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Effect of Short Glass Fiber Reinforcement on Physical, Mechanical Properties and Fire Performance of Wood Plastic Composites

Sefa DURMAZ[1*], Uğur ARAS[2]

[1]Muğla Sıtkı Koçman University, Department of Forestry and Forest Products Kavaklıdere Vocational School, Muğla, TÜRKİYE
[2]Karadeniz Technical University, Department of Materials and Materials Processing Technology, Arsin Vocational School, Trabzon, TÜRKİYE
[*]Corresponding Author: sefadurmaz@mu.edu.tr

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Abstract

Aim of study: This study aimed to improve some physical, mechanical properties, and fire resistance of wood-plastic composites (WPCs) with short glass fiber reinforcement (SGFR).

Materials and Methods: The WPCs were reinforced with different ratios of short glass fiber (SGF). The effect of reinforcement on the water absorption (WA), thickness swelling (TS) as physical properties, flexural strength, modulus of elasticity, and tensile strength as mechanical properties were determined. The fire resistance performance was also evaluated by the limit oxygen index (LOI) test.

Main results: The reinforcement improved the physical properties. The WA and TS values decreased with increasing glass fiber content. Flexural strength increased up to 28%, while 24% for tensile strength. There was a substantial enhancement in the modulus of elasticity (up to 122%). The glass fiber reinforcement also improved the fire performance of WPCs.

Highlights: The higher properties could be obtained by synthetic fiber reinforcement for WPCs.

Keywords: Short Glass Fiber, Reinforcement, LOI, Mechanical Properties, Physical Properties

Kısa Cam Lif Güçlendirmesinin Odun Plastik Kompozitlerinin Bazı Fiziksel, Mekanik Özellikleri ve Yanma Performansına Etkisi

Öz

Çalışmanın amacı: Bu çalışma kısa cam lif güçlendirmesi ile odun plastik kompozitlerinin (OPK) bazı fiziksel, mekanik özelliklerini ve yanma direncinin arttırılmasını amaçlamıştır.

*Materyal ve Yöntem:*OPK'lar farklı oranlarda kısa cam lifleri ile güçlendirilmiştir. Güçlendirmenin fiziksel özellikler olarak su alma, kalınlığa şişme, mekanik özellikler olarak eğilme direnci, elastikiyet modülü ve çekme direncine olan etkisi belirlenmiştir. Yangın direnci performansı ayrıca limit oksijen indeksi (LOI) testi ile değerlendirilmiştir.

Sonuçlar: Güçlendirme fiziksel özellikleri iyileştirmiştir. Su alma ve kalınlığa şişme değerleri artan cam lif içeriği ile azalmıştır. Eğilme direnci %28'e kadar yükselirken, çekme mukavemeti %24'e kadar artmıştır. Elastikiyet modülünde önemli bir iyileşme olmuştur (~%122). Cam elyaf takviyesi ayrıca OPK'ların yangın performansını da iyileştirmiştir.

Önemli vurgular: OPK'lar için sentetik elyaf takviyesi ile daha yüksek özellikler elde edilebilir.

Anahtar Kelimeler: Kısa Cam Lifi, Güçlendirme, LOI, Mekanik Özellikler, Fiziksel Özellikler

Introduction

The increase in the concern for the environment leads the consumer. Moreover, the raw material shortage also forces manufacturers to produce new materials which are cheap and productive as well as environmentally friendly. Therefore, wood-based composites have been popular structural material in recent years. As a result, they can be evaluated in various usage areas, such as furniture to construction. Wood-plastic composites (WPCs) are wood-based composites, having many usage areas, including siding, fences, windows frame,

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decks, gardening furniture, etc. (Kim & Pal, 2010; Klyosov, 2007). Natural fibers are sustainable, biodegradable, environmentally-friendly materials and have low cost, making them the most preferred fillers for thermoplastics (Nagarjun et al., 2021).

