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Material characterization and mechanical performance study on natural particulates of *Saccharum spontaneum* reinforced biodegradable polymeric composite

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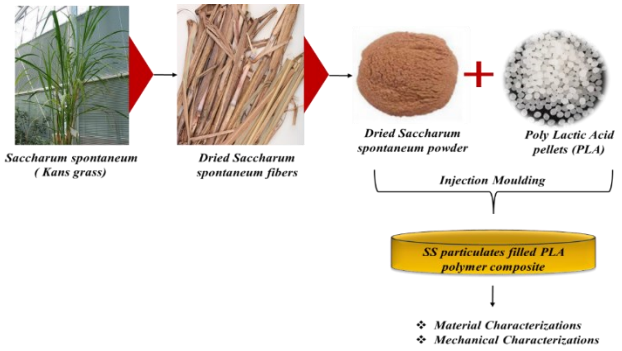
Graphical abstract



Abstract

The present work investigated the biodegradable polymer composite through the injection molding method. The matrix material of polylactic acid (PLA) and reinforcement particulates of novel Saccharum spontaneum (SS) were incorporated into the polymer matrix in the range of 5 % to 25 %. In addition to this study, Field Emission Scanning Electron Microscopy (FE-SEM), Fourier Transform infrared spectroscopy (FTIR), and X-ray diffraction analysis (XRD) were used to examine the structural and morphological analyses of a green polymer composite. Mechanical characteristics such as tensile strength, compressive strength, flexural strength, and shore D hardness have been studied. The soil degradation test and water absorption study were conducted as per the standards. The results showed that compared to pure PLA composite, the 25 wt. % SS-filled PLA composites showed better mechanical properties of tensile, flexural, compressive, and Shore D hardness at 87.41 MPa, 86.20 MPa, 86.4 MPa, and 91.4 SHN, respectively. Thus, the developed novel composite has a potential impact on low-speed applications. The excellent biodegradation property was confirmed with the help of a soil degradation test and water absorption study.

Keywords: Poly-lactic acid, *Saccharum spontaneum*, Mechanical Properties, Soil degradation, Water absorption.

1. Introduction

PLA (Polylactic Acid) polymer composites reinforced with natural fibers have gained significant attention recently due to their eco-friendly nature and potential applications in various industries. PLA is the matrix in these composites, a biodegradable and renewable thermoplastic derived from natural resources such as corn starch or sugarcane. Natural fibers from plants like jute, kenaf, hemp, sisal, or wood are incorporated as reinforcing materials, enhancing the composite's mechanical properties. Combining PLA and natural fibers results in lightweight, biodegradable, and sustainable materials, making them an attractive alternative to conventional petroleum-based plastics. These composites find applications in automotive components, packaging materials, construction, and consumer goods, contributing to the growing demand for environmentally friendly materials in the modern world. This study developed a green composite comprising high-density polyethylene (HDPE) and Kaans grass (Saccharum spontaneum). The composites were prepared using the melt-mixing method, incorporating Kaans grass in powder form (KG-filler) at maximum loading. Maleic anhydride grafted polyethylene was used as a compatibilizer, enhancing interaction between the base polymer matrices and KG-fillers. Morphological studies revealed strong interaction, leading to improved mechanical and thermal properties up to a loading of 10 parts per hundred parts of resin (phr) of KG-filler. Water absorption tests showed a moderate weight increase at higher KG-filler loadings. Thermogravimetric analysis (TGA) and melt flow index (MFI) studies demonstrated retained thermal stability and flow properties in the HDPE/KG-filler composite at lower filler loadings (Barman *et al.* 2015b).

The SS was utilized in the creation of a polymer green composite within a polypropylene matrix, aided by a malic

anhydride grafted compatibilizer. Thermal analysis indicated minor changes in thermal stability at higher KG-filler loads, while significant improvements were noted in tensile and impact strength. Enhanced mechanical properties were evidenced by increased storage and loss moduli, and the consistent damping factor (tan δ) aligned with the base polymer. Strong polymer-filler interfacial adhesion was confirmed through FT-IR peaks and morphological analyses. Melt flow tests demonstrated favourable processability with 60 parts per hundred parts of resin (phr) KG-filler content (Barman *et al.* 2015a). Previous study demonstrates that incorporating nano-SiO_2 particles enhances the interface between the PLA matrix and jute, improving mechanical properties and thermal stability. Adding SiO_2 enhances interfacial adhesion and raises the material's glass transition temperature. The study also analyses how nano-SiO_2 particles contribute to toughening in the jute/PLA composite (Song *et al.* 2022). The coupling agent's and the toughener's combined influence on the composite's morphology, mechanical properties, and thermal behaviour was assessed. By incorporating 1,2,3,4-butane tetracarboxylic acid and treating the recycled fibers with silane, the strength of the composite was enhanced by 30%. Additionally, the elongation at break and impact strength of the composite increased by 3 times and two times, respectively (Moslehi *et al.* 2022).

A sustainable method was developed to isolate microcrystalline cellulose (MCC) from SS. The process involved alkaline delignification, chlorine-free bleaching, and acid hydrolysis treatments. Utilizing Taguchi orthogonal L9 design, the acid hydrolysis conditions were optimized, resulting in an MCC yield of 83% with a minimal acid concentration of 5% H_2SO_4. This eco-friendly approach offers superior environmental benefits, low corrosiveness, reduced effluent production, and cost-effectiveness. The obtained MCC displayed excellent crystallinity and thermal stability, making it a promising precursor for high-quality polymer biocomposites in diverse applications (Baruah *et al.* 2020).

