

Sisal Fiber Reinforced Pla Nanocomposites With Improved Mechanical Thermal And Morphological Properties

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Natural fibers are derived from renewable resources like plants, animals, and minerals, offering sustainable alternatives to synthetic materials. They provide environmental benefits, cost-effectiveness, and improved mechanical properties in various industrial applications. This study investigates the development and performance of sustainable nanocomposites using sisal fiber-reinforced polylactic acid (PLA) matrices, aimed at eco-friendly applications across automotive, construction, and textile sectors. Nanotechnology is explored to enhance the mechanical and thermal properties of these nanocomposites. Sisal fibers, derived from *Agave sisalana*, offer significant tensile strength and moisture resistance, making them a preferred choice for reinforcement. PLA, a biodegradable thermoplastic from renewable sources, is used as the matrix. Two sample preparation methods are employed: one at 205 °C and another at 190 °C, with varied sisal content (1-6 wt%). The nanocomposites were then subjected to mechanical testing, thermogravimetric analysis (TGA), dynamic mechanical analysis (DMA), differential scanning calorimetry (DSC), and morphological evaluations via optical and scanning electron microscopy (SEM) to determine their properties. Results from tensile testing indicate that sisal fiber enhances the tensile modulus but reduces the tensile strength due to inherent brittleness. TGA and DMA reveal improved thermal stability with higher fiber content, while DSC demonstrates crystallization characteristics influenced by annealing. SEM images depict fiber dispersion, while FTIR analysis confirms chemical bonding within the composites.

Keywords: Sisal fiber, Polylactic acid, Nanocomposites, Mechanical properties, Thermal stability, Morphological analysis, Sustainable materials.

1. INTRODUCTION

Natural fiber-enriched polylactic acid (PLA) composites are blossoming as a captivating frontier in the realm of sustainable materials exploration. These innovative composites fuse the advantages of biodegradable PLA, sourced from renewable treasures like corn starch or sugarcane, with the robust mechanical fortitude lent by natural fibers such as flax, jute, hemp, sisal, or bamboo. As a thermoplastic polyester, PLA serves as a biodegradable and eco-conscious substitute for conventional plastics, making it an alluring choice for ventures aimed at minimizing environmental repercussions. Nonetheless, PLA on its own falls short in

strength, stiffness, and thermal resilience for numerous structural applications. By weaving in natural fibers, which boast inherent strength, feather-light nature, and minimal ecological footprint, the mechanical attributes of PLA can be remarkably amplified. This enhancement not only elevates PLA's tensile strength and rigidity but also renders the material far more adept for load-bearing roles. Consequently, natural fiber-reinforced PLA composites have carved their niche in automotive interiors, construction, consumer products, and packaging, presenting a sustainable alternative to traditional composites infused with synthetic fibers like glass or carbon.

Beyond the elevation of mechanical prowess, the natural fiber-reinforced PLA composites unveil distinctive environmental advantages. Both PLA and natural fibers spring from renewable origins, and the resulting composites can biodegrade under specific conditions, allowing them to naturally disintegrate and alleviate landfill congestion. Moreover, the integration of natural fibers in PLA composites curtails reliance on non-renewable resources, harmonizing seamlessly with the ethos of a circular economy and sustainable progression. These composites also exhibit a comparatively lower energy footprint during manufacturing when juxtaposed with conventional synthetic composites, as the processing temperatures for PLA remain relatively modest, and natural fibers demand less energy-intensive treatment than their synthetic equivalents. Yet, challenges linger, encompassing concerns with fiber-matrix harmony, moisture uptake, and long-term durability, which can sway the mechanical characteristics over time. Current investigations are honing in on surface treatments and compatibilizers to bolster fiber adhesion and moisture resilience, rendering these composites even more adept for a wider spectrum of uses. As breakthroughs persist, natural fiber-reinforced PLA composites stand ready to assume a pivotal role in the evolution of eco-friendly materials.

The study examined the tensile behavior of 3D-printed polylactic acid (PLA)-based composites reinforced with natural fibers, highlighting that the mechanical properties of the composites are significantly influenced by the type of natural fiber used. The composites with jute fibers exhibited the highest tensile strength, suggesting their potential application in lightweight structural components. Furthermore, the research emphasized the importance of fiber orientation and printing parameters in optimizing the mechanical performance of these nanocomposites (Agaliotis et al., 2022).

In addition, the research focused on the characterization efficiency of natural fiber-reinforced PLA nanocomposites for 3D printing applications. It was found that the inclusion of natural fibers enhances the mechanical properties of PLA, although it can sometimes lead to increased water absorption. The study also underscored the role of fiber-matrix interaction and the need for optimizing fiber loading to achieve balanced mechanical performance and printability (Awad et al., 2023). Moreover, the impact of fiber type and compatibility with PLA was critical in determining the overall performance of the nanocomposites. Additionally, the review of water absorption behavior in natural fiber-reinforced PLA composites highlighted the significant effect of moisture uptake on the mechanical properties of these materials. The study found that water absorption rates varied based on fiber type and content, with some fibers exhibiting better resistance to moisture. This finding is crucial for improving the

durability of these nanocomposites in applications exposed to moisture or humid environments (Azka et al., 2024). Consequently, optimizing the fiber-matrix interface and using chemical treatments could mitigate water absorption issues and improve the overall performance of PLA-based composites.

