COMPARISON OF MECHANICAL PROPERTIES OF DATE PALM FIBER- POLYETHYLENE COMPOSITE

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Date Palm Fiber (DPF) is one of the most available natural fibers in the Middle East, especially in Iran and the Persian Gulf region. This research provides a new insight into DPF, with consideration of morphological, chemical characteristics, and bulk density, as well as morphological and mechanical properties of DPF/HDPE wood plastic composite. There are three parts of date palm that are used for producing fiber, the trunk, rachis, and petiole. Results indicated that there is significant difference between trunk and petiole on fiber length but rachis has no significant differences relative to the other parts. The aspect ratios have significant differences among of three parts, with the highest and lowest values measured for the petiole and trunk, respectively. The chemical composition of various parts of the date palm tree differed significantly; with the highest amounts of cellulose and lignin content belong to rachis. Bulk density was measured for three parts of date palm, and the lowest amount was 0.082 g/cm^3. The highest strengths were achieved in composites with 30 and 40% fiber content, depended on which original parts of the tree were used.

Keywords: Wood plastic composite; Date palm fiber; Petiole, rachis; Trunk; Tensile strength; Flexural strength

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INTRODUCTION

During the last few decades, thermoplastics have gained ever-increasing acceptance as an important family of engineering materials and are steadily replacing metals in a wide variety of applications. The commercial consumption of thermoplastics has steadily increased, and this trend is expected to continue despite an increase in their prices. This situation has created an impetus for cost reduction via composites by employing fillers in thermoplastics (Kokta et al. 1983).

In the recent years, natural organic reinforcements such as cellulosic fibers have penetrated slowly into this market because they offer many advantages over most common inorganic fillers. Cellulosic fibers are abundantly available and have lower costs and density. They lead to a reduced wear of processing equipment and are renewable, recyclable, non-hazardous, and biodegradable. The replacement of inorganic fillers with comparable cellulosic fibers provides weight savings and decreases the cost without reducing the rigidity of the composites (Youngquist and Rowell 1990). Wood fiber/plastic composites (WPCs) can be a cost-effective alternative to many plastic composites or metals in terms of bending, stiffness or weight (Raj 1992; Raj et al. 1989). WPCs are becoming increasingly acceptable to consumers as a replacement for natural wood due to advantages such as durability, permanent color, and reduced maintenance, in spite of their high price (Clemons 2002).

The chemical composition of cellulose-based materials has a practically unavoidable impact on processing and properties of the resulting composite products. Briefly, cellulose provides positive effects on mechanical and other properties of the composite material (such as decreased coefficient of thermal expansion-contraction, etc.); lignin generally makes the product weaker, easily burns in the course of processing and releases CO_2 and other gaseous products, makes the product have a lower density, and greatly accelerates fading of the WPC after outdoor exposure. Wood extractives (terpenes, pinenes, tannins, carbonyl compounds, etc.) produce volatile organic compounds (VOC), and they also contribute to a lower density of the product. Hemicellulose easily decomposes at plastic melt temperatures, particularly in when subjected to sharp changes of pressure, and forms acetic acid, thereby causing significant corrosion of the equipment. This effect is particularly expressed at certain moisture content in the lignocellulosic material and is called “steam explosion” of lignocellulosics (Klyosov 2007).

The properties of agro-based thermoplastic composites are very process-dependent. Yam et al. (1990) concluded that the level of fiber attrition depended on the screw configuration and the processing temperature in wood flour/HDPE composite. The tensile strength of pure HDPE was higher than that of the wood fiber-HDPE, irrespective of the level of fiber filling. This was explained to be because of a lack of dispersion, with fibers clumping in bundles, and poor fiber-matrix bonding.

Interface compatibility between lignocellulosic fibers and thermoplastic polymers is a key problem, and pretreatments are often required and applied to enhance the adhesion between both components. Several other strategies have been tested to enhance the adhesion between the lignocellulosic fillers and the polymer matrix, as recently reviewed (Bendahou et al.2007). They generally involve fiber and/or matrix modification by physical or chemical methods. The simplest method involves the use of maleic anhydride-grafted copolymers, such as maleated poly(propylene), as compatibilizing agents to improve the interfacial compatibility. Enhanced mechanical properties and moisture resistance are generally reported (Anglès et al. 1999; Caulfield et al. 1999; Malainine et al. 2004; Faria et al. 2006). Thus, the use of maleated polyethylene that contains ethylene blocks is a better choice (Keener et al. 2004).

