# PREPARATION AND CHARACTERISATION OF SISAL FIBER POWDER REINFORCED COMPOSITES

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**Abstract:** This work investigates the fabrication and mechanical characterization of biodegradable polymer composites reinforced with sisal fiber powder, using isophthalic polyester resin as the matrix. The primary focus is to evaluate the effects of sodium hydroxide (NaOH) surface treatment and varying sisal fiber powder loadings (5wt%, 10wt%, 15wt% and 20wt%) on the tensile and flexural properties of the composites. Sisal fibers were processed into fine powder through extraction, cleaning and grinding, followed by chemical treatment to enhance surface characteristics. Composite specimens were fabricated using the hand layup technique and subjected to mechanical testing in accordance with ASTM standards. The results revealed that NaOH-treated sisal fiber powder significantly improved the mechanical performance compared to untreated samples and neat resin. The composite with 15wt% treated fiber powder exhibited highest properties, achieving a tensile strength of 23.22 MPa and a flexural strength of 68.5 MPa. These enhancements are attributed to improved interfacial bonding and effective stress transfer between the fiber powder reinforcement and the resin matrix. However, a decline in strength was observed at 20wt% fiber power loading due to fiber powder agglomeration and poor matrix infiltration. The findings confirm that alkali treatment enhances the compatibility and reinforcing efficiency of natural fibers in polymer matrices. This work enhance the potential of chemically treated sisal fiber powder as a sustainable and cost-effective alternative to synthetic reinforcements for use in lightweight structural applications such as automotive components, packaging materials and consumer products.

**Keywords:** Sisal Fiber, Composite, Hand layup process, Tensile test, Flexural test

## 1. Introduction

The global shift towards sustainable development and environmental responsibility has intensified research into green and biodegradable materials, particularly in the area of fiber-reinforced polymer composites. The environmental burden of petroleum-based synthetics characterized by high energy consumption, non-biodegradability, and disposal issues has prompted scientists and manufacturers alike to explore eco-friendly alternatives [1]. In this context, bio-composites reinforced with natural fibers have gained significant attention due to their renewable nature, biodegradability, and favorable specific mechanical properties. Among the wide array of natural fibers available, sisal (Agave sisalana), a hard fiber native to arid and semi-arid regions, is emerging as a promising candidate. Known for its high tensile strength, durability, and resistance to saltwater degradation, sisal has traditionally been used in rope and mat production but is increasingly being considered for advanced material applications [2]. Conventional synthetic fibers such as glass, carbon, and aramid dominate

