Hindawi
Journal of Engineering
Volume 2024, Article ID 9247702, 13 pages
https://doi.org/10.1155/2024/9247702

Research Article

Production and Characterization of Recycled Polypropylene Composite Reinforced with Cotton Fabric Waste

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Received 17 January 2024; Revised 20 April 2024; Accepted 7 May 2024; Published 18 May 2024

Academic Editor: Andras Szekrenyes

Composite materials have played an important role throughout human history, from housing early civilizations to enabling future innovations. This study explores the development of composite materials from recycled polypropylene and cotton fabric waste targeted for different applications. The composites were manufactured by the melt-mixing method. The effects of cotton fabric waste content on various composite characteristics were investigated using tensile strength, tensile modulus, flexural strength, flexural modulus, impact strength, compressive strength, and water absorption. The study showed that with an increase in cotton fabric waste content, properties such as tensile strength, tensile modulus, flexural strength, flexural modulus, impact strength, and compressive strength increase up to the optimum level, while a decrease in these properties is observed after the optimal level. The maximum tensile strength of 57.84 MPa, tensile modulus of 1.31 GPa, flexural strength of 55.32 MPa, flexural modulus of 2.7 GPa, impact strength of 33.06 kJ/m^2, and compressive strength of 53.68 MPa were obtained. The water absorption rate increased with an increase in the cotton fabric waste weight proportion. From the result of this study, it can be concluded that the optimal mechanical and water absorption properties were achieved at 30% cotton fabric waste content. Therefore, creating composites from recovered polypropylene and cotton fabric waste can have both environmental and financial benefits.

1. Introduction

Municipal solid trash has expanded significantly in recent years, and one such category is textile waste. The production of unique circular textile approaches has become more and more problematic due to the abundance of textile waste, which includes waste from commercial services; consumption; and streams of fiber, textile, and garment manufacturing processes. To be precise, in recent years, concerns about the management and disposal of textile waste have grown worldwide [1–6].

The textile industry is the world's second largest polluting industry, accounting for 10% of total worldwide greenhouse gas emissions [7]. There is a severe lack of post-consumer waste disposal facilities in many developing nations, raising environmental problems. Using textile waste will help add value to it and address issues with disposing of waste [8]. Therefore, to prevent pollution, recycling and the use of waste materials as resources are considerably more crucial. As a result, numerous researchers are working to recover and make use of post-consumer wastes in order to keep them out of landfills [9–11]. Pre- and post-consumer textile wastes are separated into two categories. An estimated 75% of textile waste is diverted from landfills by pre-consumer waste [12]. Post-consumer garbage is characterized as any article of apparel or household textile that is no longer usable to its original user [13]. An average person discards 37 kg of textiles each year, according to the Recycling Council of Ontario [14]. According to data from the Environmental Protection Agency, 17 million tons of textile waste—or 5.8% of all municipal solid waste (MSW) generated in 2018—went to landfills. In the previous 20 years, Americans have thrown away twice as much apparel annually: from 7 million to 14 million tons [9]. It is possible to create a value-added product with improved performance properties by using agricultural waste in an efficient manner

[15]. The mechanical characteristics of a composite reinforced with fibers increase its microlevel strength, decrease its tendency to break, and result in a reduced weight [16, 17]. The benefits of recycled fiber, including its affordability, biodegradability, and acceptable mechanical and physical qualities, have led to an increase in demand for it in industries [18]. By preserving natural resources, using high-performance combinations to strengthen infrastructure, and lowering greenhouse gas emissions, air pollution, and groundwater contamination, recycling also contributes to the greening of our infrastructures [19].

Plastics have become a significant component of our daily lives in the modern world due to increasing worldwide wealth. However, there is a limited supply of raw ingredients required to produce such vast amounts of plastic. Additionally, the ecology is negatively impacted by an annual rise in plastic trash originating from nonrenewable sources. Mechanical recycling, which allows plastic trash to be transformed back into useful products, is the simplest technique to lessen the impact on the environment. Studies reveal that less than 15% of plastics worldwide have been recycled. Polypropylene is among the polymers that may be recycled with ease [20]. Thermomechanical processing, one of the primary recycling techniques, can be used to directly prepare polymeric composites. This is a significant step toward mitigating the environmental issues that polymeric waste-related waste poses today [21–29]. The only thermoplastic that is used more frequently worldwide is polyethylene, with polypropylene coming in second [30, 31]. According to its usage, polypropylene (PP) is also the second most commonly disposed polymeric waste globally, which poses a significant environmental issue [32]. For PP trash to be used sustainably and to provide new goods and financial benefits, further options for recycling must be developed [33]. There has been successful research involving the addition of various natural fillers to polymers to create composites with improved characteristics. Natural fibers and fillers from coconut, date palm, flax, jute, kenaf, sisal, coffee ground, chicken feathers, quill, banana peel powder, hemp, wood, and so forth are among those used as reinforcement in polymers [34].

There are some important studies on polypropylene/natural filler composites and the effect of fiber or filler on other properties (like physical, mechanical, tribological, and thermal) of polymer composites. Al-Oqla et al. studied a decision-making model for selecting the most appropriate natural fiber (coir, date palm, flax, jute, kenaf, and sisal) polypropylene-based composites for automotive applications [35]. Carbonell et al. studied green composites based on polypropylene matrix and hydrophobic spent coffee ground (SCG) powder [36]. Jiménez-Cervantes studied the development of composites from chicken feather quills and recycled polypropylene [37]. Mustafa et al. studied the structural analysis of polypropylene maleic anhydride (PPMAH), polypropylene (PP), recycled acrylonitrile butadiene rubber (NBRr), and banana skin powder (BSP) composites [38]. Assarar et al. studied the acoustic emission characterization of damage in short hemp fiber-reinforced polypropylene composites [39]. Ibrahim et al. studied the dependency of the mechanical properties of sisal fiber-reinforced recycled polypropylene composites on fiber surface treatment, fiber content, and nanoclay [40]. Jiang et al. studied the significant reinforcement of polypropylene/wood flour composites by the high extent of interfacial interaction [41]. Sullins et al. studied hemp fiber-reinforced polypropylene composites and the effects of material treatments [42]. Aridi et al. studied the mechanical and morphological properties of injection-molded rice husk polypropylene composites [43]. Guna et al. studied groundnut shell/rice husk agrowaste-reinforced polypropylene [44]. Purohit et al. studied the sliding wear characterization of epoxy composites filled with wood apple dust using the Taguchi analysis and the finite element method [45]. Swain et al. studied the influence of moisture absorption on the mechanical and thermal properties of chemically treated DPL-reinforced hybrid composites [46]. Purohit and Satapathy reported a study on the erosion wear performance of Linz–Donawitz sludge-filled polypropylene matrix composites [47]. Jena et al. studied the dielectric properties, thermal analysis, and conductivity studies of biodegradable and biocompatible polymer nanocomposites [48].

