NATURAL FIBER REINFORCED COMPOSITES FROM DATE PALM FIBERS

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ABSTRACT

Stringent environmental regulations and increased interest in the preservation of natural resources have forced the composite industry to examine "ecofriendly" components. Efforts are being deployed to find alternative reinforcements and resin systems that are environmentally friendly while providing the same performance as their synthetic counterparts. The aim of this paper is to study the potential of using Date Palm Fibers (DPF) as reinforcement in polymeric materials. This objective was achieved by characterizing the DPF through the evaluation of their chemical, physical and mechanical properties and comparing them with other common used natural fibers. The flexural and impact properties of DPF/polyester composite were determined and compared with the neat resin and glass/polyester composite.

Keywords: date palm fibers, natural fiber reinforcement, unsaturated polyester resin, flexural properties, impact strength

1. INTRODUCTION

Fiber-reinforced polymeric composites have become popular for a variety of applications because of their high specific strength and modulus. Composite materials have traditionally relied on the use of man-made fibers as the reinforcement element. The possibility of replacing these with natural fibers is currently of interest. Natural fiber composites are (mainly) price-driven commodity composites that provide useable structural properties at a relatively low cost. The use of natural fibers has many advantages such as, being derived from a renewable resource, they require low energy inputs in their manufacture, and can be easily disposed of at the end of their life cycle by composting or by recovery of their calorific value in a furnace, which is not possible with glass fibers. Currently, natural fibers as reinforcements in technical applications are mainly used in the automobile and packaging industries in parts where a high load carrying capacity is not required [1].

Different types of natural fibers such as flax, jute, banana, hemp, coir and others as possible reinforcement have been investigated [2,3,4]. Natural fibers have been used as reinforcement with both thermoplastics and thermosets [3]. Knowledge of the physico-chemical properties as well as mechanical behavior of natural fibers is required in order to optimize the composite performance. Most of the work done has been to

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clarify the influence of the vegetable fiber composition and the effect of the treatment process on the composites mechanical characteristics. Natural fiber mechanical characteristics are influenced by parameters such as the crystal-structure, the degree of crystallinity, the spiral angle of the fibrils, the degree of polymerization, the porosity content, the size of the lumen (a center void), and the chemical composition [2,3]. Biofibers (lingnocelluloses) consist mainly of three components. These are cellulose, hemicelluloses and lignin. It has been reported that the mechanical properties of natural fibers is related to its cellulose type and content [3,5]. Hemicelluloses and lignin work as cementing material between cellulose microfibrils [3,4]. The composition of natural fibers, and thus the fiber properties, is affected by several parameters such as soil quality, weathering, level of plant maturity and quality of the retting process [4].

The date palm tree (Fig.1), a member of the palm tree family (phoenix dactylifera), is normally found in the Middle East, Northern Africa, the Canary Islands, Pakistan, India, and in the United States (California). There are more than 100 million date palm trees in the world and each tree can grow for more than 100 years [6]. The palm tree stem is covered with a mesh made of single fibers. These fibers create a natural woven mat of crossed fibers of different diameters. Traditionally the mat is removed from the trees and cleaned to make ropes and baskets in many parts of the world. However, these applications account for a small percentage of the total potential world production.

Fig. 1. Photograph of Date Palm plant tree.

The use of fibers surrounding the stem of date palm trees as reinforcement in polymeric materials has not been reported in the literature. This research aims to investigate the potential of using date palm fibers (DPF) as reinforcement in polymeric materials. The chemical, physical and mechanical properties of DPF were determined and compared to other common natural fibers. The flexural and impact properties of raw DPF/polyester composite were determined and compared with the neat resin and glass/polyester composite.

2. MATERIALS AND EXPERIMENTAL TECHNIQUES

Materials Used. Raw samples from the mesh surrounding the date palm trees stem were supplied kindly by Al-Ain Date Factory, Al-Ain, UAE. These samples were preserved in polyethylene bags. The samples were washed with tap water and the natural mat was dismantled into bundles of virgin fibers. The fibers were allowed to dry at room

temperature and then were cut to the desired length using a sharp blade. The fibers were then dried in a vacuum oven at 60 ^{o}C for about 24 h. Fibers were then preserved in airtight polyethylene bags to reduce moisture absorption until they were used. The fiber diameter was checked and only fibers with diameters up to 0.5 mm were used for this study. Glass/polyester samples were prepared with random E-glass fibers. General-purpose polyester resin (8120TEC) obtained from QUALIPOLY CHEMICAL CORP. TAIWAN was used. The density of the resin was determined using a picnometer and a value of 1.125g/cm^3 was obtained.