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the composites industry due to their superior mechanical strength and stiffness. For instance, glass fiber offers tensile strengths in the range of 2000–3500 MPa and a Young's modulus of approximately 70 GPa, but its manufacture is energy-intensive, and it is not biodegradable [3]. Carbon and aramid fibers further improve mechanical performance but are costly and unsustainable. In contrast, natural fibers offer lower density, are derived from renewable sources, and can be processed using energy-efficient methods. More importantly, they offer excellent specific strength and stiffness, making them competitive with traditional reinforcements in weight-sensitive applications [4]. Sisal fiber, with its long, stiff filaments, presents a strong balance of mechanical performance and environmental benefit. Typical values of tensile strength for sisal range from 400 to 700 MPa, with a Young's modulus between 9.4 and 22 GPa, depending on factors such as growth conditions, extraction techniques, and fiber processing [5]. Compared to other natural fibers: jute (200–800 MPa; 10 to 30 GPa), flax (500 to1500 MPa; 50 to 70 GPa), and kenaf (223 to 930 MPa; 14 to 60 GPa), sisal offers robust mechanical properties while being particularly resistant to environmental degradation. Its ability to grow in marginal soils with minimal agricultural input adds to its appeal as a sustainable fiber source [5], [6]. Despite their ecological advantages, natural fibers like sisal face key limitations in composite applications, primarily due to their hydrophilic nature, which impairs bonding with hydrophobic polymer matrices such as polyester or epoxy resins. This poor interfacial adhesion results in inefficient stress transfer, lowering the composite's mechanical integrity [7]. Additionally, natural fibers tend to absorb moisture, leading to swelling, microbial attack, and mechanical degradation over time. To overcome these challenges, alkaline treatment, commonly using sodium hydroxide (NaOH), is widely applied to natural fibers. This treatment removes lignin, hemicellulose, waxes, and surface impurities, increasing surface roughness and enhancing matrix adhesion [8]. NaOH-treated sisal fibers also exhibit reduced moisture uptake, increased thermal resistance, and more available hydroxyl groups, improving compatibility with polymeric matrices. Several studies have demonstrated the benefits of NaOH treatment on the mechanical properties of sisal-based composites. Increases in tensile and flexural strengths by 25–50% have been reported, with improved interfacial bonding contributing to more uniform load distribution across the fiber–matrix interface [9], [10], [11], [12]. In comparison with untreated fibers, chemically treated sisal fibers form more stable and mechanically efficient composites, particularly when optimized for weight fraction and matrix compatibility. This study investigates the mechanical behavior of sisal fiber-reinforced polymer composites fabricated using isophthalic polyester resin as the matrix [13]. Jute is cheaper and widely available but suffers from higher moisture absorption and reduced long-term durability. Coir fibers, despite their biodegradability and elasticity, offer significantly lower tensile strengths (~100 to 200 MPa), limiting their use in structural applications [14]. Sisal, on the other hand, delivers a blend of mechanical reliability, environmental resistance, and cost-effectiveness, making it ideal for semi-structural applications such as automotive interiors, packaging, and construction panels [15]. Compared to glass fiber composites (tensile strength 300 to 600 MPa), optimized sisal-based composites can achieve tensile strengths in the range of 120 to 250 MPa. Furthermore, sisal composites have lower density (~1.3 to 1.5 g/cm$^3$), are safer to handle and reduce tool wear during processing key advantages for sustainable manufacturing [16]. The broader implications of this research span across automotive, construction, furniture, and packaging industries, where natural fiber composites are increasingly replacing synthetic counterparts. For example, automotive components like door panels and dashboards can benefit from the light weight, vibration damping, and cost savings offered by sisal composites. In construction, these materials may be applied to modular boards, partitions, or insulation panels. With their biodegradability, such composites also offer waste management benefits and potential for closed-loop recycling. Moreover, promoting sisal cultivation can support rural economies, particularly in arid regions, providing employment and added value to agricultural by-products [14], [17], [18], [19].

The objective of this study is to develop biodegradable bio-composites using powdered sisal fiber as reinforcement in an isophthalic resin matrix via the hand lay-up method. The composites are tested for tensile and flexural strength according to ASTM standards to assess their suitability as sustainable replacements for conventional synthetic and metallic materials. The results contribute to the ongoing effort to design lightweight, non-toxic, renewable, and environmentally friendly composites, offering viable alternatives for diverse industrial applications aligned with global sustainability goals.

## 2. Materials and methodology:

**2.1 Extraction of Sisal fiber:** Sisal plants are commonly found in the forests near Mahabubabad, located in the Warangal district of Telangana. The fibers are extracted through a process known as retting, where the plant stems are submerged in still water. During this process, the thick-walled xylem is retained and must be removed through scutching, a method that separates and aligns the fibers by drawing them across a comb. The cell wall of the fibers is relatively thick, measuring around 6.3 μm. The plant consists of two distinct parts: the bast (bark) and the core (wood). The bast makes up approximately 40% of the plant and contains long (2–6 mm), slender fibers with a thick cell wall. The core accounts for about 60% of the plant and contains short (0.5 mm) fibers that are thick (ø 38 μm) but have thin walls (3 μm). Since paper pulp is produced from the entire stem, the fiber distribution is bimodal. The pulp quality of sisal is comparable to that of hardwood.

