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Impact of Chemical Treatments on the Mechanical Properties and Morphological Characteristics of Sisal (*Agave sisalana*).

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Abstract

Natural fibres are used in many technical components to produce cars, aircraft, home appliances, and packaging. This study aims to evaluate the impact of chemical treatment on the fibre surface characteristics of sisal fibre. Plantain fibres were treated with an alkaline reagent and characterized using a Zeiss Gemini Scanning Electron Microscope (SEM). The fibre surface morphology and crystallinity indices between treated and untreated fibres were compared. The results showed that the cellulose content of treated fibre decreased by 14.26 and 18.62%, respectively, indicating partial removal of these components.

In contrast, 17.54 and 21.82% of lignin, hemicellulose, and ash were present in the untreated and treated fibres, respectively. Moreover, treated fibre has the highest cellulose percentage of any treated fibre, at 56.25 per cent. As a result, the fibre and the manufacturing techniques are appropriate for the development of green materials for composites.

Keywords: Sisal fibre; cellulose, lignin, alkaline hemicellulose, composites.

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Introduction

Natural fibres although they have low densities and poor mechanical properties, natural fibres like coir, sisal and banana are renewable resources. The southern Mexican flowering plant Agave sisalana, known as sisal, is grown for its strong and durable fibres. Several sword-shaped leaves can grow to 2 metres on the plant. Sisal fibres from these leaves are used to make rope, twine, matting, and brushes (Stevens et al., 2023). Its drought resistance makes it a useful crop in countries with poor soil (Smith, 2021). Agave sisalana agriculture is important to Brazil, Tanzania, and Kenya, which are the main producers. Sisal fibres are strong, durable, and salt-water-resistant, making them ideal for maritime applications (Jones, 2022). Sisal may be cultivated on marginal soil that is unsuitable for other crops and uses less pesticides, making it environmentally friendly (Williams & Carter, 2020). Due to its high biomass production and low lignin concentration, sisal is easier to convert into bioethanol, making it a promising biofuel source (Garcia & Martinez, 2019). In India, sisal farms occupy around 1.5 million acres and generate 3105 tons of fibre (Salem *et al.*, 2020). Natural fibre composites are made of fibres sourced from plants and a plastic binder. Natural fibres include, for example, sisal, hemp, coconut, cotton, kenaf, flax, jute, abaca, fibres from banana leaves, bamboo, wheat straw, and other fibrous materials. Natural fibre composites provide a number of advantages, including lightweight, low energy production, and environmental friendliness. As compared to identical fibre-glass-reinforced components, natural fibres cut weight and production energy requirements by 80% and 10%, respectively, and the component costs 5% less.

In fibre composites, a plastic binder is combined with plant-based fibres. Natural fibres include, for example, sisal, hemp, coconut, cotton, kenaf, flax, jute, abaca, fibres from banana leaves, bamboo, wheat straw, and other fibrous materials. Natural fibre composites provide a number of advantages, including lightweight, low energy production, and environmental friendliness. Natural fibres reduce weight by 10%, reduce the amount of energy needed for production by 80%, and are 5% less expensive than comparable fibre-glass-reinforced components (Baghban and Mahjoub, 2020). Hussain *et al.* (2016) looked at the mechanical properties of sisal fibre. They determined that the sisal fibre's intended purpose is defeated by pulling out microfibrils and ripping off cell walls. Due to their superior attributes when compared to synthetic fibre in terms of eco-relationship, natural fibre is one of the environmentally friendly materials that are being considered for the majority of applications (Oladele *et al.*, 2016). Natural fibre is utilized in the majority of technical components for the production of cars, aircraft, home appliances, and packaging. These materials are waterproof, relatively strong, and corrosion-resistant. The market for natural fibres was expected to reach $6.4 billion in value by 2022 and develop at a compound annual growth rate of 10.2% from 2022 to 2026, according to industry analysts worldwide. By using some of the common treatments for natural fibres, this work aims to evaluate the impact of chemical alteration on the fibre surface of sisal. By following these processes, the technical fibres in the fibre bundles will be distinguished from the non-structural fibres. How do these modifications impact the extracted sisal fibre, and do the resulting fibres have increased stiffness and strength as potential reinforcement for polymer matrices (Oladele et al., 2020a)?

