Processing and characterization of natural fiber (sisal plant fiber) reinforced polyester composites

BY

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ABSTRACT

In recent years, natural fibers like sisal have garnered interest as potential reinforcements for polymer composites due to their environmentally friendly and biodegradable nature. The study focuses on exploring the processing methods and mechanical properties of sisal fiber-reinforced polyester composites. Mechanical extraction, followed by chemical treatment, yields superior fiber quality and quantity. Alkalization, utilizing different NaOH concentrations (2%, 6%, 10%) and varying soaking times (24, 48, 72 hours), investigates their impact on fiber properties. Optimal results manifest at 48 hours with 6% NaOH, significantly enhancing mechanical properties. Composites, formed by combining fibers and matrix, achieve peak efficiency at a 30:70 fiber-to-matrix ratio. Notably, the tensile and bending strength for this ratio are 44.003 MPa and 50.81 MPa, respectively. Furthermore, treated fiber composites exhibit reduced water absorption due to improved surface contact. FTIR spectroscopy analyzes raw fiber functional groups, facilitating chemical identification. In light of their cost-effectiveness, natural fiber composites emerge as viable alternatives to expensive and logistically challenging glass fibers.

Keywords: Sisal fiber, natural fiber reinforcement, sisal-polyester composites, mechanical properties

1. INTRODUCTION

The growing interest in sustainable, eco-friendly materials derived from renewable natural resources stems from global apprehensions about the environmental effects of wood-based materials and the imperative for sustainable economic practices (Debele and Belay, 2023). Additionally, they provide cost benefits by being more affordable to manufacture and frequently recyclable or reusable, thus minimizing waste and expenses (Debele and Belay, 2023). Scientists are investigating different renewable resources, such as plant-based materials, bioplastics, and bio-based composites. These materials hold promise for transforming industries like construction, manufacturing, packaging, and transportation (Girijappa, et al., 2019)

Polymer composite materials offer advantages in terms of ease of processing, productivity, and cost-effectiveness. These composites are customized materials with the unique ability to modify properties by varying the reinforcement and matrix phases (Bledzki and Gassan, 1999). In comparison to synthetic fibers, natural fibers offer several advantages due to their abundance, availability, and cost-effectiveness. These natural fibers are used as substitutes for synthetic fibers to create lighter composites. Their density (ranging from 1.2 to 1.6 g/cm^3) is lower than that of glass fibers (2.4 g/cm^3), resulting in the production of lightweight composites. Consequently, there is a growing demand for natural fiber-based composites across various industrial sectors. Hemp, jute, sisal, banana, coir, and kenaf are commonly

employed in lightweight composite production (Girijappa, et al., 2019)

.Sisal fiber, widely available globally, requires minimal investment for cultivation and is often grown in wastelands, aiding soil conservation. Its advantages include low density, high specific strength, biodegradability, and thermal/acoustic insulation. Compared to other natural fibers like jute, sisal boasts higher strength, a bright color, and large staple length. Recent interest lies in innovative applications beyond traditional uses, making sisal-reinforced composites eco-friendly and energy-efficient (Saxena, et al., 2011).

The fibers harvested and extracted from the leafs through various operations either mechanical or chemical or bacterially to separate it from the non- fibrous substances like wax, pectin, and other substances (Suharty, et al., 2016). Despite the availability of natural fiber composites, achieving properties equivalent to synthetic fiber composites remains a challenge. Most plant fibers exhibit hydrophilic behavior, leading to high water absorption. However, various interfacial surface modification techniques can effectively control this absorption (Saxena, et al., 2011). Moreover, the fiber loading have also an impact on the strength and quality of natural fiber reinforced composites (Izani, et al., 2013).

In particular, manufacturing natural fiber composites using a fiber mat approach rather than unidirectional fiber alignment allows us to explore their mechanical properties more effectively. The orientation of these fibers significantly influences the overall strength and performance of the composites. Thus, embracing natural fibers represents a better path forward for environmentally conscious and mechanically robust materials (Jaafar, et al., 2019).

Our research focuses on the processing and characterization of sisal plant fiber-reinforced polyester composites. Our primary objective is to enhance their mechanical properties, durability, and overall performance. By comprehending various processing techniques, and optimizing the fiber-matrix interface.

The study will investigate strategies to improve sisal fiber composite performance, encompassing modification techniques, and fabrication of mats with various ratio of fiber to polyester ratio. Through this research, we aspire to contribute to the development of environmentally conscious materials aligned with global sustainability objectives.

2. LITERATURE REVIEW

Traditionally, composites have been crafted from synthetic materials like glass and carbon fibers, which are neither environmentally friendly nor biodegradable. However, the growing environmental awareness has prompted a shift towards renewable natural resources. Natural fibers, such as sisal, now play a pivotal role in composite manufacturing (Uppal, et al., 2019). Sisal fiber, derived from the leaves of the Agave sisalana plant, is a robust and significant natural leaf fiber (Saxena, et al., 2011). Their advantages include ease of processing, lower weight, favorable acoustic properties, and robust mechanical strength. Despite their potential, natural fibers remain underutilized. These biodegradable materials hold significant promise for engineering applications and can effectively replace synthetic fibers in various consumer products, particularly those with structural requirements (Uppal, et al., 2019).

The mechanical performance of natural fiber-reinforced polymer composites (NFRPCs) hinges on several critical factors related to the fibers, including loading, surface treatments, interfacial adhesion, and orientation. Additionally, process parameters such as curing temperature, pressure, and composite development methodology significantly impact the overall mechanical properties of NFRPCs. These properties, including tensile, compressive, impact, and flexural strengths, as well as creep resistance and hardness, are influenced by factors like interfacial adhesion, fiber strength, and physical properties of the fibers, fiber volume fraction, orientation, and moisture resistance (Khan, et al., 2018).