Using SS (Kans grass) fibers as potential reinforcement material in polymer composites. The fibers were extracted and treated with different alkali concentrations (3 wt%, 5 wt%, and 7 wt%) to enhance their properties. Various analyses were conducted on untreated and treated fibers, including FTIR spectroscopy, SEM, XRD, AFM, mechanical testing, and TGA/DTG. Different methods were employed to determine activation energy and thermal kinetics. The 5% alkali-treated fibers showed significant improvements in activation energy, mechanical properties, crystallinity index, surface roughness, and thermal stability compared to untreated fibers (Devnani and Sinha 2019).

The green composites based on corn starch composites were developed and reinforced with graft copolymers of SS fiber and methyl methacrylates (MMA), both alone and in combination with acrylamide (AAm), acrylonitrile (AN), and acrylic acid (AA). The composites, cross-linked with resorcinol–formaldehyde, exhibited enhanced physico-chemical, thermal, and mechanical properties compared to natural corn starch. Biodegradation studies using the soil composting method showed that the composites were more thermally stable than the original corn starch. The SS-based fiber-reinforced composites displayed superior tensile strength. At the same time, Ss-g-poly (MMA) reinforced composites exhibited maximum compressive strength and wear resistance among all the tested materials (Kaith *et al.* 2010) from the wasteland weed Saccharum spontaneum through chemical activation with $ZnCl_2$. The research demonstrated that the impregnation ratio and carbonization temperature significantly influenced the activated carbon's surface area and yield percentage. Various analytical techniques, including FTIR, XRD, Raman spectroscopy, SEM, and HR-TEM, were employed to characterize the surface morphology of the samples. The study confirmed the suitability of the synthesized activated carbon samples for energy storage applications (Samantray and Mishra 2020). Another previous study investigates the extraction, characterization, surface treatment, and thermal analysis of lesser-known natural fibers from various global regions. Unlike conventional fibers like Bagasse and Coir, this research focuses on unconventional sources. The goal is to offer in-depth knowledge of these unique fibers' extraction methods, treatment processes, and properties for effective use in polymer composites. Special attention is given to thermal analysis and activation energy evaluation, which are crucial for thermal stability. This research addresses existing literature gaps, consolidating information on these rare natural fibers (Jaiswal *et al.* 2022).

This study explores eco-friendly composites made from corn starch, cross-linked with resorcinol-formaldehyde (Rf), and reinforced with graft copolymers of Saccharum spontaneum L (Ss) and methyl methacrylates (MMA), with or without acrylamide (AAM), acrylonitrile (AN), and acrylic acid (AA). The composites, processed using microwaves, exhibited enhanced thermal stability and superior physico-chemical and mechanical properties compared to natural corn starch. Notably, Ss-g-poly(MMA)-MW reinforced composites showed improved tensile strength, while Ss-g-poly(MMA þ AA)-MW reinforced composites displayed superior compressive strength and wear resistance. The study also analysed biodegradation stages during soil composting using FT-IR and SEM techniques(Maiti *et al.* 2010). The wood pulp fiber-reinforced polylactic acid (PLA) biocomposites were prepared and compared with glass fiber-reinforced polypropylene. The biocomposites exhibited mechanical properties comparable to commercial materials reinforced with 20% glass fiber by achieving proper dispersion through pre-extrusion and injection processing. Strong interfacial bonding between PLA and pulp fibers was observed, with an interfacial shear strength of approximately 29 MPa and intrinsic tensile strength of fibers at 729 MPa. These results indicate that biocomposites are a reliable and eco-friendly alternative to petroleum-based matrices reinforced with mineral fibers (Tarrés *et al.* 2022). This study focused on glass fiber (GF) reinforced poly(lactic acid) (PLA) composites, exploring the effects of incorporating an impact modifier and chain extender on their properties; the research aimed to improve the interface between GF and PLA, enhancing

crystallinity and mechanical performance. The quaternary composite, incorporating impact modifier and chain extender, exhibited a remarkable increase in crystallinity, impact strength, and flexural modulus by 58%, 63%, and 66%, respectively. Simultaneous impact modification and chain extension reduced damping and effectiveness coefficients, indicating enhanced properties in the reinforced PLA composites (Akindoyo *et al.* 2021) (Royer *et al.* 2017). The thermal behaviour and water absorption properties of polylactic acid (PLA) and starch composites were studied. The thermal properties were analysed through differential scanning calorimetry, and water absorption characteristics were evaluated. Scanning electron microscopy was used to study the composite morphology.

