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Fabrication and Characterization of Recycled Polyethylene Terephthalate Composites Reinforced with Sisal Fibre and Wood Sawdust

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ABSTRACT

Extensive use of polymers in daily life has led to increased related waste, giving rise to environmental problems. In the modern day, environmental and ecological concerns have made plastic recycling a significant issue. The majority of the world's solid trash is made up of plastic garbage, which is composed of different polymer chains. A particularly appealing method of getting rid of unwanted plastic is mechanical recycling, though there are other ways to recycle plastic as well. The recycled plastics can also be reinforced with either natural or synthetic textile fibres to manufacture composite materials. This research aims to evaluate the physical and mechanical characteristics of sisal fibre and wood sawdust-reinforced recycled polyethylene terephthalate [RPET] composites. The amount of sisal fibre content in the composites varied from 10%, 15%, 20%, and 25% to 30% by weight. Whereas the wood sawdust was used at 5% for each sample of composite. The composites were manufactured by the melt-mixing method. The effects of fibre loading on various composite characteristics were investigated using tensile strength, tensile modulus, flexural strength, flexural modulus, impact strength, compressive strength, density, and water absorption. The results show that a maximum tensile strength of 84.96 MPa, a tensile modulus of 1.77 GPa, a flexural strength of 230.8 MPa, a flexural modulus of 11.24 GPa, an impact strength of 18.96 KJ/m^2, and a compressive strength of 194.8 MPa were obtained. The water absorption of the composite increased with the increase in fibre weight proportion, and the density of composites decreased with increasing sisal fibre weight. From the results of this study, it can be concluded that a better combination of results has been found for sisal fibre (25%), wood dust (5%), and RPET (70%). Therefore, sawdust and sisal fibre can be used as filler and reinforcement in the RPET matrix, which will reduce cost and provide environmental benefits.

KEYWORDS

recycled polyethylene terephthalate composites, sisal fibre, wood sawdust, PET, properties

INTRODUCTION

The industrial world today places a great deal of significance on the environmental issue, especially for plastic processing industries where the primary focus is on recycling and reducing waste produced both during and after product transformation operations [1]. Recycling to prevent pollution and depletion of the environment, and waste management is a global concern. Reusing waste materials to create new products has several advantages, including positive effects on the environment and economic benefits [2]. Reusing industrial waste and creating environmentally friendly products from renewable resources are examples of how human consciousness is influencing efforts to achieve sustainability and reduce the impact on the environment. The fact that this demand has been increasing over the past few decades indicates that the manufacture of high-value bio-based products and the expanding field of polymer composites can both be addressed by bio-economy and circular economy strategies [3-7].To maintain a product's usefulness, material qualities, and economic value over an extended length of time, structural design may be required [8].

Furthermore, the growing awareness of environmental issues and the rapid expansion of the manufacturing sector point to the need for more affordable, biodegradable materials with superior qualities, like strong mechanical and chemical resistance, low maintenance requirements, and lower costs. Since plastic materials are so versatile, they are frequently used to package household items and drinks (such as water and soft drink bottles). Due to the vast amounts of plastic that are consumed and disposed of daily as well as their non-biodegradable nature, plastic trash is a major problem for Ethiopia. Since these polymeric materials don't break down, waste disposal is a big problem. According to reports, 192 nations produce over 275 million metric tons of plastic garbage annually, of which 12 million metric tons end up in the ocean and seriously pollute the ecosystem [9]. The developing world's use of plastic is likewise rapidly increasing compared to developed nations, these rising nations consume far less plastic per person. For instance, Ethiopia will produce 386,000 t of plastic annually by 2022, and per capita consumption will rise to 3.8 kg of plastic [50].

However, because it is not biodegradable, pollution is a result of its presence in the environment. The need to eliminate plastic trash from the ecosystem is therefore important. These plastics can be removed by burning, reusing, or recycling. Burning plastic waste produces hazardous toxic fumes, whereas reusing it is not an attractive alternative because of contamination. For this reason, recycling other products turns out to be a more attractive choice [10-12]. Numerous chemical recycling processes, including glycolysis, hydrolysis, alkalosis, methanolysis, ammonolysis, and aminolysis, are available for waste plastics [13-15]. One extremely attractive method of getting rid of waste plastics is mechanical recycling, which is collecting, shredding, and pelletizing the material before reusing it to make other plastic items. Composite materials can also be created by reinforcing the recovered plastics with natural or synthetic textile fibres [12,16]. Natural fibre-reinforced polymer composites have attracted a lot of interest during the past few decades [2,16,17,19,33,50]. Natural fibre-reinforced composites (NFRC) are becoming more and more popular because of their simple collection, biodegradability, non-carcinogenicity, affordability, eco-friendliness, and lack of health risks. Additionally, they are renewable resources, which makes them a superior choice for a sustainable supply. Because of its adaptable qualities, the NFRC is appropriate for use in the manufacturing of cars, railroad coaches, buildings, wall partitions, cabinets, furniture, and packaging [16,18].

Natural fibres are easily obtainable and reasonably priced, having been collected from renewable resources. Their unique characteristics are similar to those of synthetic fibres, including glass fibres, which are commonly utilized as reinforcing phases in composite materials based on polymers [19,20]. In contrast to synthetic fibres, in nature, natural fibres are known for their low density, readily available nature, ability to utilize agricultural waste, cost-effectiveness, reduced tool wear during processing, lack of toxic gas release during fibre production or processing, nontoxicity, high specific strength, biodegradability, renewability, and environmental friendliness [21-25]. Even with their benefits, natural fibres have certain drawbacks over synthetic ones, including excessive moisture absorption, low impact strength, and significant unpredictability [26,27].

