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Mechanical Analysis of Waste Leaf Sheath Date Palm Fibres for Composite Reinforcement

Ankush Mishra and Pankaj Kumar Singh***

ABSTRACT

Leaf sheath date palm fibres, which are now regarded as agricultural waste, will be the subject of a multi-scale investigation proposed in this paper. To begin, two distinct kinds of bundles were discovered via the use of optical and electronic microscopy. Bundles exhibited a low degree of crystallinity, but lignin concentration of roughly 17 percent gave them highly cohesive structure and outstanding thermal stability, as well as unique behaviour in dynamic vapour sorption, according to XRD and biochemical studies. However, when tensile tests were performed on bundles, it was revealed that the stiffness and strength of the cell walls were inadequate, but the elongation was substantial when using Atomic Force Microscopy in mechanical mode. Force Microscopy Using Atoms As a result of these discoveries, trash may be employed as a composite reinforcement for increased acoustics and high energy absorption at a cheap cost.

Keywords: *Mechanical properties; Natural fibres; Microstructural analysis.*

1.0 Introduction

Using plant fibres in composite materials has grown significantly in recent years. These fibres have attracted a lot of industrial attention because of their low cost, acceptable mechanical performance, and low environmental impact [1,2]. Because secondary fibres (i.e. fibres that are leftovers from some other main utilisation of the plants) are more widespread, this kind of fibre has a lesser environmental impact than the ubiquitous glass fibre reinforcements.

Cell walls are the primary source of plant fibres, which may come from a variety of locations inside a plant. Carbon-based fibres may be found in plants' xylem. These seminal hairs, which come from the seeds of cotton and kapok, have a unique structure and design; they are not 'fibres' in the botanical sense. [6] Microfibrillar angles and narrow walls contribute to the kapok's poor mechanical characteristics. When it comes to producing additional plant fibres, dicotyledonous plants often use phloem (tissues near the periphery of vascular bundles). [9] Phloem fibres may be divided into primary and secondary fibres, with the primary fibres originating from the cambium holding the most desirable properties. These plants include nettle [10], flax [11], hemp [12], and jute [13]. It's possible that all of these structures, from culms (like bamboo) to leaves (like sisal or coir) to trunks (like palm trees), contain blood vessels. [14,15,16,17] Circulatory tissue may be found in the leaves of bamboo, sisal, and abaca.

**Corresponding author; Assistant Professor, Department of Civil Engineering, KNIT Sultanpur, Uttar Pradesh, India (E-mail:ankushmishra265@gmail.com*
***M.tech Research Scholar, Department of Civil Engineering, KNIT Sultanpur, Uttar Pradesh, India (E-mail: pankaj02021992@gmail.com)*

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North Africa and the Middle East are home to date palms, especially in Egypt, Iran, and Saudi Arabia. In 2014, 1.1 million hectares of date palms throughout the globe produced high-value date fruit [18]. It takes a further 7-12 years for date palm plants to produce fruit that is economically viable [19,20]. Each year, the tree is trimmed, resulting in the removal of 10-30 new leaves [20], generating a significant amount of waste: up to 35 kg of biomass per tree, of which up to 20 kg is made up of dry leaves [21–23]. As a result, millions of tonnes of bio-waste are accumulating each year. It is estimated that up to 80% of the world's bio-waste is either burned or dumped in landfills. In addition to being used for ropes and baskets, the fibres from the leaf sheaths are also being used to strengthen the composite materials.

Fiber bundles, known as fibrillum, cover the stem of the palm tree, forming an aesthetically pleasing, naturally woven mat of fibres of varying widths. As leaves decompose, a fibrillum develops, which protects the petioles that remain from the previous leaves. The entrapped air between the fibre bundles of this fibrillum provides thermal protection for the plant [25]. Currently, it is regarded as a silviculture waste, yet it has the potential to provide revenue for farmers. The ecosystem would benefit from a more effective use of this resource as well. Composite reinforcement might provide a new market for waste fibres that are generally used in low-value goods. NaOH treatment resulted in a considerable loss in strength, whereas Young's modulus rose. They think the observed alterations are caused by a change in the primary polysaccharides of the cell wall. Research done by Al-Oqla and Sapuan [26] found that date palm fibre might be a suitable alternative for composite reinforcement in the automotive industry because of its low weight. They argued that date palm fibres may be used as a long-term resource in the automobile industry. Analysis of oil palm fibre mechanical characteristics was done by Yusoff et al. [27] in light of government rules and customer awareness. Fiber volume percentages were varied in the oil palm/epoxy composites. Oil palm fibre may be used as a reinforcing mechanism in low weight composites, according to the researchers. Environmental treatments were studied by Leman et al. [28] to see how they affected the surface characteristics of the fibres and how this affected the tensile properties of epoxy composites reinforced with sugar palm fibres. According to their findings, saltwater and freshwater treatments boosted the sugar palm fiber's surface characteristics and tensile qualities by increasing the fibre matrix's adhesiveness.