Generally, long fibers, oriented along the flow, render a composite material with improved mechanical properties, compared with short-fiber-filled composite material. In other words, a higher aspect ratio leads to better flexural properties (Klyosov 2007).

Low bulk density of agro-based materials is an inhibiting factor, especially for large-scale industrial consumption. Low bulk density can significantly increase transportation costs. In the United States, the economic procurement radius of processing and transporting of wood with dry basis gross bulk density of 240-320 kg/m^3 is about 65 km (Vaagen 1991). Unfortunately, the residual stems of herbal plants, such as kenaf or straw, cannot be compacted much beyond 135 kg/m^3, which may limit the feasible supply basin to a range of 25-35 km (Sandwell 1991).

The wood and paper industries are facing serious challenges in Iran. This study was carried out to evaluate using DPF in HDPE based on following:

1- Annually there is a wood shortage of about three million cubic meters in Iran and about one million cubic meters of wood are imported.

2- Wood harvesting has been decreasing continually due to a severe forest preservative policy and limited timberland area because of agricultural priority.

3- The Iranian population is growing rapidly, so the demand for wood and wooden products is increased constantly, and this intensifies the pressure on limited wood resources. These circumstances provide no alternative except to face the issue of fiber recourses. There are about 20 million date palm trees in southern regions of Iran, based on Jihad ministry estimation, and there is a huge pruning waste (about 15 to 20 kg per tree) that has good potential as renewable cellulosic material. In addition, there are numerous crownless date palm trunks that remained standing after the Iran-Iraq war.

Abu-Sharkh et al. (2003) stated that the modulus of a palm fiber/polypropylene composite, produced via injection molding, can be increased by increasing the fiber content. They also indicated that adhesion between PP and much stiffer palm fibers was not strong enough. This fact was used to explain the significant increase in tensile strength by fiber load addition. Epolene E-43 was used to minimize the incompatibility between the wood fibers and the PP matrix. The maleated PP additive enhanced the fiber–matrix adhesion, resulting in an improvement in composite performance, according to Abu-Sharkh's et al. results.

A comparative study between poly(propylene)- (PP) and low density polyethylene (PE-LD)-based composites is also reported. The latter matrix has been much less used in association with lignocellulosic fibers than PP or high density polyethylene (PE-HD). The effect of the palm tree fibers incorporation on the microstructure, thermal, and mechanical properties is investigated for composites processed with and without a coupling agent. It is found that the degree of crystallinity of the thermoplastic matrix plays a dominant role on its sensibility to natural fibers incorporation. The SEM analysis shows that the use of a coupling agent was successful in improving the adhesion between the polymer and the palm tree filler. From these SEMs observations higher mechanical properties are expected from compatibilized composites based on PE-LD or PP reinforced with palm tree fibers (Bendahou et al. 2008).

The main objective of the present study was to demonstrate the feasibility of creating date palm fiber/HDPE composites with acceptable mechanical properties. The specific aims of this research were to determinate what parts of date palm tree are suitable for this process and to study the effect of a coupling agent on the mechanical properties of final product.

EXPERIMENTAL

Materials

HDPE Resins

In this study, HDPE (HDPE-5620EA) supplied by Arak Petrochemical Co, which has a melt flow index (190°C/2.16 kg) 19-21 g /10 min, ASTM D-1238 and a density of

0.954-0.957 g/cm^3 (ASTM D-1505), was used as a matrix. The tensile strength at yield was 22 MPa ASTM D-638, and the tensile modulus was 900 MPa.

Coupling agent

The coupling agent used in this study was MAPE (maleic anhydride–modified PE, 2 wt %). It was supplied by Aldrich Co.

Extraction solvents

For extraction experiments, ethanol (96%), and acetone (98%) were supplied by Meikadeh Co. (Iran) and Merck Co. respectively.

Fiber

Experimental specimens were prepared from trunk, rachis, and petiole of date palm trees, from the Ahvaz countryside in southwest of Iran (Fig.1).