As well-known that plastic is hazardous material for the environment due to being petroleum-based materials (Rochman et al., 2013). However, it is one of the most preferred materials for most products. Meanwhile, combining natural fibers with plastics makes new materials greener. Moreover, the production cost decreases and increases some properties, such as stiffness, elasticity, etc. (Leu et al., 2012). Therefore, in recent years, natural fibers have been substitutes for synthetic fibers (for example, glass, carbon, and aramid fibers). However, there are also negative aspects of wood fibers. The hydrophile character makes it more sensitive to environmental humidity (Ferreira et al., 2021). The -OH groups in the structure of wood fibers can easily bond with water molecules, which results in dimension instability (Ayrilmis et al., 2011). The mechanical properties of WPCs were also affected by changing humidity (Wang & Morrell, 2005). Moreover, cracks occur on the surface of WPCs during the swelling of fibers, especially in outdoor usage (Durmaz et al., 2022; Fabiyi & McDonald, 2010; Stark & Matuana, 2004). The increase in the wood content in the composites also increases the intensity of these effects alongside greener.

The usage areas of WPCs expand due to increasing demand. Therefore, the need for high mechanical properties is inevitable. However, natural fibers substitute for synthetic fibers limits the improvement of properties of WPCs. Synthetic fibers have high physical, mechanical, and thermal properties, which ameliorate the properties of materials (Durmaz et al. 2021). Khan et al. (2010) reinforced WPCs with glass fibers, in which the improvement was 77% for tensile strength while 51% for bending strength. Valente et al. (2011) stated that glass fiber reinforcement improved the hardness of WPCs. Although there was a decrease in the mechanical properties as increasing wood content, it also positively affected mechanical properties. AlMaadeed et al. (2012) reinforced WPCs with different ratios of SGF. The increasing glass fiber content with decreasing wood flour caused remarkable improvement in the mechanical strength, in which just 5% of glass fiber increased tensile strength by 18%. Zhang et al. (2013) also obtained significant improvement with glass fiber reinforcement. On the other hand, Karsli & Aytac (2013) also stated that the poor adhesion resulted in the pull out of fiber from the matrix.

Lignocellulosic materials in the matrix decrease the heat release rate (Kozłowski & Władyka-Przybylak, 2008). The changes in the wood flour content also influenced flame retardancy (Durmaz et al., 2021). However, there are limited studies about the effect of short fiber reinforcement of WPCs on fire performance. Guo & Kethineni (2020) stated that the reinforcement with glass and carbon fiber restricted the dripping of plastics and mechanical properties.

The main purpose of this research was to enhance the physical, mechanical, and fire resistance of WPCs with SGFR. The various content of SGF (0, 5, 10, 15, 20, 30%) was added to the matrix, while the wood flour content was constant. The changes in TS and WA values with reinforcement were investigated. The SGFR influenced flexural and tensile strength. Modulus of elasticity was also examined to reveal the efficiency of reinforcement. The fractured surface of reinforced WPCs was also examined by scanning electron microscope (SEM). The effect of SGFR on the fire resistance was also evaluated by the limit oxygen index (LOI) test.

Material and Methods

Materials

Pinewood flour (Pinus sylvestris L.) was used as a lignocellulosic filler (40-60mesh). As a thermoplastic polymer, the high-density polyethylene (HDPE) was supplied from a commercial supplier (Ucar Plastic, İzmir, Türkiye) as a powder form. The melt flow index (MFI) and density of HDPE were 5.5 g/10 min (190°C/2.16 kg) and 0.965 gr/cm^3, respectively. As a coupling agent, the maleic anhydride grafted polyethylene (Licocene PE MA 4351 Fine Grain) was added, whose softening point and density were 123°C and

0.99 g/cm^3, respectively. The E-glass fiber with 4 mm fiber long and 11 µm filament diameter was used as a reinforcement agent.

Methods

The components were mixed by a mixer to be obtained a homogeneous mixture, according to Table 1. The mixture was extruded with a single screw extruder. The screw speed was arranged at 40 rpm. The temperature varied from 180 to 195 °C. Then samples were cooled and pelletized. The pellets were dried and then compressed at 180 °C under 24-26 kg/cm^2 for 15 min (CemilUsta SSP 125, Istanbul, Türkiye). The panel dimensions were 500 mm x 500 mm x 4 mm.