Furthermore, the study investigating the effects of mechanical recycling on PLA-based natural fiber-reinforced composites demonstrated that the mechanical properties, especially tensile strength, degrade after multiple recycling cycles. The research suggests that while PLA can be mechanically recycled, the process adversely affects its performance, particularly when reinforced with natural fibers. This highlights the need for developing more robust recycling techniques or integrating additional treatments to enhance the longevity and sustainability of these composites (Finnerty et al., 2023). The experimental study on PLA composites reinforced with aluminum oxide particles explored the mechanical behavior of these materials, showing improved hardness and wear resistance compared to pure PLA. This reinforced composite demonstrated promising potential for applications in environments requiring high wear resistance. The study concluded that the addition of aluminum oxide particles significantly enhances the performance of PLA-based composites, particularly in demanding industrial applications (Girimurugan et al., 2021).

Moreover, the research on natural fiber-reinforced PLA and their blends for advanced applications examined various methods for improving the performance of PLA composites, including optimizing fiber content and surface treatments. The results indicated that natural fibers significantly improve the mechanical strength and sustainability of PLA, making it a suitable material for a range of applications in automotive and construction industries (Ilyas et al., 2022). Therefore, incorporating natural fibers into PLA offers a viable solution to reduce the environmental impact of synthetic composites.

In another study, the tribological behavior of 3D braided woven fabric reinforced PLA composites was evaluated, revealing that the addition of natural fibers improves wear resistance, particularly in high-friction conditions. The study suggests that fiber orientation and weave structure are critical factors in enhancing the tribological properties of PLA composites, which can lead to more durable materials for mechanical and automotive applications (Kanakannavar et al., 2021). This reinforces the potential of PLA composites for demanding engineering applications where friction and wear are critical factors. Furthermore, a review on the potential of natural fiber reinforcement in PLA polymer filaments for fused deposition modeling (FDM) 3D printing emphasized the environmental and mechanical benefits of using natural fibers in PLA-based filaments. The research highlighted that fibers such as hemp, jute, and flax could significantly improve the strength and sustainability of PLA filaments, thus making them more viable for large-scale 3D printing applications (Lee et al., 2021). The study also discussed the challenges associated with fiber-matrix bonding and the need for better processing techniques to achieve optimal results.

Moreover, the characterization of carbon fiber-reinforced PLA composites revealed that the inclusion of carbon fibers improves the overall mechanical properties of PLA, particularly in terms of strength and stiffness. The research demonstrated that carbon fibers significantly

enhance the performance of PLA composites, making them suitable for high-performance applications in aerospace and automotive industries (Maqsood & Rimašauskas, 2021). This finding suggests that hybrid composites combining natural fibers and carbon fibers could offer enhanced properties for a wider range of applications. The study on kenaf fiber-reinforced PLA composites highlighted the mechanical, thermal, and morphological properties of these nanocomposites. It was observed that the kenaf fiber reinforcement improved the tensile and flexural properties of PLA, while also enhancing its thermal stability. The research also noted that the addition of kenaf fibers resulted in better dispersion and fiber-matrix interaction, which contributed to the improved overall performance of the composites (Mohd Nor et al., 2022).

Additionally, the review on PLA-based biopolymers reinforced with natural fibers discussed the various methods for improving the mechanical and environmental performance of these composites (Maheshwaran et al., 2022). The research suggested that surface modification techniques and fiber treatments could significantly enhance the properties of PLA composites, making them more suitable for diverse applications in packaging, automotive, and construction sectors (Mukherjee & Kao, 2011). Therefore, ongoing advancements in the processing and modification of these composites could lead to more sustainable alternatives to conventional materials. The comprehensive review of PLA-based natural fiber-reinforced composites highlighted their environmental benefits, such as biodegradability and reduced carbon footprint (Kamalakaran et al., 2022). The study emphasized that these nanocomposites could serve as a sustainable alternative to petroleum-based plastics, especially in packaging and consumer goods applications. However, challenges related to fiber-matrix compatibility and water absorption still need to be addressed for wider adoption (Rajeshkumar et al., 2021).

Moreover, a review on PLA-based bio-composites reinforced with natural fibers provided insights into their potential applications in biodegradable products. The study highlighted the importance of optimizing the fiber content and surface treatments to achieve desired mechanical properties while maintaining the sustainability of the composites (SathishKumar et al., 2022). The findings suggest that PLA-based nanocomposites could play a crucial role in reducing plastic waste and promoting environmental sustainability (Sahayaraj et al., 2021). The environmental impact assessment of nanocomposites made from PLA and natural fibers revealed that these composites offer significant reductions in environmental impact compared to conventional petroleum-based composites. The study found that the use of natural fibers in PLA composites significantly lowers the carbon footprint and energy consumption associated with their production, making them a more sustainable choice for various applications (Teixeira et al., 2023).