The primary problem with natural fibre-reinforced composites (NFRPCs) is that the hydrophilic natural fibre and the hydrophobic polymer are incompatible with one another which causes a weak interphase to form. Particle or fibre surface treatment can be used to get around this problem. One of the most popular chemical treatments for natural fibres is the alkaline treatment. Alkali treatment caused hemicellulose and lignin, two types of reinforcing components, to be partially eliminated, which increased surface roughness, and exposed cellulose on the fibre surface resulted in a large number of holes and gaps between cellulose microfibrils [28,29]. There are various sources of natural reinforcements, including forestry and agricultural resources. Agricultural waste provides polymers with abundant, naturally occurring, and renewable resources for reinforcing at a reduced cost with enhanced mechanical characteristics [30].

Global production of sisal fibre, one of the most popular natural fibres, amounts to over 4.5 million tons per year [17]. Agave sisalana, the botanical name for sisal fibre, is a member of the Asparagaceae family. This agave species is native to southern Mexico, although it can also be found in Brazil, Tanzania, China, Ethiopia, Angola, South Africa, and Morocco [21]. One of the species that can produce natural fibres is sisal (Agave sisalana), a naturally occurring plant that is widely distributed in Ethiopia. The kind of plant, the growth environment, the age of the plant, and the process used to harvest the fibres all affect the characteristics of sisal fibres [31,32].

Furthermore, wood chips, rice husks, and bagasse—all agricultural residues—are valuable natural resources. These natural fillers offer far greater strength and are lighter and less expensive. Because it is readily available, inexpensive to pretreat, and easy to handle, wood waste is the most often employed lignocellulosic reinforcement among these agricultural leftovers [33]. The most popular transparent, semi-crystalline thermoplastic in the polyester family is polyethylene terephthalate (PET), which has excellent stiffness, mechanical strength, and chemical resistance. It is used to make food packaging, synthetic fibres, audio and video cassettes, soft drink and water bottles, photographic films, and other materials because of its exceptional mechanical and chemical resistance qualities [34].

The mechanical and physical characteristics of NFRPCs made of polymer, sisal fibre, and wood sawdust have not been extensively studied. Seifu et al. studied the Mechanical behaviours of hybrid ensete/sisal fibre, reinforced low-density polyethylene (LDPE) composite materials. They found that the hybrid composites which contain 15% sisal and Ensete fibre with 75% LDPE matrixes have more tensile, flexural and compression strength than other composites [35]. Ray et al. studied the mechanical and water absorption properties of glass/jute/sisal fibre (GF/JF/SF) reinforced polypropylene (PP) hybrid composites. They found that different compositions of 70% PP + 10% GF + 10% JF + 10% SF show a maximum flexural modulus [36]. Sood et al. studied the properties of sisal fibre / recycled polyethylene (high density) composite: Effect of fibre chemical treatment [37]. Chowdhury et al. Investigate the properties of a blend of recycled bale wrap linear low-density polyethylene and polypropylene (PP) reinforced with sisal fibre [38]. Chianelli-Junior et al. studied the Mechanical characterization of sisal fibre-reinforced recycled HDPE composites [1]. Gebremedhin and Rotich studied the manufacturing of bathroom wall tile composites from recycled low-density polyethylene reinforced with pineapple leaf fibre [16]. Nonato and Bonse studied the mechanical and thermal behaviour of PP/PET composites [39]. Tong et al. studied the mechanical and morphology properties of recycled HDPE composite using rice husk filler [40]. Rahman et al. studied the physical and mechanical properties of flat-pressed wood plastic composites from sawdust and recycled polyethylene terephthalate [41]. Narayanan et al. studied the Properties of wood composite plastics made from predominantly low-density polyethylene (LDPE) plastics and their degradability in nature [42]. Martins et al. also studied the thermal, mechanical, morphological and aesthetical properties of rotational moulding PE/Pine wood sawdust composites [7]. Very little work has been done on the incorporation of wood sawdust and sisal fibre individually as filler and reinforcing raw materials in thermoplastic composite manufacturing. However, to the author's knowledge, there is no study on the hybrid composites of sisal fibre and wood sawdust as reinforcing and filler material in recycled polyethylene terephthalate (PET) composite production. The main aim of this research was to study the effect of wood sawdust and sisal fibre content on the tensile strength, tensile modulus, flexural strength, flexural modulus, impact resistance, compressive strength, density, and water absorption properties of the recycled polyethylene terephthalate (PET) matrix. This may create a new opportunity for the beneficiation of RPET, wood sawdust, and sisal fibre for high-value products. In the RPET matrix, sisal fibre and wood sawdust can be utilized as filler and reinforcement, which will lower costs and improve the environment. Process optimization, techno-economic analysis, and SEM analysis of the optimized composite are all part of the next research.

EXPERIMENTAL

Materials and Methods

Reinforcements and preparation

The wood sawdust was collected from the local sawmills in Bahir Dar, Ethiopia, and also Sisal fibre was purchased from the local market in Bahir Dar. The properties of wood sawdust and sisal fibre used for this study are given in Table 1.

