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Experimental Study onPhysical and Mechanical Propertiesof Date Palm Fronds Polymer Composites

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Abstract : Date Palm tree consists of trunk, frond, leaves and fruit bunch which have the variety of applications in the general engineering. Fronds of this tree have great potentiality for art, sport and domestic applications. In this research work, fronds of the date palms have been studied for its possibility of use in engineering application by studying physical and mechanical properties. Date palm frond mid rib was collected from five different regions of Sultanate of Oman from the seasonal pruning process. Samples were drawn as wood strips from the mid ribs as per the ASTM standards for testing mechanical properties such as tensile, bending and impact strength. Out of the five regions of the samples tested Nizwa region showed more strength of 28.61MPa whereas as Muscat region has the least strength of 13.16MPa. Fibers from Muscat region exhibited more flexural strength and the Nizwa based fibers are the least. Flexural strength of Muscat based sample showed the higher value of 56.51MPa and Nizwa origin has the least value of14.63MPa. Charpy impact strength of Al-Ameerat region exhibited highest impact strength of 5.8 J/mm and Ibra origin has the lowest of 3.2 J/mm. Composites prepared using polyester resin revealed that tensile strength of Nizwa was 20.14 MPa which was 57% higher than pure matrix strength. The lowest value of 11.81Mpa was seen in Ibra origin. The highest value of flexural strength of 46.56MPa was recorded in Nizwa region and the lowest of 20.66 MPa was from Ibra region. The highest impact strength of 11.76 J/mm was recorded in Al Suwaiq origin. All other samples showed a marginal value compared to pure matrix impact strength. Composites have recorded with the increase in the values compared to raw date palm fiber. Therefore, a study of frond mid ribs and their composites has great potential as the engineering material for various applications.
Keywords : Date Palm frond, Fibers, Polymer Composites, Physical and Mechanical Properties

1. Introduction

Natural fiber composites are used in different areas of structural, automotive and aerospace applications due to their desirable properties like more strength, less weight, less cost and easy way of manufacturing[1-5]. In the recent years, there has been much interest in natural leaves and fibers, which are comprised of cellulose, due to their light weight, high performance, abundant availability, low cost, nonabrasive, nontoxic and biodegradable properties[6-10].

The date palm fiber is one of the common waste leaves and abundantly available in the Middle East countries. These fibers can be used as reinforcement in the production of natural fiber composites[11-15]. The date palm fibers have proven to suitable reinforcement materials due to environmental concerns with recyclability and environmental safety with good physical properties[16-20]. The limitations of using these fibers include high moisture absorption, lack of good interfacial adhesion with plastics and low thermal resistance. The mechanical properties of these fiber composites are somewhat worse than the synthetic fiber composites because of the inherent nature of the fibers which usually leads to poor interfacial adhesion with hydrophobic polymer matrices. In order to improve the fiber and matrix adhesion and to improve the mechanical properties, surface modification of natural cellulosic fiber is required by physical or chemical treatment[21-25].There are many types of treatments used to improve the fiber surface to modify the strength of the fiber matrix interface which provides an effective improvement on physical and mechanical properties of the composites[26-29].

Even though many research communities studied various properties of natural fiber composites which are useful in engineering applications, it is important to understand the physical and mechanical properties of natural fibers in order to use them as reinforcement in composite materials. Hence, an experimental study on physical and mechanical properties of date palm fronts was made in this research.

2. Materials and Methods

2.1. Date Palm Fronds

Date Palm is generally found in the Middle East, India, Pakistan, California, northern Africa and Canary Islands. Tree grows about 23 metre (75 feet) height with strong and large base stem with wide spread roots all over the base of the tree. Stem is strongly marked with the pruned stubs of old leaf bases terminating in a crown form with pinnate leaves about 5 meters (16 feet) long. Figure 1 shows the parts of the tree such as trunk, leaves (whole leaves, midribs, leaflets and spines, and the sheath at the leaf base), the reproductive organs (spathes, fruit stalk, spikelet and pollen) and the number of fronds extracts. Figure 2 shows the cross section of date palm front.

Date palm fronds were collected from different regions of Sultanate of Oman (23.6100° N, 58.5400° E) such as Muscat, Ibra, Al Ameerat, Nizwa and Al Suwaiq (designated as A,B,C D and E). Shaving of the frond skin is done to an extent of 3 to 5 mm to remove dust, sand particles and exposed surface. Fronds were cut into three parts such as bottom, middle and top portion to find various properties according to ASTM-1037-D12 standard. Various physical properties such as density, moisture content and moisture absorption have been tested in the laboratory for both raw fronds and its fibers.

