Crossian Resonance

A Multidisciplinary Research Journal **ISSN 0976-5417**
(A refereed Biannual Published in June and December)
Vol. 15, No.2, December 2024
https://research.holycrossngl.edu.in/

Experimental Investigation on Sodium Acetate Treated Luffa Fibre and its Characterization

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ABSTRACT

As environmental concerns grow, natural plant fibers are becoming popular alternatives to synthetic fibers. Among these, Luffa fibers are notable for their widespread availability. These fibers have unique ligno-cellulosic properties, making them desirable. One key advantage of natural fibers is their light weight and non-toxic impact on the environment. Luffa fibers are especially valued for their elasticity. Being biodegradable, they are highly recommended for sustainable uses. This study focuses on understanding the structural, thermal, and physical properties of Luffa fibers. Basic properties like fiber diameter and density were carefully measured. The fibers were treated with alkali and sodium acetate at room temperature.

***Keywords**: FTIR, SEM, XRD*

1. Introduction

As global environmental consciousness continues to ascend, natural plant fibers are increasingly recognized as noble alternatives to synthetic counterparts. With their inherent sustainability, biodegradability, and favorable properties, these fibers are poised to supplant synthetic fibers across diverse applications [1]. The esteemed virtues of plant fibers – spanning environmental, economic, and functional domains – have garnered them growing acclaim across industries, from textiles to advanced composite materials of natural plant fibers as reinforcement in composite materials has garnered significant interest among researchers and industry leaders alike. These fibers may be deftly incorporated into various matrices, such as polymers, to forge eco-friendly, lightweight, and often economically advantageous composite structures [2]. Distinct their lower density in comparison to synthetic fibers such as glass or carbon, plant fiber composites deliver a lighter composition. This attribute proves particularly advantageous in sectors such as automotive and aerospace, where weight reduction aligns with greater fuel efficiency. Further enhancing their appeal, many plant fibers offer high tensile strength and commendable flexibility. As industries pivot

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towards materials that align with ecological priorities, these natural fibers are emerging as worthy successors to conventional structural materials, including glass and carbon fiber composites [3]. Their application spans sectors of paramount importance, including automotive, construction, aerospace, and renewable energy, affirming their place in the noble pursuit of a sustainable future [4].

2. Materials and Methods

Luffa fibers have a unique, spongy texture and are known for being environmentally friendly. To prepare the fibers, start by harvesting mature Luffa fruits. Let them dry, then separate the fibers and clean them to remove impurities. Gather the amount of fiber needed, and dry it for 10 days. After drying, soak the fibers in a 0.1 M alkali solution for 20 minutes, then allow them to dry again in the shade for 5 days. Fig 1 shows the entire chemical processing of Luffa fibre.

Fig. 1. Sodium acetate treatment of Luffa fibre

3. Results and Discussion

3.1. PXRD Analysis

The fibers are finely ground into a powder and analyzed with an X-ray diffractometer using monochromatic Cu Kα radiation at a wavelength of 1.5406 Å. The Percentage Crystallinity (% Cr), Crystallinity Index (CI), and Crystalline Size (CS) of the natural fibers are then calculated using specific equations.

$$\text{Crystallinity \%} = \frac{I_{200} - I_{amp}}{I_{200}} \times 100$$

$$\text{Crystallinity Index} = \frac{I_{200} - I_{amp}}{I_{200}}$$

where, I_{200} and I_{amp} are the crystalline and amorphous peaks at 2θ scale.

$$\text{Crystallinity Size} = \frac{K\lambda}{\beta \text{Cos}\theta}$$

where, K = 0.9, λ = 1.54060 x 10^{-10} m; β = $\frac{\pi}{180}$×FWHM, θ-Bragg's angle.

X-ray diffraction analysis is used to study the diffraction angles (2θ) of crystalline and amorphous peaks in treated Luffa fiber [5]. Fig 2 shows the PXRD pattern of chemically

processed luffa fibre. Using the formula, the percentage crystallinity of treated Luffa fiber is found to be 65.45%.