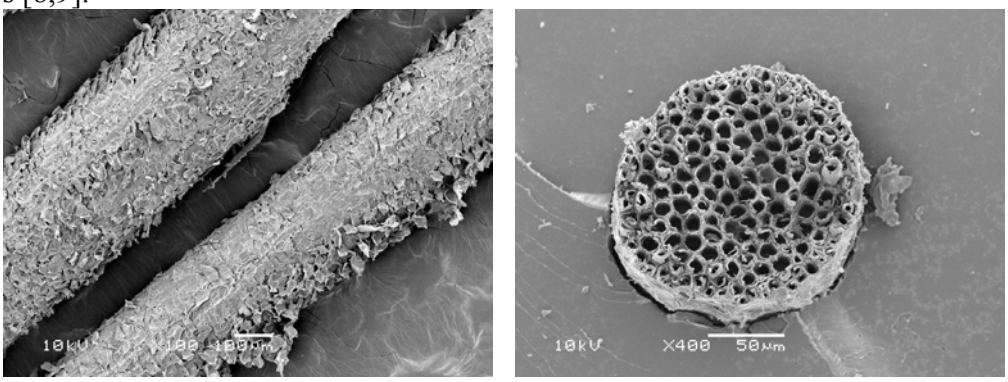
Characterization. The DPF chemical composition was determined using the Van Soest method to investigate the Neutral Detergent Fiber (NDF) and Acid Detergent Fiber (ADF) [7]. Microscopic examination was achieved using JSM-5600 Jeol scanning electron microscope (SEM). Several samples were examined to ascertain the observed phenomena. All specimens were sputtered with approximately 10 nm thick layer of gold prior to SEM observations. Fiber density was determined using a classical volumetric method (mass/volume) [2]. Ethanol (density 0.789 g/cm^3 and vapor pressure 7.87 KPa @ 25^{o}C) was used as a solvent for the density measurements. The solvent was cooled to 0 ^{o}C during density measurements in order to reduce evaporation. Thermogravimetric analysis (TGA) measurements were preformed in air using (TA instrument GA 2950) at a heating rate of 10^{o}C/min.
The elastic properties of DPF (tensile strength, Young's modulus, and elongation to break) were obtained according to ASTM D 3397-75. All measurements were conducted with a gage length of 10mm and at constant cross-head speed of 1mm/min. The cross section of the fiber was calculated from the diameter measured by a digital caliper, assuming a cylindrical fiber and an average of three different point readings. Composite flexural strength and modulus were determined according to ASTM D-790 and the cross-head speed used was 1.6 mm/min. Izod impact tests on un-notched specimens were performed using an impactometer (AVERY-DENISON) according to ASTM-D256. The flexural and impact results were taken as the average value of five measurements.

Composite fabrication. To fabricate composite specimens, an aluminum mold was used. First, the mold was polished and then a mold-releasing agent was applied on the surface. A general-purpose polyester resin was mixed with 1wt.% methyl ethyl ketone peroxide (catalyst) and thoroughly mixed. The resin mixture was degassed in a vacuum dessicator to remove entrapped air and then poured on the randomly aligned fiber placed in the mold. When the fiber was completely wet by the resin, the mold was closed, pressed and cured at room temperature for 24h. Finally, the composite specimens were placed in an oven at 100ºC for 2h for post curing.

3. RESULTS AND DISCUSSION

The characterization of raw DPF is presented in this section. Fiber structure and physical properties, mechanical properties, chemical composition and thermal stability were studied. SEM micrograph of raw DPF is shown in (Fig 2-a). The fibers are cylindrical in shape with a diameter ranging from 100-1000μm and measured density of

0.917± 0.127 g/cm^3. The fiber outer surface is not smooth and covered with some artificial impurities (sand and dust) and residual lignin. A cross-section of a single fiber is shown in (Fig 2-b). The fiber cross-section sample was prepared by impeding fibers in a polymeric matrix and fracturing the sample thus the fractured surface will show a clear cross section of the fiber. The SEM micrograph (Fig. 2-b) shows that the DPF single fiber is a collection of multicellular fibers with a central voids (lumen) in each one. The multicellular fibers (individual fibers) are 2-5μm in diameter. The multicellular fibers are bonded and covered by a relatively thick primary layer. This outer sheath is suspected to be lignin. It is worth noting that the microstructure and shape of DPF is close to coir fibers [8,9].



(a) (b)

Fig. 2. SEM micrographs of raw DPF (a) and cross sectional view of a single fiber (b).

The mechanical properties of DPF were determined and are shown in Table-1. The DPF tensile strength was found to be 170-275 MPa with a Young's modulus in the range of 5-12 GPa. The elongation to break was found to be 5-10%.

Table-1. Average mechanical properties of DPF and other common natural fibers [2,4]*.

