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SELECTED PROPERTIES OF FURNITURE PLANT WASTE FILLED THERMOPLASTIC COMPOSITES

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Abstract

With the population growth, the need of alternative raw materials is increasing. Recycling of waste lignocellulosic materials reduces the need of raw materials. Lignocellulosic materials are used as filler in the wood composite manufacturing. In the last five years, the production of wood plastic composite (WPC) materials is increasing (152%) in the world. In this study, the utilization of furniture plant waste (FPW) in the production of thermoplastic-based composite as filling material was investigated. High density polyethylene (HDPE) and polypropylene (PP) were used as thermoplastic polymer, maleic anhydrite grafted polyethylene (MAPE) and maleic anhydrite grafted polypropylene (MAPP) was also utilized as coupling agent for polyethylene and polypropylene based composites, respectively. The FPW were evaluated as filler. Composite samples were produced using combination of extrusion and compression molding methods. The tensile, flexural and impact properties of the produced composites were determined in accordance with ASTM D638, ASTM D6109, and ASTM D256, respectively. Morphological properties of the samples were characterized with scanning electron microscopy (SEM) analysis. As a result, with increase of filler amount, tensile modulus and flexural modulus were increased while tensile strength, elongation at break, impact strength and flexural strength were diminished. Manufactured composites provided acceptable flexural properties for the plastic lumber applications.

Key words: *thermoplastic composite; furniture plan waste; polyethylene; polypropylene; mechanical properties.*

INTRODUCTION

The composite material combines two or more physically different materials to achieve better properties than constituent materials. There is a growing interest on lignocellulosic material (wood dust, wheat straw flour, etc.) filled thermoplastic composites due to their availability, renewability, cost, eco-friendliness and ease of processing (Mengeloğlu and Karakuş 2008b).

Demand for the production of composite materials is rising. It was reported that the production of wood plastic composite (WPC) materials was increased from 1,515,000 to 3,825,000 tonnes for last five years in the world (Bioplastics Magazine 2015).

In previous studies, polystyrene (PS), polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC) etc. as thermoplastic materials and wood flour, agricultural residue and industrial lignocellulosic waste as lignocellulosic filler were used in the manufacturing of polymeric composites. The wood flours obtained from pine, poplar, beech, eucalyptus, etc. and agricultural residues such as wheat straw, rice straw, sunflower stalk, peanut shell, walnut shell, nutshell, pepper stem, etc. were utilized in this purpose. One of the industrial lignocellulosic waste is medium density fibreboard (MDF) production residues (Acar 2014; Avcı 2012; Dönmez Çavdar 2011; Karakuş 2008; Mengeloglu and Kabakci 2008).

There is tremendous amount of forest products industry and agricultural wastes available in Turkey and they are not utilized rationally. It is possible to utilize these wastes in the manufacture of polymeric composites (Mengeloğlu 2006). The furniture plant is middle size manufacturer generating almost 1.5 million m^3/year waste. Furniture plant waste (FPW) was combination of almost 40% particleboard (PB) dust, 30% MDF dust, 20% lumber sawdust and 5% PVC grindings (Aslan 2015). In this case study, FPW was utilized as lignocellulosic filler in HDPE and PP based thermoplastic composites and their selected properties were determined. Also their morphologies were studied using scanning electron microscopy (SEM).

EXPERIMENTAL

Materials

High-density polyethylene (HDPE) and polypropylene (PP) were used as thermoplastic matrix. These plastic were used as received from the manufacturer. Furniture plant waste flours (FPWF) were used as organic filler. The fillers were collected from furniture plant in İskenderun, Turkey. They were taken from plant's dust absorption system which included timber, veneer, PB, MDF and PVC edge banding wastes. Maleic anhydrite grafted polyethylene (Licocene PEMA 4351 by Clarient) and maleic anhydrite grafted polypropylene (Licomont AR 504 by Clariant) were utilized as coupling agents. Descriptions of coupling agents were given in Table 1. Paraffin wax (K.130.1000) was used as a lubricant.