Many researchers have researched composite materials reinforced with different textile materials, such as coconut, date palm, flax, jute, kenaf, sisal, coffee ground, chicken feather quill, banana peel powder, hemp, and wood, into polymers to generate composites in order to enhance their properties. However, to the author's knowledge, there is no study on the use of cotton fabric waste as filler and reinforcing material in recycled PP matrix composite production. This research on textile waste-reinforced composites has gained more attention in recent times. Particularly, waste cotton fabric-reinforced thermoplastic composites have also been reported. The main aim of this research was to manufacture and characterize composite materials made from 100% cotton fabric waste reinforced with recycled polypropylene. The mechanical and physical properties, such as tensile strength, flexural strength, impact strength, compressive strength, and water absorption, of the manufactured composite material were investigated and reported. The cotton fabric waste can be used as reinforcement in the recycled PP matrix, which will reduce costs and provide environmental benefits. The future study will entail process optimization, techno-economic analysis, and the degradation characteristics of the composite. In addition to this, the performance test of the optimized composite will be studied. This study is also conducted at a laboratory scale; for pilot implementation, the conversion of these processes and outcomes to a larger scale for issues such as the uniformity of mixing and properties across larger batch sizes, manufacturing challenges, and quality control aspects should be controlled for the implementation stage.

2. Materials and Methods

2.1. Materials

2.1.1. Reinforcement. For this study, the waste cotton fabric was collected from Bahir Dar Textile Share Company (BDTSC), Bahir Dar, Ethiopia.

2.1.2. Matrix. Polypropylene, which is used as a matrix for the production of cotton and PP, was collected directly from available sources such as hotel and restaurant disposal.

2.2. Method

2.2.1. Methods of Composite Manufacturing. The general experimental procedure for this study is shown in Figure 1. The content of the filler or reinforcement is selected based on earlier work by [49, 50].

2.2.2. Preparation of Cotton Fabric Waste for Reinforcement. First, the required amount of waste cotton fabric was collected directly from the Bahir Dar Textile Share Company, and then, the fabric was chopped into smaller pieces that ranged from 5 to 10 mm in length and 3–6 mm in width with the help of a scissor. The chopped waste fabric is shown in Figure 2.

2.2.3. Preparation of Recycled Low-Density Polypropylene. At the beginning, the low-density polypropylene was collected directly from different hotels and restaurants, and then, the polypropylene was shredded into smaller pieces to fit the fabric and the mold as well, so it could melt easily and achieve the desired composite. The shredded PP is shown in Figure 3.

2.2.4. Preparation of Waste Cotton Fabric-Reinforced Recycled Low-Density PP Composite. The waste composite of recycled PP and cotton fabric is orientated randomly. Melt mixing was used to create CFW-PP composites with different percentages of cotton fabric waste weight. Using a mixer, the leftover cotton cloth was combined with a polypropylene melt in this technique. Based on previous research by [49], the settings that were employed were a mixing temperature of 170°C, a rotor speed of 50 rpm, and a mixing period of 10 min. As 170°C has no effect on the qualities of waste cotton cloth, it was chosen as the temperature. Using a closed mold, composites with dimensions of 200 mm × 100 mm × 15 mm were created. The mold was modified with a releasing agent to avoid PP stabbing it. The process was melting the polypropylene (PP), adding a fixed quantity of the waste cotton fabric, thoroughly melting and mixing to create a uniform, viscous solution, and then pouring the mixture into the ready-made mold. After the mold was closed, the samples were compressed and cooled to ambient temperature for 30 minutes at a pressure of roughly 20 MPa. After curing, the samples were taken out of the mold. As shown in Figure 4, the composite specimens that were created were molded using sandpaper and used for testing.

2.2.5. Morphology Analysis. The surface morphology of the samples was studied using a metallurgical microscope (Model DG Classic). This was designed and analyzed for looking at the cross sections, structures, and properties of opaque materials such as ceramics, composites, plastics, polymers, food, metals, particles, porous materials, cosmetics, glass, films, textiles, and fibers.

2.2.6. Test Methods. The samples were conditioned for 24 hours at 23°C ± 2°C and 50 ± 5% relative humidity before each type of testing, and the tests were also carried out in the same controlled environment.

2.2.7. Characterization of Composite Samples

(1) Tensile Strength. For the tensile strength test, a rectangular-shaped specimen was prepared as per the ASTM D 3039 [51] test method with the dimension of 150 mm × 50 mm × 15 mm. The testing was conducted at controlled atmospheric conditions of 23°C ± 2°C and 50 ± 5% relative humidity, and a universal testing machine (Model WAW-600D) was used for the tensile strength test. Five specimens of each composite were tested, and an average value was reported.

(2) Flexural Strength. A flexural strength test was carried out using a three-point loading system applied to a supported beam. The tests were performed using a universal testing machine (Model WAW-600D). The flexural rigidity characteristics of the produced composites were carried out according to the ASTM D7264-2021 [52] test standard with the dimension of 150 mm × 50 mm × 15 mm. 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, 49]:

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

where L is the span length (mm); b and d are the width and thickness of the specimen (mm), respectively; and m is the slope of the tangent to the initial line portion of the load-displacement curve; five specimens were tested for each set of composite samples, and the mean values were reported.

(3) Impact Strength. The Charpy impact tester (Model JBS-500B) was used to determine the impact strength of materials. The method is also used to investigate the behavior of composites under impact conditions for estimating the relative brittleness or toughness of specimens especially for comparison with the ASTM D256 test standard [53]. The unnotched specimens

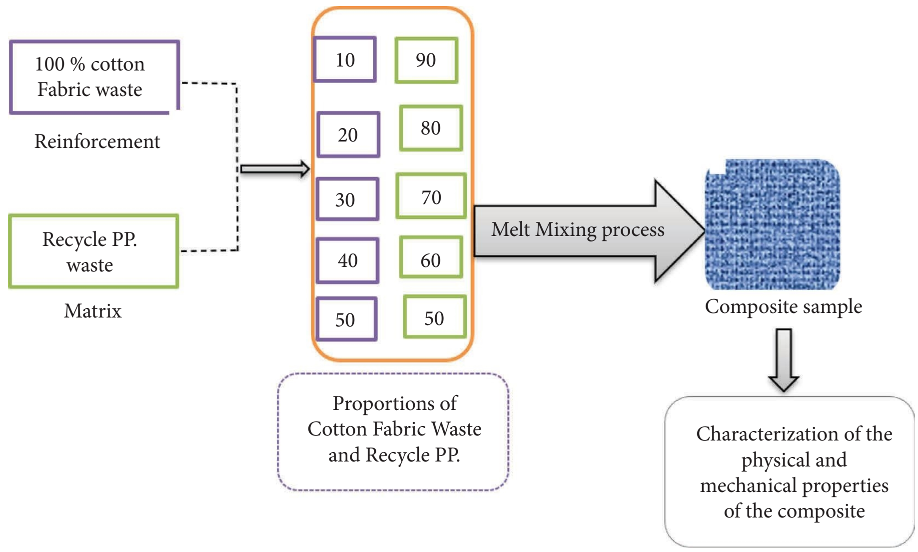

Figure 1: General method of composite manufacturing.