Properties	Density (g/cm^3)	Diameter (μm)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation to break %
DPF	**0.92**	**100-1000**	**170-275**	**5-12**	**5-10**
Jute	1.3-1.45	25-200	393-773	13-26.5	1.16-1.5
Flax	1.5	10-40	600-2000	12-85	1-4
Sisal	1.45	50-200	468-640	9.4-22.0	3-7
PALF	-	20-80	413-1627	34.5-82.51	1.6
Coir	1.15	100-450	131-175	4-6	15-40

* DPF measurements are for thirty single fiber specimens picked out randomly.

Examination of Table-1 shows that date palm fibers density is lower than other types of fiber density reported, and the DPF density is about 60% lower than glass fibers. However, the measured value comes within the range reported for natural fibers (0.9-1.5 g/cm^3) [10]. DPF measured diameter is larger than commonly examined natural fibers reported in the literature. The mechanical properties of DPF are lower than reported values for other natural fibers but comparable to the mechanical properties reported for coir.

The chemical composition analysis results of DPF and reported values of other natural fibers are shown in Table-2. The fiber chemical composition influences its properties and in many ways fibers them self can be considered as a fibrous composite material [4]. The variation in the polysaccharides content is reflected in the fiber measured mechanical properties [3,4]. For example, the cellulose content, in addition to the other parameters mentioned above, has an important influence on the mechanical properties of natural fibers [2,3]. Coir fibers show the lowest tensile strength among all other natural fibers, which can be attributed to their low cellulose content [9,11]. On the other hand, flax fibers that have the highest tensile strength have at the same time high cellulose content [2]. As shown in Table-2, DPF have higher cellulose content than coir fibers and lower cellulose content than other natural fibers. At the same time DPF have higher tensile strength than coir fibers and lower tensile strength than other natural fibers as shown in Table-1. DPF has 20% lignin and 18% hemicelluloses. The percentage of lignin is higher than common fibers, but lower than coir fibers (45%). Lignin content has been reported to influence the fiber structure, properties and morphology [4]. The hemicelluloses content is similar to that of other popular natural fibers.

Table-2. Chemical composition of raw DPF and common natural fibers [4].

Types of fiber	Cellulose Wt.%	Lignin Wt.%	Hemicelluloses Wt.%	Moisture content Wt.%
DPF	**46**	**20**	**18**	**5.0**
Jute	61-71.5	12-13	13.6-20.4	12.6
Flax	71	2.2	18.6–20.6	10.0
Sisal	67-78	8.0-11.0	10.0-14.2	11.0
Coir	36-43	41-45	0.15-0.25	8.0

The thermal stability of natural fibers has been identified as one of the disadvantages of natural fibers. It is important to know the degradation of mechanical properties when the fibers are exposed to composite processing temperature. Thermogravemetric analysis of raw DPF is shown in Figure 3. The TGA curve of raw DPF shows slight decrease in weight as temperature increases to 100 ^{o}C, which could be attributed to the fiber moisture content. The raw DPF show stability up to 250^{o}C above which degradation starts. These results are comparable with other types of natural fibers [3,4].

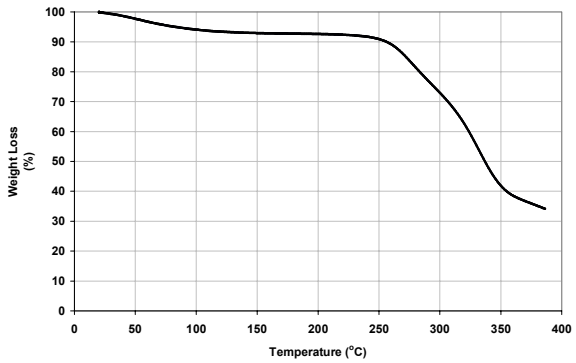
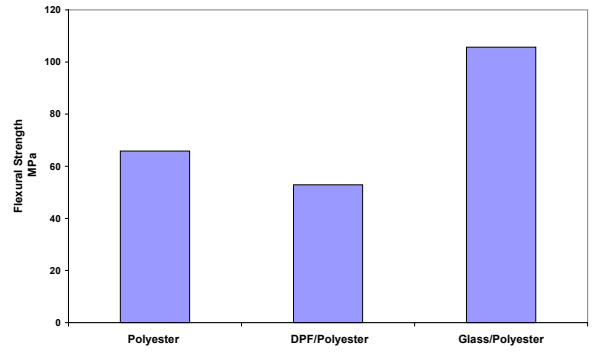
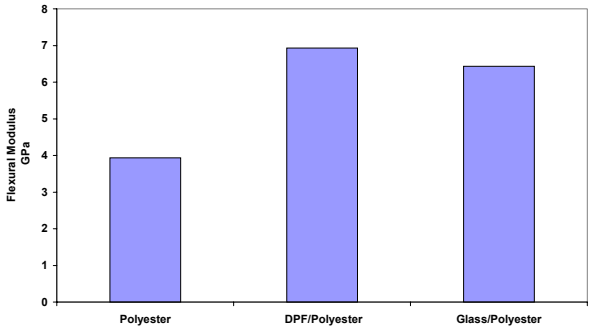


Fig.3. The (TGA) analysis of raw DPF in air atmosphere with a heating rate of 10 ^{o}C/min.

