Influence of Sisal Fiber Reinforcement on the Mechanical Properties of LDPE Matrix Composites

[1] Dr Mitali Dugvekar, [2] Dr Vandana Yadav; [3] Dr Archana Choubey

[1] Assistant Professor, The Bhopal School of Social Sciences, Bhopal
[2] Associate Professor, The Bhopal School of Social Sciences, Bhopal
[3] Assistant Professor, The Bhopal School of Social Sciences, Bhopal

Abstract: The growing emphasis on sustainable and biodegradable materials has spurred the development of natural fiber-reinforced polymer composites. This study investigates the influence of sisal fiber reinforcement on the mechanical properties of low-density polyethylene (LDPE) matrix composites. Composites were fabricated using both untreated and alkali-treated (5% NaOH) sisal fibers at varying fiber loadings (e.g., 5%, 10%, and 15% by weight) via melt blending and compression molding techniques. The mechanical behaviour of the composites was evaluated through tensile, flexural, and impact strength tests in accordance with ASTM standards.

Results indicated that NaOH treatment significantly enhanced the interfacial bonding between the sisal fibers and the LDPE matrix, leading to notable improvements in tensile and flexural properties compared to untreated fiber composites. The optimum fiber loading was identified at 10 wt%, beyond which mechanical performance declined due to poor fiber dispersion and possible agglomeration. Impact strength also followed a similar trend. The study confirms that alkali treatment effectively increases fiber surface roughness and improves mechanical interlocking, making sisal fiber-reinforced LDPE composites a viable and eco-friendly alternative for moderate load-bearing applications.

***Keywords*:** Sisal fiber, LDPE composites, Natural fiber reinforcement, Alkali treatment, Mechanical properties, green composites

1. Introduction:

Fibre-reinforced polymer composites are used extensively nowadays in various industrial sectors owing largely to quite a favourable strength-to-stiffness ratio and lightweight characteristics (Alvarez et al., 2006). Composite material consists of a Matrix and a suitable reinforcement embedded in it that may be a fiber, particle or even filler. Reinforcing fibres are derived from either man-made synthetic sources or naturally occurring substances found in various plant life and other organic matter (Goda & Cao., 2007). SFCs (Synthetic Fiber Reinforced Composites) exhibit superior mechanical properties but their major drawback lies in their undeniably non-biodegradable nature compared with NFCs. Significant concerns have been raised among researchers and policymakers about challenges stemming from disposal and recycling's huge environmental impact polluting everywhere. Growing interest lies in replacing synthetic fibres with natural alternatives in FRCs according to required mechanical performance and various applications. Natural fibres like kenaf and sisal are emerging rapidly as promising substitutes for synthetic fibres in various consumer products and automotive components. Natural fibres offer numerous benefits such as low density and biodegradability and wide availability making them rather attractive candidates as fillers in polymer composite formulations (Satishkumar et al., 2014; Yusriah et al., 2014; Sanjay & Yogesha, 2017; Chandrasekar et al., 2018).

Recent advancements in mechanical performance of sisal fibre-reinforced polymer composites have shown remarkably promising results among various natural fibre composites. Sisal fibre derived from Agave sisalana plant is extensively used naturally owing largely to broad applicability and remarkably easy cultivation geographically. Global trends suggest steady growth in sisal fibre output driven largely by an expanding gamut of industrial and commercial uses. Sisal fibre boasts unusually high cellulose content amongst leaf-extracted natural fibres thereby significantly enhancing its tensile strength pretty substantially (Takagi & Ichihara, 2004; Huang & Netravali, 2010). Sisal exhibits relatively low moisture absorption thereby further improving durability in various composite materials significantly over prolonged periods. Sisal holds a leading position in construction industry owing largely to its numerous advantageous properties such as abundant availability and high tensile strength (Mohanty et al., 2002; Kim & Netravali, 2010). Recently it has gained considerable prominence as reinforcement element in various cementitious composites pretty rapidly worldwide

apparently. Sisal fibre holds considerable promise for crafting lightweight structural materials within construction sector paradigms emphasizing eco-friendly engineering practices fervently nowadays.