Table 1

Descriptions of the coupling agents used in this study

Descriptions	**Licocene PEMA 4351 (MAPE)**	**Licomont AR 504 (MAPP)**
Appearance	White fine grain	Yellowish fine grain
Softening point	123°C	156°C
Acid value	43 mg KOH/g	41 mg KOH/g
Density at 23°C	0.99 g/cm3	0.91 g/cm^3
Viscosity at 140 °C	300 mPa.s	800 mPa.s

Composite manufacturing

The wastes granulated in Wiley Mill into the flour form. These flours, screened and retained on 60 mesh-size screen (0.25mm), were used in this study. The classified fillers were dried in oven at 103°C (±2) for 24 hours. The experimental design of the study was presented Table 2. Depending on the formulation given HDPE or PP, FPW, MAPE or MAPP and paraffin wax were dry-mixed in a high-intensity mixer to produce a homogeneous blend. These blends were compounded in a single-screw extruder at 40 rpm screw speed in the temperatures (barrel to die) of 170-180-185-190-200°C. Extruded samples were cooled in water pool and then granulated into pellets. The pellets were dried in oven at 103°C (±2) for 24 hours. Dried pellets were compression molded at 5500-6000 psi and temperatures of 200°C in a hot press with cooling capabilities. Boards in the size of 250mm by 250mm by 4mm were produced and testing samples in the sizes given in corresponding ASTM standards were cut.

Table 2

Manufacturing schedule of composites (%)

Group ID	Polymer Type (PP) / (PE)	Polymer (%)	Filler (FPWF; Furniture plant waste flours) (%)	MAPP/MAPE (%)	Wax (%)
PE-0	PE	95.0	0.0	3	2
PE-1	PE	82.5	12.5	3	2
PE-2	PE	70.0	25.0	3	2
PE-3	PE	57.5	37.5	3	2
PE-4	PE	45.0	50.0	3	2

PP-0	PP	95.0	0.0	3	2
PP-1	PP	82.5	12.5	3	2
PP-2	PP	70.0	25.0	3	2
PP-3	PP	57.5	37.5	3	2
PP-4	PP	45.0	50.0	3	2

Composite testing

Testing of the samples was conducted in a climate-controlled testing laboratory. Densities were measured by a water displacement technique according to the ASTM D 792 standard. Flexural, tensile, and impact properties of all samples were determined according to ASTM D 790, ASTM D 638, and ASTM D 256, respectively. Ten samples for each group were tested. Flexural and tensile testing were performed on Zwick 10KN while a HIT5,5P by Zwick™ was used for impact property testing on notched samples. The notches were added using a Polytest notching cutter by RayRan™.

Scanning electron microscope (SEM) study

Fractured surfaces of the samples were studied using a ZEISS scanning electron microscope (SEM, Model EVO LS10 5500LV) at 20kV accelerating voltage. First, samples were dipped into liquid nitrogen and then broken in half to prepare the fractured surfaces. Finally, samples were mounted on the sample stub and were sputtered with gold to provide electrical conductivity.

Data analysis

Design-Expert® Version 7,0,3 statistical software program was used for statistical analysis.

RESULTS AND DISCUSSION

HDPE based or PP based furniture plant waste (FPW) flour filled composites were produced in the density range of 0,91-1.17g/cm^3. Mean density values are presented in Table 3. Statistical analysis was performed using general factorial design. Plastic type and filler amounts were statistically significant ($P<0.0001$). HDPE based composites had higher density values compared to PP based ones due to the density differences of base polymers. FPW flour filled composites provided slightly higher density values compared to neat polymers. In addition, density of the composites was increased with filler loading. This increase was believed to be due to the higher cell wall density of lignocellulosic materials (Mengeloglu and Karakus 2008b). Fig. 1 shows the interaction graph of the composites. HDPE based samples and PP based samples provided parallel line on the graph. HDPE had higher density results.