The critical length and critical weight percent for DPF in polyester matrix were found to be 2cm and 9 wt.%, respectively [12]. Raw DPF/polyester samples containing the critical length and the optimal fiber fraction were prepared. The flexural and impact properties were measured and compared to neat resin and glass/polyester composite samples. The glass/ polyester composite samples were prepared with 9 wt.% glass fibers. Figure 4 and 5 show the measured flexural and impact properties for the three types of samples.



(a)



(b)

Fig.4. Flexural strength (a) and modulus (b) for neat resin, DPF/polyester composite and glass/polyester composite.

DPF/polyester flexural strength was found to be 52.86MPa, which is about 20% less than the flexural strength of the neat resin (65.84MPa). The glass/polyester composite had the highest flexural strength (105.72MPa). The DPF/polyester composite had a flexural modulus of 6.93GPa, which was about 75% higher than the measured flexural modulus of neat resin samples and 7% higher than the measured value for glass fiber composite. DPF/polyester composite had impact strength of 6.718KJm^{-2}, which is about 250% higher than the measured value for neat resin. The glass/polyester composites had impact strength of 32.732KJm^{-2}.

It has been reported that the mechanical properties of polymer composites depend generally on the properties of the fiber, the properties of the matrix and the strength of the interfacial adhesion between them [13]. Strong and efficient interfacial adhesion is needed for the transfer of stress from the matrix to the fibers. Poor interfacial adhesion will lead to lower stress transfer and thus will lower the composites mechanical properties. Since raw natural fibers are hydrophilic in nature and contain high amount of

impurities on the surface (Fig.2), it is believed that this will lead to poor bonding between untreated natural fibers and the polymeric matrix. In our case, the reduction on flexural strength of DPF/polyester composites could be attributed to the poor interfacial adhesion between fibers and matrix, which caused ineffective transfer of stress. Higher flexural strength of glass/polyester composites in return is due to surface treatment of the glass fibers, which has been highly optimized for composite applications. Raw DPF/polyester composites flexural strength is comparable to reported values for untreated coir fiber/polyester composites [8]. Different surface modifications of coir fibers in the same work had improved the strength by different levels. Usually, exposing natural fibers to different treatment process will improve the adhesion strength between the fiber and matrix and thus improve the mechanical properties of composites. Several treatment methods of date palm fibers are under investigation by this team.

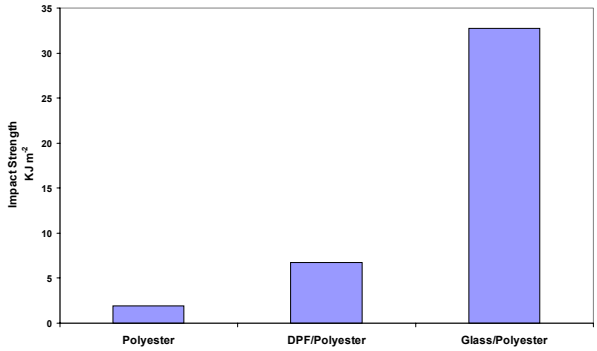


Fig.5. Izod impact strength results for neat resin, DPF/polyester and Glass /polyester un-notched specimens.

The use of DPF had increased the toughness of the polyester as shown by the Izod impact test. Again the significant increase of the glass/polyester composite impact strength is attributed to the strong adhesion between the glass fiber and the matrix. The composite toughness is influenced by many factors including the toughness properties of the reinforcement, the nature of the interfacial region, and the frictional work involved in pulling the fibers from the matrix [13,14,15].

4. CONCLUSIONS

In this study, the properties of DPF as a polymeric reinforcement were investigated. DPF fibers had a diameter of (100-1000μm) and density of 0.917± 0.127 g/cm^3. The mechanical properties of a single DPF are lower than reported values for other natural fibers but comparable to the mechanical properties reported for coir fibers. Raw DPF tensile strength ranged from 170-275 MPa, and the modulus of elasticity ranged from 5-12 GPa with an elongation to break of 5-10%. The chemical composition of DPF is comparable to that of other common natural fibers and consists of approximately 46 wt.% cellulose, 20 wt.% lignin and 18 wt.% hemicelluloses. Thermal degradation of DPF starts at 250^{o}C. Composite samples containing the critical length and the optimum fiber fraction had a flexural strength of 52.86MPa and flexural modulus of 6.93GPa. The impact strength of similar samples was determined to be 6.71KJm^{-2}. The low measured mechanical properties values could be attributed to the poor fiber-matrix adhesion.

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