### 2.2 Fiber Treatment and Preparation Process

***Step 1: Alkaline Treatment***

The peeled sisal fibers are immersed in a 1% sodium hydroxide (NaOH) solution and soaked for 24 hours to remove impurities, waxes and hemicellulose, thereby improving fiber-matrix adhesion.

***Step 2: Washing and Drying***

After alkaline treatment, the fibers are thoroughly washed with distilled water to remove residual NaOH and neutralize the fibers. The cleaned fibers are then sun-dried.

***Step 3: Grinding***

The dried, NaOH-treated fibers are ground into fine powder using a mechanical grinder to ensure uniform dispersion within the polymer matrix.

### 2.3 Chemicals Used

***Accelerator:*** An accelerator is an additive incorporated into polyester resin systems to enhance the reaction rate between the resin and the catalyst, thereby accelerating the polymerization process. It is particularly essential in resins that are cured at room temperature. In this study, Cobalt Naphthenate was used as the accelerator.

***Catalyst:*** The catalyst is a reactive chemical compound added to the resin or gel coat in precise quantities to initiate the curing process. The catalyst facilitates the cross-linking of polymer chains, leading to the hardening of the resin. The catalyst used in this study was Methyl Ethyl Ketone Peroxide (MEKP).

***Polyvinyl Alcohol (PVA):*** Polyvinyl Alcohol was applied as a release agent to ensure easy removal of the cured laminate from the glass surface during the composite fabrication process. It prevents the laminate from adhering to the mold, thereby maintaining surface quality and mold reusability.

## 2.4 Hand lay-up process:

The hand lay-up technique was employed to fabricate sisal fiber-reinforced polyester composites due to its simplicity and cost-effectiveness. A clean, flat glass plate served as the mold surface, onto which a thin layer of polyvinyl alcohol (PVA) was applied uniformly. This acted as a release agent, facilitating easy removal of the cured composite. The sisal fibers were initially treated with a 1% sodium hydroxide (NaOH) solution, then thoroughly washed with distilled water and sun-dried. Once dried, the fibers were ground into fine powder to be used as filler. Isophthalic polyester resin was used as the matrix material. Prior to lamination, cobalt naphthenate was added to the resin as an accelerator, followed by methyl ethyl ketone peroxide (MEKP) as the catalyst to initiate the curing reaction. The treated sisal fiber powder was then mixed into the resin in specific weight fractions (5wt%, 10wt%, 15wt%, and 20wt%) and stirred thoroughly to ensure homogeneous dispersion of the fibers. The fiber-resin mixture was manually poured and evenly spread over the mold surface using a brush or roller. Depending on the required thickness, multiple layers were applied while ensuring uniform distribution and removal of trapped air. The laminate was then left to cure at room temperature for 24 to 48 hours. After full curing, the composite was carefully removed from the mold, aided by the release agent. Finally, the laminate was trimmed and cut into standard test specimens as per ASTM guidelines for mechanical testing.

## 3. Mechanical characterization:

To determine the mechanical behavior of the sisal fiber powder-reinforced polymer composites, both tensile and flexural tests were carried out using a Percievestar digital Universal Testing Machine (UTM) equipped with a 3 kN load cell, sourced from AE Engineers, India. Tensile specimens were shaped in a standard dog-bone configuration, measuring 165 mm in overall length, 12 mm in width at the center and approximately 3 mm in thickness. The test procedure followed the guidelines specified by ASTM D638 and was conducted at a constant loading rate of 2 mm/min until the samples fractured. For flexural testing, the three-point bending method was employed in compliance with ASTM D790 standards. Test specimens were cut to dimensions of 125 mm in length, 12.7 mm in width, and 3 mm in thickness. These tests were also executed at a crosshead speed of 2 mm/min using the same UTM configuration. The primary aim of these evaluations was to investigate the effect of fiber surface treatment and varying weight fractions of sisal fiber powder on the mechanical performance of the composite. The data collected helped establish the relationship between fiber content, fiber treatment, and the resulting tensile and flexural strength of the composites.