The research demonstrated that wheat starch can be successfully incorporated into a PLA matrix at 10% without processing issues. Blends of wheat starch/PLA with 10% starch and 2% MDI showed comparable tensile strength, elongation, and impact strength properties to raw PLA. Additionally, adding 10% glycerol and 2% MDI resulted in a flexible material in the presence of PLA and starch blends (Silva *et al.* 2011). The extensive review explores blending polylactic acid (PLA) with natural fibers to enhance properties such as thermal stability, water resistance, crystallization, mechanical strength, antimicrobial characteristics, and biodegradability. Incorporating natural fibers reduces production costs and leads to competitive commercial products used across various industries. The paper discusses PLA synthesis, applications, and manufacturing methods for composites, emphasizing the influence of different natural fibers on PLA-based composites' unique properties. The review aims to comprehensively understand PLA-based bio composites for academics, industry professionals, and researchers (Rajeshkumar *et al.* 2021). This study focuses on the tensile properties of polylactic acid (PLA) composites reinforced with untreated and flexible epoxy-treated bamboo fiber, vetiver grass fiber, and coconut fiber. The stiffness of untreated composites increased with higher fiber content, although tensile strength decreased. Flexible epoxy treatment reduced stiffness but significantly improved tensile strength, especially in bamboo fiber and coconut fiber-reinforced composites. However, the effect on tensile strength varied based on the type of natural fiber. Bamboo fiber demonstrated the most significant improvement, making it the most effective reinforcement compared to vetiver grass and coconut fiber (Sujaritjun *et al.* 2013).

Two approaches regarding using natural fibers in polylactic acid (PLA) composites were explored to investigate the fiber treatment. Firstly, the mitigation of fiber-induced PLA hydrolysis can be achieved through thorough fiber drying before melt compounding and, to a lesser extent, through alkaline treatment of the fibers. Secondly, if the objective is to promote faster biodegradation of biocomposites, natural fibers can be harnessed to accelerate the composite's breakdown in the environment (Mazzanti *et al.* 2020) The study demonstrates the beneficial impact of CC (calcium carbonate) fillers in an HDPE (high-density polyethylene) matrix, with optimal reinforcement observed at 20 wt.% % CC filler content. While the thermal degradation behaviour remains largely unchanged, the presence of CC fillers affects the initial degradation temperature. Various ingredients undergo depolymerization and dehydration, resulting in distinct endothermic peaks in the DSC (differential scanning calorimetry) curve. Based on these findings, a partial eco-composite with 20 wt.% CC filler was chosen to develop cloth clip products (Ayyanar *et al.* 2022). These composites are suitable for applications where high strength is not the primary requirement (Balaji Ayyanar *et al.* 2023). In vitro biocompatibility testing revealed excellent cell viability, making the EtO-sterilized 30 wt.% HDPE/LC composite a promising biomaterial for medical implant applications. However, mild cytotoxicity was observed at higher MG-63 cell line concentrations (Chinnappan *et al.* 2022). This experimental study investigated biodegradable polylactic acid (PLA) composites reinforced with elephant grass fibers. Composites were prepared with different weight fractions of untreated and treated fibers using injection moulding. Treated elephant grass/PLA composites exhibited significantly higher tensile and flexural strengths than those with treated jute/PLA, sisal, and plain PLA. Additionally, the impact strength of composites with untreated elephant grass, sisal, and jute fibers was substantially higher than plain PLA. Water absorption rates increased with higher fiber content but reduced after successive alkali treatment on the fibers (Gunti *et al.* 2018). The biodegradation behaviour of blends containing poly(3-hydroxybutyrate-co-4-hydroxybutyrate) [P(3HB,4HB)] and poly(lactic acid) (PLA) were investigated in real soil environments. The research shows that P(3HB,4HB) and P(3HB,4HB)/PLA blends can biodegrade under natural soil conditions through appearance analysis, SEM, FTIR, and elemental analysis of degraded residues. The blends also show varying degradation rates in different soil depths (Weng *et al.* 2013). Biocomposites were created using a melt-mixing technique and compression moulding. The study examined mechanical properties (tensile, flexural, and impact strengths) and characteristics like thickness swelling (TS), moisture content (MC), and water absorption (WA). SEM analysis explored microstructures and interfacial bonding between the PLA matrix and oil palm empty fruit bunch (DPF) fibers at 40 wt.% DPF content, TS, MC, and WA increased by 4.10%, 4.95%, and 8.22%, respectively. Although mechanical properties decreased with higher DPF content, the study suggests these technologies could find use in non-structural applications under waste management initiatives (Awad *et al.* 2023; Ayyanar *et al.* 2023)

1.1. Current research work

After an extensive literature review, the present study selected poly-lactic acid (PLA) polymers and SS (SS particulates) to improve the mechanical strength of PLA polymer composites using natural particulates. The composites were manufactured using vertical injection moulding, with samples prepared at different weight percentages. Various characterization techniques, including FTIR, XRD, and FESEM analyses, were employed to study the composite structure. Mechanical properties

such as tensile, compressive, flexural strength, and Shore D hardness were assessed. Furthermore, the biodegradation of the composites was investigated through soil degradation and water absorption experiments.

2. Materials and methods

S. Spontaneum (SS) as reinforcement material collected from the wasteland weeds within the Coimbatore Institute of Technology campus, Coimbatore. The fibers were manually extracted from the SS plant. The composite matrix material of polylactic acid (PLA 2003D) was procured from Nature Tech Pvt Limited, with a density of approximately 1.25 g/cm3 and a melting temperature range between 165°C and 175°C. Then, collected SS fibers were allowed to be dried and converted into powder particles. These SS particles were processed for reinforcement purposes to the PLA matrix. The research workflow is depicted in Figure 1.