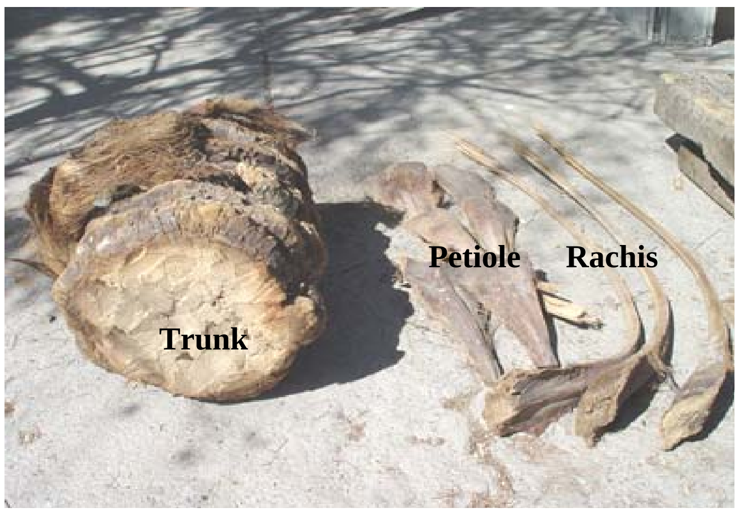


Fig. 1. Three parts of date palm

Methods

For fiber analysis, samples of approximately 1 g (wet weight) were taken from the three parts mentioned, cut into matchstick-size chips and oven dried. The chips were placed into test tubes, and enough maceration fluid (a 1:1 mixture of glacial acetic acid and 50% w/w hydrogen peroxide) was added to cover the sample. Each test tube was covered with aluminum foil to minimize evaporation and allowed to cook for 24 hours at 70°C. After delignification, the maceration fluid was decanted, and the delignified sample was gently washed once with deionized water. Then, fiber dimensions were measured by projective light microscope.

Representative samples of each part were chipped by hand and air-dried to approximately 90% consistency dealing with chemical composition analysis. Each sample was ground in a mill fitted with a 0.5 mm screen according to the CPPA Standard G.31P. The ground samples were analyzed for lignin, acetone extractives, and ash contents (TAPPI standard, T222 om-98, T280 pm-99, T211 om-02).

Bulk density of DPF was measured by a method similar to the Scan standard (CM 46:92 method) after 24h drying at 80°C.

For DPF preparation, samples were converted into pieces about 4 cm long by a Pallmann chipper device, steamed at 175°C for about 15 minutes, and then defibrated by a laboratory disk refiner (RMP process). Plastic decomposition during processing produces volatile organic compounds (VOC), hence, porosity develops at the same time. Thus, the resulting fibers were soaked in ethanol-acetone [1/2 (v/v)] to remove organic compounds for two days and then washed with cold water.

Fibers, resin and coupling agent were mixed physically in a bowl and then transferred to the extruder. Different experimental treatments are shown in Table 1. Composite components were mixed by a double-screw extruder (Brabender PL 2000). A single screw extruder type (CAM -50 model) was used to mix materials because of the low bulk density of DPF. The mixed materials, obtained from the extruder, had lumpy shapes. The material was granulated, and mechanical test samples were formed by a hot press using 150 kg/cm^2 pressure and 170°C temperature. Mechanical strengths of samples were determined with an Instron-1186 mechanical testing machine, according to ASTM D-638 and D-790 for tensile and flexural strengths measurement, respectively.

Table 1. Formulation of Composite and Treatment Conditions

Treatment no.	Fiber type	Fiber amount (%)	HDPE (%)	Compatibilizer (%)	Mix. speed (r/min)	Total time (min)	Mix. temperature (°C)
1	Trunk	20	78	2	30	10	170
2		30	68	//	//	//	//
3		40	58	//	//	//	//
4	Rachis	20	78	//	//	//	//
5		30	68	//	//	//	//
6		40	58	//	//	//	//
7	Petiole	20	78	//	//	//	//
8		30	68	//	//	//	//
9		40	58	//	//	//	//

Scanning electron microscopy (SEM) was used to investigate morphology of experimental specimens by using a LEO 440i electron microscope. Each sample was dipped first in liquid nitrogen and then fractured. The fractured surface was gold-coated by a sputter coater (E 50000C PSC), and observed using an applied tension of 20 kV.

RESULTS AND DISCUSSION

Fiber Biometry

Mechanical performances of natural fibers are influenced by complex interactions between numerous external variables and inherent structural characteristics at molecular, macromolecular, and microscopic levels. Similar effects result from other factors such as cellulose, lignin, and hemicelluloses content, degree of polymerization, or crystallinity, microscopic and molecular defects of fibers' wall, and the presence of moisture or other introduced chemicals (Rowell et al. 1997).