Figure 1: Parts of date palm **Figure 2: Cross section of Date Palm frond**

2.2. Extraction of Frond Fibers

Fibers of the fronds were extracted by stainless steel roller sugar cane crushing machine. Fronds were made to pass between the rollers till the fibers were separated as individual fibers. Fibers were separated as individual fibers and tested for mechanical properties such as tensile, flexural and impact strength.These propertieswere tested for both physical and mechanical properties. Fibers were drawn randomly from the entire length of the frond for testing density, moisture content and moisture absorption as per the ASTM D1037 standard. Palm fibers having different diameters were grouped and measured for their mass. Then entire mass was divided by number of fibers and thus mass of individual fiber was calculated. Volume of the palm fibers were calculated by measuring diameter and length.

2.3. Preparation of Polymer Composite

Date palm fiber composite was prepared using polyester resin of tensile strength of 50-60 N/mm^2, supplied by Atul Polymer Division Ltd Gujarat, India. is a The unmodified epoxy resin (Lapox L-12) and epoxy hardener (K-6) were used in this process.

All the fibers used in the experimentation were chopped to a size of 2-5 cm length. Fibers were soaked in ethanol-acetone volume ratio of 50:50 for 24 hours and then washed with cold water. Moisture content of the fibers were brought back to normal temperature of 25±2º C. Composites were made from mixing the polyester resin and fibers of date palm frond in the weight ratio of 70:30. The chopped fibers mixed with unsaturated polyester resin mixture were stirred continuously for 30 min in order to get uniform dispersion.

Vacuum bagging method shown in Figure 3 was employed to make laminates using the composite mixture. The pressure was applied to the laminate once laid up in order to improve its consolidation by sealing a plastic film over the wet laid up laminate and onto the tool. Air under the bag was extracted by a vacuum pump at one atmospheric pressure in order to consolidate the composite. Sometimes a peel ply was used to leave an imprint on the surface to enhance adhesives bonding at a later time. The breather-bleeder combination helped to distribute the vacuum and channelize the volatiles and excess resin to the vacuums port. After six hours of vacuumizing or the resin dried at room pressure-temperature condition, sealant and breather were removed to takeout composites. The laminate under the vacuum bag was trimmed to remove extra runs and specimens were prepared for different mechanical tests.

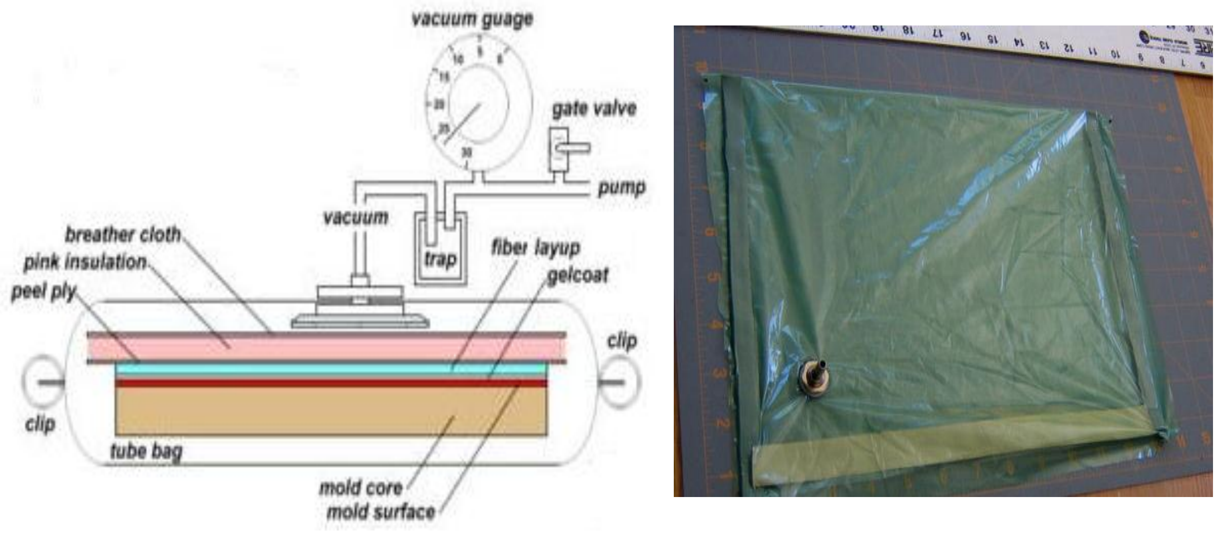

Figure 3: Vacuum bagging method

2.4 Tests

2.4.1. Density test

Mass was calculated by water displacement method whereas weight was measured with weighing machine. Then, mass density and weight density were calculated using Equation (1) and Equation (2) respectively.