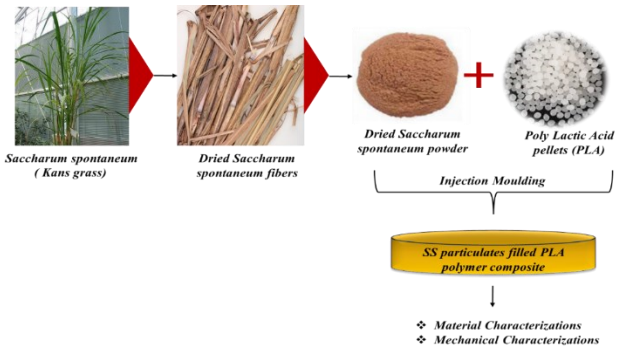


Figure 1. Flow of research methodology for current work.

2.1. Development of SS-filled PLA composites

The SS fiber leaf was chopped down and washed with double distilled water to eliminate contaminants, and the fiber was dried at room temperature for ten days until totally dry. The mechanical mixer milled 1 kg of dry S. spontaneum fiber into powder at 1500 rpm. To make the composites, matrix material PLA is reinforced with different weights. The percentage of SS particles is in the order of 5%, 10%, 15%, 20%, and 25%. Each weight % of mixes was warmed for approximately 10 minutes at 100°C before being placed in the heating chamber to be heated further. To manage the melting of the matrix, injection moulding temperatures of 110°C were selected.

The injection moulding temperature range of 65 bar was maintained as operating pressure during the injection process. The hopper was loaded with PLA pellets and S. spontaneum fiber powder particles. The material enters the injection barrel after passing through the hopper. The barrel is divided into heating zones that may be regulated independently. Semi-melted polymer mixtures were injected into mould cavities in the die and promptly withdrawn. By raising the S. Spontaneum fiber content in the PLA matrix more than 20%, SS fillers are burned during moulding. Due to these constraints, fillers were introduced up to 25% by weight in the PLA matrix.

2.2. Material Characterization and Mechanical Testing

Analytical Material characterizations of FESEM, FTIR, XRD, and Mechanical strength tests of tensile, compressive, flexural, and shore D Hardness were performed to evaluate the SS-filled PLA composite performance characteristics for industrial and household applications.

2.2.1. FESEM with EDAX analysis

The surface morphology of the SS-filled PLA composites was examined using a field emission scanning electron microscope (FESEM) model Zeiss Ultra Plus from Gemini Co. The FESEM operated at a 10 kV accelerating voltage. Energy-dispersive X-ray (EDX) analysis was conducted to determine the elemental composition and chemical analysis of materials with specific atomic numbers.

2.2.2. Fourier-transform infrared spectroscopy (FTIR)

FTIR analysis detected various functional groups in the SS-filled PLA composites. This analysis was performed using the NEXUS-870 FT-IR Spectrometer. The infrared spectrum was recorded in transmittance mode with a resolution of 5 cm^{-1}, spanning a range from 50 cm^{-1} to 4000 cm^{-1}.

2.2.3. X-ray diffraction (XRD)

The crystalline structure of the SS-filled PLA composites was examined using a Bruker diffractometer (AXS D8) equipped with Cu-K radiation (λ = 1.5406). The diffractometer operated at a voltage of 40 kV and a current of 30 mA. Composites specimens were scanned continuously within an angle 2θ range of 10° to 80°C at a rate of 0.5°per minute.

2.2.4. Mechanical characterization

The mechanical properties of SS-filled PLA composite specimens were assessed through tests including tensile, flexural, compressive, and hardness evaluations. Tensile, flexural, and compressive strengths were determined using a Universal Testing Machine (UTM) at a 3 mm/min cross-head speed and operated at room temperature. Each test was conducted six times, and the average values were recorded. Tensile tests were performed according to ASTM D638 standards with a span length of 90 mm, gauge length of 40 mm, thickness of 3 mm, and width of 7 mm. Compressive tests followed the ASTM D695 standard with a diameter of 12.5 mm and a length of 25 mm. Flexural tests adhered to ASTM D790 standard with a span length of 80 mm, width of 13 mm, and thickness of 3 mm. The hardness of composite specimens was measured using a Shore-D durometer (Ayyanar *et al.* 2022)

2.2.5. Soil Degradation test

The biodegradation assessment of the SS-filled PLA composite followed the soil burial method. Initially, a desiccator was filled with natural soil to a height of 5 cm. Equal-sized SS-filled PLA composite samples were weighed and placed inside the desiccator, where the soil moisture level was maintained by regular watering. The degradation rate of the composites was recorded at intervals from the 8th to the 16th hour. Subsequently, the composite samples were retrieved from the soil, cleaned with distilled water, and their weights were recorded. Photographs were taken to document the appearance of the buried samples in their natural environment. The weight loss percentage was calculated using the following formula: (1).

$$\text{Weight loss}(\%) = \frac{(\text{residual mass-initial mass})}{\text{Initial mass}} \times 100 \quad (1)$$

The specimens were carefully cleaned with tissue paper and weighed using a precision balance machine. Subsequently, they were placed in an oven set at 50°C for 3 hours to eliminate moisture and soil residue.

