Mobilya ve Ahşap Malzeme Araştırmaları Dergisi
Furniture and Wooden Material Research Journal
Research Article - Araştırma Makalesi 2023 6(1), 70-79

Comparative study of some properties of wood plastic composite materials produced with polyethylene, wood flour, and glass flour

Bekir Cihad Bal*

Abstract

Wood flour is the most common filler used in the production of wood plastic composite (WPC) materials. In scientific studies on this subject, wood flours obtained from different trees and fillers obtained from different annual plants are used. In addition, some mineral-based fillers are also used in materials made of plastic. In this study, a low-density polyethylene polymer obtained from recycling was used as the matrix. Larch wood flour and glass flour obtained by grinding soft drink bottles were used as fillers. Composite boards were produced using 60% polymer as the matrix, along with wood flour and glass flour in varying proportions. The density, flexural strength, flexural modulus, tensile strength, tensile modulus, elongation at break, and hardness values of the produced composites were determined. Based on the data obtained, the density increased with the addition of wood flour and glass flour as fillers, and the density-increasing effect of the glass flour was higher than that of the wood flour. Compared to the control samples, it was determined that the bending strength and elongation at break of the experimental groups decreased, and the flexural modulus and tensile modulus increased in the experimental samples using wood flour and glass flour.

Keywords: Wood flour, Glass flour, WPC, Wood plastic composites

Polietilen, odun unu ve cam unu ile üretilen odun plastik kompozit malzemelerin bazı özellikleri üzerine karşılaştırmalı bir çalışma

Öz

Odun plastik kompozit (OPK) malzemelerin üretiminde dolgu maddesi olarak çoğunlukla odun unu kullanılmaktadır. Bu konuda yapılan bilimsel çalışmalarda da farklı ağaçlardan elde edilen odun unları ve değişik yıllık bitkilerden elde edilen dolgu maddeleri kullanılmaktadır. Ayrıca, bazı mineral esaslı dolgu maddeleri de plastikten üretilen malzemelerde kullanılmaktadır. Bu çalışmada, geri dönüşümden elde edilen düşük yoğunluklu polietilen polimer matris olarak kullanılmıştır. Dolgu maddesi olarak Karaçam odun unu ve kullanılmış meşrubat şişelerinin öğütülmesi ile elde edilen cam unu kullanılmıştır. Kompozit levhalarda polimer matris %60 oranında ve odun unu ve cam unu ise değişen oranlarda kullanılmıştır. Üretilen kompozitlerin; yoğunluk, eğilme direnci, eğilmede elastikiyet modülü, çekme direnci, çekmede elastikiyet modülü, kopmada uzama ve Shore D sertlik değerleri belirlenmiştir. Elde edilen verilere göre; odun unu ve cam ununun dolgu maddesi olarak eklenmesi ile yoğunluğun arttığı ve cam ununun yoğunluğu artırıcı etkisinin daha fazla olduğu belirlenmiştir. Kontrol örneklerine kıyasla, odun unu ve cam ununun kullanıldığı deney örneklerinde, eğilme direncinin ve kopmada uzama miktarının azaldığı, eğilmede ve çekmede elastikiyet modülünün artığı belirlenmiştir.

Anahtar kelimeler: Odun unu, Cam unu, OPK, Odun plastik kompozitleri

Article history: Submitted:23.06.2023, Accepted:13.06.2023, published:30.06.2023 *e-mail: bcbal@hotmail.com
*Kahramanmaraş Sütçü İmam University, Vocational School of Technical Sciences, Kahramanmaraş/Türkiye
To cite: Bal, B.C., (2023), Comparative study of some properties of wood plastic composite materials produced with polyethylene, wood flour and glass flour, *Furniture and Wooden Material Research Journal*, 6(1), 70-79,
DOI:10.33725/mamad.1301384

