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Experimental Investigation of Date Palm Leaf Fiber Reinforced with Polymer Matrix Composite

Khadersab Adamsab[1,*], Haitham Abdullah Khamis AlAdwani[2], Mohammed Darwish Ali Khaziry[3], Emad Ramadhan Harrasi[4], Salim Suliman Fadhel Farsi[5]

Abstract

The demand for composites incorporating robust fibers is significant across diverse industries, driven by the favorable attributes of strength, lightness, and cost-effectiveness. Within GCC countries, date palm (DP) serves as a valuable source of cellulosic fibers, highly esteemed for its widespread availability. These fibers can be sourced from midribs, spadix stems, leaflets, and mesh. Date palm leaf fibers are becoming more and more popular as a way to strengthen composite materials.In this paper, an experimental investigation of date palm leaf fiber reinforced with polymer matrix composites is conducted to analyze the mechanical properties of date palm fiber laminate composites. Fibers are first cleansed of dust, air dried, chopped, and then soaked in a NaOH alkaline solution. By hand lay-up technique, the date palm fiber laminates are prepared. The results from hardness testing and tensile testing on date palm-reinforced epoxy laminates show that the hardness values of date palm-reinforced epoxy laminates with weight ratios of 5, 10, 15, and 20 wt% ratios are 26.5, 30.3, 35.3, and 32.5 HV, respectively. Increasing the weight percentage of date palm fibers in the sample raised the hardness value. While the tensile strength values for laminates are 16.5, 17.2, 20.6, and 23.5 N/mm2, respectively.

Keywords: Date Palm Leaf Fibers, mechanical properties, hardness, tensile strength, hand lay-up technique, reinforced epoxy laminates.

INTRODUCTION

Composites reinforced with fibers are in high demand in many industries because of their strong characteristics, light weight, and low cost. Historically, composite materials have been constructed with man-made fibers as the reinforcing element. Exploring the option of substituting synthetic materials with natural fibers is being explored. The production of natural fibers offers several key benefits, like deriving from a renewable source, needing less energy to produce, and being able to be decomposed naturally, or processed in a furnace, as opposed to glass fibers. Currently, natural fibers are employed in the automobile and packaging industries as reinforcements in technical applications in areas where strength is not paramount [1]. Date Palm Leaf Fibers, as a reinforcement material for composites, have emerged from among the many natural fibers.

DPLFs are affordable and eco-friendly due to the abundance of date palms in many areas [2] as it is shown in Figure 1 [3]. DPLFs possess a long length-to-width ratio, low weight, strong tensile strength, and superior biodegradability, thus being

***Author for Correspondence**
Khadersab Adamsab

[1,2]Lecturer, Department of Engineering and Technology, University of Technology and Applied Sciences-Al Musannah, Sultanate of Oman
[3-5]Students, Department of Engineering and Technology University of Technology and Applied Sciences-Al Musannah, Sultanate of Oman

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eco-friendly [4]. DPLFs contain distinctive chemical compositions, including hemicellulose, cellulose, and lignin, which contribute to increasing their strength. They are an excellent choice for improving the strength of polymer-based composites [5].

Figures 1 and 2: date palm tree and the detailed structure of date palm tree leaf respectively. In recent years, much effort has been put into exploring the mechanical properties of DPLFs reinforced composites experimentally. Comprehensive studies have been done to assess the mechanical characteristics of DPLF reinforced composites. Standardized testing methods are used to investigate the key parameters of flexural and tensile strength and impact resistance. [6] did research on date palm fiber reinforced epoxy composites and showed a major increase in tensile strength in comparison to regular epoxy. Furthermore, [7] investigated how DPLFs strengthened composites perform under flexing and found their flexural strength and impact resistance enhanced. Temperature characteristics are essential for judging whether composites are suitable for high-heat applications [8]. It has been determined that DPLF reinforced composites have high thermal stability, thermal conductivity, and coefficient of thermal expansion (CTE) [9]. These composites have greater thermal stability than pure polymers, which makes them suitable for the aerospace and automotive industries [6]. The structure of DPLF strengthened composites has been thoroughly evaluated using scanning electron microscopy (SEM) and X-ray diffraction (XRD) analysis. Additionally, morphological analysis has also been conducted [10]. SEM images can give us an understanding of the fiber-matrix interface, including the strength of the fiber-matrix connections and the adhesion between them. X-ray diffraction can be used to determine how the crystalline structure of DPLFs affects the overall characteristics of the composite [10,11]. Studies of matrix composites with DPLF have revealed their practical uses in many industries. It has become evident that date palm fibers could be used in automotive industry sustainably [6]. DPLF reinforced composites offer enhanced mechanical properties and environmental friendliness, making them ideal for the construction, aerospace, automotive, and packaging sectors [10]. Table 1 expresses the findings of previous studies of DPLFs. The use of date palm leaflets is becoming a research issue of interest in the Environmental and Analytical Research Group.