Table 3

Density of the manufactured composites

Group ID	Density (g/cm^3)
PE-0	0.96 (0.011)
PE-1	1.01 (0.011)
PE-2	1.04 (0.015)
PE-3	1.10 (0.009)
PE-4	1.13 (0.008)
PP-0	0.91 (0.005)
PP-1	0.96 (0.006)
PP-2	0.99 (0.009)
PP-3	1.03 (0.014)
PP-4	1.09 (0.007)

* Values in parenthesis are standard deviations.

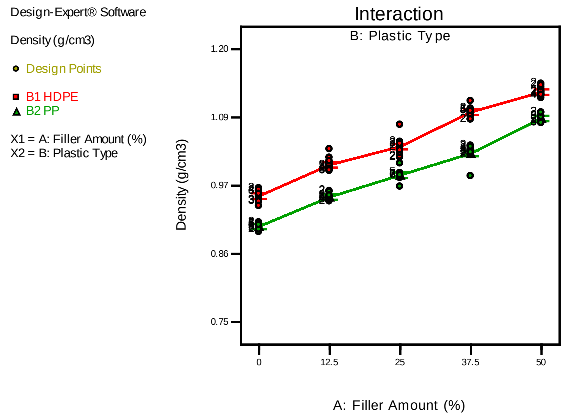


Fig. 1.
Interaction graphs of density

In this study, flexural, tensile and impact properties of all samples were determined. Mechanical properties of the polymer composites produced with FPWF were summarized in Table 4. The arithmetic mean and standard deviation values were given for each group in the table. Two different polymers and four different ratios of filler material (furniture plant waste flour) were used. ANOVA (analysis of variance) were performed and Interaction graphs (Fig. 2-4) were prepared.

Table 4

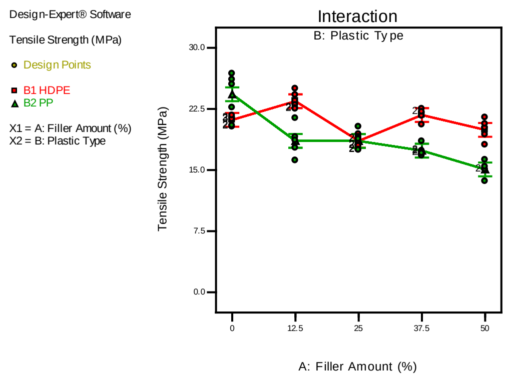
Mechanical properties of polymer composites

Group ID	Tensile Strength (MPa)	Tensile Modulus (MPa)	Elongation at Break (%)	Flexural Strength (MPa)	Flexural Modulus (MPa)	Impact Strength (kJ/m^2)
PE-0	21.16 (0.52)*	479.26 (85.98)	17.09 (5.02)	26.78 (2.92)	1229.08 (166.13)	18.66 (3.29)
PE-1	23.44 (1.09)	544.93 (103.88)	6.14 (0.62)	39.03 (2.79)	1541.95 (93.28)	2.57 (0.41)
PE-2	18.57 (0.65)	697.67 (64.90)	3.42 (0.29)	43.05 (4.63)	1957.47 (200.24)	2.34 (0.40)
PE-3	21.75 (0.74)	827.61 (80.24)	3.55 (0.17)	46.97 (4.55)	2351.73 (216.73)	2.06 (0.17)
PE-4	19.93 (1.28)	998.75 (25.02)	2.61 (0.26)	41.98 (3.70)	2839.88 (178.37)	2.00 (0.09)
PP-0	24.30 (2.67)	469.73 (84.88)	9.94 (2.00)	37.19 (1.65)	1292.17 (66.97)	3.00 (0.44)
PP-1	18.57 (1.90)	501.62 (60.34)	7.09 (3.12)	29.42 (1.10)	1082.43 (60.49)	4.35 (0.40)
PP-2	18.57 (1.17)	530.42 (70.08)	4.99 (0.45)	31.78 (1.83)	1265.17 (114.74)	3.46 (0.24)
PP-3	17.38 (0.67)	745.29 (65.39)	3.03 (0.21)	31.97 (2.81)	1608.4 (198.86)	3.05 (0.28)
PP-4	15.08 (0.95)	671.04 (117.48)	2.81 (0.48)	29.95 (3.86)	1855.23 (270.84)	2.58 (0.28)