Figure 2 shows the mean fiber length for the three parts of date palm. DPF lengths were between 1 to 1.3 mm approximately. Trunk had the longest fibers, the petiole fibers were significantly shorter than the other parts, and rachis has no significant differences related to the other parts.

As shown in Fig. 3, the other fiber characteristics showed significant differences in the same way, so the average aspect ratio values for trunk, rachis, and petiole were 33, 70, and 80, respectively. Petiole had the highest aspect ratio despite having the shortest fibers.

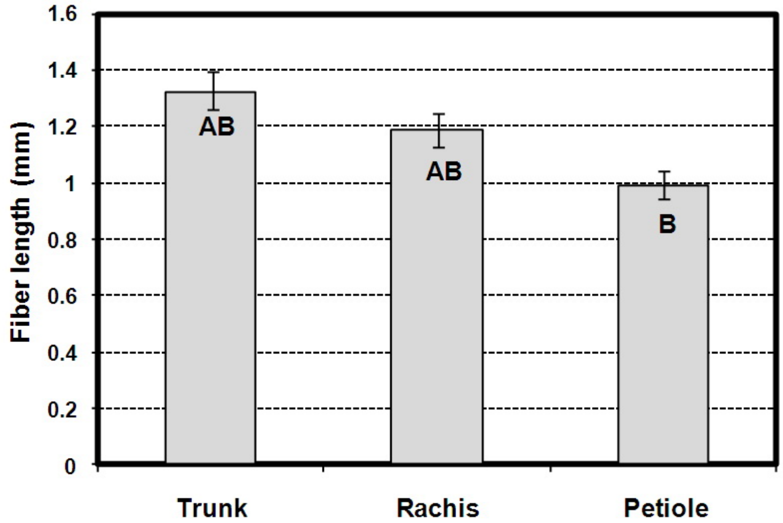


Fig. 2. Fiber length comparison among date palm tree parts and the mean statistical grouping by Duncan's multiple range test (Error bars indicate 95% confidence intervals)

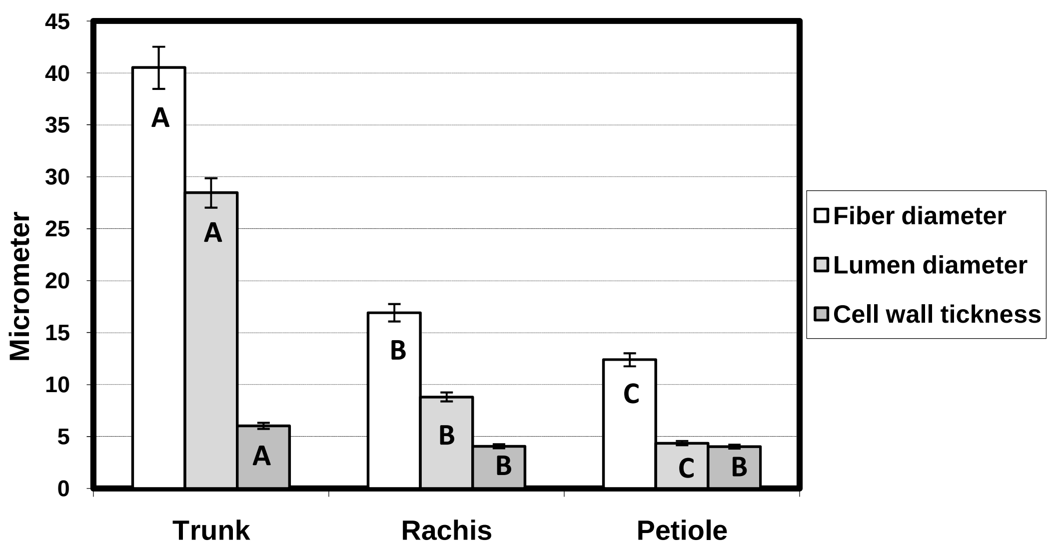


Fig. 3. Fiber dimension comparison among date palm tree parts and the mean statistical grouping by Duncan's multiple range test (Error bars indicate 95% confidence intervals)

Fiber Chemical Composition

The chemical composition of various parts of the date palm tree differed significantly, with the highest amounts of cellulose and lignin contents belonging to rachis (Fig.4).