1 Introduction

There have been many studies on wood-plastic composites. The majority of these have attempted to determine the properties of composite materials produced using a polymer matrix and one or more fillers in a lignocellulosic structure. For example, Stark and Matuana (2004) conducted a Fourier-transform infrared spectroscopic analysis and attempted to determine the mechanical properties and photodegradation of composite boards produced using wood flour (Ponderosa pine), high-density polyethylene and wax after aging tests. Ndiaye et al. (2011) determined the bending strengths of composite materials produced using pine wood flour (0%, 5%, 25%, and 50%), and polypropylene. Altuntaş et al. (2017) evaluated the mechanical properties of a composite material produced with Scotch pine wood flour and high-density polyethylene. Mengeloğlu and Çavuş (2020) investigated the effects of teak wood flour and rice husk as fillers. Narlıoğlu et al. (2018) investigated some mechanical properties of composite boards produced using pine wood flour and polypropylene.

Some mineral materials have also been used as fillers in the production of plastic composites. For example, Dündar et al. (2016) studied the effects of marble flour and wood flour contents on the technological properties of thermoplastic composites, and they reported that although the mechanical properties of the composites decreased with an increase in the marble-powder content, the water absorption of the composites significantly decreased. The physical, mechanical, and thermal properties of wood/zeolite/plastic hybrid composites were investigated by Kaymakçı et al. (2017), and they reported that the flexural and tensile properties of the wood plastic composites decreased with increasing zeolite content. Kaymakçı (2019) investigated the effect of titanium dioxide on some properties of wood-plastic nano-composites, and noted that the flexural and tensile properties of the composites increased with the TiO2 content.

In some previous studies, glass flour obtained from waste glass was used as filler in plastic composites. For example, Sadik et al. (2021) evaluated the remarkable mechanical and thermal properties of high-density polyethylene/waste glass flour composite, and they reported that the tensile properties decreased as the waste glass powder percentage increased. Bhaskar et al. (2021) investigated the tensile and flexural strengths of a glass-flour-reinforced polymer composite, and noted that using 40% crystal powder filler by volume resulted in the maximum tensile strength, whereas the maximum flexural and impact strengths were achieved with 30% and 20% volume fractions, respectively. Heriyanto et al. (2018) investigated some of the mechanical properties of a polypropylene composite filled with sawdust and glass powder. They reported that the flexural strength decreased as the sawdust decreased and glass powder increased. Karunanayake (2007) evaluated the effects of glass powder on some of the mechanical properties of some engineering thermoplastics. According to the data obtained as a result of the study, it was reported that the density and flexural modulus increased, and the flexural strength and impact strength decreased, with an increase in the glass powder. Kristiawan (2022) evaluated the effects of glass powder additive on some mechanical properties of recycled polypropylene filaments, and reported that the ultimate tensile strength and Young's modulus of rPP-based specimens with 10% glass powder additive showed increases of 38% and 42% compared to PP specimens, respectively.

To the best of the author's knowledge, there has been no adequate study on the effects of glass flour on the properties of recycled low-density polyethylene composites. Therefore, the aim of this study was to investigate the effects of wood flour and glass flour as filler materials on some of the properties of a polymer composite produced from recycled low-density polyethylene.

2 Material and Method

2.1 Material

In this study, recycled polyethylene was used to produce wood plastic composites. Polyethylene in granular form was obtained from Vepsan (Kahramanmaraş, Türkiye). Pine wood flour with a 40-mesh dimension was used as a filler material. Drink bottles collected from domestic use were used for glass flour. The bottles were smashed with a hammer into small pieces, ground with a grinder, and used as a filler material. The compositions of the composites are given in Table 1. Group 2, which contained 40% wood flour, and group 6, which contained 40% glass flour, were created to compare the effects of wood flour and glass flour on mechanical properties. Groups 3, 4, and 5 were formed to detect changes in the mechanical properties.