Several categories have been established for natural fibres. Due to their accessibility, low density, and biodegradability, it serves as a replacement for synthetic fibres. A deeper understanding of the fibre-matrix interface and the ability to transfer stress from the matrix to the fibre are necessary for the development of natural fibre-reinforced composites (Thakur and Thakur, 2014). Because they can both reduce natural fibres' water absorption and strengthen the interface between fibre and matrix, chemical alterations are viewed as a potential approach for changing the surface characteristics of fibres. Research into chemical treatments for natural fibres was conducted by several scientists (Atiqah *et al.*, 2018). Acetylated, H_2SO_4, and alkaline treatments are the most used chemical treatments. Alkaline treatment is one of the most common treatments for natural fibres when used as reinforcement in thermoplastics and thermosets. Sodium hydroxide was chosen for this experiment because of its effectiveness and affordability. Three different NaOH % concentrations were investigated in order to find the optimal concentration (Oladele *et al.*, 2020b).

Materials and Methods.

Sisal fibre was separated using soil retting and scraping in order to produce straight, long fibres. Following a thorough cleaning with lots of water, the fibre was left outside to dry for several hours in the sun. In Ado Ekiti, Ekiti State, southwest Nigeria, sisal leaves were gathered from a nearby farm at harvest time, and the fibre was extracted via soil retting methods. Dew and soil retting is the oldest and most widely used technique for separating fibres from the right plants. This process can't be used anyplace because the required humidity and temperature aren't there. The plants are frequently turned over to produce uniform retting. The retting process must be closely monitored and interrupted when necessary to prevent cellulose degradation by microorganisms; otherwise, over-retting occurs. Over-retting reduces the mechanical performance of the fibres, while under-retting makes further fibre processing difficult. Retting of soil normally takes 2-7 weeks and is weather-dependent.

Fig 1: Sisal plant

Alkaline Treatment of fibres

Natural oils, waxy compounds, and lignin in natural fibres all coat the exterior layer of the cell wall. The chemical agent used in this process, sodium hydroxide (NaOH), alters the structure of natural fibres. The alkaline reagent is used to alter the structure of the cellulose in plant fibres by first cleaning the surface and then alkalizing it. After applying NaOH to the sisal fibres at 45°C for about 3 hours, the excess NaOH was removed by washing the materials in distilled water. We compared the thermal properties, surface morphology, and crystallinity indices of the treated and untreated fibres.

Fig. 2: Alkaline treatment of the fibres (NaOH).

Scanning electron microscopy (SEM)

The morphology of the fibre surface both before and after treatment was investigated using SEM. The objective was to distinguish between the structural changes caused by therapy and differential by utilizing various concentrations.

Mechanical Properties of Sisal Fibre

Tensile tests were conducted at room temperature using general-purpose Instron testing equipment, model 3369, with a 25 N load cell full range, on both untreated and treated fibres in accordance with ASTM D 3822. Using displacement control and a crosshead speed of 1 mm/min, fibres were evaluated at a gauge length of 10 mm in their unprocessed condition. According to ASTM D3800-99, density measurements of treated and untreated fibres were taken. Plantain fibres were investigated using a Zeiss Gemini Scanning Electron Microscope (SEM) to see how chemical treatment changed the surface characteristics of the fibres.

Results and Discussions

The Chemical Composition of Treated and Untreated Sisal Fibres

Sisal fibres were chemically characterized to find out how much cellulose, hemicelluloses, lignin, and ash were present in both treated and untreated fibres. The quantitative examination of the components of treated and untreated fibres is shown in Figure 1 for comparison. NaOH, an alkaline solution, is frequently used to modify the molecular structure of cellulose materials in natural fibres. The process often enables chemicals to permeate the fibres, lowering hydrophilic hydroxyl groups and increasing the ability of the fibres to resist moisture. Furthermore, hemicelluloses, lignin, pectin, and waxes are removed to a considerable extent.

In both treated and untreated situations, there is more cellulose in the fibre than hemicellulose and lignin. The amount of lignin and hemicellulose present in the treated sisal fibre decreased by 14.26 and 18.62%, respectively, indicating partial removal of these components.

In contrast, 17.54 and 21.82% of lignin and hemicellulose were present in the untreated sisal fibre. Moreover, treated sisal fibre has the highest cellulose percentage of any treated fibre, at 56.25 per cent (i.e., hemicellulose, lignin and ash content). As a result, treated sisal fibre has been found to have a greater cellulose percentage than untreated sisal fibre.

Table (a): The Chemical Composition of Treated Sisal Fibre

Composition	Wt. Sample	Oven Wt.	Ash Wt.	Percentage	Wt. Crus.	Cts
Cellulose	1.40	42.54	41.75	56.25	-	-
Hemicellulose	1.40	34.48	34.22	18.62	-	-
Lignin	1.20	27.83	27.66	14.26	-	-
Ash Content	0.50	-	23.03	33.34	27.86	28.6

During the chemical treatment of sisal fibre, constituents like hemicelluloses were hydrolyzed by the action of alkaline solutions.