Figure 2: Chopped cotton fabric waste.

Figure 3: Shredded recycled low-density polypropylene.

were prepared according to the ASTM standard. The specimen size is a cube of 55 mm × 12 mm × 10 mm. Five specimens of each composite were tested, and an average value was reported.

(4) Compression Strength. The compressive strength test was carried out using a universal testing machine (Model WAW-600D) as per the ASTM D6641 [54] standard, and the composite specimen size was a cube of 140 mm × 12 mm × 10 mm. Five measurements have been obtained for each type of composite sample.

(5) Water Absorption. Water absorption tests were carried out in accordance with the ASTM D570-98 [55] test method. Samples of each composite type were oven-dried before their weight was recorded as the initial weight of the composites. The samples

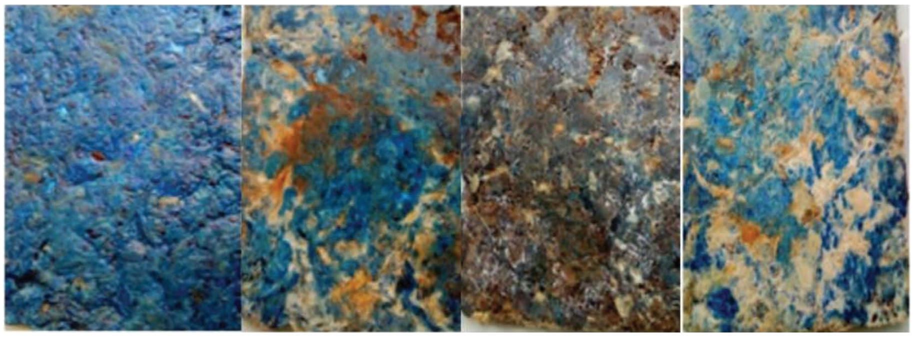

Figure 4: Cotton fabric waste-reinforced recycled polypropylene composite sample.

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 the following equation:

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

where Wt. = weight of composite after water immersion and Wo = weight of a dried sample.

3. Results and Discussion

3.1. Morphology Evaluation. Metallurgical microscope analysis and measurement of the composite location, size, and shape; grain size; surface examination; internal void analysis; and crack and failure analysis were carried out. The sample surface cross-sectional area and structure of the waste cotton fabric and recycled PP composite samples are shown in Figures 5(a)–5(e). As can be seen, the surface cross-sectional areas of Figures 5(a), 5(b), 5(d), and 5(e) are medium waste fabric pull-out, void, crack, and failure due to weak interface bonding between the reinforcement and the matrix; and also, waste cotton fabric agglomerations occur, thus causing waste cotton fabric dispersion problems in recycled PP, which led to a decrease in mechanical properties [17]. However, in Figure 5(c), samples are relatively less waste fabric. Pull-outs, voids, and cracks occur due to strong interface bonding between the reinforcement and the matrix, and waste cotton fabric agglomerations are less, thus causing good waste cotton fabric dispersion in recycled PP, which led to an increase in mechanical properties compared with other samples.

3.2. Test Result of Mechanical and Physical Properties of Cotton Fabric Waste/LDPP Composites. The mechanical and water absorption test results of the composite are shown in Table 1.

3.3. Effect of Cotton Fabric Waste Weight Proportion on Tensile Strength and Tensile Modulus. Tensile strength and tensile modulus of recycled PP and cotton fabric waste composites are shown in Figure 6. As demonstrated in Figure 6, the composite's tensile strength and tensile modulus increased as the percentage of cotton fabric waste weight increased from 10% to 30%, 33.6 MPa to 57.84 MPa, and 0.76 GPa to 1.31 GPa, respectively. However, the strength of the composite decreased after the percentage of cotton fabric waste increased to 30%. It was observed that a waste proportion of 30% was the ideal amount of cotton fabric that produced the maximum tensile strength and tensile modulus. Due to its increased strength, the reinforced recycled polypropylene (PP) became stiffer and could support a heavier load. Because the cotton fabric waste accounted for the majority of the burden, it functioned as reinforcement. A better interfacial distribution between the matrix and reinforcements is also suggested by this linear increment [56, 57].

However, at cotton fabric waste wt. % greater than 30%, the waste was excessive. As a result, there were voids in the matrix and insufficient recycled PP to moisten every cotton fabric waste, leaving the fabric vulnerable to environmental deterioration. At these weight proportions, the interfacial adhesion between waste cotton fabric and PP was poor, and waste cotton fabric agglomerations resulted in problems with cotton fabric dispersion in PP, which decreased the material's tensile strength and tensile modulus [58]. Decreased wettability and inadequate interfacial bonding between the fiber and the matrix are also responsible for the declining tensile strength and modulus [59].

3.4. Effect of Cotton Fabric Waste Weight Proportion on Flexural Strength and Flexural Modulus. Figure 7 displays the CFW-PP composite's flexural strength and flexural modulus. According to the figure, the proportion of cotton fabric waste weight grew gradually as the flexural strength increased. The flexural strength and flexural modulus increased by approximately 51% and 50%, respectively, when the waste weight content of cotton fabric was increased from 10% to 30% of the total weight. This might be because a given composite cross section has more cotton fabric waste on it to support the load at a larger proportion of cotton fabric waste weight. This could possibly be the result of the polymer chains and waste cotton fabric successfully becoming entangled, which improves the adherence of the waste cotton fabric matrix as the waste content increases [60]. However, increased stress transfer from the matrix to the cotton fabric waste is made possible by enhanced cotton fabric waste-matrix adhesion. This means that the insertion of waste cotton fabric into the matrix has produced this result.