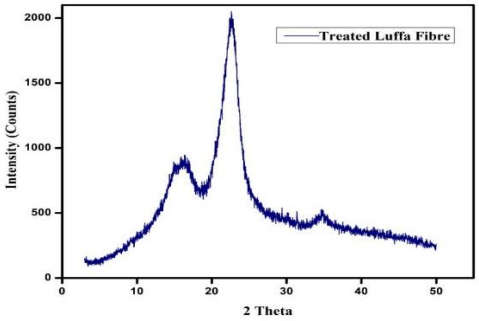

Fig. 2. PXRD Pattern of treated Luffa fibre

3.2. SEM Analysis

SEM images of treated fibers reveal irregular white spots on the surface. Sodium acetate treatment reduces hemicellulose and removes wax, creating a rougher fiber surface. This enhances bonding at the fiber-matrix interface, improving interfacial adhesion and the fiber's ability to connect. Thinner fibers are preferred in composites for added strength and stiffness. Fig 3 shows the scanning electron microscope images of luffa fibre for different magnifications.

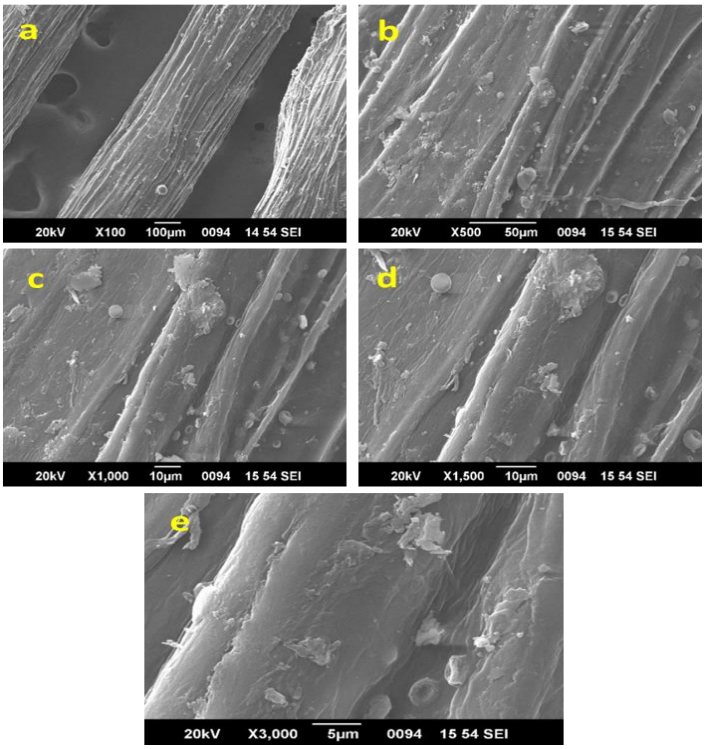

Fig. 3. SEM images of treated Luffa fibre with magnifications (a) ×100 (b)×500 (c) ×1000 (d) ×1500 (e) ×3000

3.3. EDAX Analysis

EDAX analysis measures the elemental composition on the surface of treated Luffa fiber. Table 1 shows the elements detected, with their atomic and weight percentages. The main peaks are for carbon and oxygen, and the table provides details on each element's atomic weight and percentage. Fig 4 shows the EDAX Spectrum of treated Luffa fibre.

Table 1. Weight % and Atomic % of various elements present in treated Luffa fibre

Element	Weight %	Atomic %
C	55.27	62.21
O	44.73	37.79
Total	100	100

The O/C ratio, determined through EDAX analysis, measures the oxygen-to-carbon ratio in natural fibers. A high carbon content indicates more lignin, while a high O/C ratio suggests lower lignin content. This ratio helps explain the different properties of natural fibers.