Figure 1. Recycled polyethylene (A), pine wood flour (B), waste glass flour (C)

The pine wood flour and waste glass flour were dried at 103 ± 2 °C. The wood flour, glass flour, and polyethylene were then mixed to obtain a homogenous blend before processing in the extruder. Then, the blend was mixed with a single screw extruder at temperatures of 160, 175, and 190 °C. The extruded compound was taken in a filament form from the barrel exit with a nozzle diameter of 3 mm. The extruded compound in a filament form was cooled in the air on a table. The cooled filament was cut into pellets, and these pellets were remixed with the extruder at temperatures of 160, 175, and 190 °C. The extruded compound in a filament form was recooled in the air on a table. The cooled filament was recut into pellets. These pellets were placed in a metal mold and transferred between electrical-heated metal plates at a temperature of 190 ± 5 °C. Non-stick baking paper (wax paper) was used to prevent sticking. The compound was heated, and melted over a period of 17 min. No pressure was applied during this procedure. At the end of this duration, the melted compound was removed from the heater with the metal mold and immediately placed in a cold press. A total of 2.5 kg/cm^2 of pressure was applied in the cold press for 5 min. After pressing, the formed compound was taken from the metal mold, and a composite board was thus obtained with the dimension of 3.5 × 175 × 175 mm^3 (thickness × width × length). Four composite boards were produced for each group. A total of 24 boards were produced for this present study. Test samples were prepared from these boards. Four test samples were cut from each board for each test. Sixteen test specimens were prepared for each test. Test samples were cut using a laboratory band saw. The edges of each test sample prepared for the tensile test were shaped with a CNC router. The compositions of the composites are given in Table 1. Group 2 containing 40% wood flour and group 6 containing 40% glass flour were created to compare the effects of wood flour and glass flour on mechanical properties. Group 3, group 4, and group 5 were formed to detect the change in mechanical properties.

Table 1. Composition of the Composites (wt%)

	Control group	Experimental groups				
Content (%)	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Polyethylene	100	60	60	60	60	60
Wood flour	0	0	10	20	30	40
Glass flour	0	40	30	20	10	0

2.2 Method

Flexural, tensile, and hardness tests were performed according to ASTM D790-15 (2016), ASTM D638-22 (2022), and ASTM D2240-15 (2021), respectively. Flexural tests were conducted using a three-point bending test procedure on an electromechanical universal testing machine (Natek 10kN). The span length was 56 mm. The support span-to-depth ratio was 16:1. The preload was 5 N and the test speed was 2 mm/min. The test was ended when the load decreased to 80% of the maximum load. Tensile tests were conducted on dog-bone-shaped test samples (Type I) as described in ASTM D638-22 (2022). The distance between grips was 115 mm, the preload was 5 N, and the test speed was 5 mm/min. The test was ended when the test sample broke or the load decreased to 80% of the maximum load. At the end of the test, the elongation was noted as the elongation at break. Hardness tests were performed on a Shore D test device, model LD-J loyka.

The SPSS statistical package program was used. The data were analyzed using a one-way analysis of variance (ANOVA), and significant differences among groups were determined by the Duncan multiple range test.

3 Results and Discussion

The data obtained from density, ANOVA, and Duncan tests are given in Table 2. When the density values given in the table were examined, it was determined that the density of the control group (group 1) was 920 kg/m3, and the densities of the test samples in the experimental groups, which used wood and glass flour fillers, were significantly higher than that of the control group. In addition, the effect of glass flour on the density was greater than the effect of wood flour. The highest density was measured in group 6, which was filled with 40% glass flour. Similar results were reported by Karunanayake (2007) and Heriyanto et al. (2018). According to Heriyanto et al. (2018), this was because the addition of small particles of glass flour filler provided better compaction of the larger wood flour. When the Duncan test results given for the density values in the table were examined, it was determined that there was a statistically significant difference ($P < 0.001$) between groups 1, 2, 3, 4, and 5, but this increase was not statistically significant between groups 5 and 6. In previous studies on wood plastic composite materials, similar results were obtained regarding the density values (Heriyanto et al., 2018; Atar et al., 2021; Friedrich 2021; Bal 2022).