The date palm tree is Oman's primary fruit crop, producing a considerable amount of date palm leaves and leaflets each year. In the Sultanate of Oman, the date palm contributes around 82% of all fruit trees in the country. It accounts for 49% of the country's agricultural land. Oman is currently the seventh-largest global producer of dates, accounting for approximately 240, 000 metric tons (MT) of total global production. According to world consumption data from 2011 (FAO, 2015), Oman is close to 5–6% in terms of date consumption. The Sultanate of Oman had more than 7.8 million date palm trees in 2005, and this number is steadily increasing. Many Royal Directives are issued for uplifting and developing date palm trees in and around Oman.

Each date palm tree generates approximately 20 kg of dry leaflets as waste per year. The amount of palm leaf trash generated in GCC countries is close to 3 million metric tons, with Oman producing the lion's share (180000 metric tons). In some regions, burning palm leaves in the field is regarded as a common habit, creating environmental pollution. It is important for the environment and the economy that date palm waste be used rather than burned. The purpose of this paper is to investigate the mechanical properties of matrix composites reinforced with date palm leaf fibers.

CHEMICAL TREATMENT OF FIBERS

Fibers and stems from date palms were collected near campus of University of Technology and Applied Sciences in Al-Musannah, Sultanate of Oman (Fig 1). The fibers were submerged in a water bath to remove any dust, and then air-dried. After being cleaned and air-dried for 24 hours at room temperature, they were reorganized into bundles of fiber. The fibers are chopped into tiny bits using electrical mixing for 15 minutes. To have connection between the fiber and the polymer at the interface. The fibers are submerged in a NaOH alkaline solution for 1-2 hours. The resulting sheet's

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thickness was about the mean of the various samples. Have the mechanical and physical characteristics listed in Tables 2. The effect of varying NAOH concentrations on tensile strength and young modulus for chemical treatments is depicted in Figure 3. Date Palm Fiber is a reinforcement and polyester resin employed as a matrix material used to prepare polyester composites via hand lay-up technique. Composites with a higher fiber capacity and longer fiber can be easily and affordably fabricated using the hand lay-up method. Random E-glass chopped strand mat are used to prepare the laminate, mix with date palm fiber and polyester resin. The density of the resin is 1.15 g/cm^3 was obtained as per the data sheets from supplier. Experiments are conducted and analyzed for mechanical tensile properties of date palm fiber laminates composites. To improve measurement efficiency, different sets of experiments are repeated while producing the natural fiber composites using a die. The die for preparing the polyester composite specimens is presented as shown in Figure 4

(I)

(2)

Figure 1. Date palm tree; (2) detailed structure of date palm tree leaf.

Table 1. Findings of previous studies of DPLFs.

Reference	Mechanical Properties	Thermal Properties	Morphological Characterization	Potential Applications
[6, 9, 10]	Epoxy exhibiting much higher tensile strength than usual epoxy	Significantly better thermal stability than the untreated polymer.	• Excellent interfacial adhesion between fiber and matrix noticed.	• Feasibility for sustainable automotive industry applications
[7, 8, 10, 12,13]	Improved flexural strength and impact resistance	Excellent heat resistance for use in high temperature situations.	• Efficient load transfer indicated by good fiber-matrix bonding	• These industries make use of this technology: construction, aerospace, automotive, and packaging.

Table 2. Mechanical and Physical characteristics of the date palm fibers with other natural types [14].

Fiber types	Coir	Date palm fiber	Hemp	Sisal	Jute	Flax
Density (g/cm^3)	1.15–1.46	0.9–1.2	1.4–1.5	1.33–1.5	----	----
Length (mm)	20-150	20-250	5-55	900	----	----
Diameter (µm)	100–460	100–1,000	25–500	8–200	----	----
Thermal conductivity (W/mK)	0.047	0.083	0.115	0.07	----	----
Tensile strength (MPa)	131-175	58-203	----	468-640	393-773	600-2000
Young’s Modulus (GPa)	4-6	2-7.5	----	9.4-22	13-26.5	12-85
Elongation at break (%)	15-40	5-10	----	3-7	1.16-1.5	1-4

Figure 2. (a) cleansed of dust in a water bath; (b) soaked in an alkaline NaOH solution.

