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Research article

Effect of bark flour on the mechanical properties of HDPE composites

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Abstract

The objective of this study was to evaluate the replacement of wood flour by Turkish pine bark residues for production of wood plastic composites. High density polyethylene was chosen as matrix and seven different compositions were used for production of composites. In order to compare the effect of bark residues flour as a filler, bark residues-HDPE composites were produced with various wt% bark residues loading (10, 20, 30 and 40 wt%). Bark residues filled HDPE pellets were produced by using a twin-screw extruder, then 25 cm (l) x 25 cm (w) and 2 mm (t) composites were produced with compression molding technique according to ASTM D4703-10. For each composition, three composites were produced. Tensile and flexural tests were performed with a Universal Testing machine. Impact strength was measured with a Zwick HIT5.5P Impact Testing machine. Tensile and impact strength of the composites decreased with increasing bark flour loading whereas bending strength and modulus of eleasticity values were improved with addition of the bark flour. All produced bark flour filled composites showed better modulus of elasticity and bending strength properties than ASTM D6662-13 standard requirements for polyolefin-based plastic lumber. Morphological properties of bark residues-HDPE composites were characterized by scanning electron microscopy (SEM) technique.

Keywords: *Wood plastic composites, mechanical properties, high density polyethylene, Turkish pine bark*

1. Introduction

A composite material can be defined as the heterogeneous combination of two or more components to form a filled or reinforced matrix in which the combined effect of the components possesses superior properties compared to the individual components alone [1]. Wood-plastic composites (WPC) refer to an extremely wide range of composite materials that use polymers ranging from polyetylene (PE) or polyvinyl chloride (PVC) and fillers ranging from wood flour to natural fibres [2]. In the production of WPC, recycled materials such as waste polymers and waste wood flour were generally used. The production and utilisation of WPC have showed continuous increase since 1980.

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WPC are mostly used in outdoor applications especially decking, railing, flooring and fences [3].

The thermoplastic polymers such as polypropylene (PP), PE or PVC, which have a low melting temperature, are commonly used in WPC production. Since, the application of high temperature during the production of WPC can disrupt the chemical structures of wood components and induce the formation of undesired changes in the wood structure. [4]. Wood flour waste material and saw dust are generally obtained as a by-product of the wood processing industry. In recent years, the various lignocellulosics fibers such as flax, hemp, kenaf, corn stalks are attempted to use instead of wood flour as a substitute material in WPC. WPC can be produced by using various amounts of wood flour loading (about 50% or above) [3,5,6-11].

Recently, the interest in the production and utilization of WPC has also increased in Turkey as well as in all over the world. In order to reduce the production costs of the WPC, it is necessary to find an alternative reinforcement raw material in the plastic industry. Wood bark is produced as a large quantity of waste product from forest industries and mainly assessed by incinerating material or left in the forest area after logging process, which may lead some environmental problems. It is possible to utilize this waste bark flour as an alternative and potential filler to form of higher value WPC's [12-15].

According to data received from General Directorate of Forestry, the total forest areas in Turkey constitute of 25% Turkish pine forest and approximately 20 million cubic meter round wood harvested in 2012 [16,17]. Although the ratio of wood bark is generally around 9% to 24% of the whole tree, it varies considerably depending on the wood species and the log diameters. When the average bark ratio is taken as 10% for a single tree, about 2 million cubic meter bark waste is generated annually. The aim of this study was to investigate the potential utilization of waste bark flour from Turkish pine for the production of WPC.

2. Materials and Methods

2.1. Preparation of Wood Bark

Turkish pine (*Pinus brutia*) bark was ground using an IKA brand mill and sieved to a size of 250 to 450 μm. Before production of WPC, bark flour was oven-dried overnight, at 103±2°C and allowed to cool to the room temperature in a desiccator containing phosphorous pentoxide.