Finally, the study on nanocomposites based on PLA matrix reinforced with natural fiber fabrics showed that the type of fiber and the addition of compatibilizers influence the mechanical properties of the composites (Raja et al., 2022). The research demonstrated that PLA composites reinforced with jute fibers exhibited better mechanical performance, while the addition of compatibilizers improved the interfacial bonding between the fibers and matrix, leading to enhanced overall properties (Tham et al., 2022). This underscores the importance of material selection and processing in optimizing the performance of natural fiber-reinforced

PLA composites.

2. MATERIALS

Sisal Fiber

Sisal fibers, sourced from the *Agave sisalana* plant, are widely used in sustainable materials due to their high strength and durability. This fiber typically ranges between 80–300 μm in diameter and features an impressive tensile strength, making it suitable for reinforcement applications in nanocomposites. Sisal has a modulus of elasticity that supports its stiffness while maintaining flexibility, with an elongation at break in the range of 4–6%. This fiber also demonstrates excellent resistance to wear and moisture, qualities that enhance its utility in automotive, construction, and textile industries.

Polylactic Acid (PLA)

PLA, a biodegradable thermoplastic derived from renewable sources like corn starch or sugarcane, has gained significant interest in eco-friendly applications. Commercially available PLA grades, such as those from suppliers, possess a density of approximately 1.24–1.26 g/cm^3 . With a melt flow index (MFI) typically between 10–30 $\text{g}/10 \text{ min}$ (at 210 $^{\circ}\text{C}/2.16 \text{ kg}$), PLA provides moderate processability suitable for injection molding and extrusion. The polymer's mechanical properties include a tensile strength at yield around 50 MPa and elongation at break between 2–4%, with a glass transition temperature around 55–60 $^{\circ}\text{C}$ and melting temperature range of 145–170 $^{\circ}\text{C}$, depending on its crystalline structure.

3. Methods

Preparation of composites

The preparation of sisal fiber reinforced polylactic acid (PLA) composites involves a process that optimizes the properties of the resulting material by controlling various injection molding parameters. The sisal fiber content is varied at 1, 2, and 3 wt% levels, with an injection volume set at 50 cm^3 . The switch-over point is maintained at 12 cm^3 , while the injection pressure is adjusted to 600, 700, and 740 bars for the respective sisal fiber content levels. Holding pressure is fixed at 600 bars, and holding time is set to 20 seconds to ensure proper fiber impregnation. The cooling time is set to 30 seconds, with a back pressure of 30 bars to maintain the flow consistency. Melt temperatures of 190 $^{\circ}\text{C}$ and 205 $^{\circ}\text{C}$ are used, depending on the processing conditions, and the mold temperature is controlled at 20 $^{\circ}\text{C}$ to prevent premature solidification. This combination of parameters ensures optimal fiber dispersion, strength, and stability in the final PLA-sisal composite product.

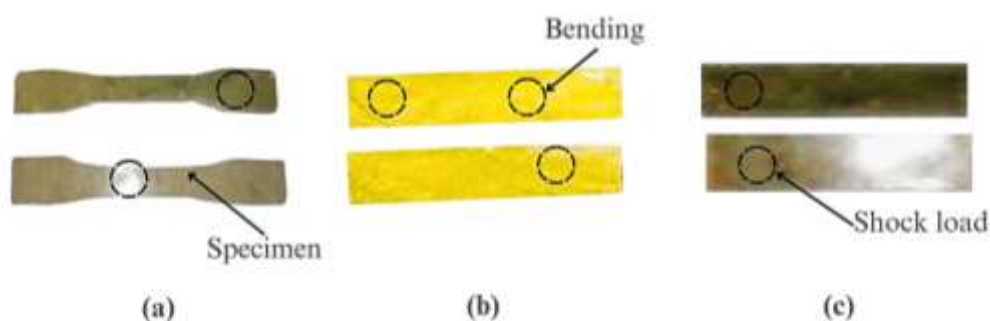
Tensile test

A tensile specimen under different loading conditions—tension, bending, and shock—demonstrates varied stress-strain responses essential for evaluating material performance. The

gauge length measured 35 mm, with an extension rate of 5 mm per minute. In tension, uniaxial stress leads to yield stress marking permanent deformation onset, while break stress represents the ultimate strength before fracture; elongation at yield indicates ductility, and elongation at break shows total tensile strain capacity. In bending, stress distribution varies across the cross-section, with compressive and tensile stresses affecting yield and fracture due to stress concentration. Shock loading involves high strain rates, often reducing ductility and increasing strength, with lower elongation at yield and break due to limited plastic deformation time, making shock resistance vital for impact-prone applications. These insights guide material selection for specific structural and dynamic uses, ensuring durability under diverse mechanical stresses.

Figure 1

Sample Tensile specimen (a) under tension (b) under bending (c) under shock load



Differential Scanning Calorimetry (DSC)

DSC is commonly applied to study the thermal properties of PLA composites, particularly to observe changes in melting temperature, glass transition temperature (T_g), and crystallization behavior. ASTM D3418 is typically used as a standard for assessing the thermal transitions of polymers. In natural fiber-reinforced PLA, the DSC results reveal how fiber incorporation affects the crystallization process, often enhancing the nucleation sites and altering the crystallization temperature. The degree of crystallinity in the PLA matrix is crucial for determining the composite's thermal stability and mechanical performance. Natural fibers typically increase crystallinity, providing improved stiffness and heat resistance in the composite, which is especially beneficial for high-temperature applications.