$$Density = Mass/Volume \tag{1}$$

$$Density = Weight/Volume \tag{2}$$

2.4.2. Moisture content test

Date palm fronds collected from five regions of Oman were tested for green and dry condition. Samples of size (10 mm x10 mm x 20 mm) were prepared along the grain from the bottom, middle and top portions of the frond. Samples were weighed and kept in a oven setting temperature to 103±2º C.The specimen were weighed at a regular interval of 30 minutes and was repeated till two successive reading of the specicimens were almost same. The moisture content was determined as per ASTM-D4442-07 using Equation (3).

$$Moisture\ Content\,(MC)_{oven\,dry\,method} = \frac{(Initial\ weight - final\ weight)}{(final\ weight)} x100 \tag{3}$$

2.4.3. Moisture absorption test

Dry oven samples prepared were kept immersed in water. Samples were taken out at an interval of 24 hrs, 48 hrs and 72hrs.The samples taken out from the water were kept on a anti water absorbent surface (glass surface) till the excess water was drained out. Moisture absorption was calculated using Equation (4).

$$Moisture\ Obsorption(MO)_{oven\,dry\,temprature} = \frac{(final\ weight - initial\ weight)}{(final\ weight)} x100 \tag{4}$$

2.4.4. Tensile test

Frond as a raw wood was taken and tested for three regions such as bottom, middle and top portions. The specimens were prepared as per ASTM D1037-12 standards. The tensile test was conducted on Houhns field 25kN tensile testing machine. Fifteen samples were tested for each locality of different regions of Oman. Various parameters such as tensile strength, modulus of elasticity, modulus of rapture are evaluated using standard formulae. The specimen samples and universal testing machine are shown in the Figure 4.

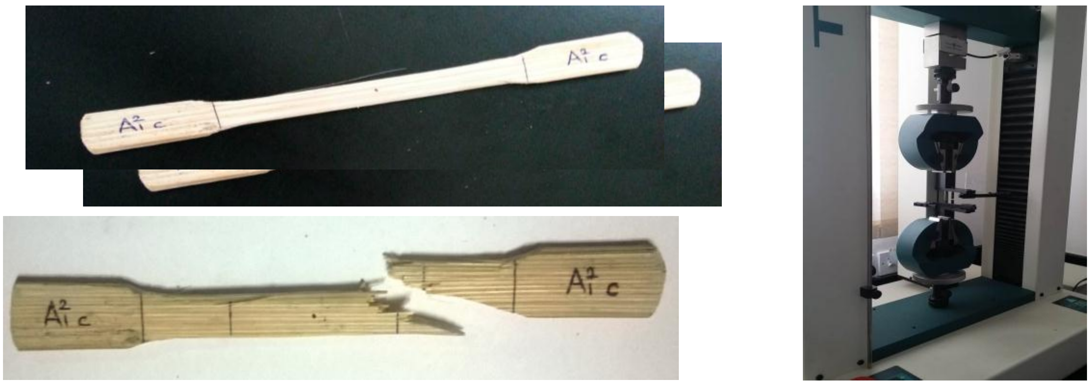

Figure 4: Tensile test

2.4.5. Bending test

The specimens(150 mm x15 mm x5 mm) were prepared as per ASTM D5942-96 standard. The flexural strength of the samples was tested using KIC-2-1000c UTM machine at a test speed of 1mm/min. Since the fronds were curvilinear in shape, test was conducted opposite to the curved surface as shown in Figure 5. Three regions of the fronds were tested and flexural strength was calculated.

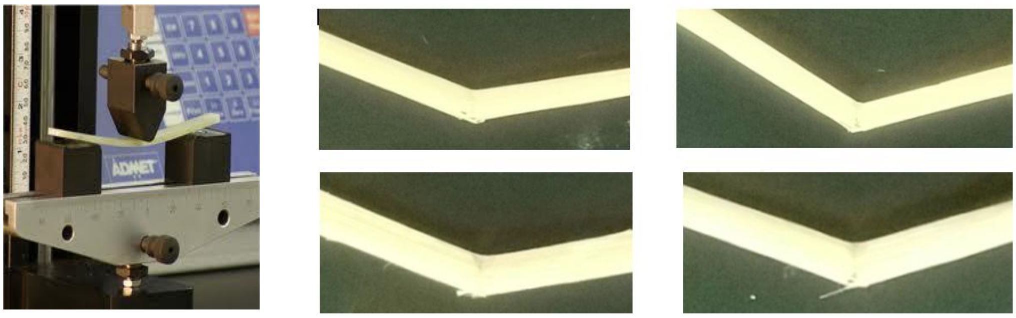

Figure5: Bending test

2.4.6. Impact test

The specimens (64mm x 12.7mm x 4mm) were prepared as per ASTM D 7137. Izod impact test was conducted on the specimens using Izod impact tester shown in Figure 6. The capacity of the impact tester is up to 250 Joule and release angle of the pendulum is 150^0.The specimen was placed in a vertical position. When the impact hammer is released, it strikes the specimen and the corresponding impact strength is displayed digitally.