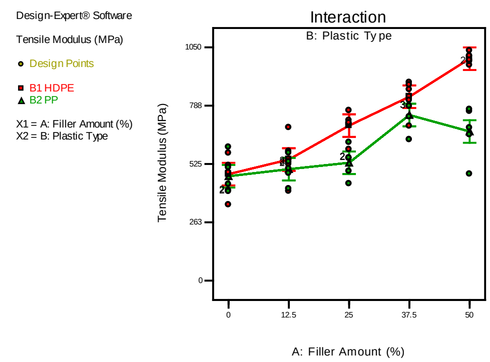
* Values in parenthesis are standard deviations.

Tensile properties include tensile strength, tensile modulus and elongation at break.The graph of tensile strain was given in Fig. 2a. With the rise of FPW flour loading tensile strength was significantly reduced in both HDPE and PP based composites (P <0.0001). It is thought that the most important reason of decline is lack of harmony between polymer matrix and lignocellulosic fillers (Mengeloglu and Karakus

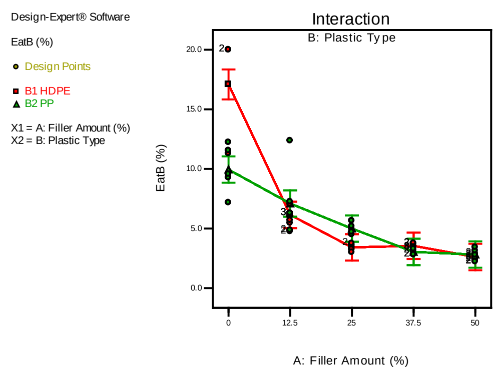
2008b). The polymer type was also effective on the tensile strength of the composite material (P <0.0001). HDPE composites relatively provide better tensile strength compared to the PP composites.



a.



b.



c.

Fig. 2.

Interaction graphs of tensile properties: a - tensile strength; b - tensile modulus; c - elongation at break

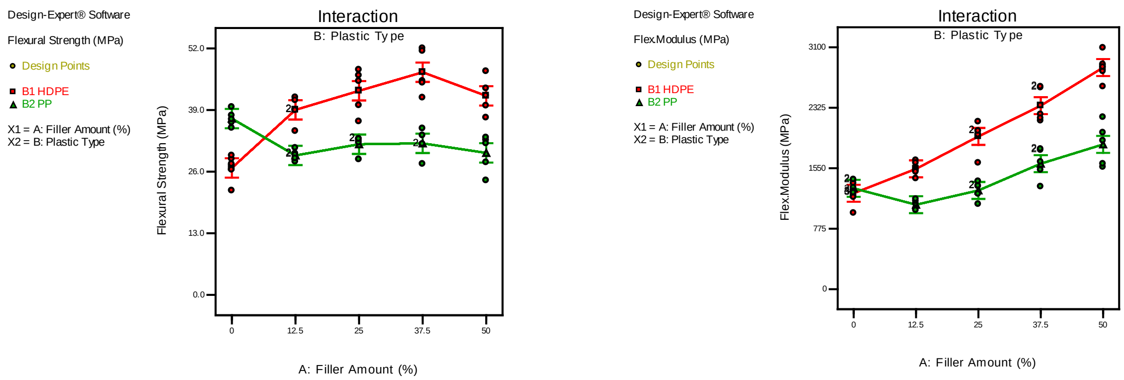
Interaction graphs of tensile modulus and elongation at break are shown in Fig. 2b and Fig. 2c, respectively. To mention of tensile modulus, rise of filler loading significantly increased the tensile modulus for both composites (P<0.0001). Similar results for other wood flours filled polymer composites were also reported (Wang et al. 2003; Qiu et al. 2004; Mengeloglu et al. 2007). The filler has significant effect on elongation at break values for both composites (P<0.0001). Significant reduction by addition of filler in elongation at break values was determined for both polymer matrixes.