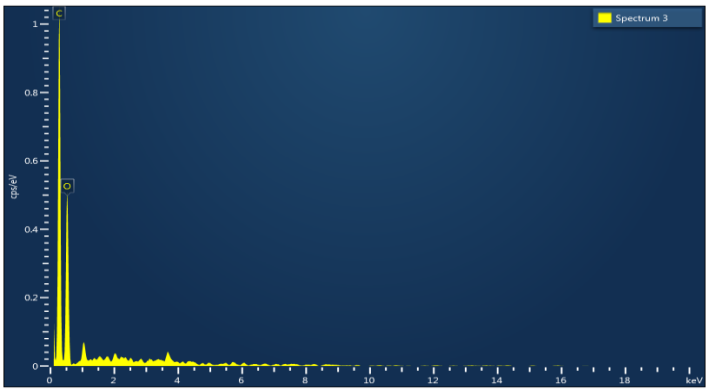

Fig. 4. EDAX Spectrum of treated Luffa fibre

3.4. Thermo-gravimetric (TGA) Analysis

Thermal analysis is a widely used method to study the decomposition of solid materials, with heat degradation occurring in two or three stages based on the fibers' chemical composition. A TG plot shows temperature (x-axis) against weight loss percentage (y-axis). Table 2 presents the mass loss for treated fibers, with degradation occurring below 340°C. The main mass loss (35-45%) happens above 290°C due to crystalline cellulose breakdown. Fig 5 (a) and (b) shows the TG and DTG curve of treated Luffa fibre.

Table 2. Thermal study of sodium acetate treated Luffa fibre

Fibre Type	Temperature during mass loss (ºC)	Mass Loss	Residual mass at 700ºC (%)
Treated Luffa Fibre	0 - 140	13%	0.38%
	140 - 290	20%	
	290 - 340	40%	

The DTG curve identifies the peak of fiber deterioration, aligning with the peak values on the TG curve, confirming the fiber's thermal stability. Table 3 shows the mass loss at T_{max} for treated Luffa fibers, while Fig. 5 (c) presents DSC profiles. An exothermic peak at 490°C indicates the release of the lignified component in treated Luffa fiber.

Table 3. Mass loss at T_{max} of treated Luffa fibre

Sample	Total mass loss (%)			Max. Temperature Limit (°C)	T (50%) (°C)
	First stage	Second stage	Third stage		
Treated luffa fibre	13%	20%	40%	340	320

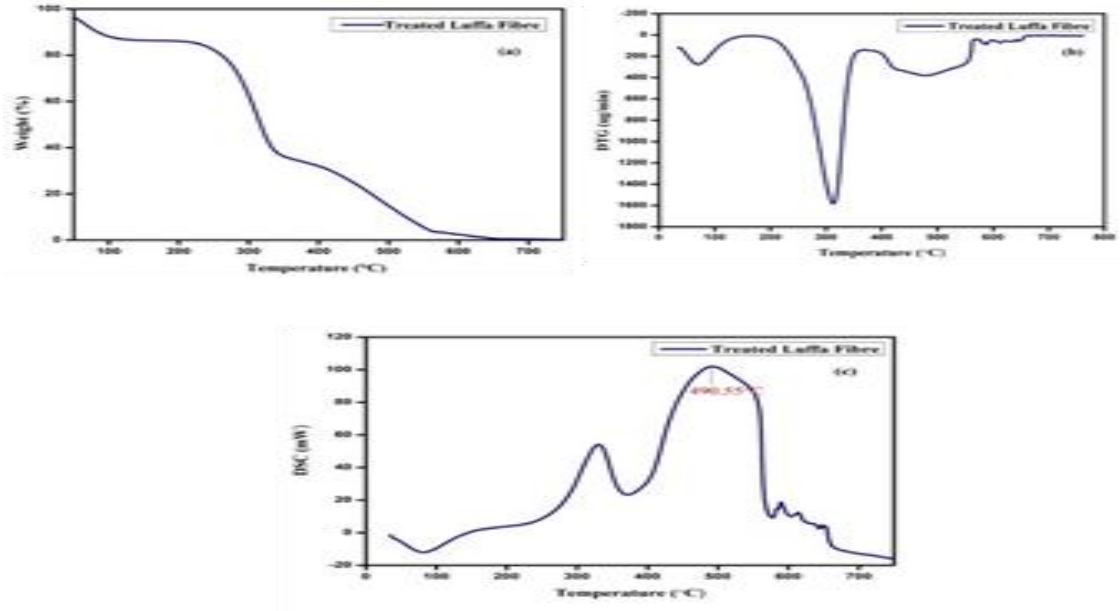

Fig. 5. (a) TG Curve (b) DTG Curve and (c) DSC Curve of sodium acetate treated Luffa Fibre