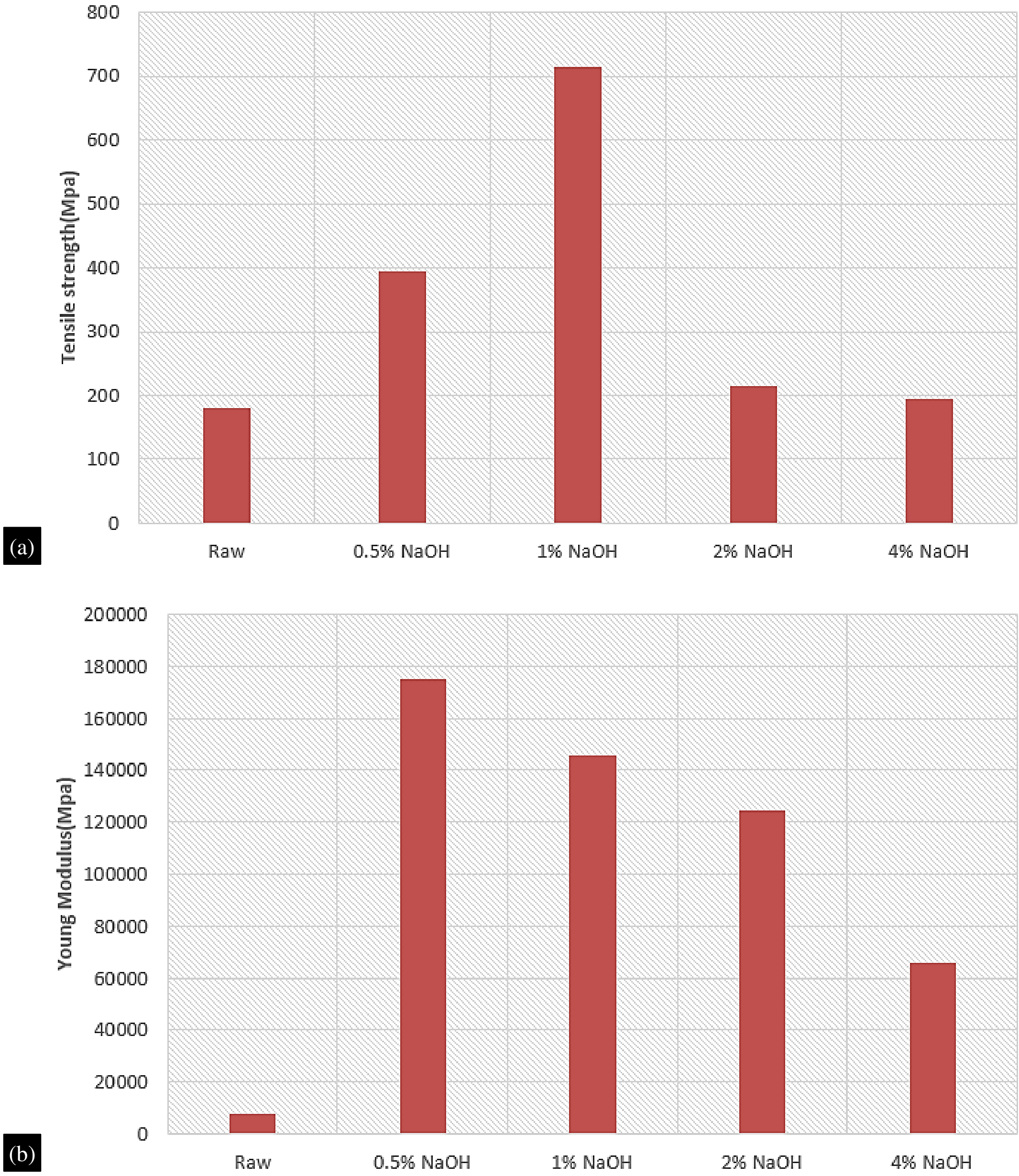

Figure 3. Tensile Strength and Young Modulus.