Water absorption and thickness swelling

The WA and TS tests were examined in accordance with ASTM D570-98 standards. The samples with 50 mm x 50 mm x 4 mm dimensions were entirely immersed in the water at 20 ± 1°C. The changes in dimensions and weights of five samples for each group were measured at different times (24 h, 72 h, 168 h, 336 h, and 672 h).

Mechanical properties

The mechanical properties were determined with a universal test machine (Marestek, Istanbul, Türkiye).

Table 1. The variation of the study.

Groups	Wood Flour (%)	HDPE (%)	MAPE (%)	Glass Fiber (%)
Neat-HDPE	-	99	1	-
W30P70	30	69	1	-
W30P65G5	30	64	1	5
W30P60G10	30	59	1	10
W30P55G15	30	54	1	15
W30P50G20	30	49	1	20
W30P40G30	30	39	1	30

The eight samples with dimensions of 127 mm x 12.7 mm x 4 mm were measured for the flexural strength and modulus of elasticity (MOE) in accordance with ASTM D790-17 standards. The dog-bone shape samples were tested for tensile strength in accordance with ASTM D638-14. Eight replicates were measured for each test group.

Limit Oxygen Index (LOI) test

The minimum amount of oxygen to continue flaming combustion for samples is measured by the LOI test. The five samples with dimensions of 127 mm x 12.7 mm x 4 mm were measured with a Dynisco LOI analyzer instrument (Franklin, USA) in accordance with ASTM D2863-19 for each test group.

Table 2. The WA and TS Values of WPCs

Groups	WA (%)					TS (%)				
	24 h	72 h	168 h	336 h	672 h	24 h	72 h	168 h	336 h	672 h
Neat-HDPE	0.11^{a}	0.18^{a}	0.20^{a}	0.26^{a}	0.39^{a}	0.18^{a}	0.36^{a}	0.44^{a}	0.78^{a}	0.96^{a}
	(0.20)	(0.27)	(0.25)	(0.29)	(0.22)	(0.25)	(0.36)	(0.29)	(0.16)	(0.17)
W30P70	4.51^{b}	9.26^{b}	13.92^{b}	15.19^{b}	15.40^{b}	4.61^{b}	11.72^{b}	12.84^{b}	14.43^{b}	15.12^{b}
	(0.60)	(0.87)	(0.79)	(1.00)	(1.01)	(0.73)	(2.64)	(1.46)	(1.50)	(1.43)
W30P65G5	0.11^{a}	0.40^{a}	0.74a	1.06^{c}	1.49^{c}	0.48^{a}	1.68^{ac}	2.62^{c}	3.34^{c}	3.66^{c}
	(0.05)	(0.16)	(0.18)	(0.23)	(0.35)	(0.18)	(0.47)	(0.22)	(0.59)	(0.55)
W30P60G10	0.11^{a}	0.40^{a}	0.44^{a}	1.00^{c}	1.18^{c}	0.94^{a}	1.75^{ac}	2.68^{c}	3.00^{c}	3.07^{c}
	(0.08)	(0.12)	(0.06)	(0.14)	(0.10)	(0.20)	(0.43)	(0.36)	(0.41)	(0.33)
W30P55G15	0.16^{a}	0.54^{a}	0.68^{a}	1.19^{c}	1.75^{c}	1.71^{c}	3.08^{cd}	4.00^{d}	4.35^{d}	4.79^{d}
	(0.06)	(0.15)	(0.08)	(0.26)	(0.27)	(0.75)	(0.64)	(0.76)	(0.72)	(0.65)
W30P50G20	0.62^{c}	1.78^{c}	2.59^{c}	3.27^{d}	4.89^{d}	1.86^{c}	3.79^{d}	4.53^{d}	4.90^{d}	5.55^{d}
	(0.23)	(0.24)	(0.46)	(0.46)	(0.40)	(0.65)	(0.51)	(0.65)	(0.84)	(0.66)
W30P40G30	0.64^{c}	1.80^{c}	2.63^{c}	4.06^{e}	5.52^{d}	1.95^{c}	3.95^{d}	4.54^{d}	5.19^{d}	5.42^{d}
	(0.17)	(0.31)	(0.76)	(0.60)	(0.72)	(0.74)	(0.25)	(1.77)	(0.22)	(0.20)