## 4. Results and discussion:

### 4.1 Tensile test:

The tensile strength of the fabricated natural fiber powder-reinforced polymer composites was evaluated for varying fiber powder contents (5wt%,10 wt%, 15wt% and 20wt%) with and without alkali (NaOH) treatment shown in Figure 1. The results demonstrate a clear influence of both fiber powder content and surface treatment on the mechanical properties of the composite, particularly the tensile strength. The baseline tensile strength of the pure resin was recorded at 16.06 MPa. This value served as the control to assess the improvement resulting from fiber powder reinforcement. With the introduction of 5wt% fiber powder into the resin matrix, the tensile strength increased slightly to 17.53 MPa for NaOH-treated fiber powder and 17.05 MPa for untreated powder. The marginal improvement in strength at this stage suggests that the fiber powder content was still relatively low, leading to only a modest enhancement in the load-bearing capacity of the composite [20]. Nevertheless, the NaOH-treated fiber powder showed a slight advantage over the untreated one, implying the initial impact of chemical treatment on interfacial bonding [9]. As the fiber powder loading increased to 10wt%, a more noticeable improvement in tensile strength was observed. The composite containing NaOH-treated fiber powder recorded a tensile strength of 20.02 MPa, whereas the untreated counterpart reached 19.23 MPa. This substantial increase from the neat resin indicates a more effective reinforcement behavior of the natural fiber powder at this concentration. The improved stress transfer between the matrix and powder particles likely contributed to the enhancement in tensile properties [10], [11]. Again, NaOH treatment proved beneficial by further boosting the performance, which can be attributed to the removal of hemicellulose, lignin, and other amorphous components that otherwise hinder strong adhesion [9]. The optimal tensile strength was achieved at 15wt% fiber powder loading. For this composition, the tensile strength peaked at 23.22 MPa for NaOH-treated fiber powder, while the untreated sample recorded 22.56 MPa. This result clearly indicates that 15wt% fiber powder content strikes the best balance between reinforcement and matrix continuity. The treatment with NaOH had a notable effect, improving the fiber powder–matrix interaction and resulting in the highest mechanical performance among all tested samples. The alkali-treated fiber powder possesses a cleaner surface with more exposed cellulose, which enhances wettability and mechanical interlocking with the resin, thereby improving tensile properties [21]. However, a further increase in fiber powder content to 20wt% led to a decline in tensile strength. The composite with NaOH-treated fiber powder recorded a strength of 16.83 MPa, while the untreated version dropped to 15.95 MPa, both falling below the value achieved at 15wt%. This decline is likely due to powder agglomeration and poor dispersion within the resin matrix at higher loading levels. Such agglomeration creates voids and stress concentration points that reduce the efficiency of stress transfer from matrix to powder particles [14], [20]. Moreover, an excessive amount of fiber powder may lead to inadequate wetting and bonding with the matrix, further deteriorating the mechanical properties [22].