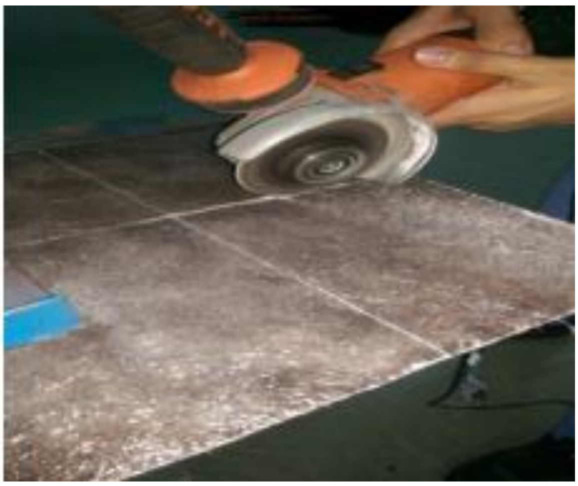

Figure 4. Preparation and testing of date palm fiber laminates.

RESULT AND DISCUSSION

The results of hardness and tensile testing on date palm-reinforced epoxy laminates are given. To withstand indentation in terms of deformation is the measure of hardness of a material. Vickers tests are used to determine hardness values. Most of the mechanical properties of composites can be inferred from the hardness measurements. porosity of the material is directly proportional to degree of hardness. The amount, length, and orientation of the date palm fiber all play a role in the hardness. The hardness testing of date palm reinforced epoxy laminates is shown in Figure 5 and 6. Date palm-reinforced epoxy laminates are produced in a variety of weight ratios of date palm fibers, such as 5, 10, 15, and 20% wt%. Date palm reinforced epoxy laminates with weight ratios of 5, 10, 15, and 20 wt%, those with a 15 wt% ratio exhibit higher hardness values compared to the others. The hardness measurements for laminates with 5, 10, 15, and 20 wt% ratios are 26.5, 30.3, 35.3, and 32.5 HV respectively, as shown in Figure 7. As the weight ratio of date palm fiber increases, there is a corresponding increase in hardness. It should be noted that the date palm fiber with 5 wt% demonstrates the lowest hardness value. The hardness increment is observed with the increase in date palm fiber content up to 15 wt% due to the favorable fiber structure, even distribution of fibers, and effective interfacial bonding between the Date palm reinforced epoxy laminates. Lignin also affects fiber structure and characteristics. Date palm reinforced epoxy laminates with 20 wt% of date fiber result in lower hardness, this may be due to agglomeration and porosity formation in hand lay-up technique [15]. Consequently, the Date palm reinforced epoxy laminates with 20 wt% date palm fiber exhibit a weakened hardness compared to other ratios.

Figure 5. Hardeness testing of date palm fiber laminates.

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Figure 6. Hardness testing of date palm reinforced epoxy laminates.