2.2.6. Water absorption test

Following ASTM D 570 1998 guidelines, the SS-filled PLA composites were placed in distilled water at room temperature for 120 days to investigate their water absorption characteristics (Barman *et al.* 2015b). Before the experiment, the SS-filled PLA composites were dried in an oven at 70°C for 24 hours and weighed precisely. Subsequently, they were submerged in clean water, and at 24-hour intervals, the composite samples were removed from the water bath and dried with tissue paper. The water absorption of each composite specimen was determined by weighing it. The composites were regularly assessed until they reached the saturation point of water absorption percentage after 120 days. Notably, there was no further increase in water absorption after the 60th day. The water absorption percentage was calculated using the following Equation (2),

$$\text{Water absorption rate}(\%) = \frac{(\text{Wi} - \text{Wo})}{\text{Wo}} \times 100 \quad (2)$$

Where Wi denotes the dry weight of the composite, the composites weight after being submerged in water is represented by "W_0."

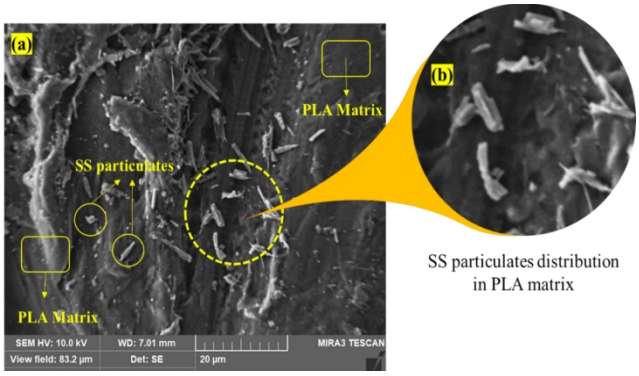


Figure 2. FESEM morphology for SS-filled PLA composite

3. Results and discussion

3.1. FESEM with EDAX analysis

The surface morphology of the SS particulate-filled PLA composite was examined through FESEM analysis, depicted in Figure 2. The micrographs confirmed the effective mixing and uniform distribution of SS particulate reinforcement within the PLA matrix. Notably, minimal agglomeration of SS particulates was observed, and this phenomenon had no adverse impact on the strength of the polymer composites. The FESEM analysis displayed a consistent blend of the PLA matrix and SS reinforcement particulates, as evident in Figure 2. The presence of particle clustering within the matrix was also evident in the FESEM analysis of the SS particulate-filled PLA polymer composite sample. Figure 3(a–c) illustrates the typical tensile fracture occurring in the region of SS particle agglomeration. Moreover, the complete bonding during the injection moulding process was observed in Figure 4, indicating that the polymer composite exhibits less ductile properties than pure PLA polymer material.

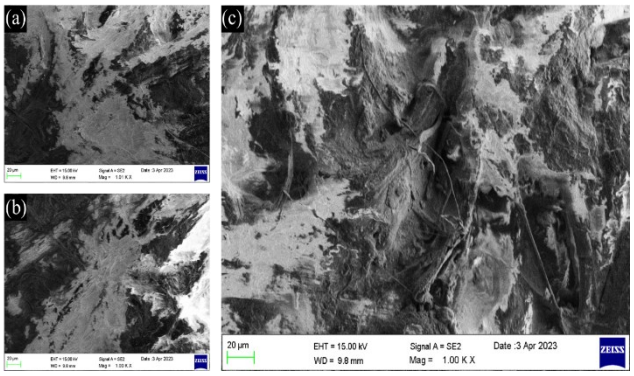


Figure 3. FESEM morphology for fracture surface of SS-filled PLA composite

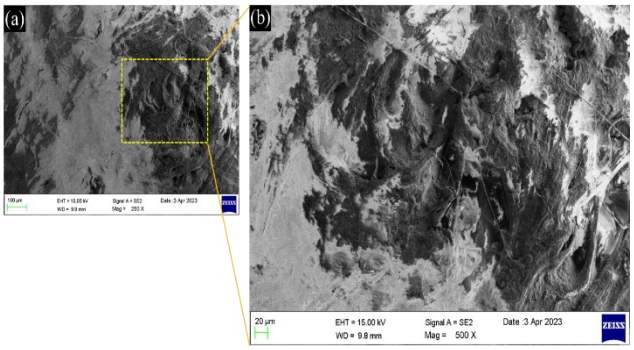
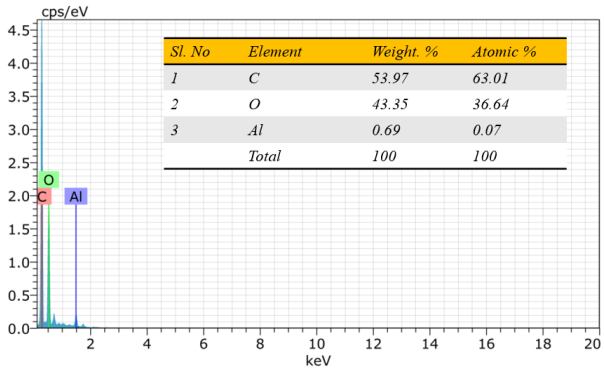


Figure 4. FESEM observation of cross-sectioned composite sample at (a) 200X and (b) 500X magnifications



Sl. No	Element	Weight. %	Atomic %
1	C	53.97	63.01
2	O	43.35	36.64
3	Al	0.69	0.07
	Total	100	100

Figure 5. EDAX elemental analysis of SS-filled PLA composites

EDAX analysis was conducted to determine the elemental composition of the SS particulates-filled PLA developed in this study. The EDAX spectrum of the composite is displayed in Figure 5. The analysis revealed the presence of three main chemical elements in the SS-filled PLA composite: oxygen, carbon, and aluminium. The weight percentage of carbon content was approximately 53.97 %, while oxygen accounted for about 43.35 %. The remaining 0.69 % of the weight percentage was attributed to aluminium content. The atomic weight percentages of carbon, oxygen, and aluminium were 63.01%, 36.64%, and 0.07%, respectively.