Date palm tree (Phoenix dactylifera) leaf sheath stem fibres are examined in this study for their potential to enhance composite materials. To put it another way, the goal of this research is to see whether date palm stem (leaf sheath) fibres may be used as composite reinforcements. Phase (I) properties of fibres and Phase (II) characteristics of composites have separate sections. An investigation of date palm fiber's mechanical characteristics is the primary emphasis of this article, although the first portion examines its potential for application in composites. Light and scanning electron microscopy were used for the ultrastructural investigation. The cell wall polysaccharide components (e.g., cellulose and lignin) and their structure were then analysed by biochemical methods. '(vis. cellulose crystallinity and microfibril angle using X-ray diffraction). Moisture absorption and mechanical properties of the fibres were explained by the biochemical analysis. Nanoindentation and fibre tensile tests were used to investigate the mechanical characteristics of fibres at the cell wall and fibre bundle scales.

2.0 Materials and Methods

2.1 Materials

Raw samples of the natural mat (mesh) that surrounds date palm stems were collected at Al-Ahsa, Saudi Arabia (in the Eastern Province of Saudi Arabia). A total of 100 samples, ranging in size from 100 to 800 nm, were used to obtain optical measurements of bundle diameters. Following the method described in density measurements returned a value of 0.968.002 g/cm3.

Figure 1: Date Palm Stems

In this section, we focus on optical microscopy. The raw material was chopped into two palm fibre bundles, one millimetre broad and the other considerably smaller, by hand. Polyethylene glycol (PEG) solutions of escalating concentrations were then used to test the samples (30, 50, and 100 percent). The last step of embedding was performed at 70°C in pure PEG. 100 m thick slices were cut using disposable microtome blades (Microm Microtech, France) and put on microscope slides. Prior to applying Congo Red solution, deionized water was used to eliminate PEG from some of the 100 m thick slices. Prior to washing, cellulose and other polysaccharides were coloured red by Congo Red staining, which was utilised to identify the (1,4)-glucan polymers.

All investigations were carried out using an Axiocam MRc camera and an Axioskop microscope. Sections of unstained palm fibres were examined under UV (mercury lamp) and visible light (bright light) conditions. When activated by excitation at 340 nm, phenolic compounds exhibit blue fluorescence when exposed to ultraviolet light. The Congo Red-stained slices were examined under a bright light source.

3.0 Thermogravimetry Analysis (TGA)

Perkin Elmer Pyris 1 TGA was used for the thermogravimetric analysis (TGA). A nitrogen gas flow of 20 mL/min was used to elevate the temperature of palm fibre samples from ambient to 800 °C (i.e. inert conditions).

3.1 Water absorption experiments

Experiments on the isotherms of water vapour desorption/sorption were carried out using equipment from Hiden Isochema Ltd. (UK). As detailed in Guicheret-Retel this strategy works in a similar manner. The two replicates utilised in this investigation included a total of 5 mg of water, and

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the sequence of water sorption (10–90 percent RH at 10% intervals) and water desorption (90–15 percent) was programmed.

4.0 Result and Discussion

4.1 Tensile strength

There were two sorts of "big" palm fibre bundles, those with mm-scale dimensions and those 3 to 5 times smaller than the former: "small" bundles (discussed further in Section 3.1). The experiment was conducted using randomly chosen bundles, and the width of the bundles had no discernible effect.

Resin-coated bundle ends increased fibre capture, according to the study. Using a photocuring adhesive and a UV-source pen, these sandwich plastic tabs were created (Diastron Ltd., Hampshire, UK). The gauge length of the samples is 10 mm.

Before testing, the samples were kept in a climate chamber for 48 hours at a temperature of 20°C and a relative humidity of 55 percent. We used a laser beam to cut five equal slices across the palm fibre sample in full rotation scan mode The typical cross-section is provided by the UvWin 3.40 programme. pneumatic side-action grips was used to conduct tensile tests in a climatic condition of 20°C and 55% RH (1kN, Instron). When the gauge length failed, the displacement rate was raised to 10mm/s, therefore the test was judged successful. This criterion was met by 33 different specimens.