Figure6: Izod test

2.4.7. Scanning electron microscopy

Morphology of the frond surface was done with the help of scanning electron microscopy (SEM) images using LEO 440i electron microscope. All the samples were tested after dipping in liquid nitrogen and then surfaces were gold coated by sputtering (E50000C PSC) method.

3. Results and Discussion

3.1. Physical properties of Date palm frond fiber

The various physical properties of date palm frond as a wood and fibers determined experimentally are listed in the following Table 1.

Table 1: Physical properties of untreated fibers

Sample	Density (g/cm^3)	Moisture content (%)	Moisture absorption (%)
A	0.42	86.54	23.36
B	0.2	58.92	22
C	0.22	56.81	22.1
D	0.35	61.23	46.45
E	0.27	59.9	28.66

3.2 Mechanical propertiesof polymer composites

Mechanical properties such as tensile strength, bending strength and imact strength of the untreated and treated fibers were evaluated and are given in Table 2and Table 3 respectively.

Table 2: Mechanical Properties of untreated fibers

S.No	Sample Type	Tensile strength (MPa)	Elongation (%)	Young's modulus (MPa)	Flexural strength (MPa)	Impact strength (J/mm)
1	MA (Material A Untreated)	13.16	1.47	1015	56.51	5.1
2	MB (Material B Untreated)	15.27	2.16	1085	29.78	3.2
3	MC (Material C Untreated)	13.57	1.21	1076	45.16	5.8
4	MD (Material D Untreated)	28.61	3.06	1024	14.63	4.3
5	ME (Material E Untreated)	13.87	1.09	1038	44.92	4.6

Table 3: Mechanical Properties of alkali (10%NaOH) treated fibers

S.No	Sample Type	Tensile strength (MPa)	% Elongation (mm)	Young's modulus (MPa)	Flexural strength MPa	Impact strength (J/mm)
1	NMP (Neat matrix polyester)	11.54	1.47	982.00	22.65	6.15
2	MA (Material A treated)	15.05	0.73	1643.00	37.01	8.41
3	MB (Material B treated)	11.81	0.59	2008.51	20.66	7.64
4	MC (Material C treated)	18.74	0.92	2042.17	27.30	9.56
5	MD (Material D treated)	20.14	0.85	2358.88	46.56	10.92
6	ME (Material E treated)	16.79	0.76	2204.42	35.77	11.76

The sample collected from Nizwa origin showed the highest tensile strength of 28.61MPa whereas lowest tensile strength was found in Muscat origin based sample. Nizwa origin sample exhibited excellent tensile strength due to the fiber wall structure, lignin and hemicelluloses contents in the fiber. The remaining samples showed the average tensile strength.

The flexural strength of Muscat based sample showed high flexural strength of 56.51MPa and least flexural strength of 14.63MPa was exhibited by Nizwa origin samples. Highest flexural strength in Muscat origin samples may be due the number of cell wall layers present in fiber which could be able to resist the bending force.

The impact strength of Al-Ameerat origin showed highest impact strength of 5.8 J/mm and lowest of 3.2 J/mm was recorded for Ibra origin based sample. There are variations in the impact and flexural strengths, which were mainly due to the alignment of fibers around the walls of fiber, composition of ligin, cellulose and hemicelluloses present in fibers.

3.3 SEM analysis

The morphology of the frond surfacei.e SEM image of the all samples is shown in the Figure 7.