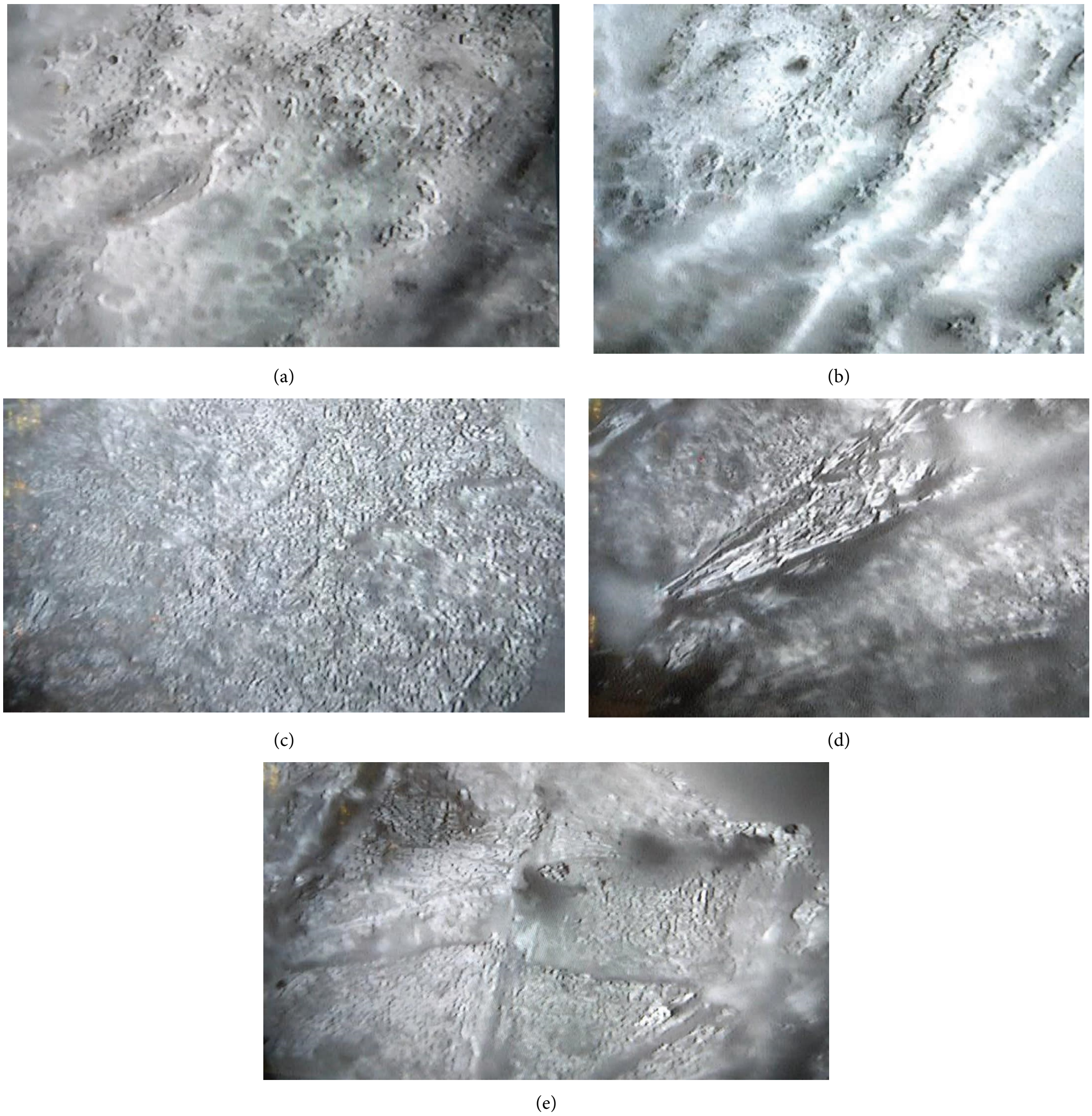

Figure 5: Sample surface cross-sectional area and structure of waste cotton fabric and recycled PP composite: (a) 10% WCF and 90% PP, (b) 20% WCF and 80% PP, (c) 30% WCF and 70% PP, (d) 40% WCF and 60% PP, and (e) 50% WCF and 50% PP.

However, flexural strength and modulus decreased with additional increases in cotton fabric waste weight content above 30%. This is because the loading of cotton fabric waste in the composite material increases with a decrease in the amount of matrix material, which is the component that envelops and sustains the waste. To protect the waste cotton fabric from damage and to transfer tensions among them, the matrix material is essential. Dispersion issues during melt-spinning may be the cause of the decrease in flexural strength and modulus at greater cotton fabric waste weight proportions [57, 61].

3.5. Effect of Cotton Fabric Waste Weight Proportion on Compressive Strength. The compressive strength findings for PP/CFW composites are shown in Figure 8. The results in Figure 8 demonstrate that when cotton fabric waste contents rise to 30 wt. %, the resulting composites' compressive strength increases. This can be attributed to several factors, including higher cotton fabric waste recycled PP matrix compatibility, more compact or dense composites, good interfacial bonding between cotton fabric waste and matrix, and the reinforcement that the waste of cotton fabric imparts, which permits stress transfer from the matrix to the

Table 1: Mechanical and physical properties of cotton fabric waste/LDPP composites.

Cotton fabric waste proportion (%)	Tensile strength (MPa)	Tensile modulus (GPa)	Flexural strength (MPa)	Flexural modulus (GPa)	Impact strength (kJ/m^2)	Compressive strength (MPa)	Water absorption (%)
10	33.6	0.760	36.6	1.79	18.13	34.56	0.3
20	41.28	0.94	37.44	1.82	19.62	37.04	5
30	57.84	1.31	55.32	2.7	33.06	53.68	10.29
40	36.32	0.82	36.6	1.78	27.46	33.4	18.51
50	34.7	0.79	35.3	1.72	23.2	32.21	22.3

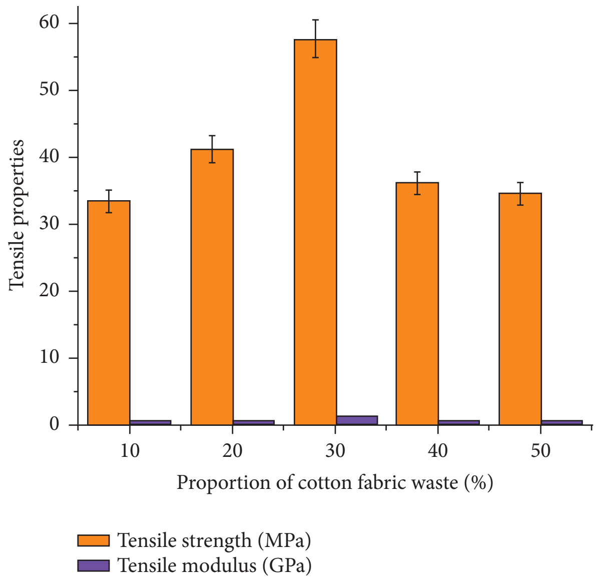

Figure 6: Effect of cotton fabric waste proportion on tensile strength and tensile modulus.

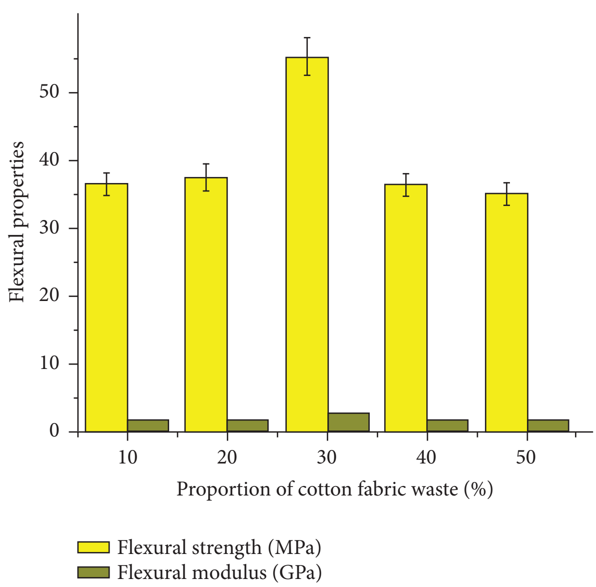

Figure 7: Effect of cotton fabric waste proportion on flexural strength and flexural modulus.

waste of cotton fabric [50]. According to the observation, the composite's ideal compressive strength was attained at a weight percentage of 30% for the waste cotton fabric. The increased bonding force between the recycled PP matrix and the discarded cotton fabric may be the cause of the increase in compressive strength.