Figure 2: Tensile Strength of Palm Sell Contain and Without Palm Shell Contain

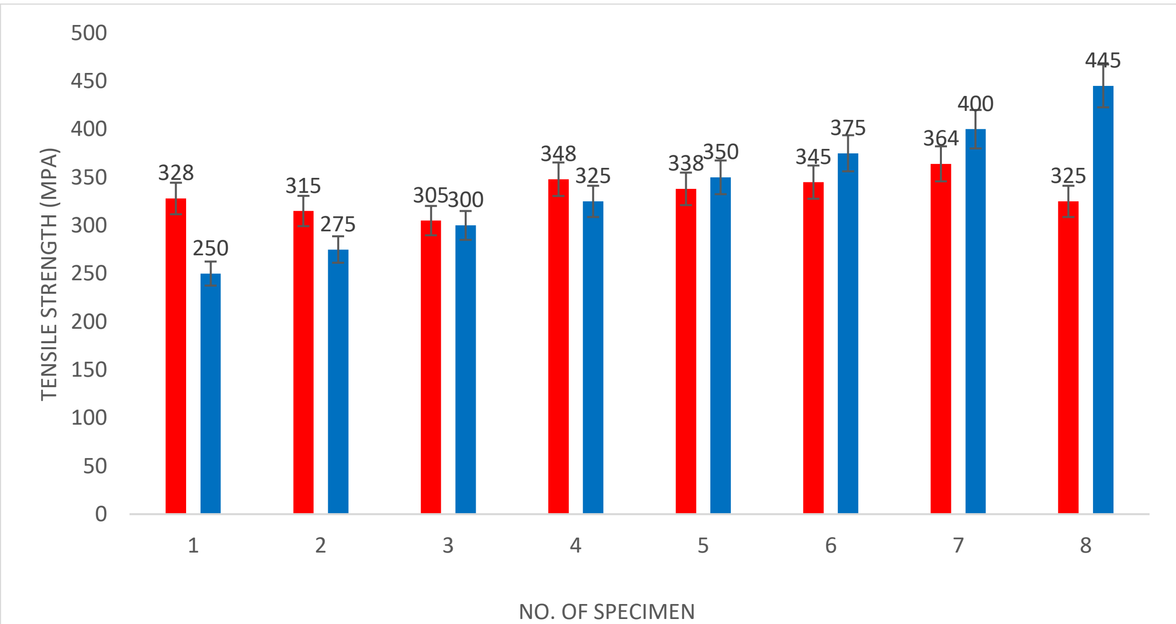

Figure 3 depicts the growth of the fibre bundles seen on the date palm tree in this investigation. It was possible to distinguish between two kinds of palm leaf sheath fibre bundles using optical microscopy and scanning electron microscopy in the fibrillum that was collected (SEM). The smaller bundles have a diameter of 70-120 m, and the bigger ones have a circumference of 600 to 1000 m. Figure 4 shows pictures taken using an optical microscope to demonstrate how the optical fiber's two components vary. Micrographs of palm fibre bundles were taken in (g)–(h) using UV exposure and (a)–(f) using visible light microscopy. Bundles of small and big bundles are shown in (a) and (b), which are not discoloured. Although the size of each bundle varies, the photos (e and (f) demonstrate a focal point of a larger bundle. The fundamental distinction between the two types of bundles is their structural composition. An average cell wall thickness is 3 to 4 nanometers (nm) in the smaller specimens, which contain fibres that are around 10 nanometers in diameter. These bundles may have a mechanical function because of the way they are arranged demonstrates that Congo red staining reveals that hemicellulose components are present in the cell walls, which may be useful in composite applications. The cell wall of lignified fibres is highlighted by UV-induced auto fluorescence. Fluorescence in the centre lamellae of flax fibres is common because of the protective rule of lignin, which provides for good bundle cohesion.

There is something odd about the large bundles' thin cell walls and high lumens, in contrast to the thick cell walls and modest lumen sizes of the smaller bundles. In addition, there are vascular tissues with a diameter of 100-200 m. Raw sap is probably allowed to flow via the big circulatory veins, whereas mature sap is likely allowed to flow through the little bundles. Veins, which are exclusively present in the cell wall, include structures that strengthen the rigidity of vascular areas by including hemicelluloses or cellulose, which may be used to protect these vital components. The high lignification rate of the cell walls, as seen in Fig. 4.h, may further increase the bundle stiffness. In addition, it is probable that the age of the cell walls may play a role in this reaction to Congo red.