Table 1. Properties of wood sawdust and sisal fibre [33,50]

Properties	Wood sawdust	Sisal fibre
Diameter (mm)	---	120 - 140
Length (cm)	---	2.5
Density (g/cm^3)	0.124	1.45
Tensile strength (MPa)	---	530 - 630
Young's modulus (GPa)	---	17 - 22
Elongation at break (%)	---	3 - 7
Moisture content (%)	--	11
Cellulose (%)	--	66 - 72
Hemicellulose (%)	--	12
Lignin (%)	--	10 - 14
Particle size (mm)	1 - 2	10

The sawdust samples were sun-dried for two days to remove excess moisture. After that, the wood sawdust was sieved out by using a 1 mm sieve, which helps to remove some unwanted materials such as pieces of plastic, pieces of metal and wood particles. The sisal fibres were also cut into 10 mm lengths using a pair of scissors in chopped form. The sieved wood sawdust and the chopped sisal fibres are shown in Figure 1.

Figure 1. Sieved wood sawdust and chopped sisal fibres

Polymer Matrix and preparation recycled polyethylene terephthalate

Recycled polyethylene terephthalate (RPET) was obtained for this study from Addis Ababa, Ethiopia. The physical and mechanical properties of the RPET are shown in Table 2.

Table 2. Physical and mechanical properties of recycled polyethylene terephthalate

Properties	RPET
Density (g/cm^3)	1.3 - 1.4
Tensile Strength (MPa)	55 - 85
Elongation at yield (%)	3.8
Young's Modulus (GPa)	2.8 - 3.5
Flexural Modulus (Gpa)	2.8 - 3.5
Flexural strength (MPa)	55 - 100
Impact strength (kJ/m^2)	4.6
Melting Point (°C)	130

The matrix materials polyethylene terephthalate plastic materials were collected locally from drainages, streets, construction sites, launch cafés, and shops where large volumes of plastic waste were generated. The collected polyethylene terephthalate was state-identified, washed to remove any dust and dirt adhering to it, and then dried and shredded into small pieces to enhance the melting process by increasing the surface area and accessibility of the polyethylene pieces to thermal energy. The shredded recycled polyethylene terephthalate (RPET) is shown in Figure 2.

Figure 2. Plastic bottle and shredded recycled polyethylene terephthalate (RPET)

Chemicals and alkaline treatment of sisal fibre

Acetic acid (CH_3COOH) was utilized as a neutralizing agent and sodium hydroxide (NaOH) in pellet form as a surface treatment agent. The two chemicals were bought from regional vendors in Addis Ababa, Ethiopia. For this study, a 10% NaOH solution was used to treat the raw sisal fibres to modify their fibre structures and improve the fibre-matrix interface. During this process, dried and chopped sisal fibres were treated with a 10% NaOH solution for 1 hour at room temperature to remove fatty impurities. The fibres were then washed several times with water to remove the excess NaOH sticking to the fibres [43]. Lastly, washing was carried out with distilled water containing a drop of acetic acid for neutralization. Then the fibres were allowed to dry in the sun's light (air-dried). The alkali treatment of sisal fibre is shown in Figure 3.

Figure 3. Alkali treatment of sisal fibre

Method of fabrication of sisal fibre and wood sawdust reinforced RPET composite

The general flow of the research method and the manufacturing process of sisal fibre and wood sawdust-reinforced recycled polyethylene terephthalate composite is shown in Figure 4.

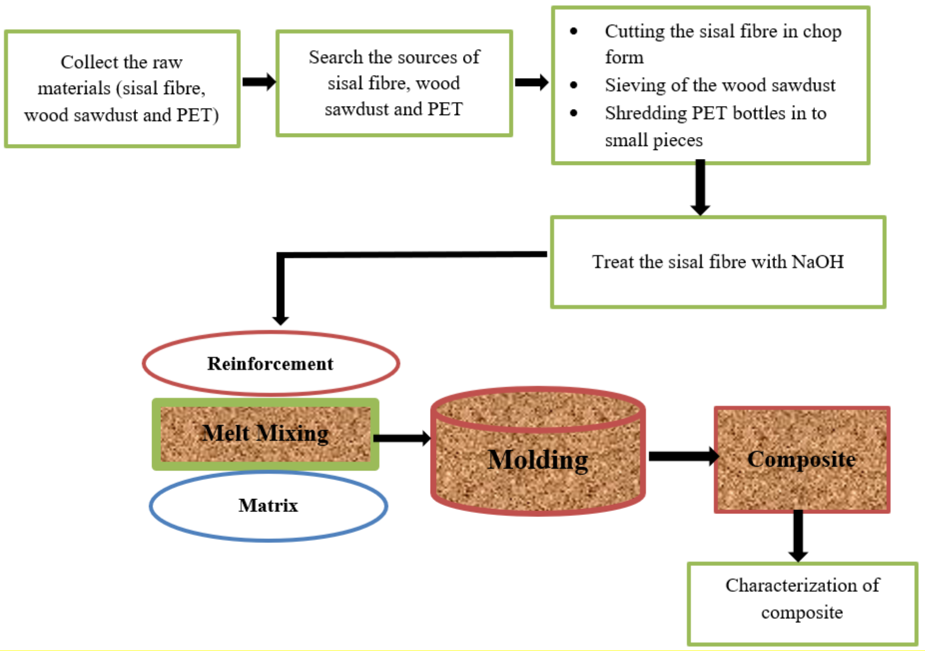

Figure 4. General flow of the production of sisal fibre and wood sawdust RPET composites

Proportions of wood sawdust, sisal fibre and recycled polyethylene terephthalate [RPET]

The proportions of wood sawdust, sisal fibre, and recycled PET are shown in Table 3.