However, as Figure 8 makes abundantly evident, the compressive strength of the resulting composite decreases when the percentage of waste cotton fabric content rises above 30%. Weak interfacial adhesion between the discarded cotton fabric and the matrix material may be the cause of this drop. Another possible explanation could be the high amount of cotton fabric waste in the resultant composite,

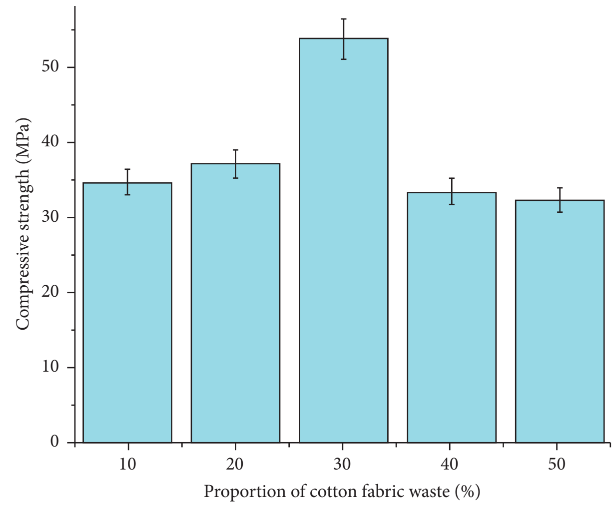

Figure 8: Effect of cotton fabric waste proportion on compressive strength.

which is extremely susceptible to fracture development because of the limited dispersion of cotton fabric waste within the matrix [57, 62].

3.6. *Effect of Cotton Fabric Waste Weight Proportion on Impact Strength.*

The impact resistance of a recycled PP composite reinforced with cotton fabric waste is shown in Figure 9. As shown in Figure 9, it was found that the impact strength rose as the percentage of waste cotton fabric increased up to 30 wt. %. The impact strength was enhanced by the cotton fabric waste's ability to absorb energy due to the strong interfacial interaction between it and the matrix. Cotton fabric waste pull-out may be the cause of an impact-related composite failure. Impact strength increases when the quantity of cotton fabric waste rises because more force is needed to remove the waste [58].

However, the impact strength above 30 wt. % has declined. This is due to the material's reduced elasticity brought on by particle amalgamation, which also lowers the matrix's deformation potential. Impact strength decreased by more than 30 wt. % when cotton fabric waste was added. Studies have shown that regions of high cotton fabric waste content-induced stress concentration are more likely to aggregate, thereby requiring less energy for fracture development. However, in general, the energy-absorbing mechanism of composites during fracture involves the use of energy needed to debone the fibers and pull them out of the matrix completely because of the weak fiber-matrix interface strength. Practically speaking, fiber pull-out, matrix crack, and fiber breakage account for a large portion of energy absorption during impact [62].

3.7. *Effect of Cotton Fabric Waste Weight Proportion on Water Absorption.*

The effect of cotton fabric waste weight proportion on water absorption is shown in Figure 10. Because lignocellulosic fibers contain OH groups in their chemical structure, they are all less resistant to absorbing water.

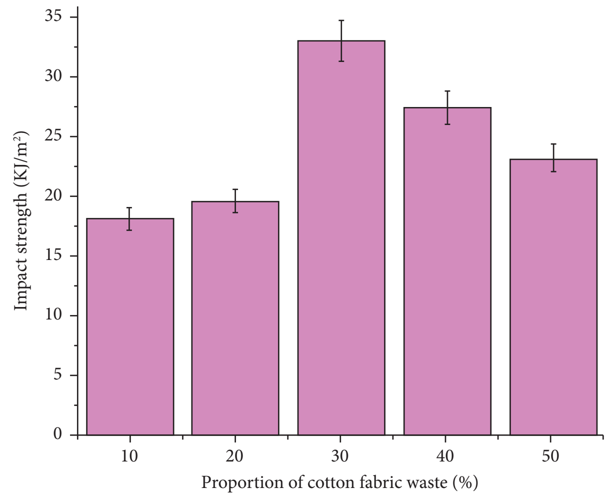

Figure 9: Effect of cotton fabric waste proportion on impact strength.

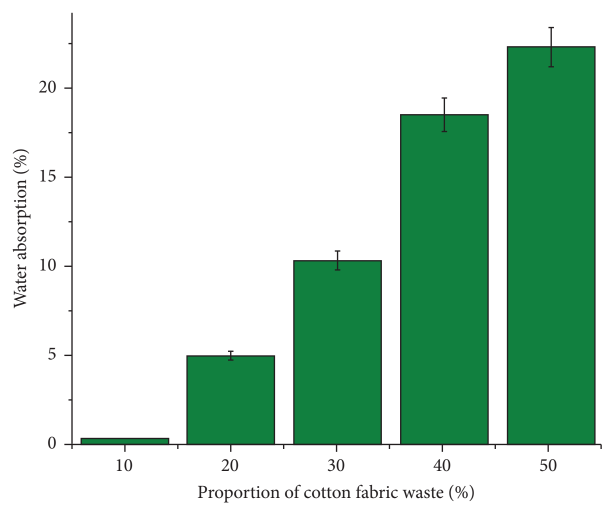

Figure 10: Effect of cotton fabric waste proportion on water absorption.

Without further chemical processing, natural fiber-reinforced polymer composite has microvoids and significant water absorption. The water absorption percentage (%) for the composites containing 10, 20, 30, 40, and 50% cotton fabric waste was evaluated. Figure 10 presents the findings. There was a noticeable impact of cotton fabric waste content on water absorption during a 24-hour soaking in water. The 10% cotton fabric waste weight percentage resulted in the lowest water absorption rate. The rate of water absorption increased when the volume of cotton fabric waste increased from 10% to 50% because more lignocellulosic materials were added to the composite, which resulted in more hydrogen bonds being formed between the OH group and water molecules in the cotton fabric waste. As the exposure time to water absorption time increases, a composite with a 50% cotton fabric waste loading will absorb more water since the percentage of water absorption also grows with cotton fabric loading in composites. The same results were observed in different studies: the rate of water absorption increased with the increase in cotton fabric waste content. This was due to the formation of less surface interaction between the matrix and cotton fabric waste when mixed together, giving higher water absorption [63, 64].

3.8. Comparison of Composite Samples. The properties of the cotton waste reinforced with recycled PP composites have been compared with those of the conventional material or the blank sample without cotton fabric waste. Table 2 shows the comparison of the mechanical and water absorption properties of composites. As shown in Table 2, for cotton waste reinforced with recycled PP composites, the tensile strength, tensile modulus, flexural strength, flexural modulus, impact strength, and compressive strength composite results are better than the conventional material or the blank sample without cotton fabric waste. This increase in mechanical properties means that the reinforced LDPP became stiffer and could withstand a higher load. The waste cotton fabric served as reinforcement because the majority of the load was taken up by the cotton fabric waste. Besides, the

Table 2: Comparison of LDPP composites with cotton fabric and without cotton fabric.