SEM examination indicated the presence of silica in the last inquiry in this Large bundles of silica were observed on the surface of our sample According to Esau silica concentrations in monocotyledonous cell walls, especially leaves, may reach 41 percent weight. Palms have silica-based tiny cells. With regard to pulping and papermaking, silica has the potential to generate a variety of issues. A plant's stems become more resistant to pathogenic fungus, predaceous chewing insects, and other herbivores when silica is deposited there. The rind generates stegmata to mechanically protect the plant when lignin is present. Prychid et al. have noted the presence and shape of silica bodies as an intriguing aid for species identification. Fiber imperfections like silica bodies may be influenced by composites' overall properties. As stress concentrators, deficits may cause harm. Fiber element designs were clearly flawed, with pits containing silicate bodies perhaps serving as crack escape mechanisms or surface faults in terms of composite characteristics, according to our findings.

4.2 Thermo-gravimetric analysis

TGA was used to examine the thermal degradation of date palm fibres and compare it to that of other natural fibres Mass losses of 6.0% at 200°C were due to the evaporation of water, according to the results. Date palm has a greater specific gravity than most other natural fibres Higher than 410°C temperatures cause rapid mass loss and degradation of the fibres, making them less durable than other natural fibres. As a composite reinforcement, palm fibres might be used in the future with a wide spectrum of thermoplastic polymers due to their high decomposition temperature and high lignin concentration. Additionally, these findings are crucial in evaluating how much temperature a thermoplastic material can be handled at without severely damaging the fibres in composite manufacturing. Even before the fiber's thermal depreciation occurs, mechanical properties may begin to deteriorate in the fibre. While denaturation happens at greater temperatures, charring occurs at higher temperatures than the range of temperatures between 250 and 450 degrees Fahrenheit Date palm fibres have two distinct degradation peaks: one at 410 degrees Celsius and another in the normal range of 250 to 350 degrees Celsius, indicating increased thermal stability. Other natural fibres often have a single peak of degradation (between 250 and 350 degrees Celsius). In my opinion, bamboo has an unique crown. Date palm fibres may have a greater silica concentration, which may explain their

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higher breakdown temperatures. After heating to 800 degrees Celsius, 15.9 percent of the remaining volume had inorganic inclusions, such as silica bodies.

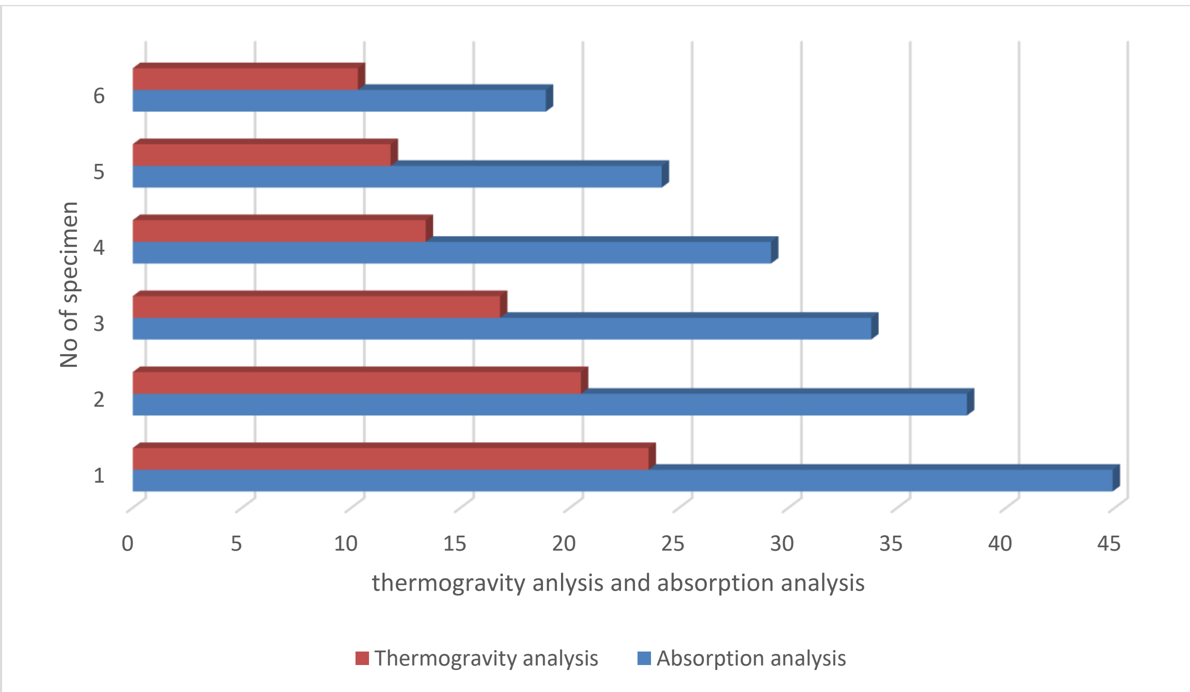
4.3 Absorption analysis

Compared to other natural fibres, date palm fibre absorbs and desorbs more moisture. [57–58] Our research discovered classic (type II) isotherms and responses to other plant fibres.