3. MATERIALS AND METHODS

Materials

Sisal leaf (source of fiber), plates (used to cover composites), knife (to cut sisal leaf), brush (to paint mixture of polyester and hardener on natural fiber mats), plastic pot (for soaking of fibers in NaOH solution), plastic jar (to mix hardener and polyester), stirrer (to mix polyester and hardener)

Equipment's

Oven (to dry), furnace (to dry fiber with high temperature), measuring electronic balance (to measure mass), crucibles (to hold the sample inside furnace), desiccators (to hold the sample after ash formation to prevent from moisture contacting)

Instruments

Universal tensile testing machine tester (to test tensile strength of fiber), universal tensile tester machine (used to measure tensile strength and bending strength of composites), hand loom machine (for mat formation), A JASCO MODEL 4100 Fourier Transformed Infrared Radiation (FTIR) Spectrometer was used to measure the absorption/transmittance of IR radiation of fiber cellulose.

Chemicals

Tap water (used to wash fibers and also for solution preparation), NaOH (for treatment) and polyester (to formulate composite, as matrix), hardener (as curing agent).

Methods

3.1.Fiber extraction and treatment

Raw sisal leaves are meticulously collected from the vicinity of Bahir Dar city, specifically Debanke Mountain. These leaves are then carefully cut with a knife and trimmed longitudinally into strips, simplifying the subsequent fiber extraction. The split leaves are clamped between sharp wood and stone, and by gently hand-pulling those in the longitudinal direction, the fibers are separated while removing any resinous materials. After the extraction process, the fibers undergo thorough washing with pure water to eliminate unwanted dust and impurities. Subsequently, the cleaned fibers are allowed to naturally dry in sunlight according to Saxena et al. (2011).

Additionally, raw extracted sisal fibers are soaked in a plastic pot with a 2 wt. % NaOH solution. Varying amounts of fibers (20g, 30g, and 40g) are treated for different durations (24, 48, and 72 hours) to enhance adhesion between the fibers and the matrix. Excess NaOH solution is neutralized through extensive rinsing with water. Finally, the neutralized fibers are dried under sunlight. This experimental process is repeated, exploring treatment with 6% NaOH solution (for 24, 48, and 72 hours) and 10% sodium hydroxide solution (for the same time intervals).

3.2. Characterization of sisal fiber

Physicochemical characteristics of fiber

3.3. Linear density and diameter calculation of sisal fiber

Linear diameter and density of raw fibers were estimated using a microscope. A microscope was used to analyses fiber diameter. The mass of fiber were measured using electronic balance and ruler was used to estimate the length of the fiber.

$$\text{Linear density} = \frac{\text{mass of fiber}}{\text{length of fiber}} \quad \text{.....equ. 1}$$

$$\text{Cross-sectional area} = \frac{\pi D^2}{4}$$

$$\text{Density of fiber} = \frac{\text{linear density}}{\text{cross-sectional area}} \quad \text{.....equ. (2)}$$

Where, D=diameter of fiber

Water absorption of raw fiber

A single sisal fiber is initially prepared and its mass is measured using an electronic balance. Subsequently, the fiber is soaked in pure water for 24 hours in a plastic pot. After immersion, the fiber's mass is re-measured. Finally, the average percentage increase in weight is calculated using the provided equation.

$$\text{Water absorption of raw fiber} = \frac{x2 - x1}{x1} * 100 \quad \text{..... (3)}$$

Where: X1 =Weight of fiber before immersion; X2 =Weight of fiber after immersion

Moisture content

A sample of sisal plant fibers is initially weighed using a measuring balance. Subsequently, the sample is placed in an oven at 105°C for 1 hour. After the specified time, the dried samples are removed from the oven, and their mass is measured. Finally, the moisture content of the raw fibers is calculated by comparing the sample weight before and after oven drying.

$$MC = \frac{M1 - M2}{M1} * 100 \quad \text{..... (5)}$$

Where; MC=moisture content (%); M1=initial wet weight; M2=final dry weight

Ash content

First, a dry sample of sisal fibers and a crucible are weighed using a measuring balance. The weighted sample is then placed into the crucible and inserted into a furnace preheated to 750°C for 1 hour. After the specified time, the sample

is removed from the furnace and transferred to a desiccator. Subsequently, the samples are taken out of the desiccator, and their mass is measured using an electronic balance. Finally, the ash content of the fiber is calculated using the provided formula.

$$\text{Ash content}=\frac{\text{Weight of ash}}{\text{dry fiber weight}} * 100$$

$$\text{Ash content} = \frac{M1-M3}{M2} * 100 \ldots\ldots\ldots \quad (6)$$

Where; M1=weight of sample after removed from desiccator; M2=dry sample fiber weight; M3=mass of crucible

The diameter and tensile strength of treated sisal fibers were measured as raw sisal fiber conducted and the results which are obtained were recorded.

a, b, c, d, e,

Figure 1: sisal plant (a); splitting sisal leafs (b); sisal fiber (c); drying sisal fiber after washing (d); alkali treated sisal fiber drying with sun (e).

3.4. Tensile strength of raw fiber

The sisal fiber is securely mounted between two grips, allowing relative movement during the test. Essential data, including fiber diameter and length, are input into the computer. As the fiber undergoes tension until it cracks, the computer displays the maximum force (in newton). Subsequently, the obtained results are recorded and averaged. Finally, the tensile stress is calculated using the provided equation.

$$\text{Tensile stress}=\frac{\text{force}}{\text{area}} \ldots\ldots \text{equ. (4)}$$

3.5. Fourier transforms infrared spectroscopy (FTIR)

Infrared spectroscopy is an analytical technique that provides insights into the hydrogen bonding and chemical composition of raw fibers. Specifically, it helps identify the functional groups present in cellulose. For this analysis, a JASCO MODEL 4100 Fourier Transformed Infrared Radiation (FTIR) Spectrometer was employed to measure the absorption/transmittance of infrared radiation by the cellulose fibers (Hospodarova, et al., 2018).