Wood fibers' lignin decomposition at plastic hot melt temperatures produces CO_2, which is taken as an indication that porosity will also increase. It is quite common knowledge in WPCs that the higher the cellulose content in the composite, the higher the water absorption (Klyosov 2007).

Petiole DPF's has the lowest lignin and cellulose contents related to the other parts. It would be estimated to have lower porosity and higher water absorption in petiole WPCs'. The mean of cellulose and lignin contents of the three parts were measured within the ranges of about 23 to 32% and 31 to 37% respectively, which are slightly different from the references. There are many varieties of date palm trees (*Phoenix dactylifera)* in the world, especially in Iran (about 400 varieties) and the differences are intrinsic.

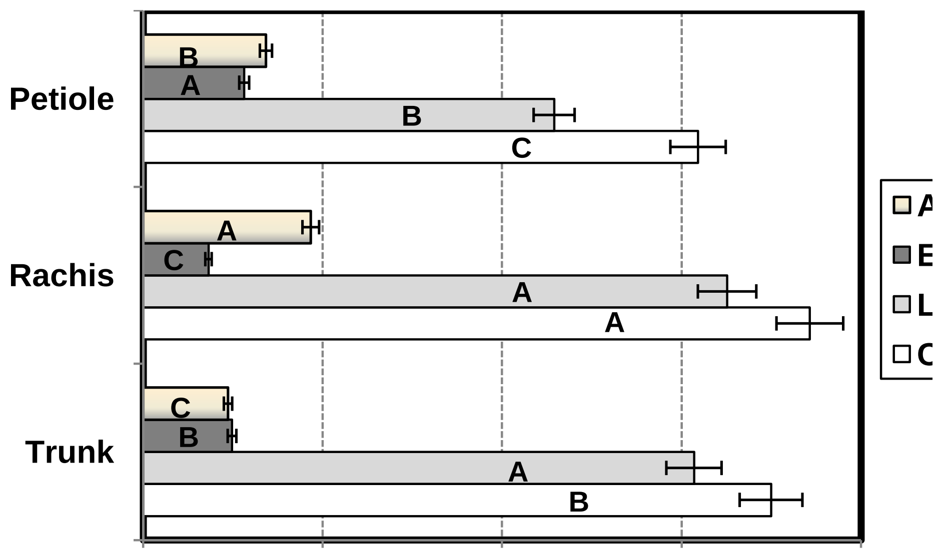


Fig. 4. Chemical composition contents among date palm tree parts and the mean statistical grouping by Duncan's multiple range test (Error bars indicate 95% confidence intervals).

Bulk Density

There were significant differences among bulk density amounts of various parts of the tree. Petiole and trunk fibers had the highest and lowest of bulk density, respectively (Fig. 5). Low bulk density of fibrous materials may cause some problems in the feeding and mixing section of an extruder. Consequently, the increasing of rachis or petiole's fiber content from 30 to 40 wt %, as these parts have bulkier fibers, resulted in fiber accumulation at some parts of the composite, so these phenomena can give rise to weak points and result in lower strength to specimens with 40 wt % rachis or petiole fibers loading. This phenomenon was not seen when adding trunk DPFs at levels from 30 to 40 wt%, which may be due to the greater length of trunk fibers.