Flexural properties include flexural strength and flexural modulus. The results showed that the flexural strengths are significantly affected by filler loading (P<0.0001). Similar results were also reported for the flexural strength of other wood flour filled thermoplastic composites (Chan et al. 1997; Li and Matuana 2003; Yang et al. 2007). With filler loading flexural strength was reduced for HDPE and PP based composites.

Interaction graph of flexural strength is shown in Fig. 3a. The results of the statistic analysis show that the rate of furniture plant waste flour was effective on flexural strength for HDPE and PP composites (P<0.0001). Compared to control samples, while there is a reduction on the flexural strength for PP based composites, the increase has been observed on flexural strength for HDPE based composites. Due to the rise of lignocellulosic filler rate, a slight increase can be seen on flexural strength of polymer composites which is produced by injection molding method (Mengeloğlu and Karakuş 2008a). The polymer type was also effective on the flexural strength of the composite material (P<0.0001).

Interaction graph of flexural modulus is shown in Fig. 3b. With the rise of filler loading increased the flexural modulus for both composites. This increase was statistically significant (P<0.0001).

Lignocellulosic fillers and polymers have different modulus of elasticity from each other. Lignocellulosic fillers have higher modulus of elasticity than polymer. This is caused to have better flexural modulus for composite from pure polymer. Therefore, flexural modulus increased with the rise of lignocellulosic filler loading. Addition of the lignocellulosic filler improves tensile modulus of the thermoplastic composites usually could simply be explained by the rule of mixtures (Matuana et al. 1998). The polymer type was also effective on the flexural modulus of the composite material (P<0.0001). HDPE composites relatively provide better flexural modulus compared to the PP composites.



a. ***b.***

Fig. 3.
Interaction graphs of flexural properties: a - Flexural strength; b - Flexural modulus

In this study, produced composite materials were usually considered as an alternative to the polyolefin-based plastic lumber decking boards. For polyolefin-based plastic lumber decking boards, ASTM D 6662 (2001) standard requires the minimum flexural strength of 6.9MPa. All composites produced in this study provided flexural strength values (29-46MPa) that are well over the requirement by the standard. ASTM D 6662 (2001) standard requires the minimum flexural modulus of 340MPa for polyolefin-based plastic lumber decking boards. All composites produced in this study provided flexural modulus values (1082-2839MPa) well over required standards.

Interaction graph of impact strength is shown in Fig. 4. The results show that pure HDPE has higher impact. Impact strength reduced when furniture plant waste flour was added to polymer matrix. There is little or no difference between impact strength of HDPE-based and PP-based sample. Filler is significantly effective on impact strength. This usually arises from increasing of brittleness of the composite material (Mengeloglu and Karakus 2008b).