3.6. Composite Fabrication

Mats of sisal fibers are meticulously formed by intertwining the fibers using a hand loom machine, akin to the weaving process used for cloth. Initially, the prepared fiber mats are cut to the appropriate size for lamination. A specific area (200 mm x 100 mm) is marked on white plastic sheets. Next, a homogeneous mixture of polyester and hardener is prepared in a plastic pot, maintaining a 2:100 ratio (hardener to polyester). The drawn area on the white plastic is then laminated with polyester, carefully overlaying it onto the prepared fiber mats. A uniform mixture of polyester and hardener is poured over the fiber mats, ensuring both vertical and horizontal orientations. Finally, the laminated mats are compressed under a substantial load and left to dry naturally in sunlight.

3.7. Characterization of composite materials

Tensile strength

The fabricated composite was cut to the desired specimen dimensions for mechanical testing. For the tensile test, specimens with sizes of 200 × 36 mm² are prepared, and their thickness varies based on the sisal fiber content (3.9 mm for 20%, 4.8 mm for 30%, and 5.3 mm for 40%). These specimens are fixed in the grips of the Universal Testing Machine (UTM). Tensile force was then applied until the specimen fractures. The experimental setup for the tensile test is depicted below.

The tensile strength was calculated using the following formula;

$$T = \frac{P}{A} \ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

Where,

T = Tensile strength in N/mm2

P = Maximum Load in Newton (N)

A = area of specimens in millimeter Square (mm2)
A=width x thickness of specimen

3.8. Flexural (bending strength) test

The UTM machine setup is meticulously prepared for bending strength measurement. The specimen, carefully positioned over the supporters, undergoes loading until it fractures. The resulting data is then recorded. This systematic approach allows accurate assessment of the material's bending properties.

The results were obtained using the following formula given by the standards (ASTM D1037: 1999) for bending strength as;

$$R = \frac{3PL}{2bt^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

Where, R = Bending strength in N/mm2

P = Load at rupture in Newton (N)

L = Length of span (distance between support), in millimeters (mm).

b = width of the test specimen in millimeters (mm).

t = thickness (depth) of specimen in millimeters (mm).

3.9. Water absorption test

The weight of composite specimens is initially measured using an electronic balance. Both treated and raw fiber composite samples are then soaked in pure water. After a specified duration, the composite sample weights are recorded. Finally, the water absorption is calculated using the provided equation.

$$\text{Water absorption} = \frac{x2-x1}{x1} * 100 \ldots\ldots\ldots \quad (9)$$

Where: X1 = weight of composite before immersion.

X2 = weight of composite of specimen after immersion

a, b, c, d,

Figure 2: hand loom machine (a), fabricated mat (b), laminating the vertical and horizontal oreintations mat with polyester and hardner (c), drying the final composite materials with solar light (d)

4. RESULT AND DISCUSSION

The analysis presented in Table 1 reveals the diameters of both raw and treated fibers. Notably, the raw fiber exhibits a larger diameter compared to the treated fiber. This disparity arises from the presence of soluble materials in the raw fibers. Conversely, the treated fibers exhibit reduced diameters as the concentration of NaOH solution and soaking time increase. This reduction is attributed to the effective removal of soluble components through alkali treatment. Specifically, the experiment yielded a raw fiber diameter of 150μm, closely aligning with the findings of Maya, who reported a raw fiber diameter range of 50-200μm (Maya, et al., 2017). As it shown in the table the fiber diameter was decreased as treated by alkali. This suggestion inconsistent with Debele and Belay works. Alkali treatment plays a crucial role in enhancing the mechanical properties of sisal fibers within composite materials. By reducing the fiber diameter, it refines the fibers and simultaneously improves adhesion between the fiber and the polymer matrix. Additionally, this treatment alters the fiber surface morphology, creating an interconnecting mechanism with the composite surface. As a result, the overall mechanical properties are significantly improved (Debele and Belay, 2023).

Table 1: Diameters of treated and untreated sisal fibers

Types of sisal plant fiber	Average diameter (μm)	Types of sisal plant fiber	Average diameter (μm)
Untreated (raw) sisal plant fiber	150.000	Soak at 6% NaOH solution for48 hrs.	106.890
Soak at 2% NaOH solution for 24 hrs.	135.416	Soak at 6% NaOH solution for72 hrs.	106.731
Soak at 2% NaOH solution for48 hrs.	120.000	Soak at 10% NaOH solution for24hrs.	104.990
Soak at 2% NaOH solution for 72 hrs.	110.560	Soak at 10% NaOH solution for 48hrs.	100.400
Soak at 6% NaOH solution for24 hrs.	108.76	Soak at 10% NaOH solution for 72 hrs.	99.990

4.1. Density of raw fiber

The density of raw sisal fiber, representing the weight per unit volume, was experimentally determined to be 1.552 g/cm³. Remarkably, this result closely aligns with the findings of Saxena who reported a density value of 1.45 g/cm³ for sisal fiber (Saxena, et al., 2011). This consistency underscores the reliability of the measurement and contributes to our understanding of sisal fiber properties.

4.2.Water absorption of raw sisal fiber

Water absorption is an inherent property of raw fibers, referring to their ability to take up water. In our experimental study, we observed that raw fiber exhibited a water absorption rate of 60%, Understanding water absorption in fibers is crucial because it significantly impacts the mechanical properties of composite materials. Consequently, surface treatment of fibers becomes essential to enhance the overall mechanical performance of composites. Debele & Belay (2023)suggests that the water absorption of sisal fiber is higher.