Table 2. Density values, ANOVA P-values, and Duncan test results

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	P values
x	920A*	1034B	1088C	1126D	1162E	1166E	P < 0.001
ss	4.2	9.5	8.9	12.0	9.6	13.4	

x: mean value, ss: standard deviation, and *: lowest value, with different letters (*a, b, c) indicating significant differences in Duncan test results

The flexural strength and modulus of elasticity data for the obtained composite material are given in Table 2. As the percentage of wood flour decreased and the percentage of glass flour increased, some mechanical properties increased while others decreased. It is known that the mechanical properties of many composite materials generally increase with the density. However, this is not the case for every mechanical property of wood-plastic composite materials. As listed in Table 2, the flexural strength first increased and then decreased as the amount of wood flour decreased and glass flour increased. The highest flexural strength was determined in the control group.

The flexural strength of the control group was 17.4 N/mm^2. The lowest flexural strength was 12.7 N/mm^2 in group 6 with 40% glass flour. The flexural strengths of all the experimental (groups 2, 3, 4, 5, and 6) test samples were lower than that of the control group (group 1) ($P < 0.001$). When the flexural strengths of groups 2 and 6 were compared, it was determined that group 2 filled with wood flour had a higher flexural strength. Similar results reported by Heriyanto et al. (2018) were related to the effects of wood flour and glass flour. According to Tabari et al. (2011) and Heriyanto et al. (2018), this was because a weak interfacial region leads to delamination of the particulates during flexural testing and reduces the efficiency of the stress transfer along the matrixes.

The flexural modulus was measured as 351 N/mm^2 in the control group, which was the lowest value. The highest was 741 N/mm^2 in group 4 (filled with 20% wood flour and 20% glass flour). In general, as the percentage of wood flour decreased and that of the glass flour increased, the flexural modulus first increased and then decreased. Comparing the flexural modulus values of group 2 filled with 40% wood flour and group 6 filled with 40% glass flour showed that group 2 had a higher flexural strength. Compared to the control group, the flexural modulus values of the experimental groups were higher. The difference was statistically significant ($P < 0.001$).

Similar results were obtained in previous studies on the flexural properties of wood-plastic composite materials. For example, Ayrılmıs, and Jarusombuti (2011) reported that the flexural strength tended to increase as the amount of wood flour increased and then decreased again, while the flexural modulus increased as the amount of wood flour increased. Mengeloğlu and Karakuş (2008) reported that as the wood flour ratio of wood plastic composites produced with eucalyptus wood flour and recycled high-density polyethylene increased, the flexural strength decreased and the flexural modulus increased. Altuntaş et al. (2017) reported that as the percentage of wood flour increased, the flexural strength decreased, but the flexural modulus increased. Çavuş (2020) determined that as the wood flour percentage of a wood-plastic composite material produced using mahogany wood and polypropylene increased, the flexural strength and flexural modulus increased.

Table 3. Flexural test data, ANOVA P values, and Duncan test results

		Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	P values
Flexural Strength N/mm^2	x	17.4D	14.4B	15.4C	15.9C	15.4C	12.7A*	P<0.001
	ss	0.5	1.0	0.8	0.8	0.6	1.1	
Flexural Modulus N/mm^2	x	351A*	686C	703CD	741D	696CD	531B	P<0.001
	ss	22	86	85	67	39	37	

x: mean value, ss: standard deviation, and *: lowest value, with different letters (*A, B, C) indicating significant differences in Duncan test results

The load–deformation graphs obtained during the flexural tests of the test specimens belonging to groups 1, 2, and 6 are shown in Fig. 1. These graphs show that the amount of deformation in bending is approximately 20 mm in group 1, where it is the highest. The smallest of approximately 16 mm was obtained in group 2. It was approximately 19 mm in the test samples of group 6. It has been reported that materials showing large areas under the load–deformation graphs produced by flexural tests are more flexible and have higher deformation ability than those showing smaller areas (Örs and Keskin 2001).