Note: Values in the parentheses are standard deviations; letters indicate the differences ($p < 0.05$) between groups depending on the Duncan test.

Scanning electron microscopy analysis

The fractured surface of WPC samples was examined by scanning electron microscope (SEM, Zeiss Evo LS10, Germany). Before the examination,samples were oven-dried and then gold-coated (Emitech SC7620, France).

Statistical analysis

The test data were statistically investigated depending on the analysis of variance (ANOVA). The Duncan test ($p<0.05$) was carried out to reveal the difference between the groups.

Results and Discussions

Water Absorption and Thickness Swelling

The impact of SGF reinforcement on the WA and TS of WPCs was investigated in this study. The WA values differed from 0.11 to 15.40, while from 0.18 to 15.12 for TS, as seen in Table 2. The WA and TS values increased with increasing immersion time. It was well-established that -OH groups in the wood fiber chemical structure easily connect with water molecules, increasing WA and TS values (Hosseinihashemi et al., 2016). However, the combination of wood fiber and plastic restricts water access due to encrusting of wood fiber with polymer. Although polymer content decreased when the glass fiber increased, WA and TS values were significantly less than W30P70 after 672 h exposure. The hydrophobic nature of glass fibers is effective in improving the WA and TS of WPCs (Khan et al., 2010).

Mechanical Properties

The effect of SGFR on the mechanical properties of WPCs was investigated in this study. The reinforcement improved the mechanical properties, as seen in Table 3. However, there was also a decrease after the addition of wood flour to neat-HDPE, except for MOE. As known, the inconsistency between wood and polymer causes low mechanical properties (Bouafif et al., 2009; Kaymakci, 2016). Nevertheless, the increase in the flexural strength reached up to 28% in comparison with W30P70. The highest values were acquired from W30P55G15 for flexural strength. The rise in the glass fiber content after 15% did not provide the expectation. However, they (above 15%) still have higher flexural strength than the W30P70. As glass fiber content increased, the polymer content decreased. The wood and glass fibers can be held together with the polymer, which acts as a bonding agent. The decrease in the polymer content influenced the stress transfer negatively. Moreover, the inconsistency between components also makes stress transfer difficult. However, reinforced WPCs with higher flexural strength values revealed the effect of reinforcement, although decreasing polymer content.

Table 3. Mechanical properties of SGF reinforced WPCs.

Groups	Flexural Strength (MPa)	Modulus of Elasticity (MPa)	Tensile Strength (MPA)
Neat-HDPE	51.23^{d} (3.34)	2581^{a} (111)	28.29^{a} (0.52)
W30P70	40.13^{a} (1.25)	3222^{b} (72)	17.63^{d} (0.29)
W30P65G5	45.67^{b} (1.43)	3731^{c} (142)	20.64^{bc} (0.58)
W30P60G10	48.83^{cd} (1.93)	5089^{d} (102)	21.80^{b} (1.00)
W30P55G15	51.48^{d} (2.33)	4725^{e} (211)	19.52^{c} (0.74)
W30P50G20	50.40^{d} (3.40)	6003^{f} (549)	19.76^{c} (0.37)
W30P40G30	46.71^{bc} (2.64)	7156^{g} (1520)	16.62^{d} (0.50)

Values in the parentheses are standard deviations; letters indicate the differences ($p < 0.05$) between groups depending on the Duncan test.