4.3. Moisture content of raw sisal plant fibers

The assessment of moisture content in raw sisal fibers serves as a critical factor. Variations in moisture content across different plant areas impact drying times, which, in turn, influence the strength of composites. Notably, in line with prior experiments by Saxena et al. (2011), a 9% moisture content closely aligns with their findings, while the raw fiber itself exhibited 10-22% moisture content **.**

4.4.Ash content of raw sisal plant fibers

Ash content, a crucial parameter, quantifies the volatile matter within raw sisal fibers. In our experiment, the raw fiber exhibited an ash content of 3.09%. Interestingly, Saxena et al. (2011) reported a significantly lower moisture content of 0.6-1.1% for raw sisal fibers. This disparity underscores that even within the same plant species, physical properties can diverge due to factors such as climate variations and soil composition.

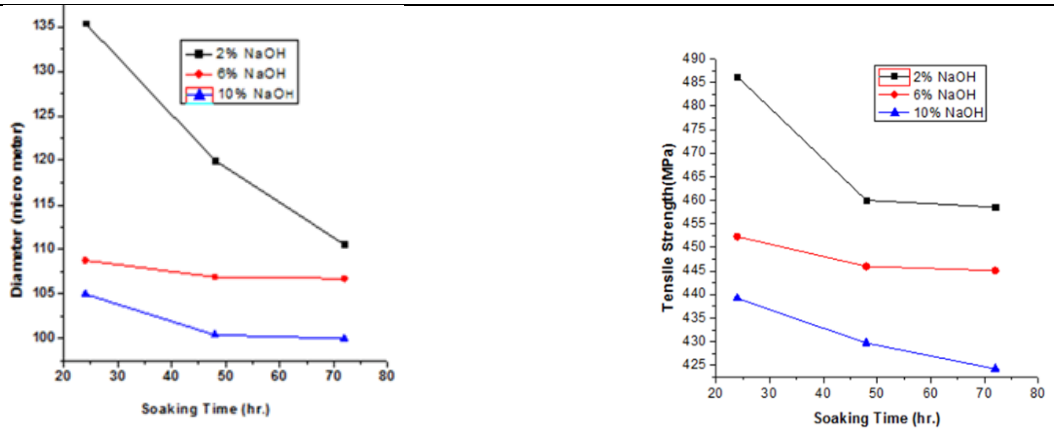
4.5. Tensile strength of untreated and treated sisal plant fiber

In an experiment examining sisal fibers, both raw and treated, their tensile strength was meticulously studied and recorded. Notably, the raw fibers demonstrated the highest tensile strength, measuring 537.8627 MPa. This superiority is attributed to the substantial presence of lignin and hemicelluloses within the plant fibers. However, as the soaking time and sodium hydroxide concentration increased, the fiber diameter decreased, impacting both the tensile force and tensile strength. This reduction directly results from the removal of lignin and hemicelluloses from within the fiber. Interestingly, a prior investigation by

Maya et al. (2017) revealed a raw sisal fiber tensile strength range of 400-700 MPa.

Table 2. Tensile strength of untreated and treated sisal plant fiber

Type of fiber	Diameter (μm)	Area (m^2)	Force (N)	Tensile strength (MPa)
Untreated fiber	150.000	1.77*10^-8	9.50	537.8627
2% NaOH for 24hrs.	135.416	1.44*10^-8	7.00	486.2823
2% NaOH for 48hrs.	120.000	1.13*10^-8	5.20	460.0142
2% NaOH for 72hrs.	110.560	9.6*10^-9	4.40	458.5503
6% NaOH for 24hrs.	108.760	9.29*10^-9	4.20	452.3153
6% NaOH for 48hrs.	106.890	8.97*10^-9	4.00	445.9808
6% NaOH for 72hrs.	106.731	8.94*10^-9	3.98	445.0740
10% NaOH for 24hrs.	104.990	8.65*10^-9	3.80	439.1552
10% NaOH for 48hrs.	100.400	7.91*10^-9	3.40	429.6767
10% NaOH for 72hrs.	99.999	7.85*10^-9	3.33	424.2123



a, b,

Figure 3: a) The effect of soaking time and NaOH concentration on diameter. b) The effect of soaking time and NaOH concentration on tensile strength of fibers

The experimental data, as depicted in Figure 3a, 3b, along with the findings from Table 2, reveal significant trends related to sisal fibers treated with sodium hydroxide (NaOH). Notably, as the soaking time in NaOH increases, several key fiber properties experience a decline. The diameter, tensile strength, and forces all exhibit this reduction. The underlying mechanism lies in the prolonged interaction between the fiber and the NaOH solution. With increased soaking time, soluble materials within the

fiber have more opportunity to be removed. Furthermore, as the concentration of NaOH in the solution increases, adverse effects become more pronounced. Specifically, the tensile strength, diameter, and forces are all reduced. This phenomenon results from enhanced solubilization of components within the fiber. Consequently, the fiber becomes progressively thinner, leading to a reduction in overall strength.

4.6. FTIR Analysis of untreated fiber

FTIR spectroscopic analysis was conducted to examine the chemical constitution of the fibers. In fig. (2) Indicates that the peaks in the band of 3869.4 and 3746.8 cm-^{1} revealed that this fiber exhibited hydrogen bonded hydroxyl groups in its cellulose structure. The sharp peak at 2156.5cm-and 2014.5cm-1, assigned to C-H and CH2 stretching vibrations in the methyl and Methylene groups. And the sharp peak at 1543.5 cm-1 of the sisal fiber is due to C=O stretching vibrations of aliphatic ester group in hemicelluloses. Transmittance at 1317.7cm-1 in the spectra of the fiber is assigned to C-O stretching in acetylated hemicelluloses. The transmittance peak at 1001.6 cm-1 indicated the presence of C-O, C=C and C-C-O stretching (Schwanninger, et al., 2004).