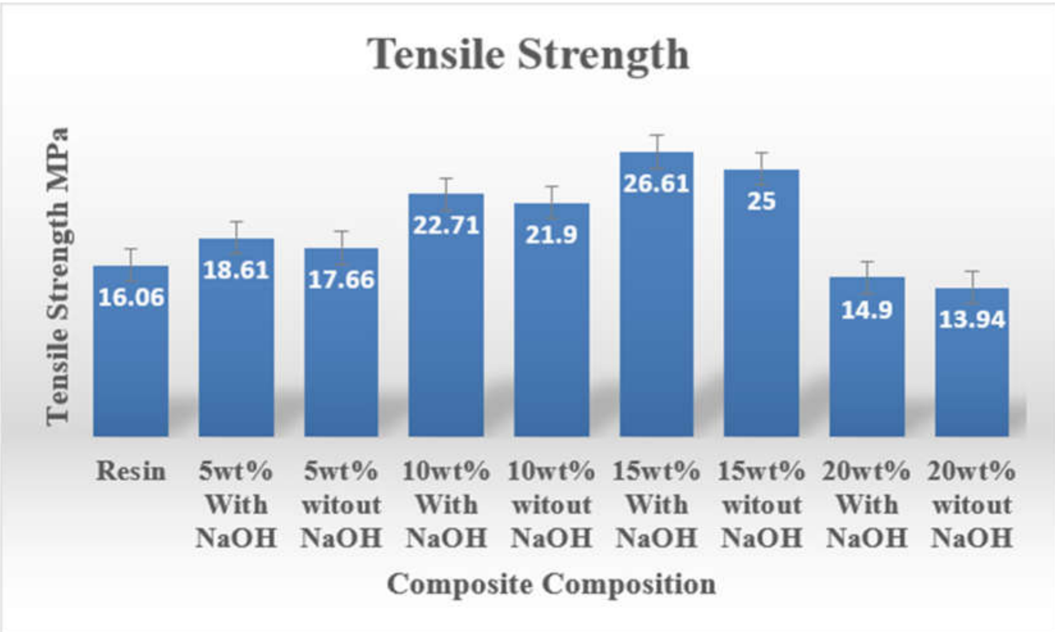


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**Figure 1: Tensile strength (MPa) of untreated and NaOH-treated sisal fiber powder-reinforced composites at varying weight fractions compared to neat isophthalic polyester resin.**

hese findings emphasize the importance of optimizing fiber powder content for maximum mechanical benefit. Comparing these results with other natural fiber-reinforced polymer composites reported in the literature helps to position the developed material within the broader context of composite research. Jute/polyester composites are reported to have tensile strengths in the range of 25 to 32 MPa, sisal/epoxy composites fall within 22 to 30 MPa, hemp/polypropylene composites typically range from 20 to 30 MPa, and sisal/polyester composites report values between 22 and 35 MPa [23]. The tensile strength of 23.22 MPa achieved in the current study at 15wt% with NaOH-treated fiber powder falls well within this competitive range. This confirms the mechanical viability of the fabricated composite for applications that typically utilize other natural fiber composites. Furthermore, the observed trend of improvement in tensile strength due to alkali treatment is consistent with the findings in prior research on natural fiber modification. NaOH treatment not only increases surface roughness for mechanical interlocking but also enhances chemical compatibility with polar matrices by increasing the availability of hydroxyl groups. This dual benefit improves the overall composite integrity [9], [12]. However, the mechanical improvement is most effective only up to an optimal fiber powder loading. Beyond this limit, issues such as powder agglomeration, insufficient matrix coverage, and poor dispersion negate the benefits of reinforcement [22].