Similarly, the addition of wood flour as filler to neat HDPE decreased the tensile strength. On the contrary, glass fiber reinforcement increased the tensile strength up to 24%, despite reduced polymer content. W30P60G10 provided the highest tensile strength compared to W30P70. However, tensile strength decreased after that content. Unlike flexural strength, tensile strength for 30% glass fiber was below the W30P70. On the other hand, although there was also a decrease for 15% and 20% glass fiber reinforced samples, they have higher than the W30P70.

The glass fiber reinforcement improved the modulus of elasticity of WPCs significantly. It is recognized that natural fibers have higher elasticity (Chaharmahali et al., 2008). Moreover, the synergic effect of wood flour and glass fiber was enlightened by MOE values. There was a 122% enhancement due to reinforcement. The highest MOE value was obtained from W30P40G30. As glass fiber content increased, MOE increased, except 15% glass fiber.

LOI Test

The effect of SGFR on the fire resistance of WPCs was examined, as seen in Fig. 1. The LOI values varied from 18.5 to 25.7. The addition of short glass fiber to WPCs improved the resistance against fire. As well-known that polymer can be easily ignited due to petroleum-based. However, wood fiber's carbonization, which creates a thermal barrier during the ignition, improves the fire resistance (Guo et al., 2019). As can be seen, the lignocellulosic fiber addition enhanced the LOI values of WPCs as compared to neat-HDPE. However, fire resistance is slightly improved with increasing glass fiber content.

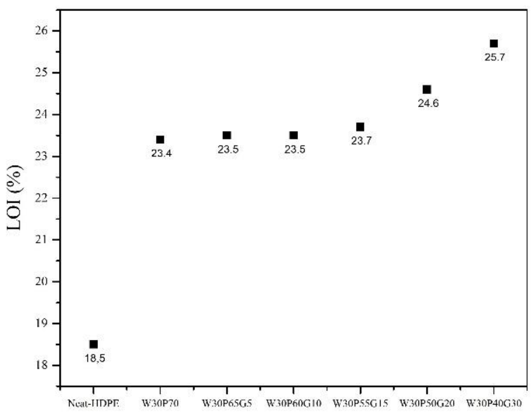

Figure 1. The LOI values of reinforced WPCs

Glass fiber is recognized as having high heat resistance (Seo et al., 2019). Therefore, the highest LOI values were acquired from W30P40G30. Moreover, the decreased polymer content with the increasing glass fiber content also improves the fire performance. On the contrary, the addition of glass fiber up to %20 content did not significantly improve fire resistance.

SEM Analysis

After the tensile strength test, the fractured surface of reinforced WPCs was investigated with SEM analysis, as seen in Figure. 2 and 3.

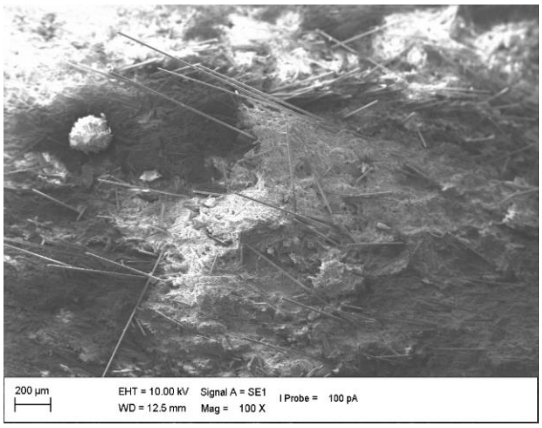

Figure. 2. The SEM images of the fractured surface of reinforced WPCs with 5% glass fiber.

SEM images showed that the glass fibers were homogeneously dispersed in the matrix, which is crucial in transporting the stress. However, many black holes exist in the fractured surface after tensile strength (Fig. 3).