2.2. Production of Wood Plastic Composites (WPC)

High-density polyethylene used in the experiments was obtained from Petkim, Turkey (HDPE; Petilen® YYS0464). Bark flour and HDPE were extruded using co-rotating twin screw Rondol brand extruder and seven different compositions were prepared (Table 1 and Fig. 1). The temperature setting from the hopper to die was 90, 150, 170, and 177°C and the screw speed was 50 rpm. Then, the extrudate was passed through a water bath and automatically pelletized at 2 mm size by Rondol pellet machine (Fig. 2).

Table 1
The compositions used for production of WPCs

	(wt%)			
ID	**HDPE**	**Wood flour**	**Bark flour**	**MAPE**
HDPE	100	-	-	-
HDPE + WF_{20}	80	20	-	-
HDPE + BF_{10}	90	-	10	-
HDPE + BF_{20}	80	-	20	-
HDPE + BF_{30}	70	-	30	-
HDPE + BF_{40}	60	-	40	-
HDPE + BF_{20MAPE}	75	-	20	5

Fig. 1 Rondol brand twin screw extruder and pelletizer

(a) (b) (c)

Fig. 2 (a) HDPE pellets, (b) Milled red pine bark flour, (c) Extruded and pelletized bark flour and HDPE mixture (bark flour loading 40%)

The pellets were dried at 70±2°C for 24 hrs and then composites were produced with compression molding technique by using Carver press (Model 12-12 H, USA) according to ASTM D4703-10 [18]. For composite production, Carver brand tile mold 25 cm (l) x 25 cm (w) and 2 mm (t)) was used. The pellets were initially heated for 10 min, and then pressed at a force of 9 ton for 5 min at 177°C. Following that, the composites were cooled down the Cooling Method B according to ASTM D4703-10 [18]. For each composition, three composites were produced. The composites were then cut into dumbbell-shape, and two bar-shapes by using special mold to produce the samples for tensile strength, flexural and impact specimens (Fig. 3).

2.3. Determination of Mechanical Properties

Tensile and flexural tests were performed with a Universal Testing machine (Zwick Roell Z010), following ASTM 638 [19] and ASTM D6109 [20], in order to determine tensile strength and flexural strength for the samples after conditioned at 23±2°C with a relative humidity of 65±5% for 7 days. The test rate was 5 mm/min. Impact strength were measured with a Zwick HIT5.5P Impact Testing machine following ASTM256 [21]. The notches of impact specimens were cut using a Polytest notching cutter by RayRan.

(a) (b)

Fig. 3 (a) Produced bark flour filled composites, (b) Test samples

2.4. Scanning Electron Microscope (SEM) analysis

The WPC bars were dipped in liquid nitrogen and then snapped in two to get fractured surfaces for SEM analysis. The surfaces were analyzed directly with a JEOL scanning electron microscope (Model NeoScope JCM-5000).

3. Results and Discussion

In this study, Turkish pine bark flour was used as thermoplastic filler in the production of wood plastic composites. Firstly, the effect of various bark flour wt% loading (10 wt% to 40 wt%) on the properties of composites was determined. Production conditions were summarized in Table 1. Press molding technique was used for the production of composites. The composites consist of neat HDPE showed white color then turned to brown color with increasing the bark flour addition.

Effect of bark flour wt% loading levels on the tensile strength values are shown in Fig. 4. With the increase of bark flour wt% loading, tensile strength values of the composites showed a significant decrease up to a loading of 30 wt% (from 23 MPa to 12.6 MPa) and afterwards achieved to value of 12.9 MPa with 40 wt% loading. It was reported [10] that when the surface interaction is not strong enough in the soft fillers such as wood flour reduce the tensile strength. As can be seen from SEM photographs (Fig. 5) with increasing the bark flour wt% loading, the filler was not homogenously distributed in polymer matrix and also some aggregations were occurred. As a result of this, surface area of the filler reduced and interaction between bark flour and HDPE matrix decreased. This might be the reason of the tensile strength reduction in bark flour filled composites. It can be seen from Fig. 6, composites made with 40 wt% filler loading exhibited poor dispersion and aggregation of the bark flour in the matrix which may be the main reason of the lower tensile strength values.