PP and cotton fabric waste proportion (%)	Tensile strength (MPa)	Tensile modulus (GPa)	Flexural strength (MPa)	Flexural modulus (GPa)	Impact strength (kJ/m^2)	Compressive strength (MPa)	Water absorption (%)
100/0	21.2	0.50	23.75	1.1	9.35	22.4	0.1
90/10	33.6	0.760	36.6	1.79	18.13	34.56	0.3
80/20	41.28	0.94	37.44	1.82	19.62	37.04	5
70/30	57.84	1.31	55.32	2.7	33.06	53.68	10.29
60/40	36.32	0.82	36.6	1.78	27.46	33.4	18.51
50/50	34.7	0.79	35.3	1.72	23.2	32.21	22.3

water absorption of cotton waste with recycled PP and only recycled PP had comparable properties, as demonstrated in Table 2.

4. Conclusion

The current study discloses a brand-new class of composites made from cotton fabric waste and recycled PP with different ratios of cotton fabric waste, and their tensile strength, tensile modulus, flexural strength, flexural modulus, compressive strength, impact strength, and water absorption properties have been investigated. The results of this study showed that the mechanical properties of cotton fabric waste with PP composites increased drastically up to the optimum level of cotton fabric waste weight proportion. The cotton fabric waste content of 30% yielded the highest tensile strength, tensile modulus, flexural strength, flexural modulus, impact strength, and compressive strength characteristics. Composite S30 has been discovered to have a maximum tensile strength of 57.84 MPa and a maximum tensile modulus of 1.31 GPa. The tensile strength of composite S30 is 72%, 40%, 59%, and 67% greater than the improvements of composites S10, S20, S40, and S50, respectively. Similarly, the tensile modulus of composite S30 is 72%, 39%, 59%, and 66% greater than those of composites S10, S20, S40, and S50, respectively. The highest values of the flexural strength and modulus—55.32 MPa and 2.7 GPa, respectively—have been found for composite S30. The flexural strength of composite S30 is found to be 51%, 48%, 51%, and 57% greater than those of composites S10, S20, S40, and S50, respectively; correspondingly, the flexural modulus of composite S30 is 50%, 48%, 52%, and 57% greater than those of composites S10, S20, S40, and S50. The composite's maximum compressive strength and impact strength were measured at 33.06 kJ/m^2 and 53.68 MPa, respectively, with a 30% cotton fabric waste content. Composite S30 has been found to have impact strength that is 82%, 68%, 20%, and 42% greater than the improvements of composites S10, S20, S40, and S50, respectively. Similarly, the compressive strength of composite S30 is 55%, 45%, 61%, and 67% greater than those of composites S10, S20, S40, and S50, respectively. The composites containing 10% cotton fabric waste show lower water absorption than the other samples. This is because the OH groups in the cotton fabric waste and water interact to enhance the quantity of water absorbed by the composites. The materials recovered from textile waste were successfully employed to reinforce the polymeric composite materials. The result of this composite material shows that it is suitable for buildings, wall partitions, floor and wall tiles, ceiling boards, cabinets, and furniture applications. The performance of cotton fabric waste in making composites for mainstream applications will be further studied by varying the process parameters, exploring other types of waste fabrics, varying the proportions of fabric waste beyond the current ranges, or using different composite processing techniques to optimize the properties and applications according to their performance characteristics. The future study will entail, for the pilot implementation of the composite, some analyses, such as process optimization and techno-economic analysis of the composite. In addition to this, the degradation property, life cycle assessment, and performance tests of the optimized composite will be studied in the future.

Data Availability

All data are included within the manuscript.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Authors' Contributions

Eyasu Ferede conceptualized the study; Eyasu Ferede, Genet Gebru, Tsigemariam Worku, and Desalegn Atalie designed the methodology; Eyasu Ferede, Tsigemariam Jambo, Worku Zerefa, and Genet Gebru involved in formal analysis; Eyasu Ferede investigated the study; Eyasu Ferede, Worku Zerefa, and Genet Gebru provided resources; Eyasu Ferede wrote the original draft and prepared the manuscript; Eyasu Ferede, Desalegn Atalie, Worku Zerefa, Genet Gebru, Tsigemariam Worku, and Tsigemariam Jambo wrote, reviewed, and edited the manuscript; Eyasu Ferede and Worku Zerefa visualized the data; and Desalegn Atalie supervised the data. All authors have read and agreed to the published version of the manuscript.

Acknowledgments

The authors would like to acknowledge the Ethiopian Institute of Textile and Fashion Technology, Bahir Dar University, Bahir Dar, Ethiopia, for the laboratory facilities provided.

References

[1] M. P. Todor, C. Bulei, T. Heput, and I. Kiss, "Researches on the development of new composite materials complete/partially biodegradable using natural textile fibers of new vegetable origin and those recovered from textile waste," in *Proceedings of the IOP Conference Series: Materials Science and Engineering*, vol. 294, IOP Publishing, Bristol, UK, January 2018.

[2] J. M. Hawley, "Textile recycling as a system: a micro/macro analysis," *Journal of Family and Consumer Sciences*, vol. 92, no. 4, p. 40, 2000.

[3] A. Bartl, A. Hackl, B. Mihalyi, M. Wistuba, and I. Marini, "Recycling of fibre materials," *Process Safety and Environmental Protection*, vol. 83, no. 4, pp. 351–358, 2005.

[4] D. Bhatia, A. Sharma, and U. Malhotra, "Recycled fibers: an overview," *International Journal of Fiber and Textile Research*, vol. 4, no. 4, pp. 77–82, 2014.

[5] M. P. Todor, C. Bulei, and I. Kiss, "Composite materials manufacturing using textile inserts with natural origins fibres," in *Proceedings of the IOP Conference Series: Materials Science and Engineering*, vol. 393, p. 012088, IOP Publishing, Bristol, UK, July 2018.

[6] M. P. Todor, C. Bulei, I. Kiss, and V. Alexa, "Recycling of textile wastes into textile composites based on natural fibres:

the valorisation potential," in *Proceedings of the IOP Conference Series: Materials Science and Engineering*, vol. 477, p. 012004, IOP Publishing, Bristol, UK, February 2019.

[7] C. A. Echeverria, W. Handoko, F. Pahlevani, and V. Sahajwalla, "Cascading use of textile waste for the advancement of fibre reinforced composites for building applications," *Journal of Cleaner Production*, vol. 208, pp. 1524–1536, 2019.

[8] I. Frydrych, S. Ahmad, M. Umair, K. Shaker, Y. Nawab, and M. E. H. M. E. T. Karahan, "Mechanical behaviour of hybrid composites developed from textile waste," *Fibres and Textiles in Eastern Europe*, vol. 26, no. 1(127), pp. 46–52, 2018.

[9] Epa, "Facts and figures about materials, waste and recycling, textiles: material-specific data," 2018, https://www.Epa.Gov/Facts-and-Figures-about-Materials-Waste-and-Recycling/Textiles-Material-Specific-Data.