Table (b) shows the Chemical Composition of Untreated Sisal Fibre

Composition	Wt.Sample	Oven Wt.	Ash Wt.	Percentage	Wt. Crus	Cts
Cellulose	1.20	41.40	40.91	41.08	-	-
Hemicellulose	1.20	40.01	39.75	21.82	-	-
Lignin	1.20	23.75	23.54	17.54	-	-
Ash Content	0.50	-	23.96	41.07	23.75	24.25

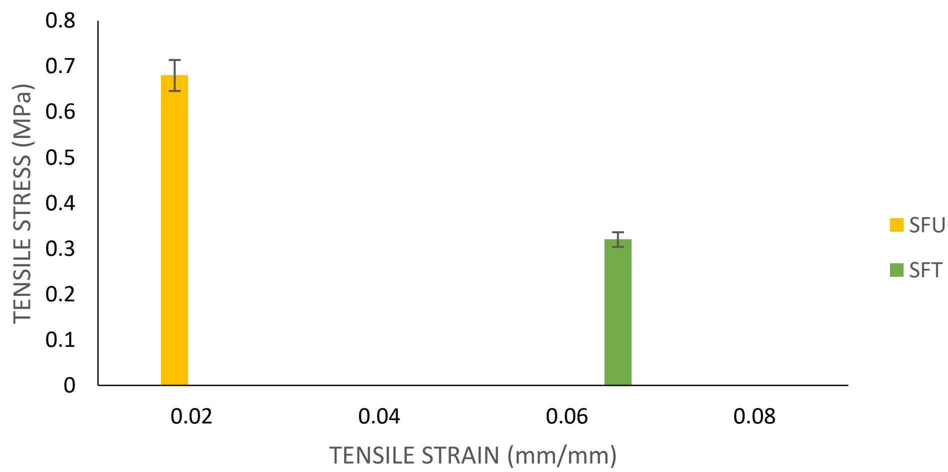

Figure 3: Graphical Representation of Tensile Stress - Tensile Strain Graph

Optical Microscopy

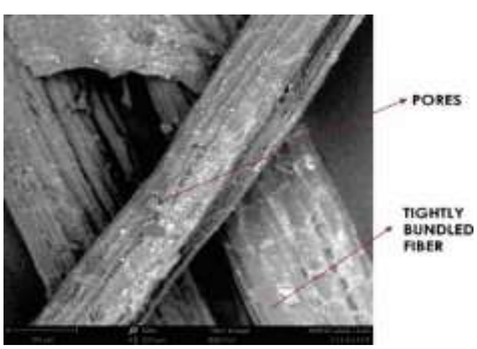

Figure 4(a) (Treated Sisal Fibre)

Figure 4 (a) shows how the alkali treatment of the sisal fibres removed some artificial and natural contaminants (b). It has been discovered that alkali treatment causes a process known as fibrillation or fibre separation, which results in the disintegration of the fibre composites' bundles into individual fibres. The surfaces after the alkali treatment exhibit a noticeable difference. Following alkali treatment, it was shown that surface contaminants were removed, and the final cells were separated as a result of the elimination of the cementing elements, such as lignin and hemicellulose. The interfibrillar region was expanded, and the surface's texture was made rougher by the dissolving of waxy components.

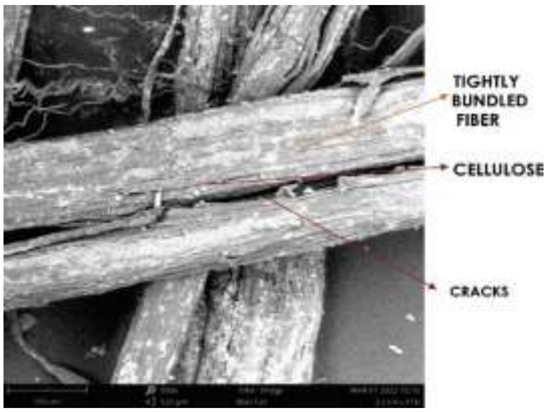

Figure 4(b) (Untreated Sisal Fibre)

Conclusion

Sisal fibre was found to be suitable for extraction and surface roughening in soil retting and alkaline modification, which promoted interfacial adhesion between fibre and matrix and improved the mechanical properties of the composites. In comparison to untreated fibre, alkaline treatment increased the cellulose content and strengthened the fibre. As a result, the fibre and the manufacturing techniques are appropriate for the development of green materials for composites.

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