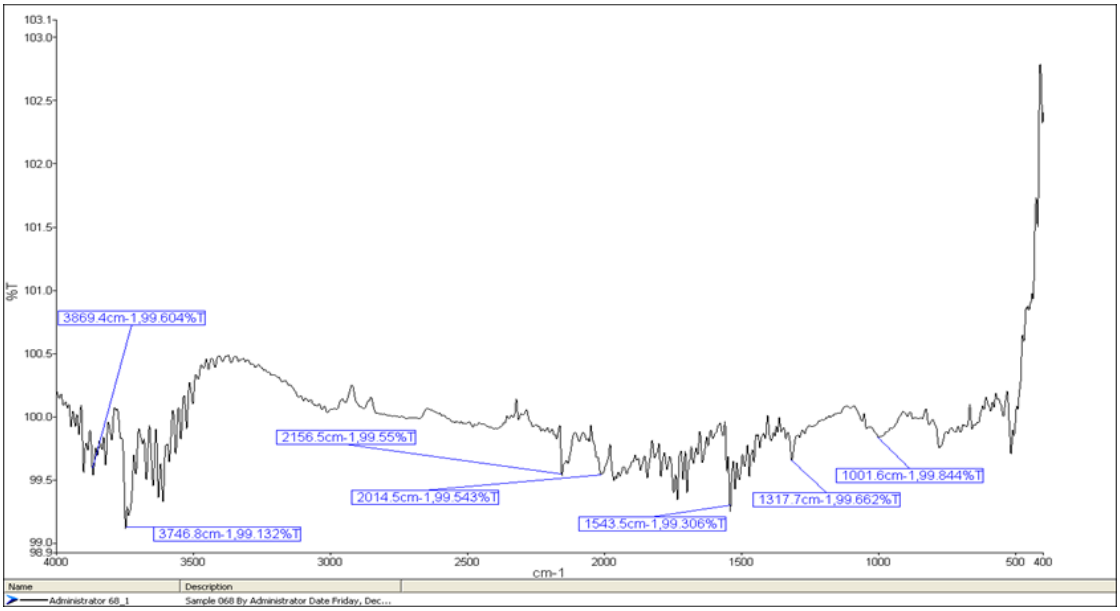


Figure 4: FTIR Analysis of untreated fiber

Table 3: Functional Group present in the sisal plant fiber

Bond - Functional Group	Raw sisal fiber (wave number cm^{-1})
O-H stretching, Free hydroxyl -Alcohol, Water, Phenols	3746.8 and 3869.4
C≡C stretching, C≡N stretching – Nitriles, Alkynes	2156.5 and 2014.5
C = O	1543.5
1^0 and 2^0 alcohol	1317.7

C-O stretching - Alcohol (cellulose; hemi-cellulose ; lignin)	1001.6

4.7. Tensile and Bending strength of composites

The tensile test results, meticulously tabulated in Table 4 and visually depicted in Figure 3, shed light on the intricate interplay of soaking time, fiber-to-polyester ratio, and NaOH concentration in sisal fiber-reinforced polyester composites. As the soaking time of the fiber increases within the sodium hydroxide solution, a nuanced pattern emerges: initially, tensile strength rises due to robust adhesive bonding between matrix and fiber. However, beyond an optimal threshold, the tensile strength diminishes. This decline results from the gradual removal of hemicelluloses and lignin—essential components—due to prolonged exposure. Notably, at 72 hours, the fiber solubilizes significantly, rendering it progressively thinner and less capable of withstanding load. The experiment identifies the optimum soaking time as 48 hours.

The bending test results, meticulously tabulated in Table 4 and visually depicted in Figure 4, unequivocally establish that the bending strength reached its peak when using 48 hours of NaOH-treated sisal fiber. The interfacial zone, crucial for fiber reinforcement, facilitates load transfer between the fiber and matrix, significantly influencing mechanical properties. Notably, surface morphology analysis reveals that the interfacial zone is notably improved in the case of 48 hours of NaOH treatment. This underscores that bending strength failure primarily hinges on the adhesion between the fiber and matrix.

The tensile and bending strength properties of sisal fiber polyester composites, evaluated at different NaOH concentrations within an optimal 48-hour soaking time, are depicted in Figure 3 and Figure 4 (or Table 4). Notably, the 6% NaOH solution yields the best tensile strength, attributed to favorable surface characteristics. However, concentrations exceeding 6% lead to reduced tensile strength due to the removal of lignin and hemicelluloses. In the composite formed with varying fiber-to-matrix ratios, the optimal strength emerged at a 30:70 ratio. Proper interlocking between fiber and matrix played a pivotal role, surpassing both lower and higher ratios. Specifically, at 48 hours of 6% NaOH treatment, the results were impressive: 44.003 MPa tensile strength and 50.81 MPa bending strength. Notably, this tensile strength aligns with a similar study involving 35:65 treated sisal fiber to polyester composites (Sardar, et al., 2014). Additionally, compared to unidirectional sisal fiber laminated with polyester at a 20:80 ratio, our results outperformed with a higher recorded strength at the same treatment duration and NaOH concentration (Madhuri, et al., 2014).

As shown in the table (4) the tensile and bending strength properties of treated fiber were better properties than the untreated one. The treated sisal fiber exhibits superior tensile and bending strength properties compared to the untreated counterpart. Raw sisal fibers, amenable to modification, undergo surface cleaning and chemical alterations. Hydroxyl groups within the fibers play a role in hydrogen bonding, affecting matrix interaction. However, prolonged treatment beyond optimal conditions leads to strength reduction due to surface trenching. The optimum alkali concentration and soaking time are 6% and 72 hrs.' respectively were found.