Table 3. The proportion of different components in sisal and wood-reinforced RPET composites

Proportion of WS/SF/RPET (%)	Wood sawdust (%)	Sisal fibre (%)	Recycled polyethylene terephthalate [RPET]
WS/SF/RPET	5	10	85
WS/SF/RPET	5	15	80
WS/SF/RPET	5	20	75
WS/SF/RPET	5	25	70
WS/SF/RPET	5	30	65

Preparation of sisal fibre and wood sawdust reinforced RPET composite

Preparing RPET Composite using Sisal Fibre and Wood Sawdust. Melt-mixing was used to create randomly oriented Sisal Fibre and Wood Sawdust - RPET composites with different fibre weight proportions. Based on early research by [16] the settings employed were a mixing temperature of 130 °C, a rotor speed of 60 rpm, and a mixing period of 8 minutes. Since the temperature of 130 °C does not affect the qualities of the fibre, it was chosen. Using a closed mold, 200 × 150 x 10 mm composites were created. To stop RPET from adhering to the mould, a lubricating oil-releasing agent was used to polish it. Melting the shredded RPET, adding a preset number of chopped fibres, thoroughly melting and combining to create a homogenous viscous solution, and then pouring the mixture into the ready-made mould were the steps in the procedure. After the mould was closed, the samples were chilled to ambient temperature for 30 minutes while being compressed to 12.5 MPa. Sandpaper was used to mould the composite specimens, which were then employed for testing, as Figure 5 illustrates.

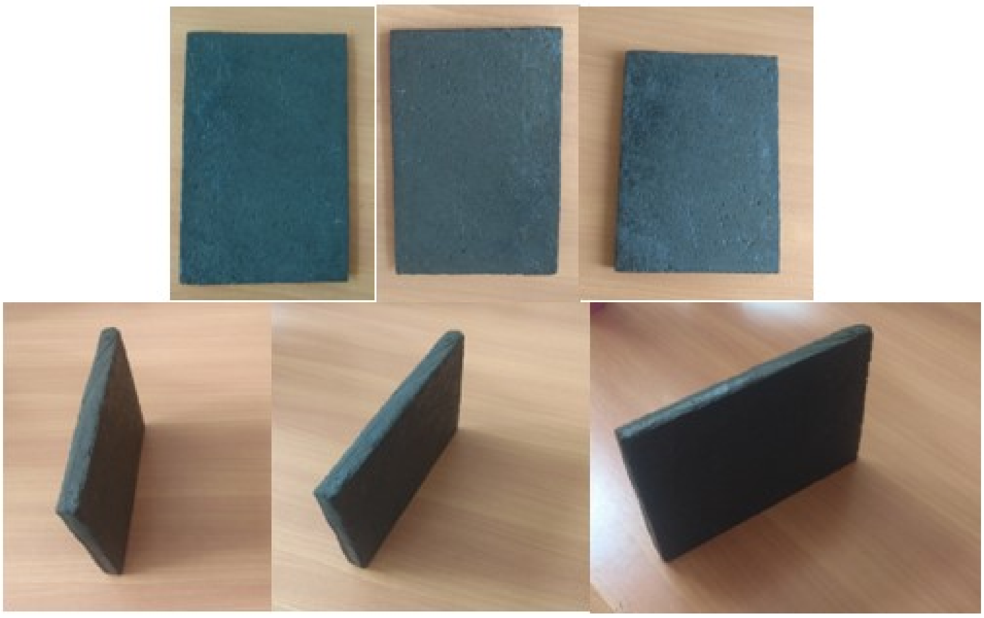

Figure 5. Sisal fibre and wood sawdust reinforced RPET composite sample

Tensile strength

Tensile property tests were performed by a universal tensile strength testing machine (Model WAW-600D). The tensile strength of the produced composites was tested according to the ASTM D3039-17 [44] test standard. The dimensions of the test specimens were 100 × 50 × 10 mm. The value was recorded until the specimen was fractured, five specimens were tested for each set of composite samples, and the mean values were reported.

Flexural strength

A flexural strength test was carried out in a three-point loading system applied on a supported beam. The tests were performed using a universal tensile machine (WAW-600D). The flexural rigidity characteristics of the produced composites were carried out according to ASTM D7264-2021 [45] test standard with dimensions 100 × 50 × 10 mm^3. The specimens were tested on a support span of 130 mm as per the standard. The flexural modulus of the composite was calculated using the following equation 1 [21,22].

$$\text{Flexural Modulus } = \frac{\text{mL}^3}{4\text{bd}^3} \tag{1}$$

Where L, is the span length (mm); b and d, are the width and thickness of the specimen in (mm) respectively; and m, is the slope of the tangent to the initial line portion of the load displacement

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curve. Five specimens were tested for each Set of composite samples and the mean values were reported.

Impact strength

The impact strength tests were performed by Charpy impact tests using a pendulum impact testing machine (JBS-500B model). The testing was carried out according to the ASTM D256-23 [46] test standard, with a dimension of 100 mm long and a cross-sectional area of 5 cm^2. Five specimens were tested for each set of composite samples, and the mean values were reported.

Compressive Strength

The compressive properties of the composite specimens were measured with a universal testing machine (Model WAW-600D) according to the ASTM D6641/D6641M-16e1 [47] test standard with a sample dimension of 50 × 50 × 10 mm. Five specimens were tested for each set of composite samples, and the mean values were reported.