### 4.2 Flexural Test:

The mechanical performance of natural fiber-reinforced composites depends significantly on the type of fiber, its surface treatment, and the proportion used in the composite matrix. In this study, sisal fiber powder was incorporated into an isophthalic polyester resin matrix at four different weight fractions: 5wt%, 10wt%, 15wt% and 20wt%—to evaluate its potential as a biodegradable reinforcing material. Both untreated and chemically treated fibers were investigated, with sodium hydroxide (NaOH) used for the alkali treatment. The resulting composites were subjected to flexural testing in accordance with ASTM standards, and the results are presented in Figure 2. The neat isophthalic polyester resin, used as the control sample, displayed a flexural strength of 46 MPa. Upon adding 5wt% sisal fiber, a noticeable improvement was observed. The untreated composite registered a flexural strength of 52.2 MPa, while the NaOH-treated counterpart achieved 53.8 MPa. This initial increase demonstrates the reinforcing effect of sisal fibers, even at low content, and highlights the role of surface modification in enhancing fiber–matrix bonding. NaOH treatment contributes to this improvement by removing hemicellulose, lignin, and other surface impurities, which results in increased surface roughness and a more reactive surface for better matrix adhesion [9], [10]. At 10wt% fiber loading, the treated and untreated composites exhibited further gains in flexural strength, reaching 57.6 MPa and 56.43 MPa respectively. These results suggest that increased fiber content enhances stiffness and load-bearing capacity to a certain extent. The improvement is more pronounced in treated fibers, confirming that alkali treatment promotes stronger interfacial bonding and more effective stress transfer from the matrix to the fiber. The highest flexural strength was observed at 15wt% fiber content. Here, the NaOH-treated composite reached a maximum of 68.5 MPa, while the untreated version registered 67.2 MPa. This marks an increase of nearly 49% compared to the neat resin. The superior performance at this composition can be attributed to an optimal balance between fiber dispersion, matrix coverage and load transfer. Beyond this loading level, the risk of fiber agglomeration and incomplete wetting increases, this impairs structural integrity [21]. This trend is evident in the composites with 20wt% fiber content. For untreated fibers, the flexural strength dropped to 45.4 MPa, slightly below that of the pure resin. The treated sample performed marginally better at 47.7 MPa but still showed a significant decrease from the peak value at 15wt%. The reduced performance at higher loading levels is attributed to fiber clustering, insufficient matrix penetration, and the presence of voids or defects introduced during fabrication. These factors hinder the efficient transfer of stress and lead to premature failure under bending loads. The enhancement in mechanical properties due to NaOH treatment can be explained by the chemical and physical changes induced in the fiber. The treatment removes non-cellulosic components, which not only increases surface roughness but also enhances thermal stability and reduces hydrophilicity. These improvements lead to better compatibility with the hydrophobic polyester matrix, resulting in composites with superior flexural properties. The treated fibers also exhibit improved dispersion within the matrix, reducing the chances of stress concentration points [12].

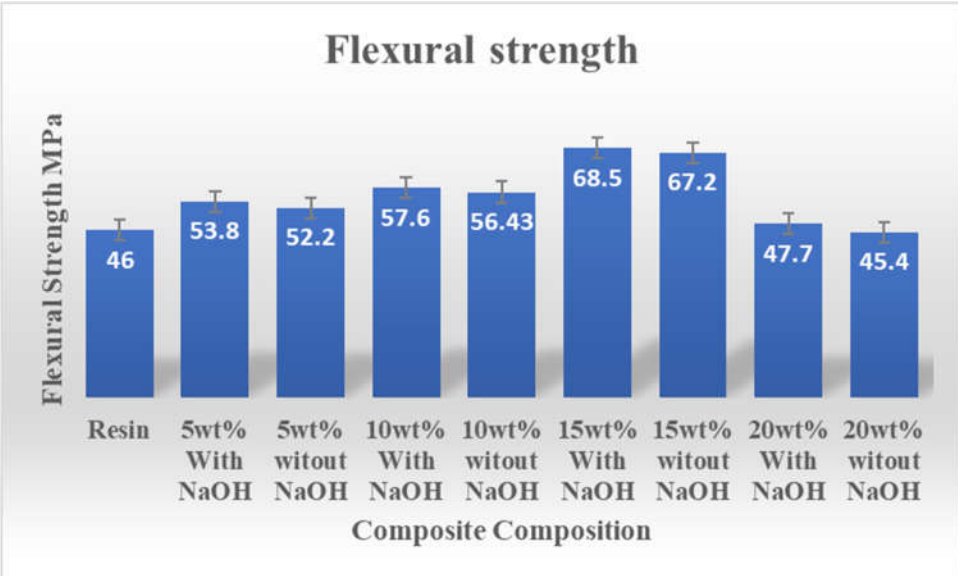


**Figure 2: Flexural strength (MPa) of untreated and NaOH-treated sisal fiber powder-reinforced composites at varying weight fractions compared to neat isophthalic polyester resin.**