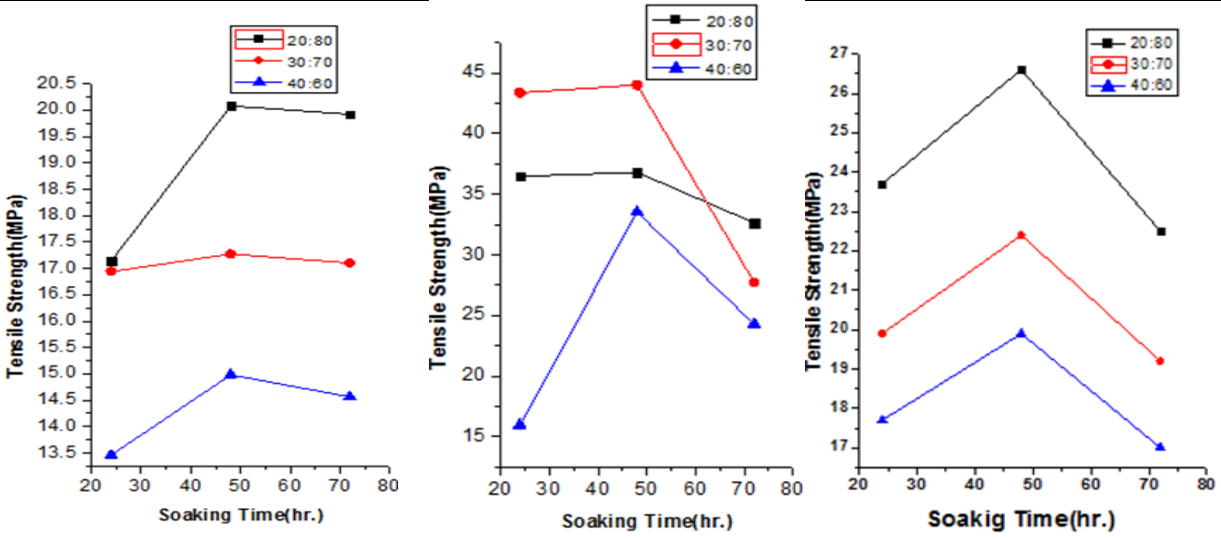
4.8. Water absorptions of composite materials

The water absorption of sisal fiber-reinforced composite decreased as soaking

time increased from 24 hours to 72 hours in 2%, 6%, and 10% NaOH solutions as depicted in table 5. This reduction is attributed to the removal of hydrophilic components (such as lignin, cellulose, and hemicellulose) from the fibers. Interestingly, increasing fiber content within the same concentration treatment led to higher water absorption due to micro voids forming in the matrix. However, at 72 hours, the composite exhibited lower water absorption with 6% NaOH concentration and a 20:80 fiber-to-polyester ratio (3.194%). This reduction is linked to the presence of excess hydrophobic polyester and the removal of hydrophilic fiber components. The findings align with previous research by Khan et al. (2018) on sisal fiber-reinforced epoxy (Khan, et al., 2018). Additionally, alkali treatment modifies the cellulosic structure, creating a protective fiber-cell-O-Na region that enhances moisture resistance (Madhuri, et al., 2014).

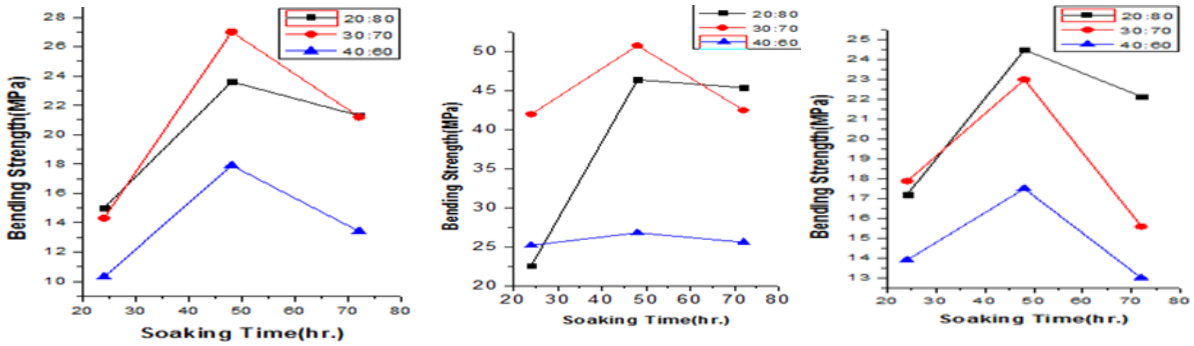
Table 4: The tensile and bending strength of composites

Sisal: polyester ratio (w:w)		20 :80		30 : 70		40 : 60	
Measured parameters		Tensile strength (Mpa)	Bending strength (Mpa)	Tensile strength (Mpa)	Bending strength (Mpa)	Tensile strength (Mpa)	Bending strength (Mpa)
Raw fiber		20.156	21.929	35.000	18.592	12.500	14.319
Concentration (%)	Time (hr.)						
2	24	17.140	15.049	16.941	14.335	13.455	10.244
	48	20.081	23.649	17.270	26.966	14.982	17.927
	72	19.921	21.284	17.099	20.154	14.556	13.387
6	24	36.459	22.574	43.356	42.011	15.995	25.261
	48	36.864	46.438	44.003	50.810	33.523	26.891
	72	32.632	45.363	27.727	42.578	24.294	25.611
10	24	23.701	17.199	19.898	17.883	17.743	13.853
	48	26.642	24.509	22.442	22.992	19.867	17.462
	72	22.534	22.144	19.172	15.612	17.018	13.038



a, b, c,

Figure 1: Effect of fiber to polyester ratio for tensile strength of composites with, a) 2%, b) 6% and c) 10% NaOH