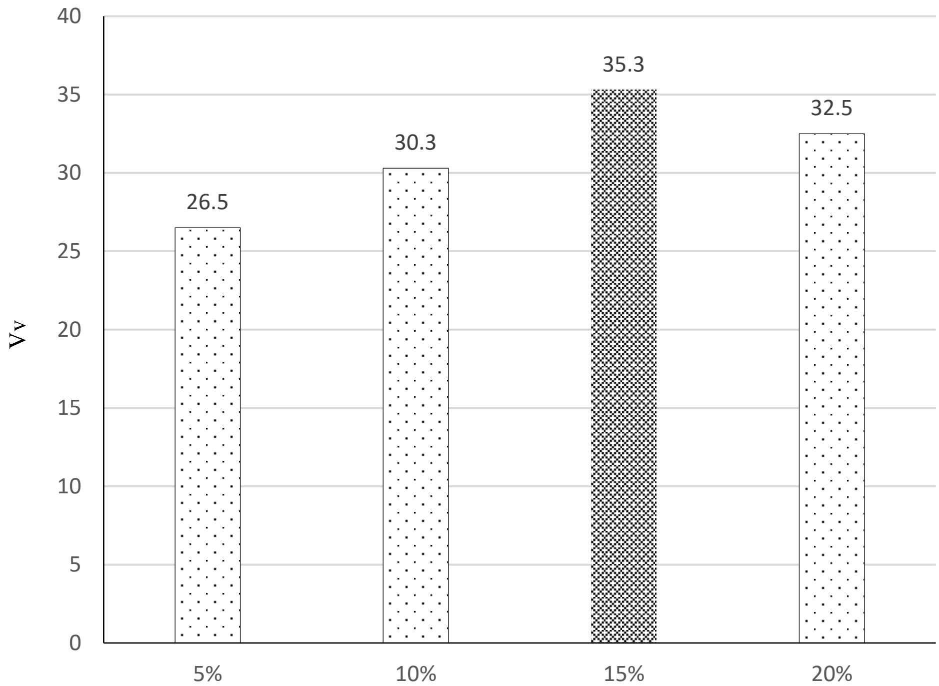

Figure 7. Hardness Values of Date palm-reinforced epoxy laminates**.**

The tensile testing of date palm reinforced epoxy laminates is shown in Figure 4. Date palm-reinforced epoxy laminates are produced in a variety of weight ratios of date palm fibers, such as 5, 10, 15, and 20% wt%. Date palm reinforced epoxy laminates with weight ratios of 5, 10, 15, and 20 wt%, those with a 20 wt% ratio exhibit higher tensile strength compared to the others. The tensile strength for laminates with 5, 10, 15, and 20 wt% ratios are 16.5, 17.2, 20.6, and 23.5 N/mm2 respectively is shown in Figure 8.

As the weight ratio of date palm fiber increases, there is a corresponding increase in hardness. It should be noted that the date palm fiber with 5 wt% demonstrates the lowest tensile strength. The tensile strength increment is observed with the increase in date palm fiber content. Date palm reinforced epoxy laminates with 20 wt% of date fiber result in higher tensile strength.

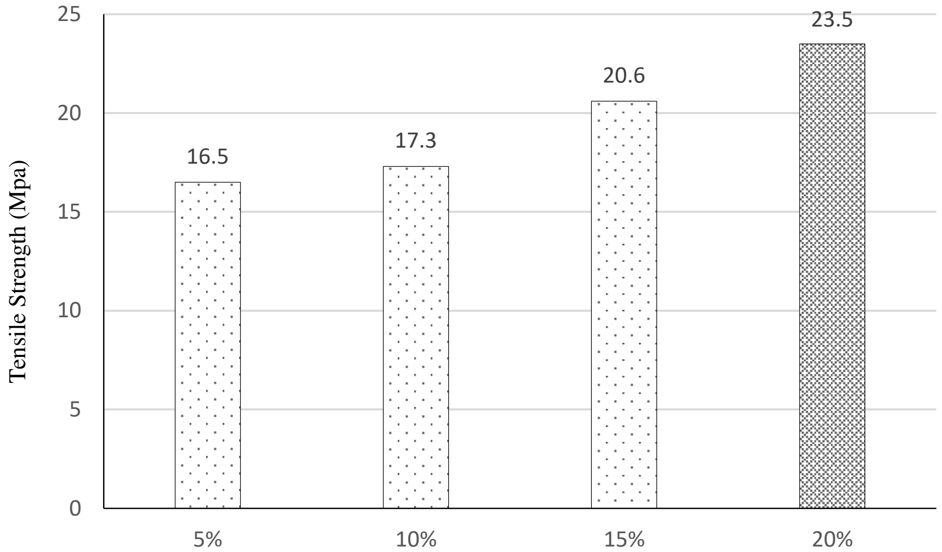

Figure 8. Tensile Strength of Date palm-reinforced epoxy laminates.

CONSCLUSION

The results of hardness and tensile testing unveiled a clear relationship between the weight percentage of date palm fibers and the mechanical properties of the composite laminates. With an increase in the weight ratio of date palm fibers, both hardness and tensile strength exhibited positive augmentation. In this experiment investigation of date palm leaf fiber reinforced with polymer matrix composites is conducted for analyzing the mechanical properties of date palm fiber laminates composites. From the results of hardness testing and tensile testing, the hardness value in the different weight ratios of date palm fibers, it shows that when the weight ratio increases, the hardness increases, and it is maximum increased in 15 wt% of date palm fibers. While the tensile testing of date palm reinforced epoxy laminates which is produced in a variety of weight ratios, it shows that the tensile strength value is maximum increased in 20 wt% ratio of date palm fibers. It indicates that that when the weight ratio increases, the tensile strength increases. This signifies the potential for tailoring the mechanical characteristics of the composite material by varying the fibre content, enabling the formulation of composites with desirable properties for specific applications. The utilization of date palm leaf fibers as a reinforcing material not only contributes to the development of sustainable and environmentally friendly composites but also adds value to the agricultural byproducts. The abundant availability of date palm trees in GCC countries further emphasizes the viability and economic potential of utilizing date palm leaf fibers in composite manufacturing. Further research and optimization of processing techniques could enhance the integration of date palm fibers into composite materials, paving the way for innovative and sustainable applications across various industries.

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