A comparative assessment of sisal fiber composites with other natural fiber-reinforced materials helps contextualize its mechanical performance. For example, jute fiber composites have shown flexural strengths in the range of 60–70 MPa after NaOH treatment, while kenaf fiber composites achieve values around 65–70 MPa. Sisal composites, especially when treated, exhibit comparable flexural strength, with the added advantages of greater availability in certain regions and faster regrowth potential [24]. Flax and hemp fibers offer higher intrinsic strengths, with post-treatment flexural strengths reaching 80–100 MPa and 85–95 MPa respectively. However, these fibers are typically more expensive, and their cultivation is limited by regional and regulatory constraints. Coir fibers, while highly biodegradable and elastic, display much lower flexural strength (30–45 MPa) and are better suited for cushioning or insulation rather than structural applications [25]. In contrast to synthetic reinforcements like glass fiber, which provides flexural strengths in the range of 300–500 MPa, natural fibers like sisal fall short in absolute performance [16], [26], [27]. However, sisal composites offer key advantages such as low density (1.2 to 1.5 g/cm³ compared to ~2.5 g/cm³ for glass fiber), biodegradability, non-toxicity, and ease of handling during processing [27]. These factors make them suitable candidates for low- to medium-load applications, particularly where environmental impact is a primary concern. The findings of this study underscore the potential of sisal fiber powder as a viable reinforcement material in biodegradable composite systems. The optimal performance was achieved at 15wt% fiber content, particularly when NaOH treatment was applied.

This composition provided the highest flexural strength while maintaining good processability. Further increases in fiber loading led to reduced performance, highlighting the importance of optimizing fiber content for specific applications [22]. In summary, sisal fiber powder, especially when treated with NaOH, significantly enhances the flexural strength of polyester resin composites. These materials can serve as eco-friendly alternatives to conventional composites in various industries, including automotive interiors, construction panels, furniture, and packaging. The results encourage continued exploration of natural fiber treatments and composite formulations for sustainable engineering solutions.

## 5. Conclusion

This work demonstrated the mechanical enhancement potential of sisal fiber powder as a natural reinforcement in isophthalic polyester resin composites. Both tensile and flexural properties were evaluated for composites fabricated with varying fiber powder loadings (5wt%, 10wt%, 15wt% and 20wt%) and subjected to alkali (NaOH) treatment to assess the effects of fiber content and surface modification on composite performance.

- The results clearly show that the mechanical properties of the composites are significantly influenced by both the amount of fiber powder and the application of chemical treatment. For tensile strength, the highest performance was achieved at 15wt% fiber content, with the NaOH-treated composite exhibiting a maximum tensile strength of 23.22 MPa, an increase of over 44% compared to the neat resin. Similarly, flexural strength peaked at 68.5 MPa for the NaOH-treated composite with 15wt% fiber, representing nearly a 49% enhancement over the baseline resin.
- NaOH treatment consistently improved both tensile and flexural properties across all fiber contents. This improvement is attributed to enhanced fiber–matrix interfacial bonding facilitated by the removal of surface impurities and non-cellulosic components from the fiber powder, which promotes better stress transfer and wettability. However, beyond 15 wt% loading, mechanical performance declined, primarily due to fiber powder agglomeration, inadequate wetting, and poor dispersion, which introduce voids and stress concentration sites within the composite.
- Comparative analysis with literature data revealed that the developed sisal fiber powder composites fall within or close to the performance range of other widely studied natural fiber-reinforced polymers such as jute, kenaf, and hemp. These results affirm the mechanical competitiveness of sisal-based composites, especially when optimized with alkali treatment. Furthermore, sisal fibers offer advantages such as biodegradability, cost-effectiveness, renewability, and lower environmental impact, making them attractive candidates for eco-friendly, semi-structural composite applications.
- In conclusion, sisal fiber powder, particularly when treated with NaOH and used at an optimal concentration of 15wt%, serves as a promising reinforcement for polymer composites. These findings support the development of sustainable composite materials for use in automotive interiors, construction panels, furniture, and packaging, where a balance between mechanical performance and environmental responsibility is essential. Future research may focus on hybrid reinforcements, coupling agents, or alternative surface treatments to further enhance performance and broaden application potential.

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