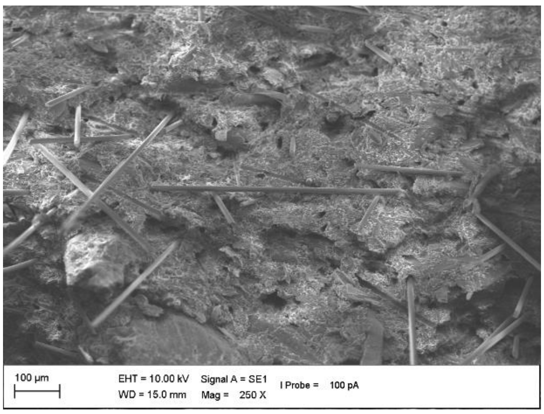

Figure. 3. The SEM images of the fractured surface of reinforced WPCs with 15% glass fiber.

The smooth and undamaged holes are proof of weak adhesion between matrix and glass fibers, which clearly explains why the improvement in the mechanical properties is restricted. Li and Cai (2011) also stated that poor adhesion makes debonding easier for fibers. The smoothest surface of glass fiber is one of the main factors for debonding as well as inconsistency between polymer and fibers.

As seen in the SEM images, the weak adhesion resulted in glass fibers pulling out from the matrix, restricting high mechanical properties.

Conclusion

The effect of SGF reinforcement on some physical and mechanical properties of WPCs was examined in this study. The obtained results showed that WA and TS values of WPCs were improved with reinforcement. However, with the decrease in the polymer content with increasing glass fiber content, WA and TS values were smaller than the W30P70. The hydrophobic character of glass fiber played an essential role in this regard. However, mechanical properties did not improve with the increasing glass fiber content. While the highest flexural strength was acquired from 15% glass fiber, 10% glass fiber is for tensile strength. However, MOE ascended with increasing glass fiber content. The SEM images showed the poor adhesion between the matrix and glass fibers, which resulted in limited improvement in the mechanical properties. The effect of reinforcement on fire performance was limited. The reinforcement did not provide an improvement for fire resistance like mechanical properties. Consequently, the reinforcement of WPCs with SGF enhanced the physical and mechanical properties, enabling WPCs to raise the usage areas where high mechanical properties are needed.

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Ethics Committee Approval

N/A

Peer-review

Externally peer-reviewed.

Author Contributions

Conceptualization: S.D., U.A.; Investigation: S.D., U.A.; Material and Methodology: S.D., U.A.; Supervision: S.D., U.A.; Visualization: S.D., U.A.; Writing-Original Draft: S.D., U.A.; Writing-review & Editing: S.D., U.A. All authors have read and agreed to the published version of manuscript.

Conflict of Interest

The authors have no conflicts of interest to declare.

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References

ASTM D570-98 (2018). Standard Test Method for Water Absorption of Plastics, ASTM International, West Conshohocken, PA, USA.

ASTM D790-17 (2017). Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials, ASTM International, West Conshohocken, PA, USA.

ASTM D638-14 (2017). Standard Test Method for Tensile Properties of Plastics, ASTM International, West Conshohocken, PA, USA.

ASTM D2863-19 (2019). Standard Test Method for Measuring the Minimum Oxygen Concentration to Support Candle-Like Combustion of Plastics (Oxygen Index), ASTM International, West Conshohocken, PA, USA.

AlMaadeed, M.A., Kahraman, R., Khanam, P.N. & Madi, N. (2012). Date palm wood flour/glass fibre reinforced hybrid composites of recycled polypropylene: Mechanical and thermal properties. *Materials & Design*, 42, 289-294.

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.

Bouafif, H., Koubaa, A., Perré, P. & Cloutier, A. (2009). Effects of fiber characteristics on the physical and mechanical properties of wood plastic composites. *Composites Part A: Applied Science and Manufacturing*, 40(12), 1975-1981.

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.

Durmaz, S., Erdil, Y.Z. & Avci, E. (2021). Improvement of technological properties of wood plastic composites reinforced with glass and carbon fibre fabric. *Polymers and Polymer Composites*, 29(9), S1457-S1465.

Durmaz, S., Erdil, Y.Z. & Ozgenc, O. (2022). Accelerated weathering performance of wood-plastic composites reinforced with carbon and glass fibre-woven fabrics. *Coloration Technology*, 138(1), 71-81.