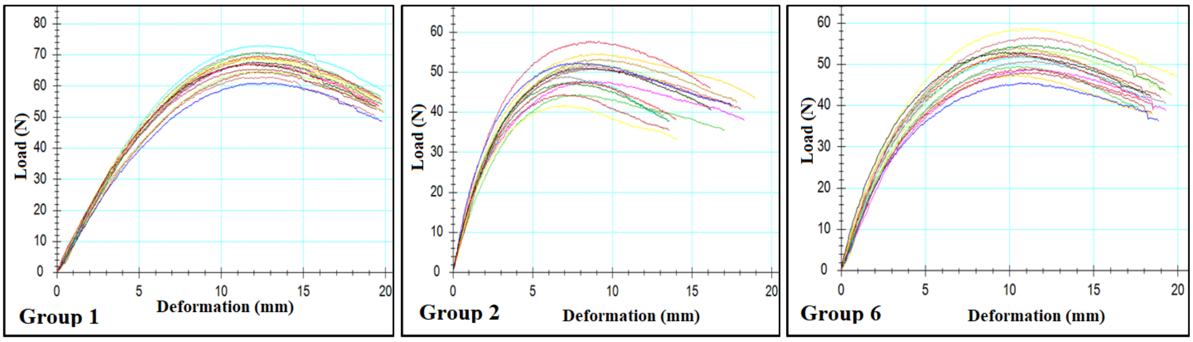

Figure 2. Load–deformation curves from flexural tests (group 1, group 2, and group6)

The tensile strength, tensile modulus, and elongation at break data are given in Table 3. The highest tensile strength was determined to be 10.1 N/mm^2 in group 1 and the lowest was 5.7 N/mm^2 in group 2. The tensile strengths of all the experimental groups (groups 2, 3, 4, 5, and 6) were smaller than that of the control group (group 1). Similar results were reported by Sadik et al. (2021) and Karunanayake (2007). The tensile strengths of the experimental groups increased as the percentage of wood flour decreased and the percentage of glass flour increased. The difference was statistically significant ($P < 0.001$). According to the Duncan tests, there was no statistical difference between the tensile strengths of groups 5 and 6. The smallest tensile modulus was 139 N/mm^2 in group 1, and the highest was 332 N/mm^2 in group 3. In contrast to the tensile strength, the tensile modulus values of all the experimental groups (groups 2, 3, 4, 5, and 6) were greater than that of the control group. The difference was statistically significant ($P < 0.001$). According to the Duncan test results, there was no difference between groups 4, 5, and 6. The elongation at break was 219% in group 1, which was the highest, and 4.5% in group 3, which was the lowest. The elongation at break values of all experimental groups (groups 2, 3, 4, 5, and 6) were smaller than that of the control group. Similar results related to plastic composites filled with glass flour were reported by Sadik et al. (2021) and Karunanayake (2007). The difference was statistically significant ($P < 0.001$). However, the difference between the Duncan test results for the experimental groups was insignificant. The elongation at break of group 6 was greater than the elongation at break of group 2. Similar results have been reported for the tensile strength, tensile modulus, and elongation at break in previous studies on wood plastic composites. Mengeloğlu and Karakuş (2008) determined that as the wood flour ratio of wood–plastic composites produced using eucalyptus wood flour and recycled high-density polyethylene increased, the tensile strength and elongation at break values decreased, and the tensile modulus increased. Similar results were obtained in the study conducted by Atar et al. (2016) using eggplant stalks as filler. In the study conducted by Altuntaş et al. (2017), it was determined that as the percentage of Scotch pine wood flour increased, the tensile strength decreased and the tensile modulus increased. Akbas et al. (2013) determined that both the tensile strength and tensile modulus decreased with an increase in the filling percentage in their study using hazelnut flour. Çavuş

(2020) reported that as the wood flour percentage of a wood–plastic composite material produced using mahogany wood and polypropylene increased, the tensile modulus increased, but the tensile strength and elongation at break decreased. Similar results were obtained in the studies by Çavuş and Mengeloğlu (2017) and Kısmet (2015). It can be said that the reasons that these studies obtained different results are related to the characteristics of the filler and polymer used.