It has been observed that Sisal fiber reinforced composites can be extensively used in high impact requirement applications owing to good impact strength of the fiber. With average Tensile and Flexural strength, these fibers contribute being a suitable alternative to synthetic fiber composites. One disadvantage of Natural fibers is that they are inherently hydrophilic which does not permit their proper adhesion to matrix material and thus reduces the mechanical strength of the Composite. It has been observed by (Kolpaketal et al., 1978) that the mercerization of cotton fibers changed their structure from the native form of cellulose I (parallel structure) to the more stable cellulose II (anti-parallel structure) which has some inter-sheet hydrogen bonding. A study done by Rosa et al., 2009 and Geethamma et al., 1998 proved that when the alkali treatment of coir fibers was done, there was improved wettability of Natural fiber and ethylenevinyl copolymer composites.

In this research paper, sisal fibers were alkali treated to render them hydrophobic and composites were fabricated by Compression Molding using Low Density Polyethylene as matrix material. The fibers were obtained from Chennai and LDPE used was in the form of used and discarded milk pouches. In the present study, sisal fibers were mercerized using alkaline (NaOH) solution following different optimization ratio. Unmodified (control) and mercerized sisal fiber-reinforced composites were fabricated by Compression molding technique and their mechanical properties like Tensile strength, Impact strength and Flexural strength were evaluated. Biodegradability test were also carried and the observations were recorded. A comparative assessment of all properties of mercerized and control specimens was performed and conclusions formulated. This paper is also a step towards Sustainability as it incorporates the non-biodegradable waste which holds a major share towards Plastic and Land Pollution.

Table 1. Chemical Composition of Sisal Fibers

Chemical	Percentage Composition
Cellulose	68-79
Hemicellulose	10-14
Pectin	10
Lignin	8-11
Waxes	*traces*

2. Experimental:

2.1 Materials

The sisal fibers were obtained from GO GREEN PRODUCTS, Chennai, India. These fibers were about 1.3-1.5mm in length and 200-300 µm in diameter which made them easy to undergo chemical treatment. They were undergone mercerization with varying % of NaOH solutions. Sisal fibers are rich in cellulose with 68-79%, followed by hemicellulose 10-14%, lignin 8-11%, pectin 10% and traces of wax. LDPE used was in the form of recycled milk pouches. They were obtained from local ragpickers of Bhopal, washed thoroughly several times, dried and grinded to a particle size of 2-3cm following sieve size analysis.

2.2 Mercerization of Sisal fibers

Raw sisal fibers were washed to remove impurities, and oven-dried at 60°C for 24 hours. Analytical-grade sodium hydroxide (NaOH) and distilled water were used for alkali treatment. For each batch, fibers were soaked in NaOH solution (fiber-to-solution ratio 1:20 w/v) for 4 hours at room temperature (~25°C). After treatment, fibers were rinsed thoroughly with distilled water until the rinse water reached neutral pH. Treated fibers were then air-dried for 12 hours followed by oven drying at 60°C for 24 hours. The dried fibers were stored in moisture-free containers for further use.

2.3 Fabrication of Composites

Sisal fiber-reinforced LDPE composites were fabricated using the compression molding technique. Both untreated and alkali-treated sisal fibers (5%, 10%, and 15% by weight) were used as reinforcement.

LDPE granules were first melted at 130–140°C using a laboratory hot press. Pre-weighed, chopped sisal fibers were then uniformly mixed with the molten polymer and transferred into a pre-heated mold. The mixture was compressed at 10–15 MPa pressure for 10 minutes at the same temperature, followed by cooling under pressure to room temperature. The molded sheets were then removed, trimmed, and stored for further mechanical and physical testing.

The optimized ratios of LDPE and sisal fibers used is described in Table 2.

Table 2. Optimization of Polymer Composites

Sample No.	LDPE (%)	Sisal fibers (%)
1.	100	0
2.	95	5
3.	90	10

4.	85	15
5.	80	20
6.	75	25
7.	70	30

2.4 Mechanical testing of Composites

Tensile testing of rectangular specimens of size 150 mm 13 mm 4 mm was carried out in an Instron Universal Testing Machine model 3382 at a cross head speed of 50 mm min and a gauge length of 50 mm. For calculation of Flexural Strength, rectangular shaped specimens were prepared. The Izod Impact testing of composite samples was performed on a Tinius Olsen Impact 104 instrument and test was done following ASTM D 256. An average of five specimens for each composition for each property was tested and results reported.