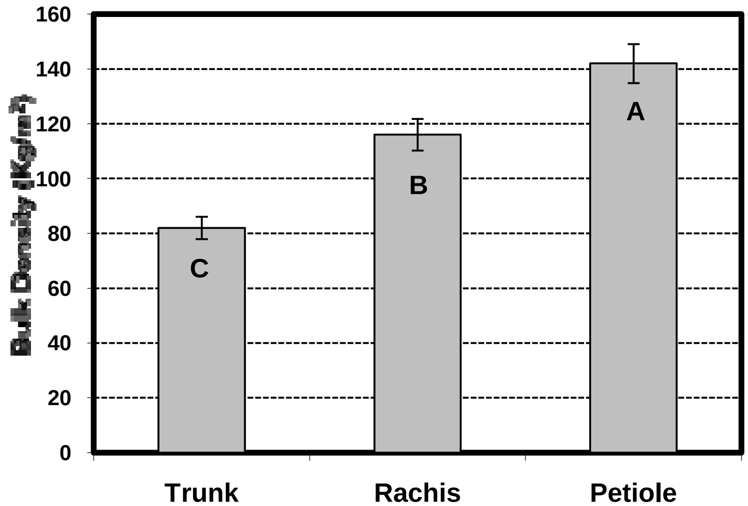
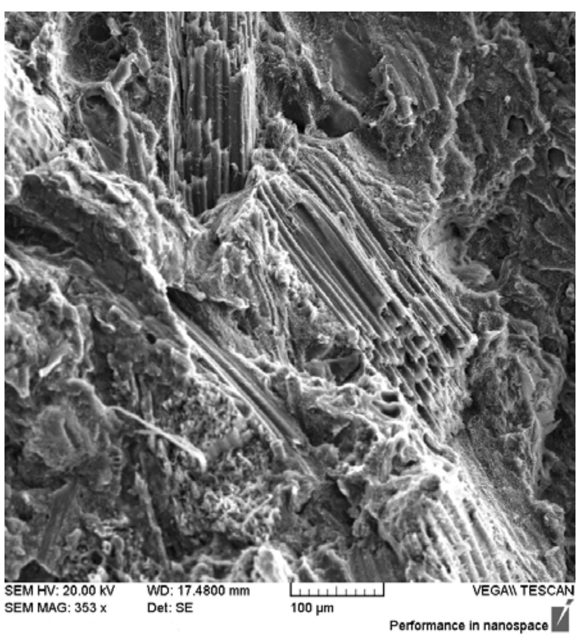
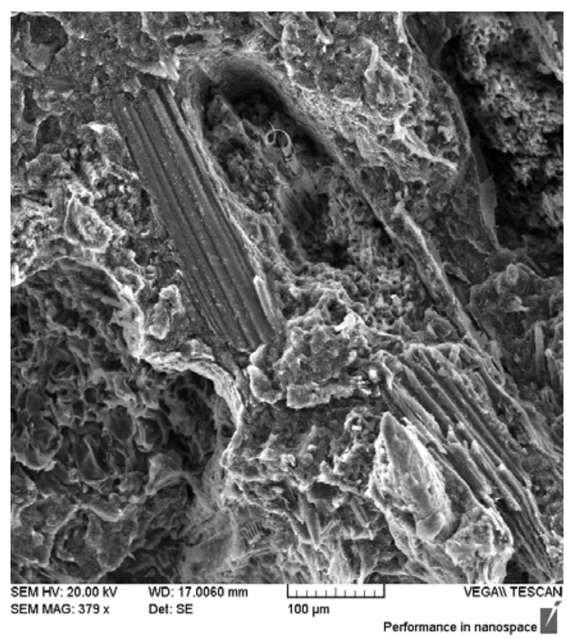


Fig. 5. Packed bulk density of fiber comparison among date palm tree parts and the mean statistical grouping by Duncan's multiple range test (Error bars indicate 95% confidence intervals).

Morphology

Figures 6 and 7 show SEMs of freshly fractured surfaces of DPF composite specimens. The SEM micrographs indicate sufficient interfacial adhesion between filler fibers and HDPE matrix. It can be readily seen that fibers were not pulled out from the thermoplastic matrix and their surfaces were covered by polymer.





Figs. 6 and 7. SEM micrographs of a fractured surface of DPF/HDPE composite compatibilized with 2 wt % MAPE.

Also, fracturing the samples led to breakage of palm fibers. Moreover, better adhesion was achieved under the conditions represented in the figures in comparison with the other references (Abu-Sharkh et al. 2003; Bendahou et al. 2008), but such differences may be attributed to the sue of different manufacturing processes such as extrusion, compression, or injection molding, and thermoplastic polymers would be effective.

Mechanical Properties

Figure 8 illustrates the effect of fiber content on the tensile strength of the palm fiber/HDPE composite. As the fiber content increased from 20 to 30 wt %, the tensile strength was increased. Rachis fiber specimens had the highest tensile strength, as this part has the longest fibers. The increase in fiber content up to 30 wt % caused a slight decrease in tensile strength of rachis and petiole composites, whereas the same effect was not observed in the case of trunk composite, as similarly reported by Bataille and et al. (1989). This was probably due to better mixing and more uniform distribution of shorter trunk fibers in the HDPE matrix.