3.5. FTIR Analysis

Fourier Transform Infrared (FTIR) analysis identifies the functional groups in treated Luffa fiber, with IR spectra measured between 4000 and 400 cm^{-1}. Each material shows unique IR absorption frequencies based on the atomic masses in each bond. Key wave

numbers include 3424 cm^{-1} for O-H stretching (α-hemicellulose), 2921 cm^{-1} for C-H stretching (α-cellulose), and 1635 cm^{-1} for C-O carboxyl stretching (hemicellulose). Additional peaks, such as 1383 cm^{-1} and 1241 cm^{-1}, correspond to COC and C-O stretching in lignin and hemicellulose, shows in Fig 6.

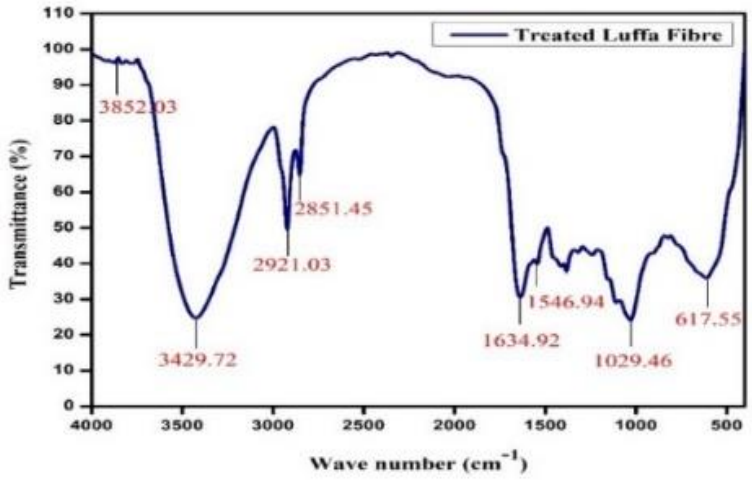

Fig. 6. FTIR Spectrum of sodium acetate treated Luffa Fibre

3.6. Physical analysis

3.6.1. Density

Low density is a key feature of natural fibers, distinguishing them from synthetic fibers as reinforcements in lightweight applications. Fiber density is crucial when assessing suitability for composite materials. Figure 7 shows a pycnometer, with toluene as the immersion liquid.

Fig. 7. Density of the fibre using Pycnometer

The density of the treated luffa fibre can be calculated by using the formula,

$$\text{Density of the fibre, } \rho = \frac{(m_2 - m_1)}{(m_3 - m_1) - (m_4 - m_2)} \rho_t$$

Where,

m_1 - mass of dry empty pycnometer (g)

m_2 - mass of pycnometer + fibre (g)

m_3 - mass of pycnometer + Toluene (g)

m_4 - mass of pycnometer + Toluene +fibre (g)

ρ_t - density of toluene (0.867g/cm^3)

Table 4. Density Measurement using Pycnometer

Sample	Mass (g)				Density of Toluene ρ_t (g/cm^3)	Density of fibre ρ (g/cm^3)
	m_1 (g)	m_2 (g)	m_3 (g)	m_4 (g)		
Treated Luffa Fibre	13.77	15.192	22.733	23.226	0.867	1.346

Lower density values of 1.346 g/cc are recorded for the Luffa fibres. Lower density gives a wide scope for the firers to be employed as reinforcement while making composites. Table 4 shows the density measurements using a pycnometer.

3.6.2. Diameter of the Fibre

The diameter of a natural fiber, measured through its center, impacts the fabric's performance and texture. For sodium acetate-treated *Luffa cylindrica* samples, the average fiber diameter is 0.0453 cm.

4. Conclusion

Modified Luffa fiber, analyzed using PXRD, SEM-EDAX, TGDTA, FTIR, and density methods, shows high crystallinity (65.45%), strong mechanical strength, and a rough surface, ideal for composite matrices. High carbon content enhances its thermal stability, while thermal and FTIR studies identify its functional properties. These qualities make treated Luffa fiber an eco-friendly reinforcement option for biocomposites in industries like furniture, automotive, and construction.

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