2.5 Degradation Studies

The Degradation of Composite samples was studies following the two methods:

2.5.1 Water Immersion: ASTM D570 measures the amount of water absorbed by a plastic or composite material under controlled conditions, usually by immersing the specimen in water for a defined period. Following the ASTM D570, composite samples were immersed in water and the mechanical properties were assessed on this basis.

2.5.2 Soil Burial test: This test method is used to determine the aerobic biodegradation of organic materials (like biodegradable plastics or natural fiber composites) by measuring the CO_2 evolved when the material is exposed to a natural soil environment under controlled laboratory conditions. According to ASTM D5988, composite samples were buried in soil sample in sealed vessels to collect the CO_2. Percentage Biodegradation was then calculated on the basis of CO_2 collected.

3. Results and Discussion

3.1 Effect of Mercerization on Mechanical properties

3.1.1 Effect of Mercerization on Tensile strength

The tensile strength of untreated composites demonstrated a moderate improvement with fiber loading up to 15 wt.%, beyond which a decrement was noted due to interfacial debonding and stress concentration around fiber agglomerates. In contrast, NaOH-treated composites exhibited superior tensile properties across all fiber loadings, with the peak strength observed at 15 wt.% sisal incorporation.

The mercerization treatment effectively **disrupted the lignocellulosic matrix** of the fiber, partially removing hemicellulose and surface lignin, thereby enhancing the fiber's surface roughness and promoting **mechanical interlocking** with the hydrophobic LDPE matrix. Furthermore, NaOH-induced fibrillation increased the aspect ratio of fibers, which facilitated more efficient stress transfer.

- **Untreated composite (85:15 LDPE:Sisal):** 13.4 MPa
- **Treated composite (85:15 LDPE:Sisal):** 15.2 MPa

This corresponds to a **~13.4% increase in tensile strength**, corroborating earlier findings (Oladele & Agbabiaka, 2015) on alkali-treated sisal–polypropylene systems.

3.1.2 Effect of Mercerization on Flexural strength

Flexural strength improved significantly upon alkali treatment of the fibers. The untreated samples revealed insufficient load transfer during bending, attributed to inadequate wetting of the fiber surface by the LDPE matrix. Conversely, treated fibers exhibited **enhanced interfacial compatibility**, minimizing delamination under flexural load.

The alkaline hydrolysis process augmented the **crystallinity index** and reduced fiber polarity, which synergistically contributed to increased **flexural rigidity** and **resistance to microcracking**.

- **Untreated composite (85:15):** 18.9 MPa
- **Treated composite (85:15):** 21.0 MPa

This enhancement (~11%) is indicative of improved **fiber–matrix interfacial shear strength** due to chemical and morphological modifications induced by NaOH treatment.

3.1.2 Effect of Mercerization on Impact strength

Impact strength data revealed a decreasing trend with increasing fiber content for untreated composites, likely due to stress localization and insufficient fiber dispersion. However, treated composites demonstrated improved energy absorption capacity, attributed to **optimized interfacial stress dissipation mechanisms**.

Alkaline-treated fibers showed a **mitigated fiber pull-out tendency** and enhanced bonding with the LDPE

matrix, resulting in higher energy absorption upon impact.

- **Untreated composite (85:15):** 19.8 kJ/m²
- **Treated composite (85:15):** 22.5 kJ/m²

A **~13.6% enhancement** in impact resistance was noted, affirming the role of mercerization in augmenting the composite's **toughness and dynamic fracture resistance**.

Table 3. shows the Mechanical Strength results of various composite samples and its comparison with the control counterparts.