Dynamic Mechanical Analysis (DMA)

DMA is crucial for evaluating the viscoelastic properties of natural fiber-reinforced PLA composites, including storage modulus, loss modulus, and damping factor ($\tan \delta$). ASTM D4065 is frequently used to standardize these measurements, as it ensures consistency in testing the material's response to dynamic loading across a range of temperatures. In the case of PLA composites, DMA reveals the fiber's influence on the matrix by enhancing rigidity, as

indicated by an increase in storage modulus. Additionally, DMA can track the T_g shift, which helps assess fiber-matrix interfacial adhesion and its effect on the composite's damping properties. Strong interfacial adhesion typically shifts T_g to higher temperatures, thus enhancing composite stiffness and durability.

Scanning Electron Microscopy (SEM) Analysis

SEM analysis is indispensable for studying the surface morphology and fiber dispersion in natural fiber-reinforced PLA composites. This technique provides a detailed view of fiber orientation, distribution, and the interfacial bonding between the PLA matrix and the natural fibers. SEM images help identify issues such as fiber pull-out, matrix cracking, or voids at the fiber-matrix interface, which indicate poor interfacial adhesion and can detract from mechanical properties. SEM analysis, often referenced alongside ASTM E986 for morphology characterization, can reveal the effects of different fiber treatments (e.g., alkali treatment) on the composite's structure. Enhanced fiber-matrix bonding observed in SEM images usually corresponds with improved mechanical properties, as better adhesion minimizes stress concentrations at the interface.

Fourier Transform Infrared Spectroscopy (FTIR) Analysis

FTIR is essential for analyzing the chemical interactions within natural fiber-reinforced PLA composites, allowing for the identification of functional groups and monitoring chemical changes due to fiber addition. Using ASTM E1252 for infrared spectroscopic analysis, FTIR spectra can reveal chemical bonds present in both PLA and natural fibers, such as hydroxyl (–OH) groups in fibers, which often interact with PLA's ester groups, potentially forming hydrogen bonds. Such interactions improve interfacial adhesion, contributing to mechanical performance. FTIR can also detect any chemical modifications applied to fibers (such as silane treatments), which can reduce hydrophilicity and enhance compatibility with the hydrophobic PLA matrix, thereby improving moisture resistance and durability of the composite.

4. RESULT AND DISCUSSION

Mechanical properties

Tensile analysis

Figure 2 shows the relationship between sisal content (in weight percentage) and tensile modulus (in MPa) of a material. As sisal content increases from 0% to 3%, the tensile modulus initially decreases, reaching a minimum around 1.5% sisal content before gradually increasing again. This trend suggests that introducing sisal fibers affects the material's tensile modulus, with lower content levels slightly reducing the modulus, potentially due to initial fiber-matrix interaction issues. However, at higher sisal contents, the modulus increases, likely due to enhanced fiber reinforcement, which strengthens the material. The error bars indicate variability in the measurements, emphasizing that while there is a general trend, there is some degree of fluctuation in the tensile modulus values across different sisal content levels.

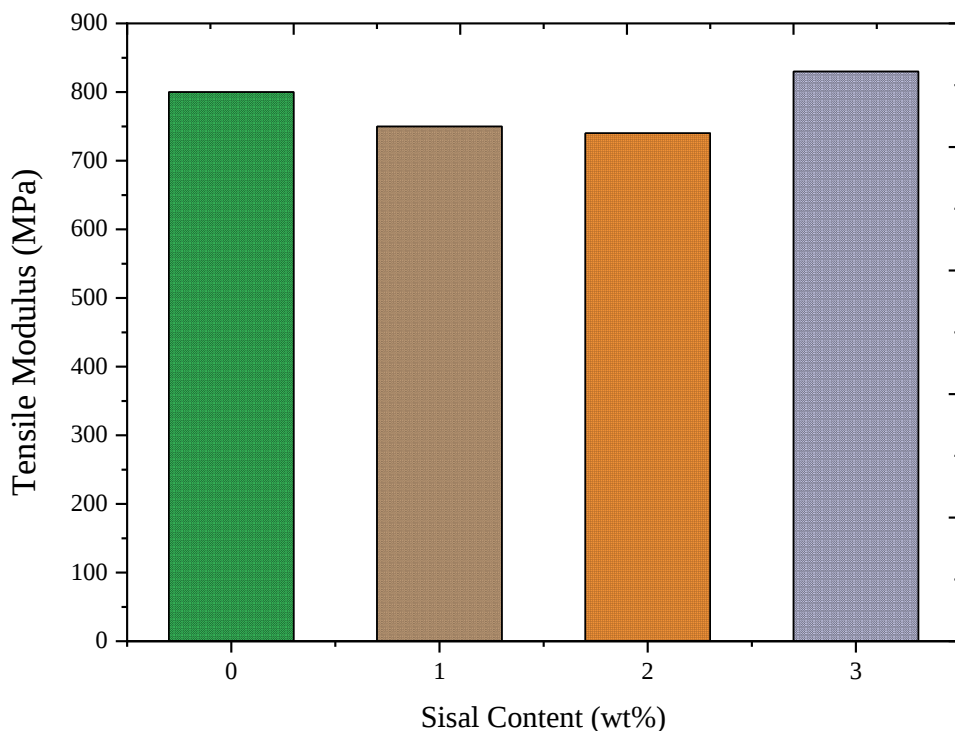
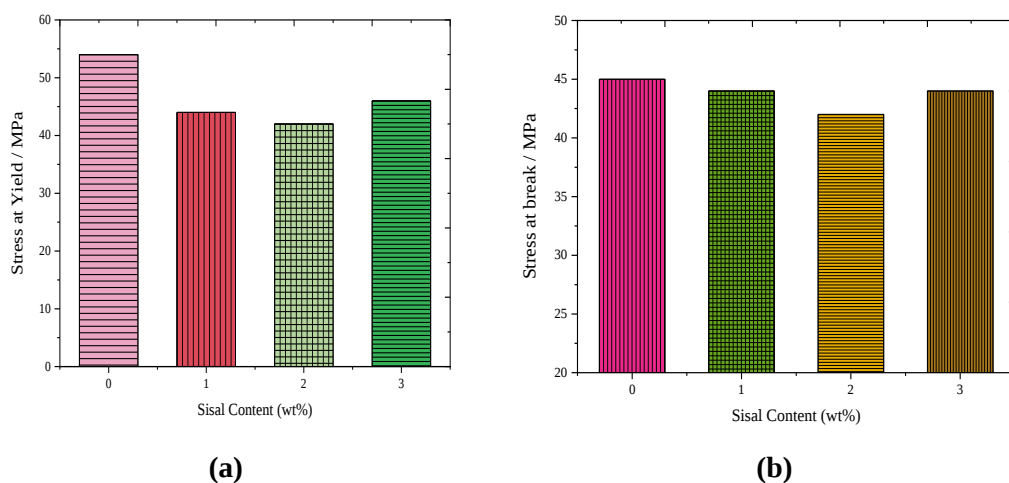