3.2. FTIR analysis

The functional group of the fabricated SS-filled PLA composite has been determined using FTIR spectroscopy. Figure 6 shows the PLA polymer spectra and the varied weight percent of SS-particle-filled composite samples. The carbon-hydrogen bonded C-H stretching is responsible for the unique peak in pure PLA that can be found at 2985 cm^{-1}. The C–H symmetric and asymmetric stretching of saturated aliphatic compounds, which correspond to the aliphatic moieties of cellulose and hemicelluloses, can be identified by the peak at 2213 cm^{-1} in SS filler. This peak is characteristic of saturated aliphatic compounds' C–H stretching. The peaks shown in the composites at a frequency of 2857 cm^{-1} are due to C–H stretching in the saturated aliphatic compounds included in the SS-filler.

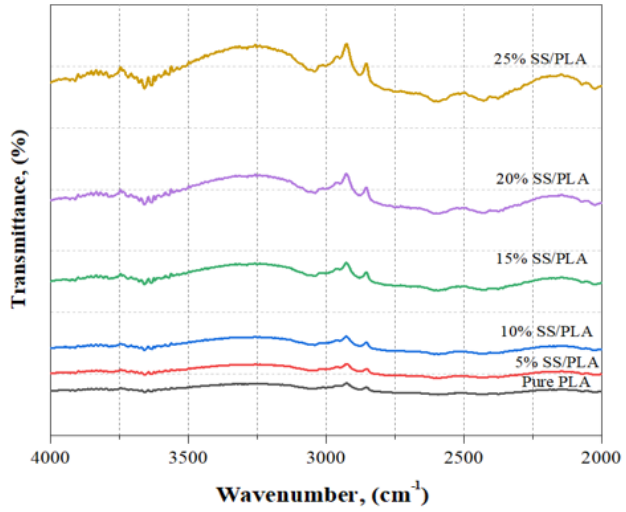


Figure 6. FTIR spectrum of SS-filled PLA composites

3.3. XRD analysis

The XRD technique determines the crystal nature of a composite material. The XRD peak between 20° and 30°, as illustrated in Figure 7, is obtained from the XRD test results. It confirmed the presence of a PLA polymer matrix with an (hkl) parameter of (100). The sharp peak observed in the samples at the 2Θ value 47.2 confirms the PLA polymer. A slight shift was observed in the sharp peaks, which helped to confirm the incorporation of SS particulates in the PLA polymer composite. The sharp peaks observed during the investigation confirmed the complete crystallization of the polymer composite. Hence, the developed composite has excellent crystallinity.

3.4. Tensile strength

The tensile strength and tensile modulus of the SS-filled PLA composite are shown in Figure 8. The tensile strength of the SS-filled PLA composite found were 55.5 MPa, 53.4 MPa, 68.3 MPa, 81.1Mpa, and 87.9 MPa, respectively, for pure PLA, 10 wt.% SS loaded PLA composite, 15 wt% SS loaded PLA composite,20 wt.% SS loaded PLA composite and 25 wt.% SS loaded PLA composite. Strong hardness values interfacial interaction between the hydrophilic filler and the hydrophobic matrix with increased filler content, increasing the interfacial area and improving tensile strength. The maximum tensile strength was 25 wt.% of SS/PLA (87.9 MPa) compared with the 5 to 20 wt% of SS /PLA composite.