Water absorption

Water absorption tests were carried out in accordance with the ASTM D570-98 [48] test method with sample dimensions of 100 × 50 × 10 mm. Samples of each composite type were oven-dried before their weight was recorded as the initial weight of the composites. The samples were then placed in distilled water and maintained at room temperature (25 °C) for 24 hours. The samples were then removed from the water, dried, and weighed. The amount of water absorbed by the composites (in percentage) was calculated using Equation 2.

$$\% \mathrm{W} = \frac{(\mathrm{Wt}-\mathrm{Wo})}{\mathrm{Wo}} \times 100 \qquad (2)$$

Density

The density of composite material is calculated based on the dimensions and arithmetical formula 3.

$$\text{Density (D)} = \frac{\mathrm{M}}{\mathrm{V}} \qquad (3)$$

Where M – Mass of the sample (kilogram) and V – Volume of the sample (mm^3). Volume is calculated by using the following equation, V = W x T x L, where W is – Width of the sample, T is – Thickness of the sample, and L – Length of the sample.

RESULTS AND DISCUSSION

Effect of alkaline treatment on mechanical properties of composite

The mechanical characteristics of sisal and wood sawdust-RPET composites with varying fibre weight proportions, both untreated and alkali-treated, are displayed in Table 4. The table clearly shows that the alkali-treated composites exhibited better mechanical properties than the untreated composites in terms of tensile strength, tensile modulus, flexural strength, flexural modulus impact strength, and compressive strength with fibre weight proportion. This is because alkali treatment creates a rough surface topography by eliminating both artificial and natural impurities, which enhances the fibre surface adhesive properties. It should be mentioned that after being treated with alkali, the fibres became thinner. This might be the result of some of the fibre's lignin components dissolving and leaching along with certain fatty acids. Furthermore, alkali treatment aids in exposing cellulose's active hydrogen molecules, which improves the fibres' surface adherence to hydrophobic matrix materials in fibre-reinforced polymer composites. Alkali treatment of natural fibres reduces hydrophilic hydroxyl groups on their surface, improving their moisture resistance. Through the dissolution of waxy and gummy materials on the surface of natural fibres, alkali treatment also improves the uniformity of the fibre surface. This process causes a swelling reaction in the natural fibres, which relaxes the structure of natural cellulose. Finally, the interfacial bonding between the treated sisal fibre and RPET matrix increased as a result of the majority of the hydroxyl groups in the sisal fibre being eliminated. This led to composites with high tensile strength, tensile modulus, flexural strength, flexural modulus, impact strength, and compressive strength [49,50].

Table 4. Mechanical properties of untreated and treated sisal fibre and wood sawdust /RPET composites

Proportion of WS/SF/RPET (%)	Tensile strength (MPa)	Tensile modulus (GPa)	Flexural strength (MPa)	Flexural modulus (GPa)	Impact strength (KJ/m^2)	Compressive strength (MPa)
0	35	0.74	175.4	6.89	4.8	155.35
5/10/85	42.3 (38.13)	0.96(0.88)	180.2(175.18)	8.78(8.51)	5.71(4.57)	162.8(160.39)
5/15/80	58.64(55.81)	1.22(1.16)	192.7(187.82)	9.39(9.04)	6.98(6.48)	174.5(169.8)
5/20/75	69.42(66.36)	1.45(1.38)	202.3(198.8)	9.86(9.41)	9.32(8.44)	183.6(176.48)
5/25/70	84.96(79.02)	1.77(1.66)	230.8(222.4)	11.24(10.45)	18.96(17.715)	194.8(185.72)
5/30/65	72.43(69.23)	1.51(1.43)	215.6(210.52)	10.5(10.2)	13.27(12.245)	181.4(173.74)

*Values given in parentheses are those of untreated composites.

Effect of reinforcement content on Tensile strength and Tensile modulus

Numerous elements, including matrix, interfacial adhesion between the fibre and matrix, fibre type, length, and content, influence the strength of natural fibre-reinforced composites [51]. Based on the experimental findings, Figure 6 displays the tensile strength and tensile modulus of an RPET composite including wood sawdust and sisal fibre at varying fibre weight proportions. Throughout the experiment, wood sawdust was maintained at a consistent amount because it had little effect on the tensile and tensile modulus when compared to other reinforcement materials in composites. Figure 6 illustrates the observation that tensile strength and tensile modulus increase up to 25 weight per cent as the percentage of sisal fibre increases. The reason for this is the sisal fibres' high adherence to the RPET. the reinforced recycled polyethylene terephthalate (RPET) grew stiffer and could take larger loads due to the matrix, which permits a homogeneous transmission of stress from the matrix to the fibres. The fibre functioned as reinforcement since it carried the majority of the load [16,22].