Figure 2 Impact of Sisal Fiber on PLA Tensile Properties

Stress at yield and break analysis

The tensile strength of PLA, as illustrated in the informative Figures 3 (a) and (b), exhibited a noticeable decline when the introduction of sisal fibre was implemented into the composite material. This observation suggests that the relatively small loadings of the sisal fibres were insufficient to effectively impart the desired reinforcement properties, resulting in the fibres functioning instead as defect centres that compromised the overall structural integrity due to inadequate stress transfer across the interface between the fibres and the polymer.

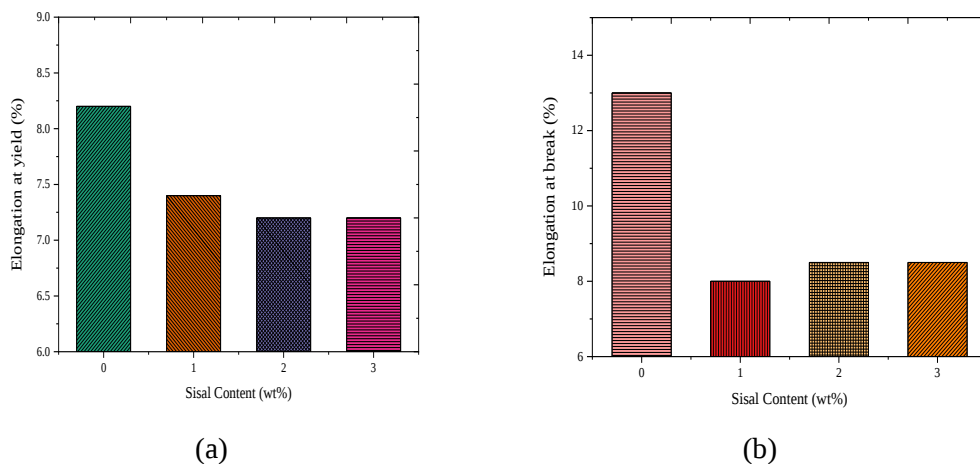
Figure 3 Effect of Sisal Fiber on (a)Yield and (b)Break Stress in PLA



The underlying reason for this phenomenon can be attributed to the lack of sufficient interfacial bonding between the reinforcing sisal fibres and the PLA polymer matrix, a conclusion that is further supported by the findings from the SEM and FTIR analyses, which indicated some level of interaction and close contact between the fibres and the PLA matrix despite the observed deficiencies in performance.

Elongation at yield and at break

Figure 4 Effect of Sisal Fiber on Elongation at (a)Yield and (b)Break in PLA



The elongation at yield, as well as the elongation at break, which can be observed in the detailed illustrations presented in Figure 4 (a) and (b), exhibited a notable decrease as the content of fibre was increased, showcasing a clear inverse relationship between these two parameters and the fibre content. This phenomenon is frequently encountered in the realm of short fibre-filled composites, as the fibres play a crucial role in restricting the ability of the

matrix to elongate, primarily by generating specific points of stress concentration that interfere with the overall material flow.