Table 3. Comparison of tensile strength (MPa), flexural strength (MPa), and impact strength (kJ/m²) for untreated and NaOH-treated LDPE–sisal fiber composites at different fiber loadings

LDPE:Sisal (%)	Tensile Strength (MPa)		Flexural Strength (MPa)		Impact Strength (kJ/m²)	
	Untreated	Treated	Untreated	Treated	Untreated	Treated
100:0	11.2	–	16.5	–	22.1	–
95:5	12.5	13.7	17.4	18.8	21.5	23.4
90:10	13.1	14.8	18.2	20.1	20.6	22.9
85:15	13.4	15.2	18.9	21.0	19.8	22.5
80:20	12.9	14.6	18.1	20.3	18.3	21.0
75:25	12.0	13.5	17.2	19.1	17.1	19.5
70:30	11.1	12.4	16.0	17.8	15.8	18.2

3.2 Degradation Studies

3.2. Biodegradability Assessment via water absorption

In the present study, water absorption tests were conducted by immersing composite samples in distilled water at ambient temperature, and their mechanical properties were evaluated before and after saturation. The results demonstrated a decline in tensile, flexural, and impact strengths after water uptake, especially in untreated composites.

The untreated LDPE–sisal composites showed a higher rate of water absorption and greater deterioration in mechanical properties compared to their alkali-treated counterparts. This is attributed to the enhanced hydrophilicity and poor interfacial adhesion in untreated samples, which allowed water molecules to penetrate and disrupt the composite microstructure. In contrast, NaOH-treated fibers, having reduced hemicellulose and surface impurities, exhibited lower water uptake due to decreased polarity and improved compatibility with the hydrophobic LDPE matrix.

Post-immersion mechanical testing revealed that:

- Tensile strength decreased by up to 10–15% in untreated composites but only by 5–8% in treated ones.
- Flexural strength exhibited a similar trend, with greater loss in untreated samples due to the weakening of the fiber–matrix interface.
- Impact strength was significantly affected in untreated composites due to increased fiber pull-out and void formation, whereas treated composites retained better integrity.

3.2.2 Biodegradability Assessment via Soil Burial Test

Over the 90-day period, a gradual increase in weight loss was observed in the composite samples, indicating progressive degradation. The treated sisal/LDPE composites showed a slower rate of degradation compared to untreated fiber composites, attributed to improved interfacial bonding which initially resists microbial intrusion and moisture uptake. The untreated composites exhibited faster debonding and surface erosion, in agreement with previous findings (Zhou & Lucas, 1995), where water absorption at the fibre/matrix interface was found to cause fiber swelling, shear stress, and eventual loss of mechanical integrity. Treated composites, on the other hand, demonstrated improved resistance due to reduced hydrophilicity resulting from the alkali treatment, as also noted in similar green composites (Prabhakaran et al., 2022). Visual and microstructural inspection using SEM revealed surface roughening, void formation, and micro-cracks in both composite types, with more pronounced damage in the untreated variants. This morphological evidence supported the weight loss data, confirming ongoing biodegradation. The data related to soil burial test presented here, corresponds to Sample No.4 which gave best mechanical results out of the other samples.

Table 4: Weight Loss (%) of Sisal/LDPE Composites During Soil Burial Test

Time (Days)	Untreated Sisal/LDPE Composite (%)	Treated Sisal/LDPE Composite (%)
0	0.00	0.00
30	2.85	1.26
60	5.94	2.74
90	9.31	4.51

Figure 1. Comparison of tensile strength, flexural strength, and impact strength of untreated and alkali-treated (NaOH) LDPE–sisal fiber composites at varying fiber loadings (0–30 wt%)

4. Conclusion

This study demonstrated that reinforcing LDPE with sisal fiber improves mechanical properties, especially when fibers are treated with NaOH. Alkali treatment enhanced tensile, flexural, and impact strengths by improving fiber–matrix adhesion and reducing moisture sensitivity. Water absorption studies showed that untreated composites suffered greater mechanical degradation due to fiber swelling and interface debonding, whereas treated composites maintained better structural integrity.

Biodegradability assessment via soil burial indicated that sisal incorporation accelerated degradation compared to neat LDPE. Untreated composites degraded more rapidly due to higher cellulose exposure, while treated composites balanced mechanical performance with satisfactory environmental breakdown.

In summary, alkali-treated LDPE–sisal fiber composites present a promising balance between mechanical strength and environmental sustainability. They offer enhanced durability during service life and improved degradation post-disposal, making them suitable candidates for eco-friendly applications such as agricultural films, packaging materials, and low-load structural components.

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