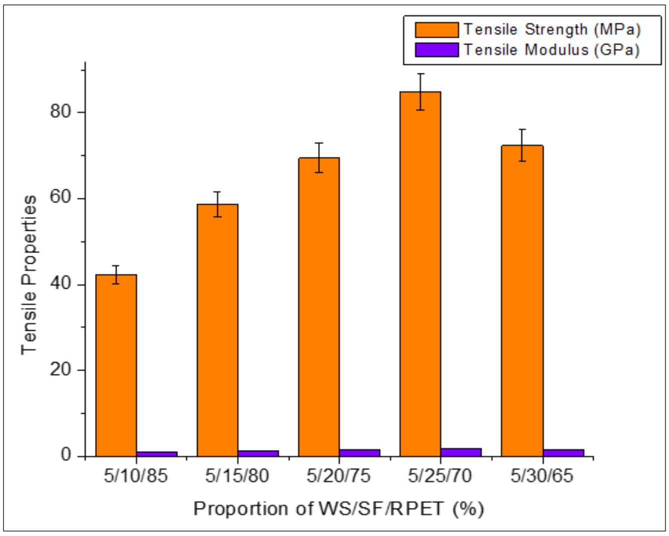

Figure 6. Tensile properties of treated sisal fibre and wood sawdust-reinforced RPET composites

The tensile strength and tensile modulus of the sisal and wood sawdust RPET composite decreased over a 25% fibre proportion, as also indicated in Figure 6. When more fibre is added to a composite, the link between the fibre and matrix becomes weaker. According to different studies, fibre-fibre contact rather than fibre-matrix interaction is the cause of the composite's decreased tensile strength and modulus. The depletion in strength and modulus is mostly the result of the extra fibres; hence, there were voids left by the insufficient matrix RPET to permeate and wet every fibre, leaving the fibres vulnerable to environmental deterioration. The increased fibre content raised the possibility of fibre aggregation and the formation of voids in the composites, which decreased the composite's tensile strength and tensile modulus [16,17,49,50]. From this data, it can be shown that 25% fibre content was the ideal tensile strength and tensile modulus. The composite's maximum tensile strength and tensile modulus values are 84.96 MPa and 1.77 GPa, respectively, at 5% WS/25% SF and 70% RPET.

Effect of reinforcement content on Flexural strength and Flexural modulus

Flexural strength, which is expressed in terms of stress, is a material's capacity to withstand deformation under bending loads. The stiffness at the beginning or first stage of the bending process is measured by the flexural modulus. Figure 7 makes this evident: as the fibre weight fraction increased to 25%, the flexural strength and flexural modulus increased progressively. The composite with 25% fibre weight, according to observation, has the highest flexural strength and modulus values, at 230.8 MPa and 11.24 GPa, respectively. The improved interfacial adhesion between the fibre and matrix may be the cause of the improvement in flexural strength and modulus. According to different researchers, a larger fibre weight percentage can be achieved by increasing the number of fibres present on a particular composite cross-section, which increases the composite's flexural strength and modulus [16,22,50,52].

As seen in Figure 7, flexural strength and flexural modulus values slightly decreased with additional increases in fibre weight content above 25%. The flexural strength and flexural modulus of the composite decrease at maximum fibre loading, as reported by different researchers this is because more fibre-fibre interaction forms than fibre-matrix interaction, and the applied load cannot be transferred from the polymer matrix to the rigid fibre particles. Higher fibre weight proportions may cause a loss in flexural strength and modulus because of problems with fibre dispersion in the matrix. The fibre content of the composite also increased, requiring the matrix material to attach additional fibre surfaces for adequate stress transfer and good contact. However, upon adding more fibres, the strength hits a plateau value or begins to decrease because there are fewer polymers available at increasing fibre loading to wet the fibres [50,53,54].

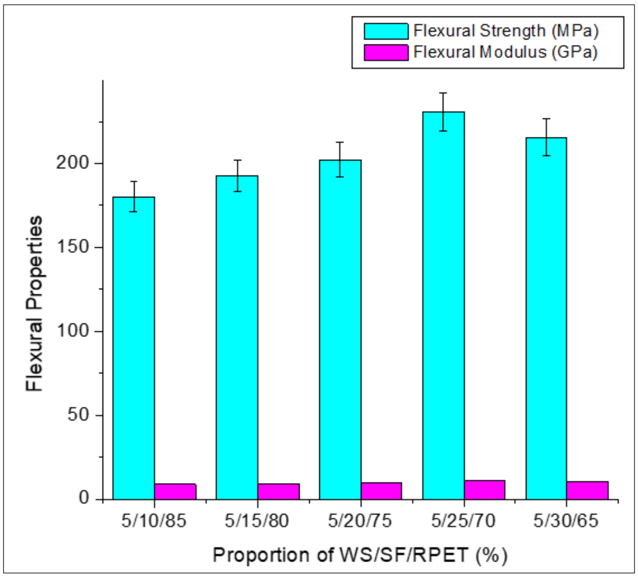

Figure 7. Flexural properties of treated sisal fibre and wood sawdust reinforced RPET composites

Effect of reinforcement content on Impact strength

The impact strength of composite material is its ability to absorb and dissipate energy in the form of creating new surfaces under shock or sudden blows [21]. The impact strength increased as the sisal fibre percentage increased up to 25%, as Figure 8 clearly illustrates. Based on observations, 25% is the ideal fibre proportion that results in the best impact strength; this may be because the matrix and fibre mechanically interlock more effectively. The significant micro-scale debonding that occurs at the fibre/matrix interface at high fibre loading is linked to the high impact strength at high fibre loading [55].

Nevertheless, the impact strength of the composite decreases above 25% fibre content due to poor interfacial bonding between the fibre and matrix and the creation of stress concentration regions that require relatively less energy to initiate a crack. According to different studies, the sisal fibre inclusion reduces the composites' toughness fibre pull-out and the fracture of the fibres and matrix dissipates energy during the impact fracture of fibre-reinforced polymer composites. Composites with a strong interfacial binding are less likely to have fibre fracture, whereas composites with a poor interfacial bond are more likely to experience fibre pull-out. Practically speaking, fibre pull-out, matrix crack, and fibre breakage account for a large portion of energy absorption during impact strength [16,17,56].