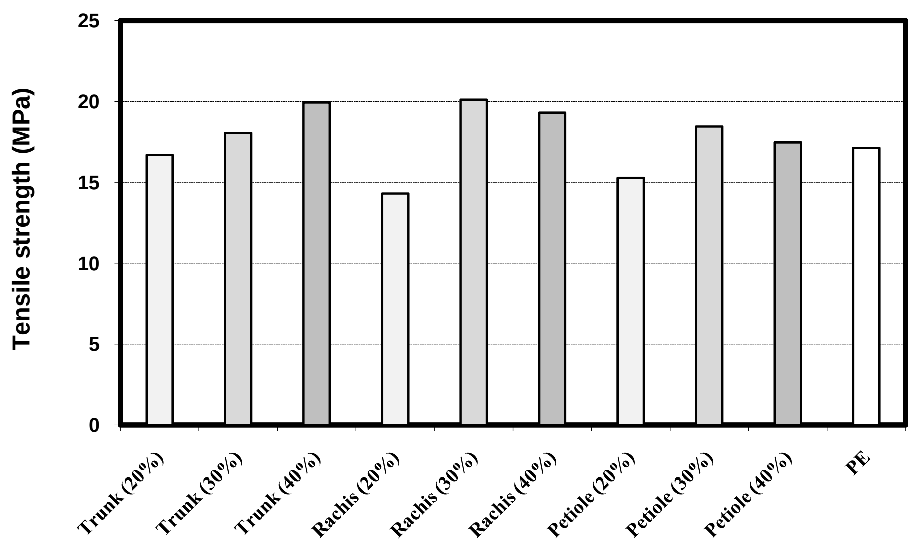


Fig. 8. Tensile strength versus fiber content for HDPE reinforced with DPF

Figure 9 shows the effect of fiber content on the tensile modulus of the date palm Fiber/PE composite. As shown, there was significant improvement in tensile modulus as the fiber content increased.

Figure 10 and 11 illustrate the effect of adding fibers on flexural strength and flexural modulus. Both of these characteristics increased as fiber load did, with one exception (petiole fibers load decreased from 30 to 40 wt %). The variation trends of tensile strength and modulus were similar. The flexural strength of DPF/HDPE specimens was greater than those were pure HDPE. Almost all experimental specimens had higher flexural strength than pure HDPE, except for two compositions (20 wt% of rachis and petiole fiber loads which have not significant difference from pure plastic). The highest flexural strength and modulus means were achieved by using petiole fiber.

Petiole fiber has a higher aspect ratio, which yielded better flexural properties of the composite. Also, lower lignin content of petiole gave rise to an increase of the hydrophilic character of the fibers. As a consequence, the wettability of the fiber surface will be increased. This difference can be explained from the stronger interaction developed by the carboxylic groups created on the petiole fibers. These findings are consistent with opinions stated by Klyosov (2007) and Sbiai et al. (2010).