[10] R. Leblanc, "Textile and garment recycling facts and figures," 2020, https://www.Thebalancesmb.Com/Textile-RecyclingFacts-and-Figures-2878122.

[11] E. Parliament, "The impact of textile production and waste on the environment (infographic), textile waste in landfills," 2020, https://www.Europarl.Europa.Eu/News/En/Headlines/Society/20201208STO93327/the-Impact-of-TextileProduction.

[12] P. P. Pichardo, G. Martínez-Barrera, M. Martínez-López, F. Ureña-Núñez, and L. I. Ávila-Córdoba, "Waste and recycled textiles as reinforcements of building materials," *Natural and Artificial Fiber-Reinforced Composites as Renewable Sources*, vol. 89, 2018.

[13] D. B. DeVallance, J. Gray, and H. Lentz, "Properties of wood/recycled textile composite panels," *Wood and Fiber Science*, vol. 14, pp. 310–318, 2012.

[14] S. M. Sapuan and M. A. Maleque, "Design and fabrication of natural woven fabric reinforced epoxy composite for household telephone stand," *Materials and Design*, vol. 26, no. 1, pp. 65–71, 2005.

[15] K. Shaker, M. Umair, S. Shahid et al., "Cellulosic fillers extracted from Argyreia speciose waste: a potential reinforcement for composites to enhance properties," *Journal of Natural Fibers*, vol. 19, no. 11, pp. 4210–4222, 2022.

[16] S. C. Ugbolue, Y. K. Kim, S. B. Warner et al., "The formation and performance of auxetic textiles. Part II: geometry and structural properties," *Journal of the Textile Institute*, vol. 102, no. 5, pp. 424–433, 2011.

[17] M. Zeeshan, M. Ali, A. S. Anjum, and Y. Nawab, "Optimization of mechanical/thermal properties of glass/flax/waste cotton hybrid composite," *Journal of Industrial Textiles*, vol. 51, no. 5, pp. 768–787, 2021.

[18] S. Santhanam, S. Temesgen, S. Temesgen, D. Atalie, and G. Ashagre, "Recycling of cotton and polyester fibers to produce nonwoven fabric for functional sound absorption material," *Journal of Natural Fibers*, vol. 16, no. 2, pp. 300–306, 2019.

[19] A. O. Sojobi, S. E. Nwobodo, and O. J. Aladegboye, "Recycling of polyethylene terephthalate (PET) plastic bottle wastes in bituminous asphaltic concrete," *Cogent engineering*, vol. 3, no. 1, Article ID 1133480, 2016.

[20] M. Mihelčič, A. Oseli, M. Huskić, and L. Slemenik Perše, "Influence of stabilization additive on rheological, thermal and mechanical properties of recycled polypropylene," *Polymers*, vol. 14, no. 24, p. 5438, 2022.

[21] K. Ragaert, L. Delva, and K. Van Geem, "Mechanical and chemical recycling of solid plastic waste," *Waste Management*, vol. 69, pp. 24–58, 2017.

[22] A. Rahimi and J. M. García, "Chemical recycling of waste plastics for new materials production," *Nature Reviews Chemistry*, vol. 1, no. 6, p. 0046, 2017.

[23] M. Niaounakis, "Recycling of biopolymers–the patent perspective," *European Polymer Journal*, vol. 114, pp. 464–475, 2019.

[24] B. Brüster, F. Addiego, F. Hassouna, D. Ruch, J. M. Raquez, and P. Dubois, "Thermo-mechanical degradation of plasticized poly (lactide) after multiple reprocessing to simulate recycling: multi-scale analysis and underlying mechanisms," *Polymer Degradation and Stability*, vol. 131, pp. 132–144, 2016.

[25] N. Singh, D. Hui, R. Singh, I. P. Ahuja, L. Feo, and F. Fraternali, "Recycling of plastic solid waste: a state of art review and future applications," *Composites Part B: Engineering*, vol. 115, pp. 409–422, 2017.

[26] J. Maris, S. Bourdon, J. M. Brossard, L. Cauret, L. Fontaine, and V. Montembault, "Mechanical recycling: compatibilization of mixed thermoplastic wastes," *Polymer Degradation and Stability*, vol. 147, pp. 245–266, 2018.

[27] D. M. Panaitescu, C. A. Nicolae, Z. Vuluga et al., "Influence of hemp fibers with modified surface on polypropylene composites," *Journal of Industrial and Engineering Chemistry*, vol. 37, pp. 137–146, 2016.

[28] L. Sun, Q. Wu, Y. Xie, K. Song, S. Lee, and Q. Wang, "Thermal decomposition of fire-retarded wood flour/polypropylene composites: kinetic property and degradation mechanisms," *Journal of Thermal Analysis and Calorimetry*, vol. 123, no. 1, pp. 309–318, 2016.

[29] Y. B. Zhao, X. D. Lv, and H. G. Ni, "Solvent-based separation and recycling of waste plastics: a review," *Chemosphere*, vol. 209, pp. 707–720, 2018.

[30] G. Lopez, M. Artetxe, M. Amutio, J. Bilbao, and M. Olazar, "Thermochemical routes for the valorization of waste polyolefinic plastics to produce fuels and chemicals. A review," *Renewable and Sustainable Energy Reviews*, vol. 73, pp. 346–368, 2017.

[31] H. A. Maddah, "Polypropylene as a promising plastic: a review," *American Journal of Polymer Science*, vol. 6, no. 1, p. 1, 2016.

[32] R. Geyer, J. R. Jambeck, and K. L. Law, "Production, use, and fate of all plastics ever made," *Science Advances*, vol. 3, no. 7, Article ID e1700782, 2017.

[33] L. Delva, S. Hubo, L. Cardon, and K. Ragaert, "On the role of flame retardants in mechanical recycling of solid plastic waste," *Waste Management*, vol. 82, pp. 198–206, 2018.

[34] D. D. Moreno, R. V. de Camargo, D. dos Santos Luiz, L. T. Branco, C. C. Grillo, and C. Saron, "Composites of recycled polypropylene from cotton swab waste with pyrolyzed rice husk," *Journal of Polymers and the Environment*, vol. 29, no. 1, pp. 350–362, 2021.

[35] F. M. Al-Oqla, S. M. Sapuan, M. R. Ishak, and A. A. Nuraini, "A decision-making model for selecting the most appropriate natural fiber–Polypropylene-based composites for automotive applications," *Journal of Composite Materials*, vol. 50, no. 4, pp. 543–556, 2016.

[36] D. García-García, A. Carbonell, M. D. Samper, D. García-Sanoguera, and R. Balart, "Green composites based on polypropylene matrix and hydrophobized spend coffee ground (SCG) powder," *Composites Part B: Engineering*, vol. 78, pp. 256–265, 2015.

[37] E. J. Amieva, C. Velasco-Santos, A. L. Martínez-Hernández, J. L. Rivera-Armenta, A. M. Mendoza-Martínez, and V. M. Castaño, "Composites from chicken feathers quill and

recycled polypropylene," *Journal of Composite Materials*, vol. 49, no. 3, pp. 275–283, 2015.