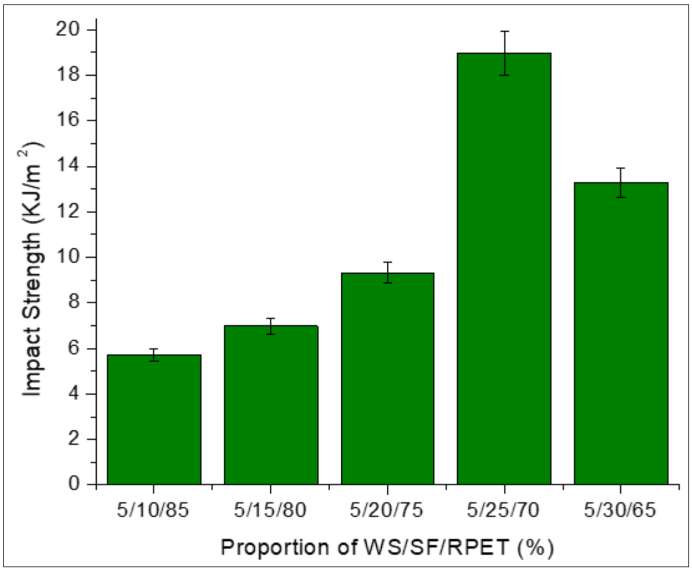

Figure 8. Impact properties of treated sisal fibre and wood sawdust reinforced RPET composites

Effect of reinforcement content on Compressive strength

Figure 9 illustrates how fibre loading affects the compressive strength of RPET composites reinforced with sisal fibres and wood sawdust. The result in Figure 9 demonstrates that the composite's compressive strength increases with a 25% increase in fibre content. This is because the sisal fibre and RPET matrix form a strong interfacial bond that allows the fibre to bridge microcracks and inhibit crack extension. The presence of fibre in the composite mix may also have increased the bonding force between its components, which has increased in compressive strength [33,50,57].

Nevertheless, as Figure 9 makes evident, the compressive strength of the composite decreases above 25% fibre content. This is because more fibre is added to the composite during production, which weakens the interfacial bond between the fibre and the RPET matrix. Previous studies have confirmed that a higher fibre content in the composite material results in decreased compactness and increased susceptibility to crack formation because of the limited dispersion of sisal fibre in the RPET matrix [33,50]. Ultimately, the optimum percentage to add to increase the composite's compressive strength was 25% sisal fibre content, it may be concluded.

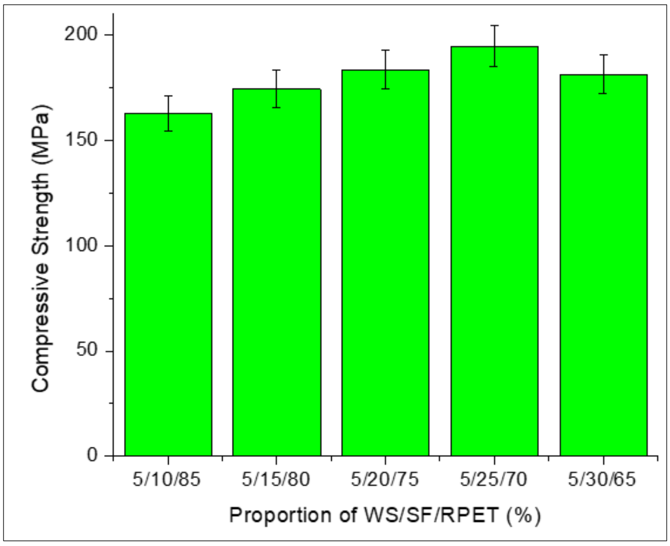

Figure 9. Compressive properties of treated sisal fibre and wood sawdust reinforced RPET composites

Effect of reinforcement on the physical properties

The Density and water absorption are important physical properties of the composites. Table 5 shows the test results of the sisal fibre and wood sawdust RPET composites.

Table 5. The physical properties of sisal fibre and wood sawdust /RPET composites

Proportion of WS/SF/RPET (%)	Density (kg/mm^3)	Water absorption (%)
WS/SF/RPET	104.67	2.73
WS/SF/RPET	101.97	4.12
WS/SF/RPET	97.43	4.96
WS/SF/RPET	96.25	5.45
WS/SF/RPET	94.19	6.3

Effect of reinforcement content on density

The composite density of samples with varying compositions of wood dust and sisal fibre-reinforced composites is displayed in Figure 10. It displays the declining trend of the density value from a low to a large proportion of sisal fibre used for weight reinforcement. Wood sawdust is kept constant throughout the experiment because it has little effect on density when compared to other reinforcement components in composites. The density of the composite material has decreased due to an increase in sisal fibre weight. It might result from textile fibres' lower density when compared to other types of reinforcing materials [2]. The result confirms the low density (94.19 kg/mm^3) and high density (104.67 kg/mm^3) of 10 wt% and 30 wt% sisal fibre, respectively. The pattern of the result makes it evident how density affects the composite's mechanical characteristics. The effect of density on the mechanical properties of the composite is visible from the trend of the result. The mechanical properties initially increase and then decrease as the wt% of sisal fibre is increased. Therefore 5% wood dust and 25% weight percentage sisal fibre, composites can have the ideal density and suitable mechanical properties.