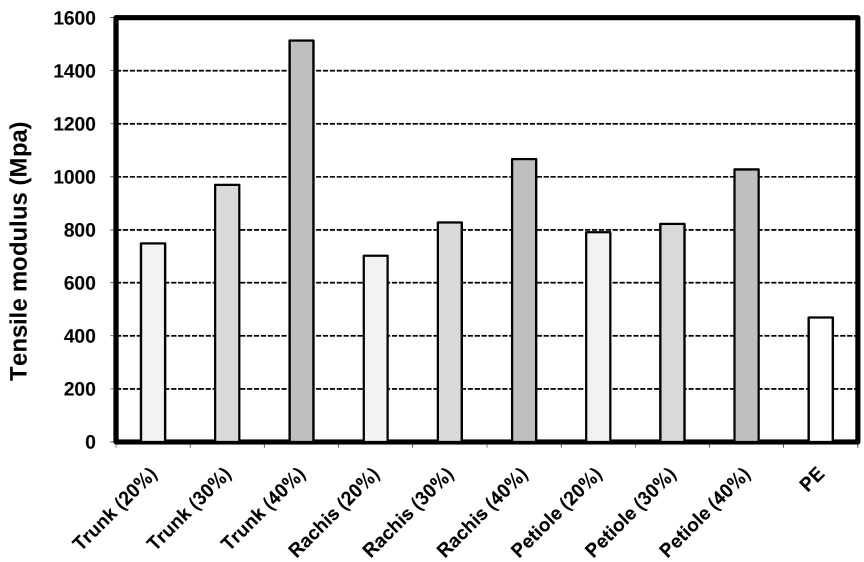


Fig. 9. Tensile modulus versus fiber content for HDPE reinforced with DPF

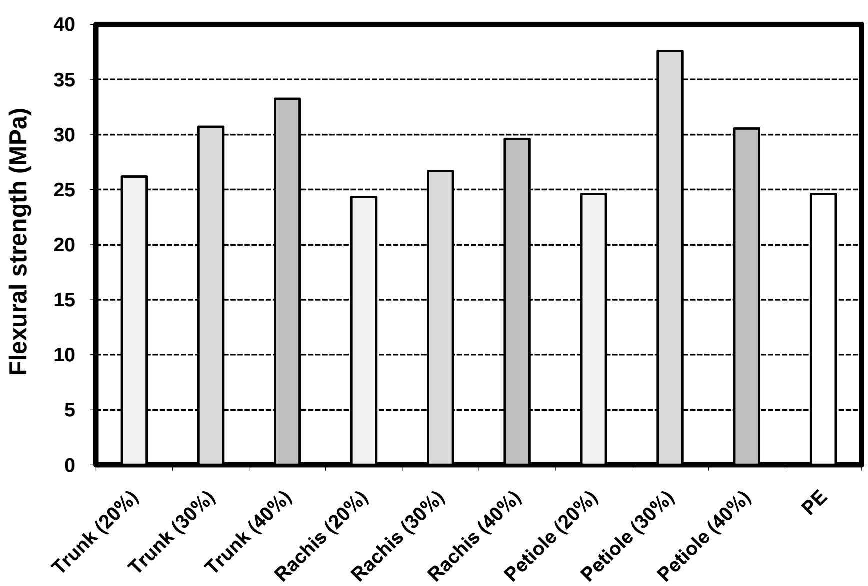


Fig. 10. Flexural strength versus fiber content for HDPE reinforced with DPF

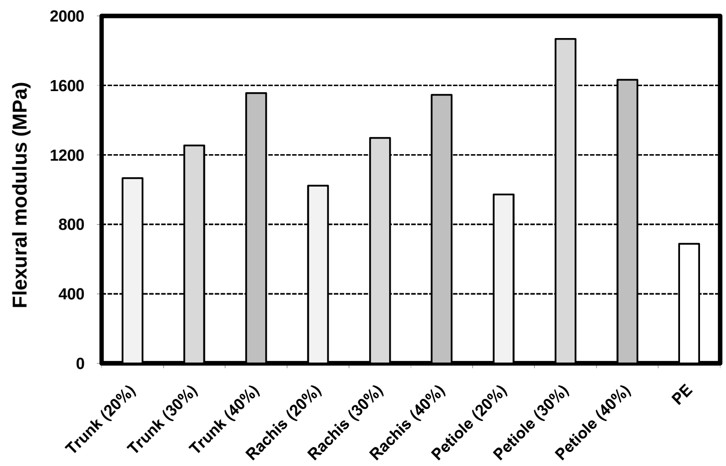


Fig. 11. Flexural modulus versus fiber content for HDPE reinforced with DPF

CONCLUSIONS

1. There are significant differences among the anatomical, physical, and chemical properties of different parts of date palm tree that could affect composite properties.
2. The SEM micrographs indicated sufficient interfacial adhesion between filler fibers and HDPE matrix. Fibers were not pulled out from thermoplastic matrix and their surfaces were covered by polymer.
3. The addition of more than 20 wt% of DPF prepared from the three parts resulted in better composite performance than pure HDPE. The best performance for trunk fiber adding was achieved at 40 wt%. Also, this ratio is similar to the best for rachis fiber using, except for tensile strength which showed a negligible effect. To attain the highest strengths, it’s recommended to add petiole fiber at 30 wt%.
4. Petiole fiber has the highest aspect ratio, and its lower lignin content led to better flexural properties of composite. Lower lignin content gave rise to an increase of the hydrophilic character of the fibers in WPCs.
5. Injection molding and fiber preparation methods, and especially chemical processes, could have significant positive effects on composite strengths. The fibers that are oriented along the flow in the injection molding process could increase the flexural properties of the material, in comparison with compression processes.
6. Overall, the application of the DPF to involve in HDPE is feasible, especially in the case of annual pruning wastes, noting an abundance of available biomass of this type.

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