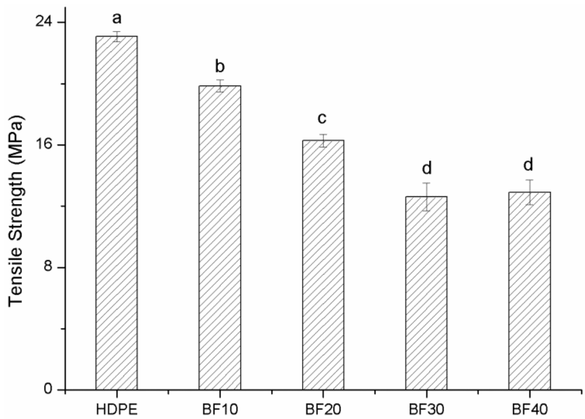

Fig. 4 Effect of bark flour (% loading levels) on the tensile strength values of HDPE composites (Bars with the same letter are not significantly different)

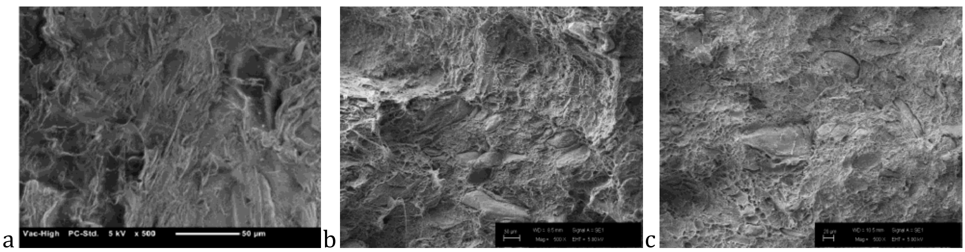

Fig. 5 SEM micrographs of fracture surface of 20% red pine wood flour/HDPE, (a) 20% red pine bark flour/HDPE, (b) 5% MAPE added 20% red pine bark flour/HDPE, and (c) composites

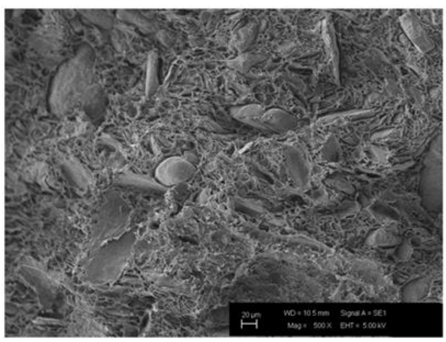

Fig. 6 SEM micrographs of fracture surface of 40% red pine bark flour/HDPE composite

At the same filler loading level (20 wt%), wood flour filled composites gave higher tensile strength values (20.6 MPa) than bark flour filled composites (16 MPa). The reason for this may be the differences in chemical compositions of these two fillers [15]. Incorporation of 5 wt% maleated polyethylene (MAPE) in the bark flour filled composites (20 wt% bark flour loading) increased the tensile strength values from 16.3 MPa to 20.5 MPa (Fig. 7). It can be concluded that addition of MAPE compatibilizers significantly enhanced the tensile strength properties of the produced composites. As can also be seen from SEM photographs (Fig. 5c), it seems necessary to use MAPE to improve the quality of adhesion between bark flour and HDPE to reduce the gaps in interfacial region and block the hydrophilic groups.

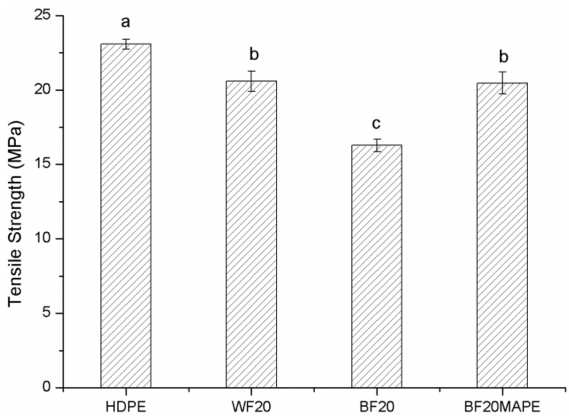

Fig. 7 Effect of MAPE on the tensile strength of 20% bark flour/HDPE composites (HDPE: Neat polymer composite, WF20: Wood flour/HDPE composite, BF: Bark flour/HDPE composite, BF20MAPE: Bark flour/HDPE composite with 5% MAPE)

The flexural modulus of the bark flour HDPE composites improved with increasing bark flour loading (Fig. 8). The highest flexural modulus value was obtained as 1.88 GPa at 30 wt% bark flour loading. After this point, the flexural modulus showed slight decrease to 1.71 GPa at 40 wt% bark flour loading.