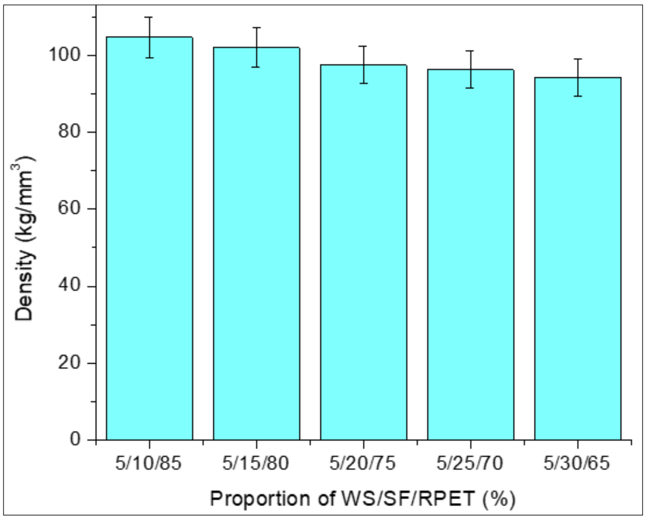

Figure 10. Density properties of treated sisal fibre and wood sawdust reinforced RPET composites

Effect of reinforcement content on water absorption

The amount of water absorbed under particular circumstances is ascertained via water absorption. The type of plastic, the additives used, the temperature, and the duration of exposure are the factors that determine water absorption. Because lignocellulose fibres contain OH groups in their chemical composition, they are all less resistant to absorbing water. As Figure 11 makes evident, the RPET composites' water absorption rose as the amount of fibre increased. This might be because sisal fibre's hydrophilic nature allows for a significant absorption of moisture. Due to the presence of micro-voids in the matrix, which cause water molecules to diffuse into them until saturation, the water absorption increases as the fibre concentration rises from 10% to 30% [16,50,58].

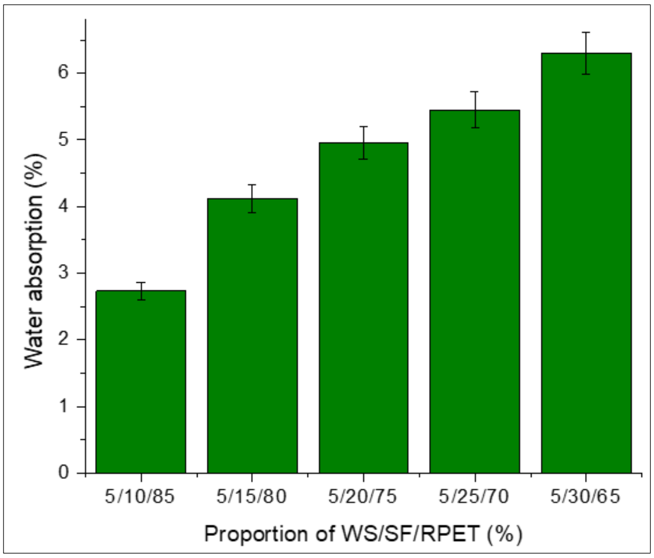

Figure 11. Water absorption properties of treated sisal fibre and wood sawdust-reinforced RPET composites

CONCLUSION

This is an experimental study of the mechanical and physical properties of RPET composites reinforced with sisal fibre and wood sawdust. From the experimental results, it has been observed that the fibre weight proportion has a significant effect on the mechanical and physical properties of the composites, including tensile strength, tensile modulus, flexural strength, flexural modulus, impact strength, compressive strength, density, and water absorption. Throughout the experiment, the amount of wood sawdust was kept constant. The study showed that a maximum tensile strength of 84.96 MPa, a tensile modulus of 1.77 MPa, a flexural strength of 230.8 MPa, a flexural modulus of 11.24 MPa, an impact strength of 18.96 KJ/m^2, and a compressive strength of 194.8 MPa was obtained for compositions of 70% RPET, 25% sisal fibre and 5% wood sawdust. The water absorption rate increased with an increase in the sisal fibre weight proportion, i.e., 10% sisal fibre content absorbs less water than other samples. This is due to the hydrophilic properties of the reinforcements and the formation of interactions between the OH groups in fibres and water. The density of the composite material has decreased due to an increase in sisal fibre weight. It might result from textile fibres' lower density when compared to other types of reinforcing materials. The result confirms the low density (94.19 kg/mm^3) and high density (104.67 kg/mm^3) of 30 wt% and 10 wt% sisal fibre, respectively. This might offer an additional source of raw materials for the production of composites as well as a different way to value underutilized sisal fibre and wood sawdust because of their strong mechanical and water-absorbing qualities, sisal fibre and wood sawdust composites have the potential to be used in different applications. The result of the present study reveals that sisal fibre and wood sawdust RPET composites with good mechanical properties could be successfully developed using the appropriate wood sawdust and sisal fibre compositions. The sisal fibre and wood sawdust can be used as filler and reinforcement in the RPET matrix, which will reduce cost and give environmental benefits. The future study will entail mechanical characterization and SEM analysis of the optimized composite.

Author Contributions

Conceptualization - Ferede E; methodology – Ferede E, Muhammed A, Tesfaye T; formal analysis – Ferede E, Muhammed A ,Kassa A and Kedir S; investigation – Ferede E; resources – Ferede E, Zerefa W and Tesfaye T; writing-original draft preparation – Ferede E; writing-review and editing – Ferede E, Tesfay T, Muhammed A, Kassa A, Kedir S and Zerefa W; visualization – Ferede E, Kedir S and Kassa A; supervision - Tesfaye T and Zerefa W. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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