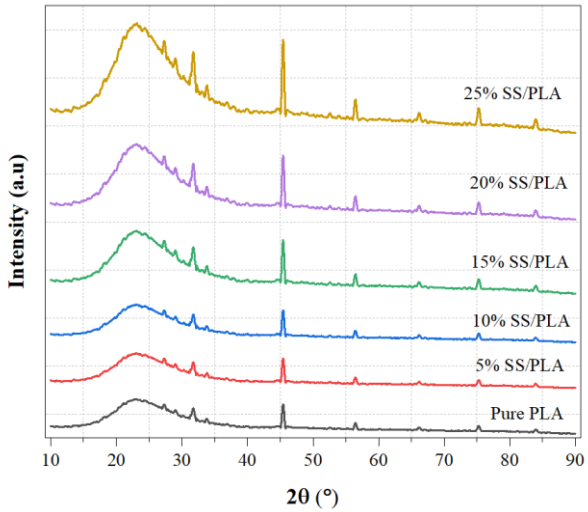


Figure 7. XRD pattern of SS-filled PLA composites

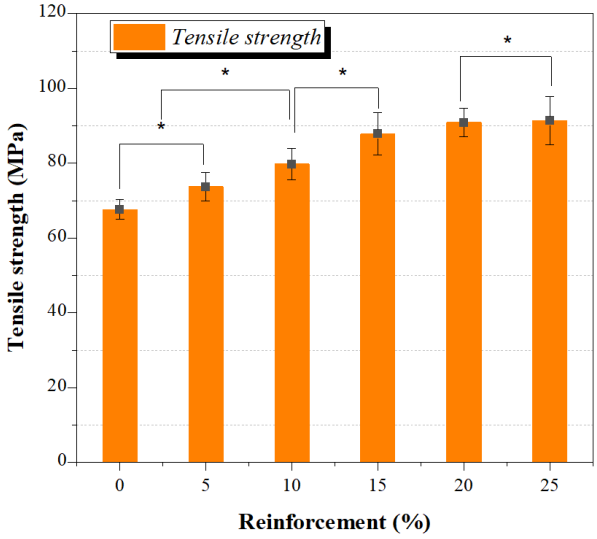


Figure 8. Tensile strength of SS-filled PLA composites

3.5. Compressive strength

The compressive strength for SS-filled PLA composites is shown in Figure 9. According to ASTM D695 standards, the compressive strength of SS particulates-filled PLA composite was investigated. The neat PLA exhibited a compressive strength of 54.01 MPa. The addition of SS particle reinforcement in the PLA matrix increases compressive strength.(Ayyanar *et al.* 2022) The range of compressive strength of the SS-filled is between 58.16 MPa and 86.20 MPa at 5 wt. % of SS reinforcement and 25 wt., % of SS reinforcement, respectively.

3.6. Flexural strength

The flexural specimens were prepared according to the ASTM D 790 standard, and the flexural strengths were compared, as shown in Figure 10. The flexural strength range of PLA composites was found to be between 71.6 and 86.41 MPa. The composites with other reinforcements, such as the 5% SS-loaded PLA composite, showed a flexural strength of 74.21 MPa, the 10% SS-loaded PLA composite exhibited 78.28 MPa, the 15 wt.% SS-loaded PLA composite

measured 81.33Mpa, and the 20 wt.% SS-loaded PLA composite has 83.36 MPa, respectively. The maximum flexural strength was found to be 86.241 MPa at 25 wt.% SS-loaded PLA composite.

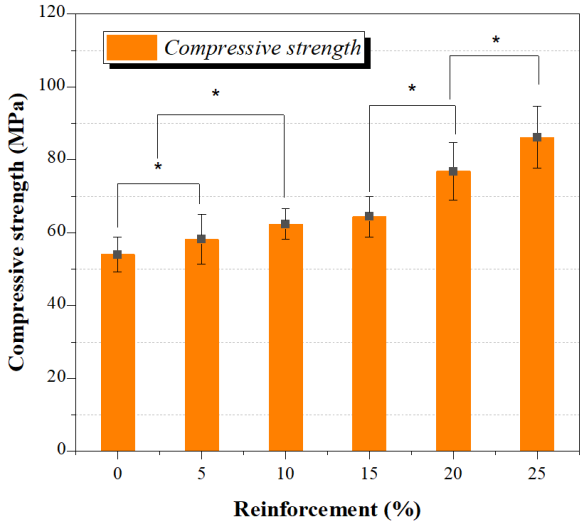


Figure 9. Compressive strength of SS-filled PLA composites

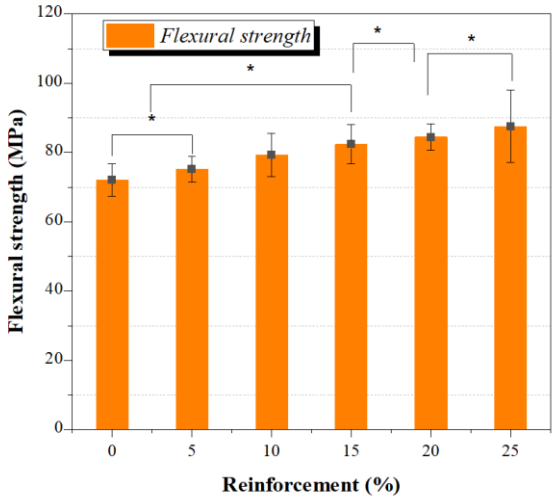


Figure 10. Flexural strength of SS-filled PLA composites

3.7. Shore D hardness

The Shore D hardness test was conducted following ASTM D2240 standards, and the results are shown in Figure 11. Pure PLA exhibited a Shore D hardness of 67.67 SHN, while the 25% SS-filled PLA composite demonstrated the highest hardness at 91.40 SHN. Increasing the reinforcement in PLA composites enhanced their resistance to indentation damage(Ayyanar *et al.* 2023), with Shore D hardness ranging from 67.67 to 91.4 SHN. The other SS-loaded PLA composite hardness, such as 5 % SS-loaded PLA composite, showed a hardness of 73.7 SHN, the 10% SS-loaded PLA composite exhibited 79.7 SHN, the 15 wt.% SS-loaded PLA composite measured 87.2 SHN, and the 20 wt.% SS-loaded PLA composite has 90.5 SHN, respectively.