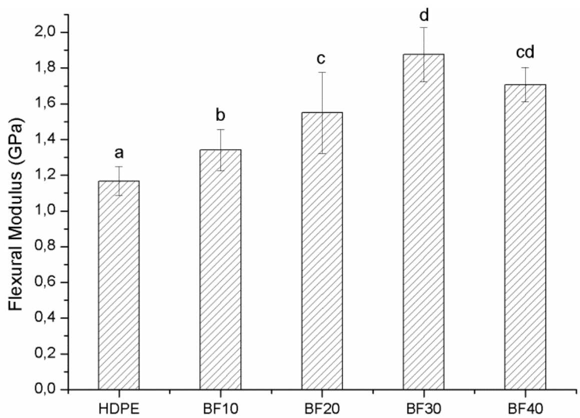

Fig. 8 Effect of bark flour (% loading levels) on the flexural modulus values of HDPE composites (Bars with the same letter are not significantly different)

Fig. 9 shows the flexural modulus values of the composites filled with wood flour, bark flour and 5 wt% MAPE added bark flour at the same filler loading (20 wt%). Addition of wood or bark flour in matrix improved the flexural modulus of the composites compared to neat polymer composites. Bark flour composites showed the maximum flexural modulus (1.55 GPa) at 20 wt% loading. Addition of the 5 wt% MAPE slightly reduced the flexural modulus of bark flour/HDPE composite (1.45 GPa).

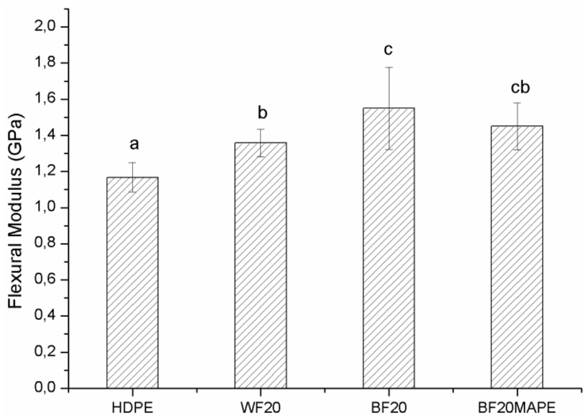

Fig. 9 Effect of MAPE on the flexural modulus of 20% bark flour/HDPE composites (HDPE: Neat polymer composite, WF20: Wood flour/HDPE composite, BF: Bark flour/HDPE composite, BF20MAPE: Bark flour/HDPE composite with 5% MAPE)

The effect of various weight percent bark flour loading on the values of the flexural strength of HDPE composites are shown in Fig. 10. The values of the flexural strength increased from 20 MPa to 21.5 MPa by addition of 10 wt% bark flour in HDPE. As would be expected, flexural strength values increase with the increase in bark flour loading. The maximum flexural strength (24.9 MPa) was obtained at 30 wt% bark flour loading, after this point flexural strength value decreased (23.5 MPa at 40 wt% loading).

The utilization area of the produced bark flour filled composites was thought in the area of the plastic lumber industry. Thus, the plastic lumber standard based on ASTM D 6662-13 [22] was chosen in order to compare the results obtained from bark flour filled composites. According to this standard, the minimum requirement flexural modulus and flexural strength values of plastic lumber are 340 MPa and 6.9 MPa, respectively. As shown from Figs. 8 to 10, all the produced bark flour/HDPE composites at various filler loading showed higher flexural modulus and flexural strength values than the required values by the standard. Therefore, bark flour/HDPE composites can be possibly used in the plastic lumbers applications.