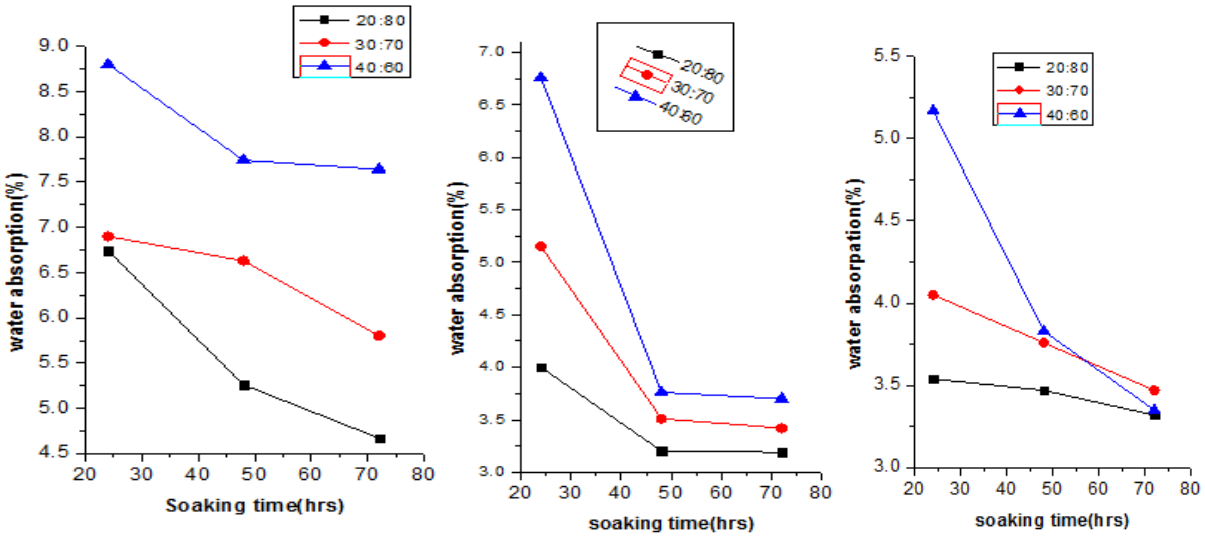
a, b, c,

Figure 3: Effect of fiber to polyester ratio for bending strength of composites with, a) 2%, b) 6% and c) 10% NaOH

Table 5: Water absorptions of composite materials

Sisal: polyester ratio (w:w)		20 :80			30 : 70			40 : 60		
Measured parameters		Mass in (%)	Mass out (%)	Water absorption (%)	Mass in (%)	Mass out (%)	Water absorption (%)	Mass in (%)	Mass out (%)	Water absorption (%)
Raw fiber		8.6	9.2	6.977	8.3	8.9	7.229	7.9	8.6	8.861
Concentration (%)	Time (hr)									
2	24	8.9	9.5	6.742	8.7	9.3	6.897	9.1	9.9	8.791
	48	7.79	8.2	5.263	8.3	8.8	6.627	8.14	8.77	7.740
	72	7.5	7.85	4.667	6.9	7.3	5.797	7.2	7.75	7.640
6	24	6.25	6.5	4.000	6.8	7.1	5.147	7.4	7.9	6.757
	48	6.2	6.4	3.226	5.7	5.9	3.509	8.77	9.1	3.763
	72	6.105	6.3	3.194	8.2	8.4	3.415	6.22	6.45	3.698
10	24	5.65	5.85	3.540	8.65	9	4.046	7.54	7.93	5.172
	48	7.21	7.46	3.467	6.12	6.3	3.758	5.88	6.105	3.827
	72	6.32	6.53	3.323	7.21	7.4	3.467	5.61	5.91	5.348

Effect of Treated fiber to polyester ration on water absorption



a, b, c,

Figure 5: Effect of fiber to polyester ratio for water absorption of composites with, a) 2%, b) 6% and c) 10% NaOH

4.9.Effect of untreated (raw) fiber to polyester ratio on water absorption, tensile and bending strength

The water absorption of untreated sisal fiber-reinforced composites increased as the fiber content rose from 20:80 to 40:60 ratios. This rise is attributed to the inherent hydrophilic nature of untreated fibers, owing to the presence of lignin, cellulose, and hemicellulose. Conversely, treated fiber composites exhibited reduced water absorption due to a larger surface contact area between fiber and matrix, which has lower water permeability than natural fibers. However, excessive water absorption occurs due to the hydrophilic nature of sisal fiber and increased interfacial area. Chemical treatment mitigates water absorption, enhancing mechanical properties. While the tensile strength initially improves up to a 30:70 fiber-to-polyester ratio, it declines at a 40:60 ratio due to poor adhesion between fiber and polyester. Additionally, bending strength decreases with higher fiber content.