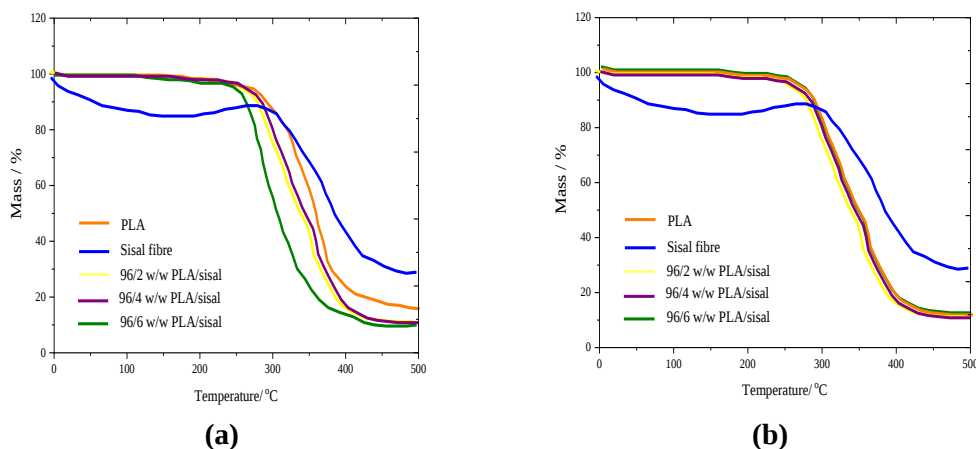
In their extensive studies focusing on polylactic acid (PLA) reinforced with microcrystalline cellulose (MCC), researchers have consistently reported a significant reduction in elongation metrics when fibres are incorporated into a thermoplastic polymer matrix, establishing this as a common trend that is widely recognized within the domain of such composite materials. The underlying reason for this notable change can be attributed to the transformation of the material's characteristics from a state of toughness to one that is distinctly stiffer, a direct consequence of the incorporation of cellulose fibre into the composite structure.

Thermogravimetric analysis (TGA)

The TGA curves (Figure 5) showcase an absence of a distinct degradation phase for sisal within the composites, likely stemming from minimal fiber presence and robust interactions between sisal and PLA. In contrast to numerous researchers' conclusions, where wood fiber compromised PLA's thermal resilience due to feeble fiber-matrix adhesion, the incorporation of sisal fiber in our investigation surprisingly elevated PLA's degradation temperature.

Figure 5

TGA Comparison of PLA and PLA/Sisal at(a) 190°C and (b)205°C



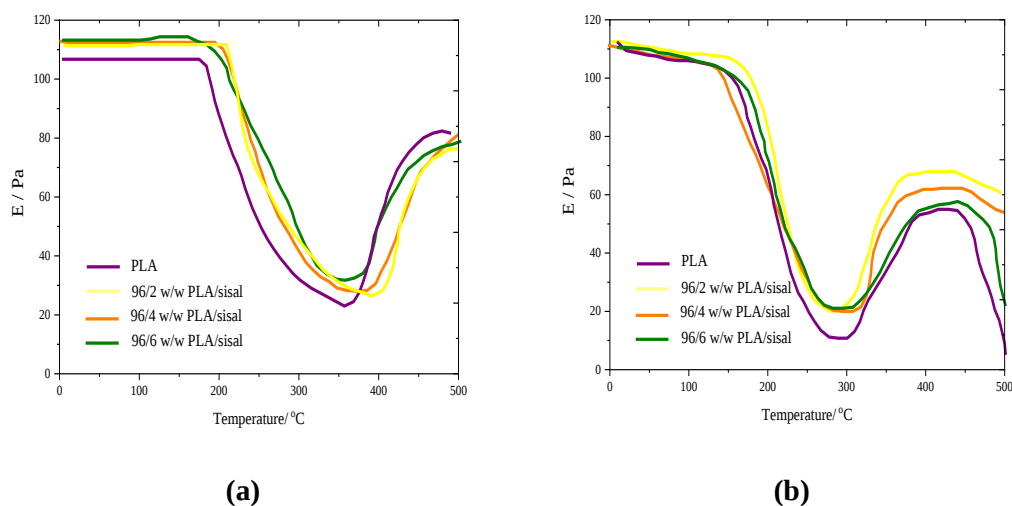
Likewise, many researchers documented that both MAPP-treated and untreated PLA/ nano composites exhibited a singular degradation phase, with neither the fiber nor the compatibilizer influencing PLA's degradation temperature, owing to the closely aligned degradation temperatures of kenaf and PLA. Nonetheless, a multitude of researchers noted that sisal fiber within PLA diminished PLA's thermal degradation by over 50 °C, a phenomenon attributed to the decline in molecular weight at elevated processing temperatures (180 °C).

Dynamic mechanical analysis (DMA)

Figure 6 unveils the intriguing impact of fluctuating sisal fiber proportions on the loss modulus (E''), damping factor ($\tan \delta$), and storage modulus (E') of PLA and its composite creations. Beneath the glass transition threshold, the storage modulus (E') of the freshly crafted PLA composites surpassed that of the pristine PLA, showcasing enhanced rigidity thanks to the infusion of fiber reinforcement. The annealed PLA specimens exhibited even loftier E' readings, attributed to the heightened crystallinity fostered by the annealing process, though the presence of fiber did not further elevate the modulus within this spectrum.