The isotherm plots may be categorised into three distinct groups: Water absorption in these locations is primarily facilitated by hydrogen bonds in the innermost cell wall layer, up to saturation, and micro-capillaries between 10% and 60% RH in region B, and above 60% RH in region C. Because sorption and desorption occur in separate situations, it is feasible that hysteresis may be described. Fig 2 analysis of Thermo-gravimetric and absorption. The expansion of microcapillaries during adsorption causes the fibres of the date palm to bend. The kinetic hindrance during desorption causes the free volume (i.e. micro-capillary space) to increase in contrast to the adsorption scenario.

A significant degree of hysteresis and comparable isotherm profiles were found in date palm fibres by Hill and colleagues s well as similar isotherm profiles in coir (coconut palm) and Sitka spruce wood. Between 50% and 70% RH, date palm fiber's hysteresis may be as high as 4%, which is much greater than the typical 1.5-3.2 percent for other plant fibres. Due to a high concentration of polysaccharides in the date palm's fibres, they are more able to adsorb water (amorphous cellulose, hemicellulose and lignin). As their high lignin content and the large micro-scale porosity on their fibre surface explain the high degree of date palm fibre hysteresis, so do However, it was shown that the RH zones where the adsorption and desorption curves overlapped were smaller in other fibres (such as jute, coir, flax, hemp, and cotton) (up to 10 percent). The hysteresis zone of zero percent It may be possible for date palm fibres to absorb and hold moisture in certain climates, which may be vital for the development of these plants in dry places.

Figure 2: Analysis of Thermo-gravimetric and Absorption



4.4 Bundles tensile characterization

Tensile testing were carried out on fibre bundles. The tensile characteristics of the fibres were assessed using a Fibre Dimensional Analysis System (FDAS). We observed that elliptical cross sections were more accurate in identifying the structure of date palm fibre bundles than circular ones. This approach yielded areas that were 14.7% bigger than those obtained using the circular geometry approximation using an estimate based on a measured mean diameter/width. Several plant fibre testing studies have been hampered by the non-circular cross-sectional shape of plant fibres and insensitive (but common) area measuring procedures (e.g. 'apparent' area based on an assumed circular cross-section shape and measurement of mean diameter/width). Fibre qualities (strength and stiffness) may be overstated by 40 to 70 percent because the cross-section area is underestimated according to several research. For mechanical property calculations, the FDAS provides a more precise assessment of fibre geometrical features.

Fiber tensile testing revealed the most important mechanical qualities, which are shown. The initial linear area's Young's modulus was found to be 1.8 0.6 GPa. At a stress-strain curve knee of around 2% applied strain, a yield point could be seen. Failing strength and stress ranges were determined to be between 135 and 34 MPa. An Ashby plot in Figure 8 shows that our date palm stem fibre has mechanical characteristics that are comparable to many other plant fibres. This fibre has an area under the stress and strain curve that is 13.9 6.9 MJm3. When compared to other fibres, they have the lowest absolute and specific stiffness and strength values. To mention just a few seed fibres, cotton, oil palm, and coir all have similar characteristics (coconut palm). Coir, oil palm, and date palm fibres all have high failure stress levels (15-30 percent). Date palm fibres have a higher failure strain but a moderate toughness when compared to other strong-brittle bast fibres, such as flax.

5.0 Conclusions

Our research focused on the structure, physiochemical composition, and mechanical characteristics of palm leaf sheath fibre bundles. In our investigation, we discovered two distinct bundles, each serving a specialised purpose in the plant. Although the lumens of cells in larger conduction bundles are tiny, those in smaller bundles are much thicker and have a structural role.

Because of their high thermal stability and unique water absorption characteristics, stiffness tests on intermediate lamellas reveal that they are an excellent choice for water storage and absorption.

The tiny cell wall thickness and the high relative lumen size hinder bundle behaviour. The elongation of these bundles, on the other hand, is much greater when split. Because of their cohesive structure and deformability, they may be used in energy absorption composites.

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