Table 3. Tensile test data for composites, ANOVA P-values, and Duncan test results

		Group 1	Grup 2	Grup 3	Grup 4	Grup 5	Group 6	P values
Tensile Strength N/mm²	x	10.1D	5.7A*	6.0B	6.1B	6.6C	6.6C	P<0.001
	ss	0.7	0.3	0.5	0.4	0.4	0.3	
Tensile Modulus N/mm²	x	139A	233B	332D	310C	292C	289C	P<0.001
	ss	30	29	34	25	24	39	
Elongation at break (%)	x	219B	4.7A	4.5A	5.7A	9.2A	29.4A	P<0.001
	ss	93.6	0.8	0.6	1.0	2.5	11.1	

x: mean value, ss: standard deviation, and *: lowest value, with different letters (*A, B, C) indicating significant differences in the Duncan test results

Stress–strain graphs were produced using the data obtained during the tensile tests. These graphs are given in Figure 2. It can be seen that there are very important differences between the graph of group 1, which is the control group, and the other graphs. The elongation at break was measured as 219% in the control group. In group 2, a very rapid decrease in the elongation at break occurred. The smallest elongation at break was measured as 4.7% in group 2. It is thought that the elongation at break decreased because of the weakening of the internal adhesion of the polymer matrix due to the filler.

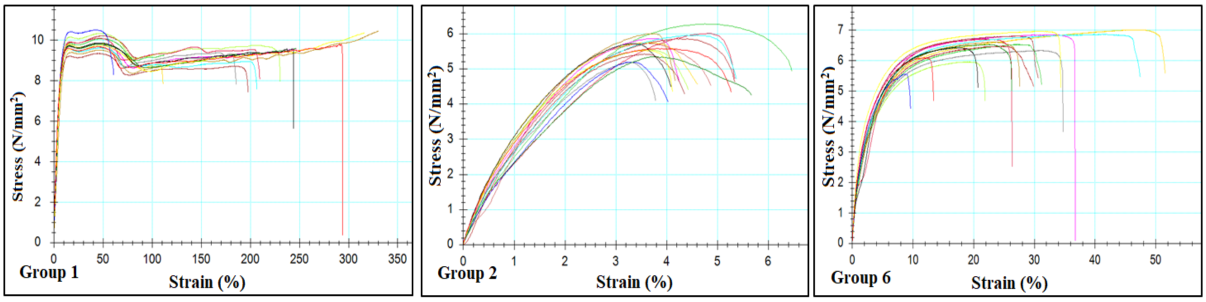

Figure 2. Stress-strain curves of tensile tests of the group 1, 2 and 6

The Shore D hardness values of the composites produced in this study are given in Table 4. The hardness values of all the experimental groups were greater than that of the control group. The Shore D hardness of group 2 was higher than that of group 6. The differences among groups were significant ($P < 0.01$). As the percentage of wood flour in the composite material decreased and the percentage of glass flour increased, the hardness value decreased. In fact, glass is a harder material than wood. However, the amount of wood flour added to the composite as a weight percentage was much greater than the amount of glass flour. Therefore, as the wood flour in the composite decreased, the hardness decreased. Similar results have been reported in previous studies. Çavuş (2020) determined that the Shore D hardness value increased as the percentage of wood flour increased in wood–plastic composite materials produced with mahogany wood and polypropylene. Similar results were obtained in the study by Çavuş and Mengeloğlu (2017) and in the study by Mengeloğlu and Çavuş (2020), in which teak wood flour and rice husk were used as fillers.

The hardness value increased with increasing filler material. In general, with the addition of lignocellulosic or mineral-based filler to the composite, the density of the produced composite material also increased. As a natural consequence of this, the hardness value increased. However, it cannot be generalized that all of the mechanical properties and modulus of elasticity of wood–plastic composite materials increase with the density. There was no such claim in previous studies. In this study and previous studies on similar subjects, the increase in the density of the wood–plastic material caused an increase in the static hardness value. However, some other mechanical properties such as the tensile strength and elongation at break decreased.