Figure 6

DMA Analysis of Storage Modulus in PLA/Sisal Composites at (a) 205°C and (b) 190°C



A drop in E' within the range of 59–63 °C for all specimens corresponds with the α -relaxation occurring in the amorphous domains of PLA. A consistent pattern in T_g was elusive for the as-prepared specimens with varying sisal content; however, the T_g of the annealed samples showed an uptick with increased fiber inclusion, hinting at the confinement of polymer chain mobility. Approaching 100 °C, E' experienced a resurgence due to PLA's cold crystallization, as revealed by DSC, while a modulus decline near 140 °C signaled the softening of samples prior to the melting phase.

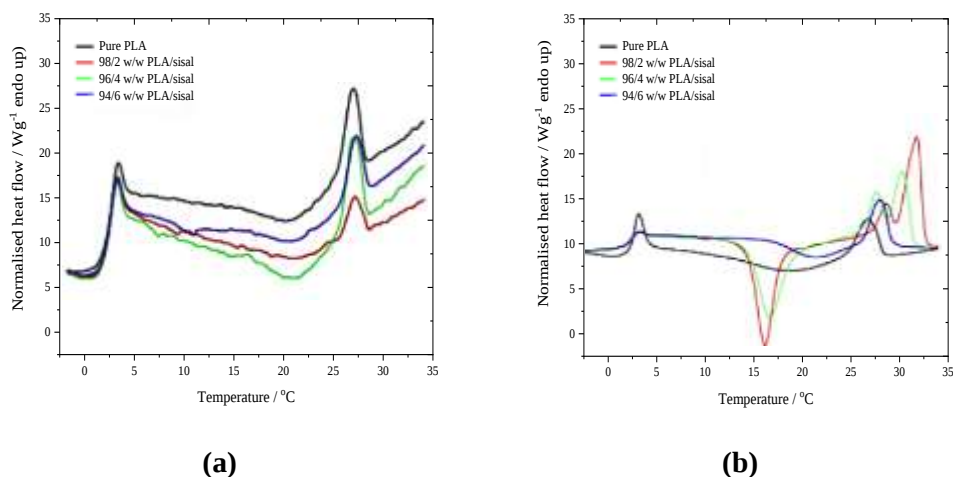
Differential scanning calorimetry (DSC)

DSC outcomes (Figure 7) for both the freshly crafted and thermally treated PLA and PLA/sisal composites at 205 °C and 190 °C reveal a peculiar phenomenon where the glass transition temperature drops as fiber content rises in the as-prepared specimens, an intriguing behavior potentially attributed to the fibers functioning as a plasticizer in smaller amounts or experiencing some degradation at elevated temperatures. In the freshly crafted samples, cold crystallization around 130 °C remains largely unperturbed by the presence of sisal, while the

melting temperature (T_m) exhibits a slight uptick, hinting that sisal fibers might act as nucleation sites.

A solitary melting peak was detected, signifying a singular crystalline architecture within these composites. In the thermally treated specimens, the glass transition, cold crystallization, and melting events are distinctly observable, with the glass transition displaying a pronounced hysteresis peak typical of semicrystalline polymers. The intensity of this peak lessens with the incorporation of sisal fibers, indicating alterations in the polymer's amorphous domain. The glass transition temperature in the thermally treated samples surpasses that of the freshly prepared ones, likely a result of the formation of more refined crystals through annealing, which curtails the mobility of amorphous segments by serving as physical crosslinking points.

Figure 7 Effect of Temperature on DMA Storage Modulus of PLA/Sisal at (a) 205°C and (b) 190°C



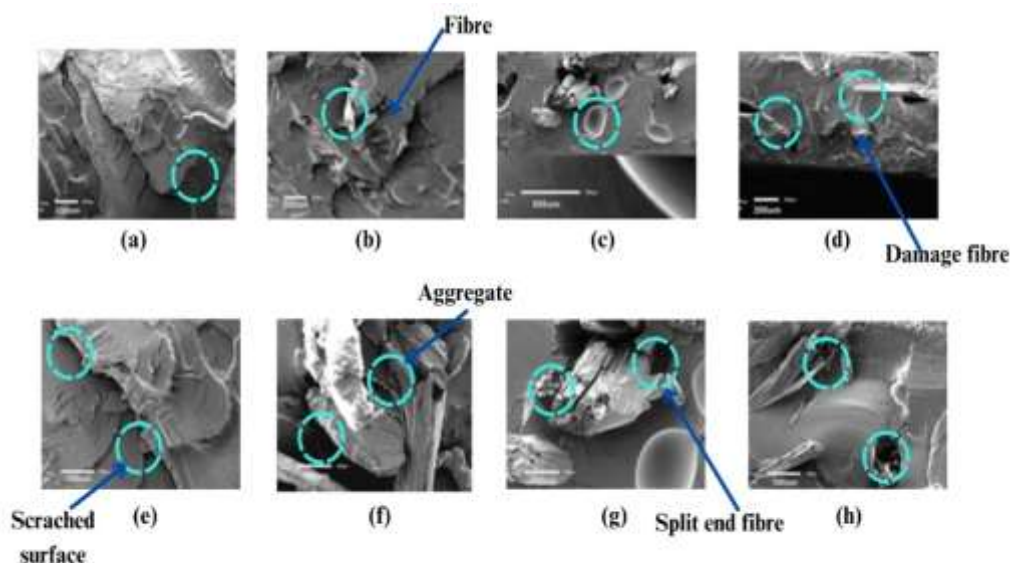
Morphological analysis

SEM

The scanning electron microscopy (SEM) micrographs of the fracture surfaces at varying magnifications (100x and 300x) reveal the structural features of different PLA composites. The PLA sample (a, b) exhibits smooth, relatively uniform fracture surfaces, with minimal signs of fiber reinforcement. In contrast, the 99/1 w/w PLA/sisal composite (c, d) shows a more textured surface with the initial signs of sisal fiber incorporation, which improves the roughness and mechanical interlocking at the interface.