[38] W. A. Mustafa, M. Zainal, R. Santiagoo, A. A. Ghani, N. S. Othman, and R. D. Affandi, "Structure analysis on polypropylene maleic anhydride (PPMAH)/polypropylene (PP)/recycled acrylonitrile butadiene rubber (NBRr)/banana skin powder (BSP) composites treatment," *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, vol. 50, no. 1, pp. 40–46, 2018.

[39] M. Assarar, D. Scida, W. Zouari, E. H. Saidane, and R. Ayad, "Acoustic emission characterization of damage in short hemp-fiber-reinforced polypropylene composites," *Polymer Composites*, vol. 37, no. 4, pp. 1101–1112, 2016.

[40] I. D. Ibrahim, T. Jamiru, R. E. Sadiku, W. K. Kupolati, and S. C. Agwuncha, "Dependency of the mechanical properties of sisal fiber reinforced recycled polypropylene composites on fiber surface treatment, fiber content and nanoclay," *Journal of Polymers and the Environment*, vol. 25, no. 2, pp. 427–434, 2017.

[41] X. Jiang, J. Wang, G. Wu, X. Peng, and X. Ma, "Significant reinforcement of polypropylene/wood flour composites by high extent of interfacial interaction," *Journal of Thermoplastic Composite Materials*, vol. 32, no. 5, pp. 577–592, 2019.

[42] T. Sullins, S. Pillay, A. Komus, and H. Ning, "Hemp fiber reinforced polypropylene composites: the effects of material treatments," *Composites Part B: Engineering*, vol. 114, pp. 15–22, 2017.

[43] N. A. Aridi, S. M. Sapuan, E. S. Zainudin, and F. M. Al-Oqla, "Mechanical and morphological properties of injection-molded rice husk polypropylene composites," *International Journal of Polymer Analysis and Characterization*, vol. 21, no. 4, pp. 305–313, 2016.

[44] V. Guna, M. Ilangovan, M. H. Rather et al., "Groundnut shell/rice husk agro-waste reinforced polypropylene hybrid biocomposites," *Journal of Building Engineering*, vol. 27, Article ID 100991, 2020.

[45] A. Purohit, P. Pradhan, G. Gupta, H. Jena, and J. Singh, "Sliding wear characterization of epoxy composites filled with wood apple dust using Taguchi analysis and finite element method," *Journal of Vinyl and Additive Technology*, vol. 30, no. 3, pp. 788–800, 2023.

[46] P. T. Swain, S. N. Das, P. K. Patnaik, and A. Purohit, "The influence of moisture absorption on the mechanical and thermal properties of chemically treated DPL reinforced hybrid composite," in *Materials Science Forum*, Trans Tech Publications Ltd, Bäch SZ, Switzerland, 2020.

[47] A. Purohit and A. Satapathy, "A study on erosion wear performance of Linz-Donawitz sludge filled polypropylene matrix composites," in *Proceedings of the IOP Conference Series: Materials Science and Engineering*, p. 012045, IOP Publishing, Bristol, UK, June 2018.

[48] H. Jena, P. Pradhan, and A. Purohit, "Dielectric properties, thermal analysis, and conductivity studies of biodegradable and biocompatible polymer nanocomposites," in *Biodegradable and Biocompatible Polymer Nanocomposites*, Elsevier, Amsterdam, Netherlands, 2023.

[49] E. Ferede and D. Atalie, "Mechanical and water absorption characteristics of sisal fiber reinforced polypropylene composite," *Journal of Natural Fibers*, vol. 19, no. 16, pp. 14825–14838, 2022.

[50] E. Ferede, "Evaluation of mechanical and water absorption properties of alkaline-treated sawdust-reinforced polypropylene composite," *Journal of Engineering*, vol. 2020, Article ID 3706176, 8 pages, 2020.

[51] "Standard test method for tensile properties of polymer matrix composite materials," *Book ASTM D3039-Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials*, ASTM International, West Conshohocken, PA, USA, 2017.

[52] Astm International, *Standard Test Method for Flexural Properties of Polymer Matrix Composite Materials*, ASTM International, West Conshohocken, PA, USA, 2007.

[53] Astm International, *Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics; ASTM D256-10e1*, ASTM International, West Conshohocken, PA, USA, 2010.

[54] ASTM, *Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials Using a Combined Loading Compression (CLC) Test Fixture*, ASTM Internationals, West Conshohocken, PA, USA, 2016.

[55] ASTM, *Standard Test Method for Water Absorption of Plastics*, ASTM Internationals, West Conshohocken, PA, USA, 2018.

[56] B. Gedif and D. Atalie, "Recycling of 100% cotton fabric waste to produce unsaturated polyester-based composite for false ceiling board application," *International Journal of Polymer Science*, vol. 27, 2022.

[57] E. Ferede, A. Muhammed, A. Kassa, S. Kedir, T. Tesfaye, and W. Zerefa, "Fabrication and characterization of recycled polyethylene terephthalate composites reinforced with sisal fibre and wood sawdust," *Textile & Leather Review*, vol. 7, pp. 493–516, 2024.

[58] T. Chowdhury, M. Ahmed, E. Mahdi et al., "An experimental study on mechanical, physical, and thermal properties of waste hair-rattan hybrid fiber-reinforced composite," *Biomass Conversion and Biorefinery*, vol. 1, pp. 1–4, 2023.

[59] M. M. Haque, M. Hasan, M. S. Islam, and M. E. Ali, "Physico-mechanical properties of chemically treated palm and coir fiber reinforced polypropylene composites," *Bioresource Technology*, vol. 100, no. 20, pp. 4903–4906, 2009.

[60] S. Siddika, F. Mansura, M. Hasan, and A. Hassan, "Effect of reinforcement and chemical treatment of fiber on the properties of jute-coir fiber reinforced hybrid polypropylene composites," *Fibers and Polymers*, vol. 15, no. 5, pp. 1023–1028, 2014.

[61] S. K. Chattopadhyay, R. K. Khandal, R. Uppaluri, and A. K. Ghoshal, "Bamboo fiber reinforced polypropylene composites and their mechanical, thermal, and morphological properties," *Journal of Applied Polymer Science*, vol. 119, no. 3, pp. 1619–1626, 2011.

[62] N. Gebremedhin and G. K. Rotich, "Manufacturing of bathroom wall tile composites from recycled low-density polyethylene reinforced with pineapple leaf fiber," *International Journal of Polymer Science*, vol. 2020, Article ID 2732571, 9 pages, 2020.

[63] W. Z. Zahari, R. N. Badri, H. Ardyananta, D. Kurniawan, and F. M. Nor, "Mechanical properties and water absorption behavior of polypropylene/ijuk fiber composite by using silane treatment," *Procedia Manufacturing*, vol. 2, pp. 573–578, 2015.

[64] K. Savitha, G. S. Annapoorani, V. R. Sampath, and D. Atalie, "Physical characterization of cellulosic fibres from Sesbania grandiflora stem," *Indian Journal of Fibre and Textile Research*, vol. 44, no. 4, pp. 437–441, 2019.