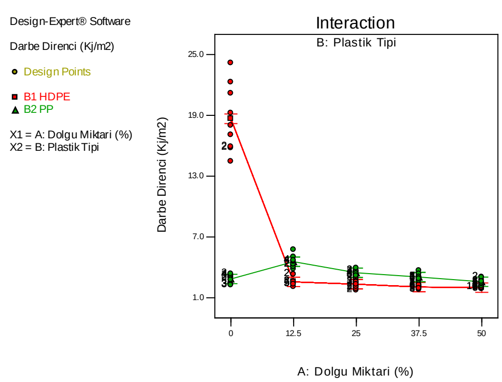


Fig. 4.
Interaction graphs of impact properties

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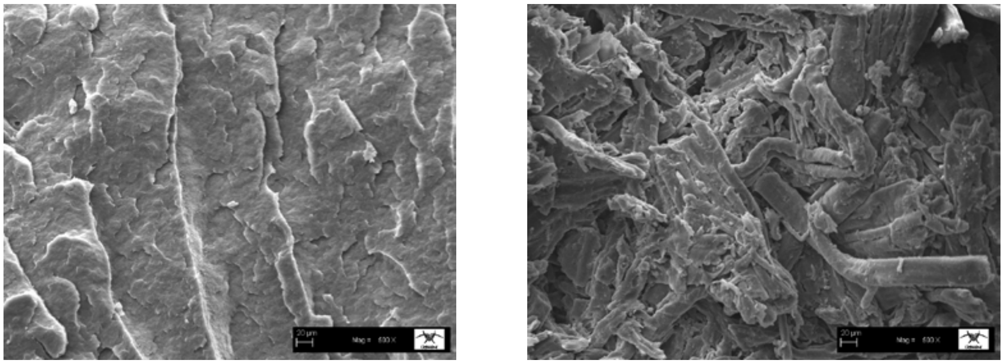
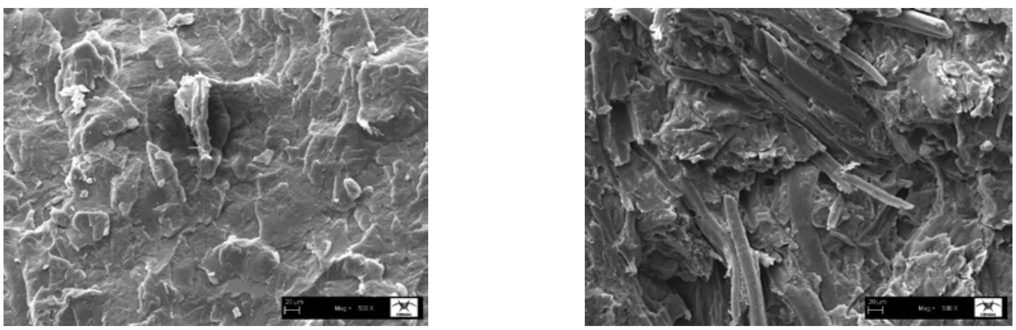
Morphology of the produced samples was also studied. SEM images of pure HDPE samples (sample ID: PE-0) and with highest filler rate (sample ID: PE-4) was presented in Fig. 5. SEM images of PP samples (sample ID: PP-0) and with highest filler rate (sample ID: PP-4) was shown in Fig. 6.



a. **b.**

Fig. 5.
SEM images of HDPE samples: a - Neat HDPE (PE-0); b - HDPE composites (PE-4)



a. **b.**

Fig. 6.
SEM images of PP samples: a - Neat PP (PP-0); b - PP composites (PP-4)

From these images, it is clear that polymer matrix and FPW flours were successfully mixed. In both HDPE- and PP-based composites, there are individual fibres pull out of the matrix indicating the lack of adhesion between the hydrophilic lignocellulosic filler and hydrophobic polymer matrix. These images also support the finding of reduced tensile and flexural strength values.

CONCLUSIONS

Polypropylene (PP) and high-density polyethylene (PE) based polymer composites including different ratios of furniture plant waste flour are manufactured by press molding. The mechanical properties of the produced composite (tensile strength, tensile modulus, flexural strength, flexural modulus, elongation at break and impact strength) were determined.

Furniture plant waste (FPW) flour filled composites were successfully produced and the following conclusions were reached;

1. HDPE based composites provided better mechanical properties compared to PP based composites.
2. Addition of FPW flour into polymeric matrices improved modulus values while reducing strength, elongation and impact values.
3. Through SEM studies, lack of sufficient adhesion between filler and polymer matrices were determined.
4. HDPE and PP based polymer composites provide adequate mechanical properties according to ASTM D 6662 (2001).

As a result, FPW flour might be utilized as filler for HDPE and PP based thermoplastic composites. The utilization of the furniture plant waste flours in plastic industry could provide extra income for manufacturers and clear environment for the people.

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