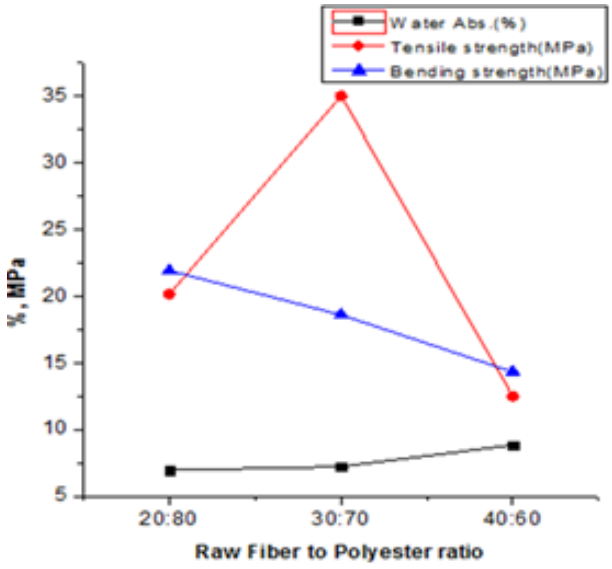


Figure 6: Effect of untreated (raw) fiber to poly ester ratio on water absorption, tensile and bending strength

5. CONCLUSION

In this study, we investigated sisal fiber reinforced polyester composites to enhance our understanding of sustainable material development. Our findings indicate that sisal plant fibers hold significant potential for composite material formation with better mechanical properties. We systematically evaluated factors affecting the strength of natural fiber composites, which demonstrated a substantial impact on their mechanical properties. Optimal conditions for enhancing strength were identified and documented. Further research is recommended to explore additional applications for the prepared composites.

REFERENCES

[1] G. Debele and M. Belay, "Preparation and characterization of sisal fiber-reinforced wheat straw cellulose polymer matrix composite for fiberboard application," *Springer*, no. 0123456789, p. 16, 2023, doi: 10.1007/s00289-023-05019-6.

[2] Y. G. Thyavihalli Girijappa, S. Mavinkere Rangappa, J. Parameswaranpillai, and S. Siengchin, "Natural Fibers as Sustainable and Renewable Resource for Development of Eco-Friendly Composites: A Comprehensive Review," *Front. Mater.*, vol. 6, no. September, pp. 1–14, 2019, doi: 10.3389/fmats.2019.00226.

[3] A. . Bledzki and J. Gassan, "Composites reinforced with cellulose.pdf," *Prog. Polym. Sci*, vol. 24, pp. 221–274, 1999, [Online]. Available: http://ac.els-cdn.com/S0079670098000185/1-s2.0-S0079670098000185-main.pdf?_tid=af34542c-0260-11e7-a49c-00000aab0f27&acdnat=1488800173_c95596c7ddcc4673fe88c8ec84262bb9

[4] M. Saxena, A. Pappu, R. Haque, and A. Sharma, "Cellulose Fibers: Bio- and Nano-Polymer Composites," *Springer-Verlag Berlin Heidelb.*, pp. 589–659, 2011, doi: 10.1007/978-3-642-17370-7.

[5] N. S. Suharty, H. Ismail, K. Diharjo, D. S. Handayani, and M. Firdaus, "Effect of Kenaf Fiber as a Reinforcement on the Tensile, Flexural Strength and Impact Toughness Properties of Recycled Polypropylene/Halloysite Composites," *ELSEVIER*, vol. 19, pp. 253–258, 2016, doi: 10.1016/j.proche.2016.03.102.

[6] M. A. Norul Izani, M. T. Paridah, U. M. K. Anwar, M. Y. Mohd Nor, and P. S. H'Ng, "Effects of fiber treatment on morphology, tensile and thermogravimetric analysis of oil palm empty fruit bunches fibers," *ResearchGate*, vol. 45, no. 1, pp. 1251–1257, 2013, doi: 10.1016/j.compositesb.2012.07.027.

[7] J. Jaafar, J. P. Siregar, S. Mohd Salleh, M. H. Mohd Hamdan, T. Cionita, and T. Rihayat, "Important Considerations in Manufacturing of Natural Fiber Composites: A Review," *Int. J. Precis. Eng. Manuf. - Green Technol.*, vol. 6, no. 3, pp. 647–664, 2019, doi: 10.1007/s40684-019-00097-2.

[8] N. Uppal, A. Pappu, R. Patidar, and V. Sorna Gowri, "Synthesis and characterization of short sisal fibre polyester composites," *Bull. Mater. Sci.*, vol. 42, no. 3, 2019, doi: 10.1007/s12034-019-1792-6.

[9] M. Z. R. Khan, S. K. Srivastava, and M. K. Gupta, "Tensile and flexural properties of natural fiber reinforced polymer composites: A review," *J. Reinf. Plast. Compos.*, vol. 37, no. 24, pp. 1435–1455, 2018, doi: 10.1177/0731684418799528.

[10] V. Hospodarova, E. Singovszka, and N. Stevulova, "Characterization of Cellulosic Fibers by FTIR Spectroscopy for Their Further Implementation to Building Materials," *Am. J. Anal. Chem.*, vol. 09, no. 06, pp. 303–310, 2018, doi: 10.4236/ajac.2018.96023.

[11] M. G. Maya, S. C. George, T. Jose, M. S. Sreekala, and S. Thomas, "Mechanical properties of short sisal fibre reinforced phenol formaldehyde eco-friendly composites," *ResearchGate*, vol. 8, no. 1, pp. 27–42, 2017, doi: 10.1177/204124791700800103.

[12] M. Schwanninger, J. C. Rodrigues, H. Pereira, and B. Hinterstoisser, "Effects of short-time vibratory ball milling on the shape of FT-IR spectra of wood and cellulose," *ELSEVIER*, vol. 36, no. 1, pp. 23–40, 2004, doi: 10.1016/j.vibspec.2004.02.003.

[13] K. Sardar, K. Veeresh, and M. Gowda, "Characterization and Investigation of Tensile Test on Kenaf Fiber Reinforced Polyester Composite Material," *Int. J. Recent Dev. Eng. Technol.*, vol. 2, no. 6, pp.

104–112, 2014.

[14] K. S. Madhuri, H. R. Rao, and M. Engineering, “An investigation of mechanical and thermal properties of reinforced sisal-glass fibers epoxy hybrid composites Corresponding Email :,” *Int. J. Eng. Res.*, vol. 5013, no. 3, pp. 112–115, 2014.