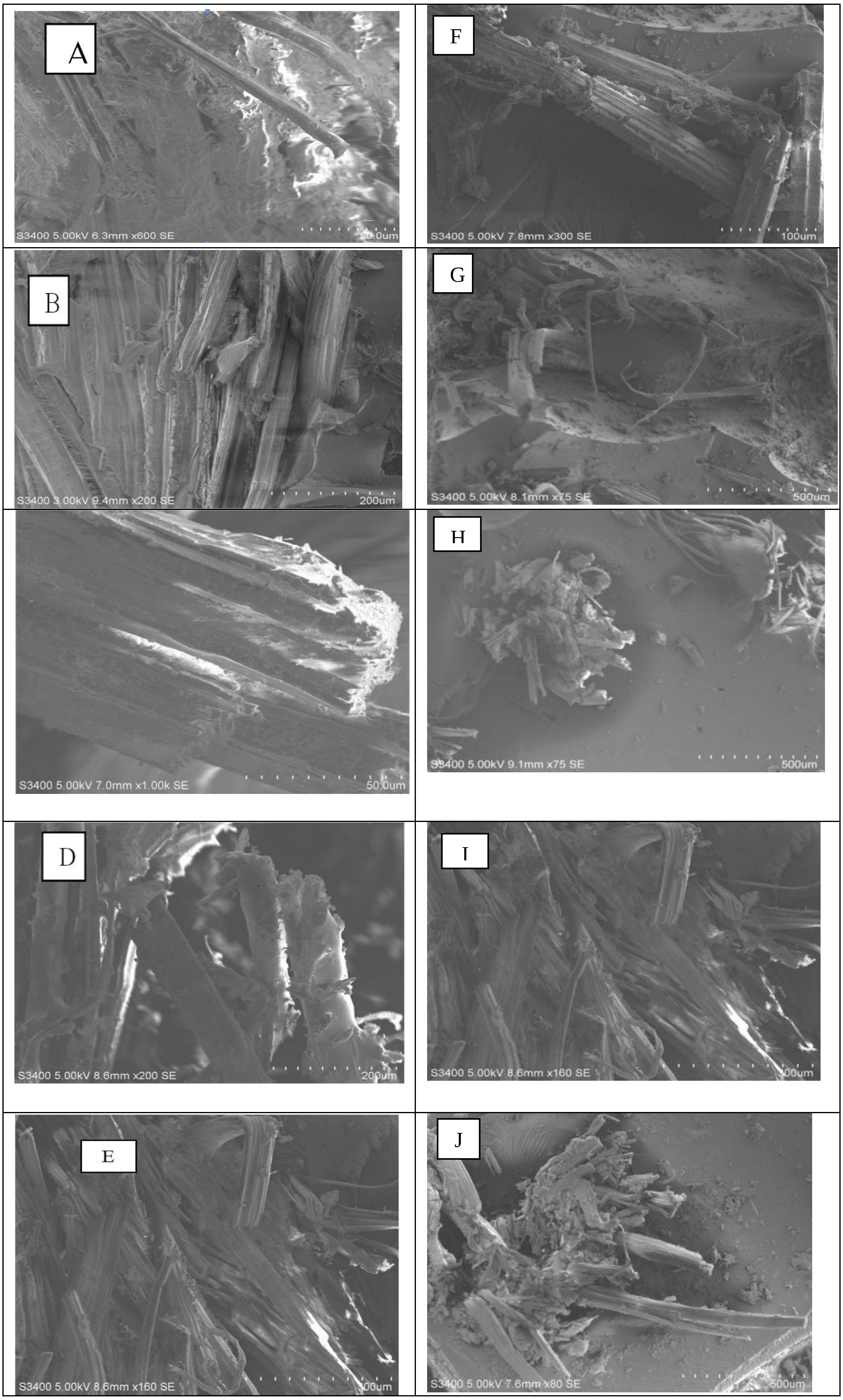

Figure7: SEM images of the raw wood frond (A to E) and Date palm fiber polyester composite (F to I)

4. Conclusion

The mechanical properties of date palm materials collected from various place were shown different strength. The incorporation of date palm fibers at different loading in polyester polymer significantly improved tensile strength of the composites. The raw wood frond material collected from Nizwa origin showed highest tensile strength of 28.61MPa and lowest tensile strength was found in Muscat origin based wood sample. The flexural strength of Muscat based sample showed highest flexural strength of 56.51MPa and lowest flexural strength of 14.63MPa was exhibited by Nizwa origin samples. The sample from Al Ameerat origin showed highest impact strength of 5.8 J/mm and lowest of 3.2 J/mm was recorded for Ibra origin based sample.

In the composites, the tensile strength of Material D (Nizwa origin) showed highest tensile strength of 20.14 MPa. The lowest value of tensile strength 11.81 MPa was found in material B(Ibra origin).The Highest value of flexural strength 46.56MPa was also recorded in Material D (Nizwa origin) and lowest bending strength 20.66 MPa was shown in material B(Ibra origin).Highest Impact strength of 11.76 J/mm was recorded in Material E (Al Suwaiq origin). All other samples showed a marginal value compared to pure matrix impact strength. The SEM images of fractured surface showed fiber breakage with ductile fracture.

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