice for conditioning plastics for testing, Annual Book of ASTM Standards, ASTM, Philadelphia, Vol. 08.01, 2001.

ASTM D 638–99 ISO 527–1. 2007, Standard test methods for tensile properties of plastics, Annual Book of ASTM Standards, West Conshohocken, PA, USA, Vol. 08, 01.

ASTM D 790 ISO 178. 2007, Standard test methods for flexural properties of unreinforced and reinforced plastics and electrical insulating materials, Annual Book of ASTM Standards, West Conshohocken, PA, Vol. 08, 01.

Boccardi S., Meola C., Carlomagno G. M., Sorrentino L., Simeoli G., Russo P. 2016. Effects of interface strength gradation on impact damage mechanisms in polypropylene/woven glass fabric composites. Composites Part B: Engineering, 90: 179–187.

Fabiyi J. S., McDonald A. G. 2010. Effect of wood species on property and weathering performance of wood plastic composites. Composites Part A: Applied Science and Manufacturing, 41, (10): 1434–1440.

Feist W. C., Hon D. N.–S. 1984. Chemistry of weathering and protection – Chapter 11: The chemistry of solid wood. Washington, Advances in Chemistry series.

Frederic, N. C. 1992. Thermoplastic aromatic polymer composites. Oxford, Butterworth Heinemann Ltd.

Fu S. Y., Lauke B., Mäder E., Yue C. Y., Hu X. 2000. Tensile properties of short–glass–fiber– and short–carbon–fiber–reinforced polypropylene composites. Composites Part A: Applied Science and Manufacturing, 31, (10): 1117–1125.

Gullu A., Ozdemir A., Ozdemir E. 2006. Experimental investigation of the effect of glass fibers on the mechanical properties of polypropylene (PP) and polyamide 6 (PA6) plastics. Materials and design, 27 (4): 316–323.

Hill C. A. 2007. Wood Modification: Chemical, Thermal and Other Processes. England, John Wiley and Sons.

Hon D. N. S., Shiraishi N. 2001. Wood and Cellulosic Chemistry. New York, Marcel Dekker.

Kaymakci A., Ayrilmis N., Gulec T., Tufan M. 2017. Preparation and characterization of high–performance wood polymer nanocomposites using multi–walled carbon nanotubes. Journal of Composite Materials, 51, (9): 1187–1195.

Kim J. K., Pal K. 2010. Recent advances in the processing of wood–plastic composites. Springer Science and Business Media.

Klyosov A. A. 2007. Wood–plastic composites. New Jersey, John Wiley and Sons.

Kollerov M. Y., Spektor V. S., Skoblin A. A., Gurtovoi S. I., Saakyan A. V., Gusev D. E. 2019. Mechanical Properties of a Carbon Fiber Reinforced Plastic–Titanium Nickelide Functional Composite Material. Russian Metallurgy (Metally), 2019 (4): 331–335.

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.

MENGELOGLU F., KABAKCI A. 2008. Determination of thermal properties and morphology of eucalyptus wood residue filled high density polyethylene composites. International journal of molecular sciences, 9, (2): 107–119.

OZGENC O., YILDIZ U. C. 2014. Surface characteristics of wood treated with new generation preservatives after artificial weathering. Wood Research, 59 (4): 605–616.

RUSSO P., ACIERNO D., SIMEOLI G., IANNACE S., SORRENTINO L. 2013. Flexural and impact response of woven glass fiber fabric/polypropylene composites. Composites Part B: Engineering, 54: 415–421.

SCHMIDT, O. 2006. Wood and tree fungi. Berlin, Heidelberg: Springer Verlag: 119–133.

SIMEOLI G., ACIERNO D., MEOLA C., SORRENTINO L., IANNACE S., RUSSO P. 2014. The role of interface strength on the low velocity impact behaviour of PP/glass fiber laminates. Composites Part B: Engineering, 62: 88–96.

SORRENTINO L., SIMEOLI G., IANNACE S., RUSSO P. 2015. Mechanical performance optimization through interface strength gradation in PP/glass fiber reinforced composites. Composites Part B: Engineering, 76: 201–208.

VALENTE M., SARASINI F., MARRA F., TIRILLÒ J., PULCI G. 2011. Hybrid recycled glass fiber/wood flour thermoplastic composites: Manufacturing and mechanical characterization. Composites Part A: Applied Science and Manufacturing, 42, (6): 649–657.

ZOGHI M. 2013. The international handbook of FRP composites in civil engineering. Boca Raton, CRC Press.

UNIVERSITY OF FORESTRY

FACULTY OF FOREST INDUSTRY

INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN

2/2021

INNO vol. X Sofia

ISSN 1314-6149
e-ISSN 2367-6663

Indexed with and included in CABI

INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN

Science Journal
Vol. 10/p. 1–90
Sofia 2/2021

ISSN 1314-6149
e-ISSN 2367-6663

Edition of
FACULTY OF FOREST INDUSTRY – UNIVERSITY OF FORESTRY – SOFIA

The Scientific Journal is indexed with and included in CABI.

Cover Design: DESISLAVA ANGELOVA

Printed by: INTEL ENTRANCE
Publisher address: UNIVERSITY OF FORESTRY – FACULTY OF FOREST INDUSTRY
Kliment Ohridski Bul., 10, Sofia, 1797, BULGARIA
http://inno.ltu.bg
http://www.scjournal-inno.com/

CONTENTS