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.

Ferreira, S.R., de Andrade, R.G.M., Koenders, E., de Andrade Silva, F., Fairbairn, E.D.M.R. & Toledo Filho, R.D. (2021). Pull-out behavior and tensile response of natural fibers under different relative humidity levels. *Construction and Building Materials*, 308, 124823.

Guo, Y., Zhu, S., Chen, Y. & Li, D. (2019). Thermal properties of wood-plastic composites with different compositions. *Materials*, 12(6), 881.

Guo, G. & Kethineni, C. (2020). Direct injection molding of hybrid polypropylene/wood-fiber composites reinforced with glass fiber and carbon fiber. *The International Journal of Advanced Manufacturing Technology*, 106(1), 201-209.

Hosseinihashemi, S. K., Arwinfar, F., Najafi, A., Nemli, G. & Ayrilmis, N. (2016). Long-term water absorption behavior of thermoplastic composites produced with thermally treated wood. *Measurement*, 86, 202-208.

Karsli, N.G. & Aytac, A. (2013). Tensile and thermomechanical properties of short carbon fiber reinforced polyamide 6 composites. *Composites Part B: Engineering*, 51, 270-275.

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.

Kim J.K. & Pal, K., (2010). Recent Advances in the Processing of Wood-Plastic Composites. *1th ed. Berlin: Springer Science and Business Media*, 2010, p. 1.

Khan, R.A., Khan, M.A., Zaman, H.U., Pervin, S., Khan, N., Sultana, S. & Mustafa, A. I. (2010). Comparative studies of mechanical and interfacial properties between jute and E-glass fiber-reinforced polypropylene composites. *Journal of Reinforced Plastics and Composites*, 29(7), 1078-1088.

Klyosov, A.A. (2007). Wood-plastic Composites. 1th ed. New Jersey: John Wiley & Sons, 75p.

Kozłowski, R. & Władyka-Przybylak, M. (2008). Flammability and fire resistance of composites reinforced by natural fibers. *Polymers for advanced technologies*, 19(6), 446-453.

Leu, S.Y., Yang, T.H., Lo, S.F. & Yang, T.H. (2012). Optimized material composition to improve the physical and mechanical properties of extruded wood–plastic composites (WPCs). *Construction and Building Materials*, 29, 120-127.

Li, J. & Cai, C.L. (2011). The carbon fiber surface treatment and addition of PA6 on tensile properties of ABS composites. *Current Applied Physics*, 11(1), 50-54.

Nagarjun, J., Kanchana, J., RajeshKumar, G., Manimaran, S. & Krishnaprakash, M. (2021). Enhancement of Mechanical Behavior of PLA Matrix Using Tamarind and Date Seed Micro Fillers. *Journal of Natural Fibers*, 1-13.

Rochman, C.M., Hoh, E., Kurobe, T. & Teh, S.J. (2013). Ingested plastic transfers hazardous chemicals to fish and induces hepatic stress. *Scientific reports*, 3(1), 1-7.

Seo, Y.R., Kim, B.J. & Lee, S.Y. (2019). Effects of nanoclay and glass fiber on the microstructural, mechanical, thermal, and water absorption properties of recycled WPCs. *Journal of the Korean Wood Science and Technology*, 47(4), 472-485.

Stark, N.M. & Matuana, L.M. (2004). Surface chemistry and mechanical property changes of wood-flour/high-density-polyethylene composites after accelerated weathering. *Journal of Applied Polymer Science*, 94(6), 2263-2273.

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.

Wang, W. & Morrell, J.J. (2005). Effects of moisture and temperature cycling on material properties of a wood/plastic composite. *Forest products journal*, 55(10), 81-83.

Zhang, X., Yang, H., Lin, Z. & Tan, S. (2013). Polypropylene hybrid composites filled by wood flour and short glass fiber: effect of compatibilizer on structure and properties. *Journal of Thermoplastic Composite Materials*, 26(1), 16-29.