Table 4. Hardness test data for composites, ANOVA P-values, and Duncan test results

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	P values
x	48.3A*	56.9E	58.6F	55.5D	54.0C	51.6B	P < 0.001
ss	1.2	0.7	0.5	0.5	1.1	0.7	

x: mean value, ss: standard deviation, and *: lowest value, with different letters (*A, B, C) indicating significant differences in the Duncan test results

4 Conclusions

In this study, the effects of wood flour and glass flour as filler materials on the some properties of a polymer composite produced from recycled low-density polyethylene were investigated comparatively. According to the data obtained, the following conclusions can be made.

- In this study, composite materials were successfully produced using wood flour and glass flour as fillers, along with recycled polyethylene.
- The flexural strength, tensile strength, and elongation at break values of the produced composites decreased with the addition of filler, whereas the bending and tensile modules increased.
- The flexural strength and flexural modulus of group 2, which used 40% wood flour, were higher than those of group 6, which used 40% glass flour.
- The tensile strength, tensile modulus, and elongation at break of group 2, which used 40% wood flour, were lower than those of group 6, which used 40% glass flour.
- It was determined that the hardness values of all experimental groups were greater than that of the control group. Because the volume of wood flour added to the composite was much higher than that of glass flour, the wood flour produced a greater increase in the hardness than the glass flour.
- Considering the flexural and tensile test results, it can be said that wood flour and glass flour should be used in equal amounts in a wood–polymer composite.

Acknowledgement
This work was supported by a grant from the Kahramanmaraş Sütçü İmam University Scientific Research Projects Unit, Project Number: 2022/2-17M. I would like to thank Mr. Ümit Ayata for his contributions to the Shore D hardness tests.

Author contributions
Bekir Cihad Bal: Determining the research topic, planning and conducting laboratory studies, obtaining data, writing the article, publishing the article.

Funding statement

This work was supported by a grant from the Kahramanmaraş Sütçü İmam university scientific research projects unit, Project Number: 2022/2-17M.

Conflict of interest statement

The author declares no conflict of interest.

References

Akbaş, S., Tufan, M., Güleç, T., Taşçıoğlu, C., Peker, H. (2013), Fındık kabuklarının polipropilen esaslı polimer kompozit üretiminde değerlendirilmesi, *Artvin Çoruh Üniversitesi Orman Fakültesi Dergisi*, 14(1), 50-56.

Altuntaş, E., Yılmaz, E., Salan, T. (2017), Yüksek oranda lif dolgu maddesi kullanımının odun plastik kompozit malzemenin mekanik özellikleri üzerine etkisinin araştırılması, *Turkish Journal of Forestry*, 18(3), 258-263.

ASTM D 638 (2022), Standard test method for tensile properties of plastics, ASTM International, West Conshohocken, PA. 1–24 s.

ASTM D 790 (2016), Flexural properties of unreinforced and reinforced plastics and electrical insulating materials, ASTM International, West Conshohocken, Philadelphia, PA. 1–9 s.

ASTM D 2240 (2021), Standard test method for rubber property-durometer hardness, American Society for Testing and Materials, West Conshohocken, Pennsylvania, United States, 1–27 s.

Atar İ., Başboğa, İ. H., Karakuş, K., Mengeloğlu, F. (2016), Utilization of eggplant (*Solanum melongena*) stalks as a filler ın manufacturıng of compress molded PP based composites, *European Journal of Technique* (EJT), 6(2), 138-144.

Atar İ., Başboğa, İ. H., Karakus, K., Mengeloğlu, F. (2021), Effect of waste tea (Camellia sinensis) wood fibers and mape on some propertıes of high density polyethylene (HDPE) based polymer composites, *Turkish Journal of Forest Science*, 5(2), 606-619.

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.

Bal B.C. (2022), Lineer düşük yoğunluklu polietilen (LDYPE) ve odun unu ile üretilen kompozit malzemenin bazı mekanik özellikleri üzerine bir araştırma, *Mobilya ve Ahşap Malzeme Araştırmaları Dergisi*, 5 (1), 40-49, DOI: 10.33725/mamad.1126534

Bhaskar, K. B., Devaraju, A., Paramasivam, A. (2021), Experimental investigation of glass powder reinforced polymer composite. *Materials Today: Proceedings*, 39, 484-487.