The effect of various weight percent bark flour loadings on the values of the izod impact strength of HDPE composites are shown in Fig. 11. At 10 wt% bark flour loading, the impact strength showed a significant decrease from 457.3 J/m to 64.3 J/m compared to the neat composite ones. Impact strength values were decreased with increasing bark flour loading. At the same filler loading level (20 wt%), wood flour filled composites gave higher impact strength values (74.2 J/m) than bark flour filled composites. Incorporation of 5 wt% maleated polyethylene (MAPE) in the bark flour filled composites (20 wt% bark flour loading) did not have any significant effect on the impact strength value.

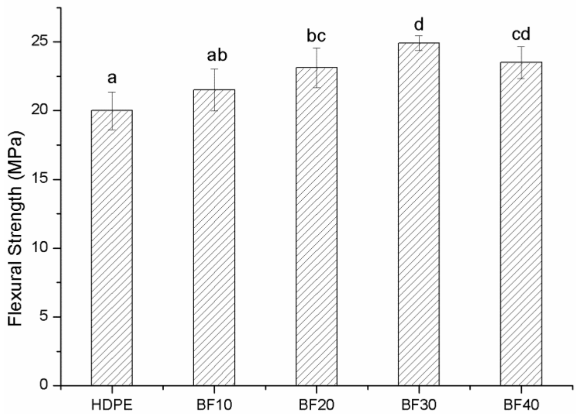

Fig. 10 Effect of bark flour (% loading levels) on the flexural strength values of HDPE

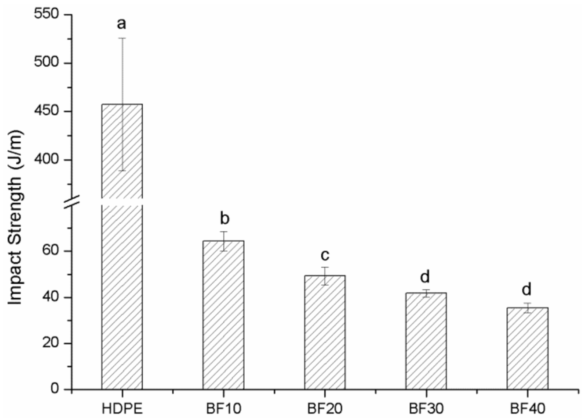

Fig. 11 Effect of bark flour (% loading levels) on the impact strength values of HDPE

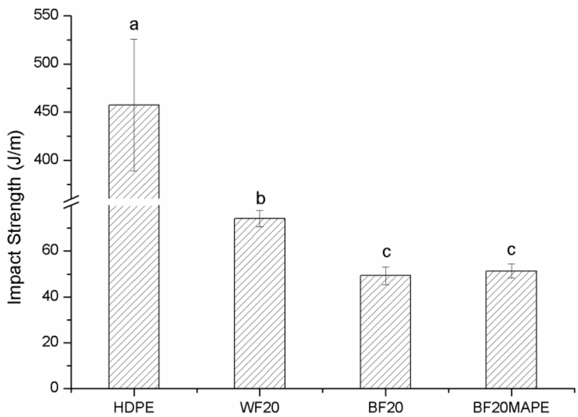

Fig. 12 Effect of MAPE on the impact strength of 20% bark flour/HDPE composites (HDPE: Neat polymer composite, WF20: Wood flour/HDPE composite, BF: Bark flour/HDPE composite, BF20MAPE: Bark flour/HDPE composite with 5% MAPE)

4. Conclusions

As a conclusion, Turkish pine bark flour filled-HDPE composites exhibited lower tensile and impact strength values with increasing bark flour loading. However, flexural modulus and flexural strength properties were significantly improved as the bark flour loading increased. Both wood and bark flour composites considerably indicated higher mechanical strength than the minimum requirement values by the plastic lumber standard based on ASTM D 6662-13 [22]. Therefore, it is possible to use these composites where the plastic lumbers were applied.

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