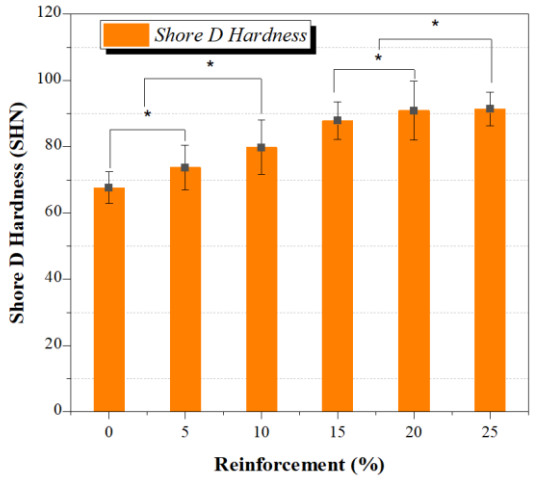


Figure 11. Shore D hardness of SS-filled PLA composites

3.8. Degradation rate

The soil degradation percentage of the Pure PLA, 5%SS/PLA,15%SS/PLA,20% SS/PLA, and 25% SS/PLA composites is shown in Figure 12. The percentage of degraded composite material was determined using an equation and noted at intervals of eight days each time. The degrading mechanisms of five different soil samples have been broken down into three distinct phases: the first phase of decay, the second growth phase of decay, and the third phase of the plateau phase. The results of the first phase decay showed that anything from ten to twenty percent of weight loss had been detected. Next, in the second growth phase decay, the composite degraded by 30% to 40%, which was the reinforcement of SS particulates in the PLA matrix. The percentage of SS particulates increases in the PLA matrix, enhancing the composite's soil degradation. The maximum weight loss amount of 52 % was observed for 25 % SS/PLA composite, and the minimum percentage of weight loss was found for 5% SS/PLA composite.

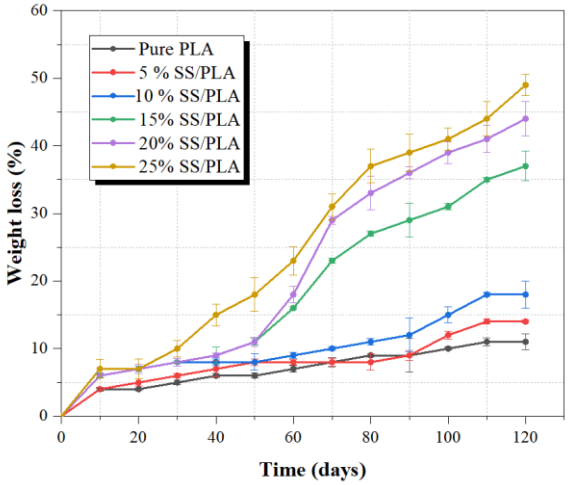


Figure 12. Soil Degradation rate of SS-filled PLA composites

3.9. Water absorption rate

Water absorption characteristics of natural fiber composites require studying their moisture absorption behaviour. Figure 13 shows the relationship between the amount of water absorbed and the number of days passed. The results showed that the water absorption rate

increased with increasing SS particle content in the PLA composite and by using Equation (2). calculated the water absorption characteristics of SS-loaded PLA composite samples. After 15 days in water, the absorption rate stabilized at a constant proportion. The highest water absorption percentage (14.5%) was found in the PLA composite with 25% SS-loaded PLA composite, whereas the lowest was found in the PLA composite with 5% SS-loaded PLA composite. The amount of SS particles used as reinforcement determines the difference in density between the hybrid composites with a 5 wt. % density and those with a 25 wt. % density. Enhanced interaction between water molecules and SS particles at higher reinforcement led to more excellent water absorption. Water absorption by natural particle composites was also demonstrated by a linear increase in the percentage of water absorbed beginning early in the immersion duration. The ultimate finding of the study was that the percentage of SS particle content rises with increasing levels of water absorption characteristics in PLA composites.

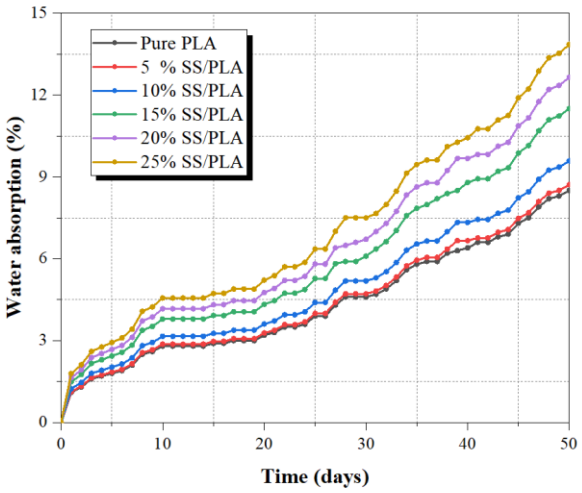


Figure 13. Water absorption rate of SS-filled PLA composites

4. Conclusion

The natural particulate of Saccharum spontaneum reinforced PLA polymer composite developed through Injection moulding. The uniform distribution of SS particulate reinforcement in the PLA matrix was confirmed with the help of the FESEM investigation. The presence of elements such as carbon, oxygen, and aluminium in the composite was analysed using EDAX spectral analysis. The significant functional group present in the developed PLA composites was identified using FTIR spectral analysis. The results showed that 25% S. spontaneum fiber-reinforced PLA polymer composites have more excellent mechanical properties and significantly improved other reinforced SS-filled PLA composites. The maximum flexural, compressive, and Shore D hardness were 86.41 MPa, 86.20 MPa, and 80.1 SHN, respectively. Hence, the developed SS particulates filled PLA composite has improved mechanical properties for low-load applications. The results of the soil degradation investigation show that adding natural fiber into the polymer matrix pronounced excellent degradation properties and water absorption. The SS filler content increases the water absorption capacity of the polymer composite. Hence, the developed composite could be best suited as a biodegradable natural particulates-filled PLA polymer composite.

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