Çavuş, V., Mengeloğlu, F. (2017), The effect of lignocellulosic filler types and concentrations on the mechanical properties of wood plastic composites produced with polypropylene having various melt flowing index (MFI), *Pamukkale University Journal of Engineering Sciences*, 23(8).

Çavuş, V. (2020), Selected properties of mahogany wood flour filled polypropylene composites: the effect of maleic anhydride-grafted polypropylene (MAPP), *BioResources*, 15(2), 2227-2236.

Dundar, T., Ayrilmis, N., Akkus, M., Ulay, G. (2016), Effect of the marble powder and wood powder content on the technological properties of thermoplastic composites, *Machines Technologies Materials*, 10(6), 13-16.

Friedrich, D. (2021), Thermoplastic moulding of Wood-Polymer Composites (WPC): A review on physical and mechanical behaviour under hot-pressing technique, *Composite Structures*, 262, 113649.

Heriyanto, Pahlevani, F., Sahajwalla, V. (2018), Waste glass powder–innovative value-adding resource for hybrid wood-based products, *Journal of Cleaner Production*, 195, 215-225.

Karunanayake, L. (2007), The effects of glass powder on some mechanical properties of engineering thermoplastics, *J. Natn. Sci Foundation Sri Lank*, 35(1), 13-17.

Kaymakci, A., Gulec, T., Hosseinihashemi, S. K., Ayrilmis, N. (2017), Physical, mechanical and thermal properties of wood/zeolite/plastic hybrid composites, *Maderas Ciencia y tecnología*, 19(3), 339-348.

Kaymakci, A. (2019), Effect of titanium dioxide on some mechanical, thermal, and surface properties of wood-plastic nanocomposites, *BioResources*, 14(1), 1969-1979.

Kısmet, Y. (2015), Kurutulmuş kolza bitkisinin dolgu malzemesi olarak alçak yoğunluklu polietilenin mekanik özelliklerine, yoğunluğuna ve su emme kapasitesine etkileri, *Politeknik Dergisi*, 18(4), 203-209.

Kristiawan, R. B., Rusdyanto, B., Imaduddin, F., Ariawan, D. (2022), Glass powder additive on recycled polypropylene filaments: A sustainable material in 3D printing, *Polymers*, 14(1), 5.

Mengeloğlu, F., Karakuş, K. (2008), Some properties of eucalyptus wood flour filled recycled high density polyethylene polymer-composites, *Turkish journal of agriculture and forestry*, 32(6), 537-546.

Mengeloğlu, F., Çavuş, V. (2020), Preparation of Thermoplastic Polyurethane-based Biocomposites through Injection Molding: Effect of the Filler Type and Content, *BioResources*, 15(3), 5749-5763.

Narlıoğlu, N., Çetin, N. S., & Alma, M. H. (2018), Karaçam testere talaşının polipropilen kompozitlerin mekanik özelliklerine etkisi, *Mobilya ve Ahşap Malzeme Araştırmaları Dergisi*, 1(1), 38-45.

Ndiaye, D., Matuana, L. M., Morlat-Therias, S., Vidal, L., Tidjani, A., Gardette, J. L. (2011), Thermal and mechanical properties of polypropylene/wood-flour composites, *Journal of applied polymer science*, 119(6), 3321-3328.

Örs, Y., Keskin, H., (2001). Ağaç malzeme bilgisi, Gazi üniversitesi ders kitabı, S:77, Ankara.

Sadik, W. A., El-Demerdash, A. G. M., Abokhateeb, A. E., Elessawy, N. A. (2021), Innovative high-density polyethylene/waste glass powder composite with remarkable mechanical, thermal and recyclable properties for technical applications, *Heliyon*, 7(4), e06627.

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.

Tabari, H.Z., Danesh, M.A., Pia, R.H., Nourbakhsh, A., (2011), Evaluation of mechanical and morphological behaviour of polypropylene/wood fiber nanocomposite prepared by melts compounding, In: International Conference on Nanotechnology and Biosensors IPCBEE, vol. 2, pp. 1-4.