Figure 8

SEM Micrographs of PLA and PLA/Sisal Composites at Various Magnifications (100x, 300x)

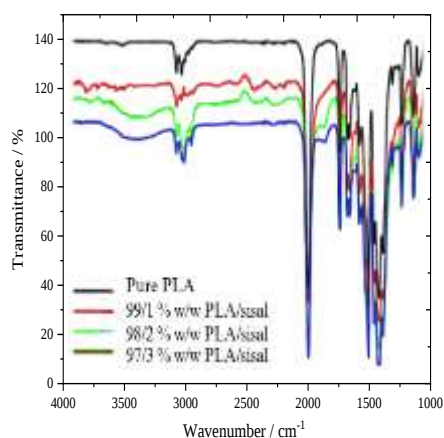


The 98/2 w/w PLA/sisal composite (e, f) displays a more pronounced interaction between the fibers and the matrix, with enhanced fiber pull-out and debonding effects, suggesting stronger bonding. The 97/3 w/w PLA/sisal composite (g, h) reveals a more pronounced fracture surface with larger fiber pull-out regions, indicating a further increase in fiber content that may influence the overall matrix-fiber adhesion and composite strength. These micrographs highlight the progressive reinforcement and mechanical properties of PLA-sisal composites with increasing sisal content.

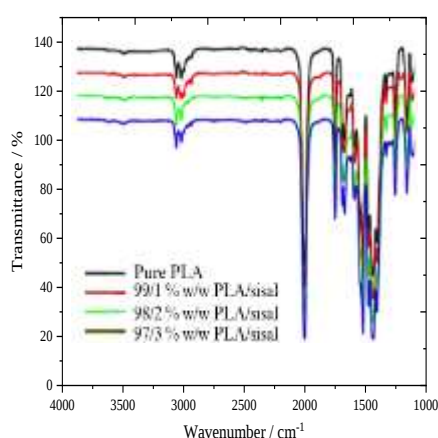
Fourier transform infrared (FTIR) spectroscopy

Figure 9 illustrates the FTIR spectra of PLA and its composites at varying sisal content. Figure 9 (a) presents the FTIR spectra of PLA and its composites with 2, 4, and 6 wt% sisal content, showcasing characteristic peaks corresponding to PLA's functional groups, along with changes attributed to the incorporation of sisal fibers. The intensity and shifting of certain peaks, such as those related to C-H stretching and ester bonds, indicate modifications in the chemical structure due to fiber reinforcement. The annealing process results in subtle shifts and intensity variations in the spectra, particularly in the regions associated with polymer crystallinity and fiber-matrix interactions, reflecting the thermal treatment's impact on the material's chemical and physical properties. These spectra confirm the influence of sisal content and annealing on the composite structure.

Figure 9 FTIR spectra of PLA and its composites with varying sisal content (a) 2, 4, and 6 wt%; (b) annealed composites with 1-3 wt%.



(a)



(b)

5. Conclusion

This study explored the development and characterization of PLA/sisal and PP/sisal nanocomposites, analyzing their mechanical and thermal properties to assess suitability for sustainable applications. The findings highlighted that the inclusion of sisal fibers in PLA and PP matrices enhances certain mechanical properties, offering promising potential for industrial uses. Tensile testing demonstrated that sisal fiber content moderately influences the tensile modulus, especially at lower percentages, with PLA composites maintaining a high modulus due to their intrinsic rigidity. However, increased sisal content in PLA composites slightly reduced the tensile strength, as observed in stress-yield and stress-break analyses, signifying a trade-off between stiffness and tensile strength. These observations suggest that for applications where stiffness is crucial, sisal reinforcement in PLA composites can be beneficial, though careful consideration of fiber content is necessary to optimize mechanical performance. Thermal analysis through TGA and DSC showed that sisal-reinforced PLA and PP composites possess improved thermal stability and delayed degradation compared to neat PLA or PP, which enhances their performance at elevated temperatures. The TGA analysis confirmed that the onset degradation temperature increased with sisal content, indicating improved thermal durability. DMA further revealed enhanced thermo-mechanical stability in PLA/sisal composites, particularly in their glass transition and melting behaviors. Additionally, FTIR and SEM analyses provided insights into the molecular structure and morphology of the composites, showing uniform fiber dispersion and strong interfacial bonding with the matrix. The study concludes that PLA and PP reinforced with sisal fiber have considerable potential in applications demanding high mechanical stability and thermal resistance, marking them as sustainable alternatives for automotive, construction, and other eco-friendly industries.

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